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Geoarcheology in North-Central Texas: A Framework for Archeological Investigation, and Cultural Resource Management in the Fort Worth Highway District

James T. Abbott

Texas Department of Transportation

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Geoarcheology in North-Central Texas: A Framework for Archeological Investigation, and Cultural Resource Management in the Fort Worth Highway District

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Geoarcheology in North–Central Texas

**A Framework for Archeological Investigation,
and Cultural Resource Management
in the Fort Worth Highway District**

by

James T. Abbott

Texas Department of Transportation
Environmental Affairs Division
Archeological Studies Program, Report No. 130
Austin

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The volume is dedicated to the memory of Dr. David Kuehn.

James T. Abbott

January, 2011

Introduction and Statement of Purpose

This document represents an examination of geoarcheological issues affecting a nine-county area in and around Fort Worth, Texas. The study area includes Tarrant, Wise, Jack, Parker, Palo Pinto, Erath, Hood, Somervell, and Johnson Counties (Figure 1–1), which collectively make up the Fort Worth District, a regional administrative entity of the Texas Department of Transportation (TxDOT). This study represents the second phase of a district-focused geoarcheological program being implemented at TxDOT. A similar study of the Houston District was published previously (Abbott 2001a), and studies of other districts are planned. The current study is intended to familiarize archeologists, planners, and transportation professionals working in the region with relevant geoarcheological issues, thus serving as a resource for those involved in prospection, assessment, and interpretation of prehistoric archeological sites. Readers of the previous Houston study are warned that the overall organization of the document and some of the text may seem familiar, as a certain degree of self-plagiarism was practiced, particularly in the discussion of geomorphic and soil processes in Part II. Although the focus of investigation is on the nine counties making up the Fort Worth District, many of the issues addressed are equally applicable to adjacent areas of north-central Texas.

Archeology is the study of people through the remains that they leave behind. In many cases, these remains are buried within soils or sediments. For this reason, the collaboration between archeologists and geologists, geomorphologists, stratigraphers, pedologists, and other types of earth scientists is both necessary and advantageous, and has a long history (Butzer 1982:35–36). Nevertheless, the term geoarcheology, and the related term archeological geology, are used in many different senses by various authors (e.g., Butzer 1975; 1982; 2008; Gladfelter 1977; 1981; Rapp et al. 1974; Renfrew 1976; Hertz and Garrison 1998; French 2003). Gladfelter (1981) identifies a number of lines of geoarcheological investigation, including regional and site-specific remote sensing investigations using geophysical or geochemical techniques; documentation and interpretation of site formation processes; examination of site setting and landscape context; paleoenvironmental and paleotopographic reconstruction; and relative or absolute chronological

assessment. Similarly, Butzer (1982:38) identifies five basic geoarcheological themes, each of which may be addressed at a variety of scales: (1) landscape context; (2) stratigraphic context; (3) site formation; (4) site modification; and (5) intentional and unintentional landscape modification. Other definitions of geoarcheology and archeological geology (e.g., Rapp et al. 1974; Renfrew 1976) are equally broad.

It is therefore appropriate to define the range of geoarcheological issues addressed in this document. The purpose of this report is to (1) outline the broad geologic, geomorphic, and pedologic character of the Fort Worth District; (2) briefly summarize the modern climatic and biotic character and the late Quaternary paleoenvironmental history of the region as it is currently understood; (3) summarize what is known about the late Quaternary stratigraphy of depositional systems in the region; and (4) identify and map the geoarcheological potential of different landscape components as an aid for future archeological research. The database used to address these issues includes extant regional and process literature, as well as new data that are reported here for the first time.

Figure 1–1: Counties making up the Fort Worth Highway District.

The preceding topics are of importance to archeology for several reasons. First, they provide a context for interpretation of individual sites and broader cultural networks. Archeological paradigms are diverse, but it is commonly accepted that culture (broadly construed) is “an extra-somatic means of adaptation for the human organism” (White 1959:8), and that cultural systems are superimposed upon and provide mechanisms of adaptation to the natural environment (Binford 1962; Butzer 1982). Although the notion that the natural environment dictates cultural systems (i.e. Huntington 1924) has long fallen from favor, few would dispute that the natural environment provides opportunities and constraints that shape the fabric of culture, and that hunter-gatherer cultural systems in particular are intimately tied to the character of the landscape.

However, landscapes are not static entities. They evolve constantly under the influence of physical and biotic influences. Over the long term, the earth’s surface is remade completely; mountains rise and are worn flat, seas open and fill with sediment, and continents glide over the surface of the earth, smashing into each other and wrenching the topography into new shapes in what has been termed “a slow ballet of unimaginable violence”. Although the timescale of these fundamental changes is so long that it has little bearing on archeology (particularly in the New World), other mechanisms are operating that affect the landscape as a habitat for people. As time passes, the character and density of vegetative cover changes, soils deepen and erode, rivers migrate across their floodplains and change character; rockshelters grow and collapse; dunes form and are grown over by grass; and springs turn on and off. These and many more changes can affect the terrain over the span of years, decades, centuries, and millennia. Consequently, the landscape present when a site is occupied may bear little resemblance to what is present when the material remains of that cultural system are exhumed for study hundreds or thousands of years later. Too often, this dynamism is underappreciated, leading to archeological interpretations that are simplistic or erroneous.

Second, geoarcheological data provide a basis for assessing site integrity. In essence, archeology is the study of humans through examination of the debris that they leave behind. Under ideal circumstances, examination of this debris can yield information about behavioral and adaptive traits of the people that left it, including (but not limited to) information on technological adaptations, resource exploitation, settlement organization and patterning on the landscape, and social organization. There are two distinct types of data that are relevant to the archeological interpretation of human material remains (e.g., artifacts, organic residues and remains). The first of these is the suite of attributes characteristic of an individual artifact or a suite of artifacts. A stone tool, for

example, possesses distinct physical characteristics (e.g., length, width, form, flaking pattern, raw material type and provenience, evidence of heat modification, evidence of use wear, etc.) that can be used to interpret its place in the cultural system of interest. However, a second, equally important type of data is the archeological context of the artifact; its spatial and stratigraphic relationships with related materials. Typically, human occupation of a given locality results in the production of a variety of materials through discard, loss, and various biophysical processes. Collectively, these materials make up an occupational assemblage, and are initially arranged in a manner that reflects behavioral patterning (e.g., the spatial arrangement of activities, patterns of discard, associations between elements of the cultural system).

During the use-life of a given artifact, it can be said to be in *systemic context* (Schiffer 1987), and exhibits a dynamic relationship with other elements of the material culture that is directly contingent on behavior. However, upon loss or discard, an artifact enters *archeological context*, and may be affected by either subsequent cultural processes or by natural processes. In almost every case, the spatial relationships between a given artifact and other elements of a site assemblage continue to evolve under the influence of a variety of mechanisms that Schiffer (1987) terms *natural formation processes*. Such processes can affect, and ultimately destroy, the original spatial (horizontal) and stratigraphic (vertical) relationships between artifacts. The degree to which these relationships are maintained is frequently termed the integrity of the assemblage. If the behaviorally-dictated context of a given assemblage is disrupted to such a degree that inferences about that behavior cannot be made, archeological integrity is lost and the research value of the site is severely diminished. In such instances, the site is normally considered ineligible for consideration under existing Federal and State Antiquity Laws.

It follows that archeological interpretation can benefit from careful consideration of the natural formation processes in operation at any given site or in any given region. Natural formation processes include a vast suite of interacting geomorphic, pedologic, and biotic processes that serve to alter and transform archeological sediments and cultural deposits (Butzer 1982; Schiffer 1987). While it is impractical to perform an intensive review and synthesis of information on the suite of natural processes relevant to a given area in conjunction with most individual projects, preparation of a single document as a resource for subsequent investigations can provide tremendous benefits for archeological interpretation and cultural resource management in the region. This document represents such a synthesis, and is intended as a resource to familiarize TxDOT archeologists, archeological contractors, area transportation planners,

regulatory agencies, and other interested parties with relevant geologic, geomorphic, and pedologic issues, as well as familiarizing geomorphological consultants with aspects of the late Quaternary record that are of particular importance to archeology.

This document consists of three main parts, and is supplemented by a series of appendices. Part I presents a summary of the environmental context of the Fort Worth District based upon a literature review. The content is similar to the environmental summaries in project-specific archeological reports, albeit here in relatively more detail than is typical. The goal of Part I is to summarize and synthesize existing climatic, geological, soils, biotic, and paleoclimatic data. Part II outlines what is known about the geomorphic/stratigraphic context and the geoarcheological potential of the district. It is organized around classification of the overall landscape into discrete landscape elements, which reflect differences in geomorphic setting, soils, and geology. Extant stratigraphic models for a variety of specific environments are presented in this section, as is all primary fieldwork conducted during this study. Part III describes the rationale, methodology, and legal basis for the design and implementation of a management/planning tool termed the Fort Worth District Potential Archeological Liability Map (FTW-PALM).

Several abbreviations are used throughout this document that may not be familiar to all readers. These include: ka (thousand years ago), ma (million years ago), rybp (radiocarbon years before present), and bgs (below ground surface). A Glossary of Terms is also included (Appendix I) to provide the reader with definitions of unfamiliar terms used in the document. Except where noted, radiocarbon ages obtained during

this study are presented in the document as $\delta^{13}\text{C}$ corrected radiocarbon ages BP (before the reference year 1950, which defines the radiocarbon scale). Associated error factors and calendrically-calibrated ages are typically not provided in the text, but are presented in Appendix II.

Finally, it should be explained that the term “geoarcheological potential” used throughout this document refers to the likelihood that Clovis-age (roughly 12.5 ka) or later materials could be preserved in a given setting with sufficient integrity to yield reliable information relevant to our understanding of prehistory. While we acknowledge that a growing body of evidence suggests that people were probably present in the New World before the advent of the Clovis culture (e.g., Dillehay 1997; Meltzer et al. 1997, Waters and Stafford 2007), most candidate sites are only a few thousand years older and would likely be encountered in the same part of the stratigraphic sequence; in other words, because there is no clear regional marker horizon for the initiation of Clovis-age sediments, a reasonable and good faith effort to search for such remains would be just as likely to encounter remains that are slightly older if they are present. However, discovery of substantially older (i.e., 20–50 ka) archeological remains, such as have been proposed at sites like the Topper Site in South Carolina (Chandler 2001), Meadowcroft Shelter in Pennsylvania (e.g., Adovasio et al. 2005), and Pendejo Cave in southern New Mexico (MacNeish and Libby 2003), would require considerable modification of search strategies. While we take no position on the legitimacy of these claims, we are of the opinion that the paucity of convincing evidence for remains substantially older than Clovis in the south-central United States does not currently justify the additional effort and public expense that a routine and systematic search for such remains would require.

Part I:
Late Quaternary
Environmental Context
of the Fort Worth District

PART I: Late Quaternary Environmental Context of the Fort Worth District

1.1 Introduction

The nine county (TxDOT) Fort Worth District encompasses an area of approximately 6,965 mi² (1,803,990 ha) (Kingston 1986), and varies in elevation from approximately 150 m (500 ft) in eastern Tarrant County to 530 m (1750 ft) in Erath County. The district is dominated by the greater Fort Worth area (the western part of the Dallas–Fort Worth Metroplex), which occupies a large percentage of the total acreage in the eastern part of the district, particularly Tarrant and northern Johnson Counties, and subsumes communities such as Mansfield, Arlington, Burleson, Benbrook, Crowley, White Settlement, and Richland Hills. The western part of the District is largely rural, but is growing rapidly. Relatively large communities that are not part of the Dallas–Fort Worth Metroplex *per se* include Decatur and Bridgeport (Wise County), Weatherford (Parker County), Glen Rose (Somervell County), Stephenville and Dublin (Erath County), Mineral Wells (Palo Pinto County), Granbury (Hood County), Jacksboro (Jack County), and Cleburne, Alvarado, and Grandview (Johnson County). According to the 2000 census, the overall population of the nine county area is 1,827,017, with 1,446,219 (79%) of those residing in Tarrant County. However, growth is occurring in all parts of the district. Counties close enough to the Metroplex to contain “bedroom community” suburbs (Hood, Johnson, Parker, and Wise Counties) exhibit population increases of between 30% and 42% between 1990 and 2000. The more distant counties (i.e., Somervell, Erath, Palo Pinto, and Jack) grew between approximately 8% and 27% in the same period, but remain rural, with a combined population of slightly over 75,000 in 3137 square miles (approx. 24/mi²). In contrast, the four counties close to Fort Worth have a population of 305,199 in 2960 square miles (approx 103/mi²), while Tarrant County exhibits a population density of approximately 1,666/mi².

The Fort Worth District includes portions of three different natural regions, as defined by the LBJ School of Public Affairs (1978) and mapped by the Texas Parks and Wildlife Department (<http://www.tpwd.state.tx.us/nature/tx-eco95.htm>). These regions are termed the Blackland Prairies, Oak Woods and Prairies,

and Rolling Plains, and include one or more defined Subregions. The Blackland Prairies includes the Blackland Prairie and Grand Prairie Subregions, the Oak Prairies and Woods includes the Eastern and Western Cross Timbers, and the Rolling Plains are represented by the Mesquite Plains subregion. These natural subregions are arrayed across the district in north–south oriented stripes (Figure 1–2). This pattern results from the combined influence of a pronounced east–west moisture gradient and the character and pattern of outcropping bedrock. In aggregate, the Fort Worth district is a relatively diverse landscape with a patterned distribution of natural resources and a strongly differing potential to bury and preserve archeological sites.

Figure 1–2: Distribution of Texas Natural Regions in the Fort Worth District. Generated from GIS data published by Texas Parks & Wildlife Department, based on a classification developed by the LBJ School of Public Affairs (1978).

1.2 Climate and Hydrology

The term “climate” refers to the long-term weather of any given location, including the norms and the extremes of factors that contribute to a locality’s weather, including temperature, precipitation, wind, incident radiation, humidity, and cloud cover. The climate of north-central Texas, including all of the Fort Worth District, is classified as Subtropical Humid (Larkin and Bomar 1983). The Fort Worth District lies in a transitional zone between the humid eastern United States and the semi-arid to arid west, and between the ameliorated climate of the Gulf Coast and the more severe seasonal climate of the continental interior. The climate reflects the influence of latitude, elevation, distance from a moisture source, and the interaction between continental air masses from the continental interior, the Pacific, and the Gulf of Mexico. These factors combine to give the district a climate with hot summers and relatively mild winters where snow and ice storms occur but are typically short-lived.

Figure 1–3 depicts climographs for four stations in different parts of the Fort Worth District. There are two precipitation peaks throughout the year, one of which occurs in late spring (May–June) due to the passage of infrequent cold fronts that spawn chains of powerful frontal thunderstorms, and a second in late summer/early autumn (September–October) that is primarily due to the incidence of tropical moisture associated with storms and hurricanes in the Atlantic and, occasionally, Pacific (Bomar 1995). Winter and early spring, in contrast, are relatively dry, and high summer rainfall is dominated by convectional thunderstorms that are relatively brief and localized, albeit frequently intense. However, storms generating intense and/or prolonged precipitation can occur at any time of year, while large-scale circulation anomalies, such as those accompanying *El Niño* and *La Niña*, can alter the typical trend for months or years at a time.

Except where otherwise attributed, the following climatic statistics are extracted from the NOAA website (www.srh.noaa.gov).

Figure 1–3: Climographs illustrating average monthly temperature and precipitation at four different stations in the Fort Worth District, based on National Weather Service climate data.

noaa.gov/fwd/CLIMO/dfw). Average annual precipitation in the Fort Worth District varies from a low of slightly less than 30 inches (76 cm) in north-central Erath County to a high of slightly more than 36 inches (91 cm) in parts of eastern Wise, Tarrant, and Johnson Counties (Figure 1-4). Average monthly rainfall at DFW airport varies from a low of 1.83 inches (4.65 cm) in January to a high of 4.88 inches (12.4 cm) in May. Freezing rain and sleet is common during winter months. Normal annual snowfall is 3.1 inches (7.9 cm), with trace amounts or greater recorded in every month except June, July, August, and September. Snow cover is rarely maintained on the ground for more than a day or two. Relative humidity averages 66% throughout the year, varying from a mean daily high of 70% in May to a low of 60% in July and August. On average, daily relative humidity fluctuates by 20% in December (59% to 79%) and by 36% in July and August (44% to 80%). Heavy fog occurs 10.9 days per year, and is most common in December and January. Thunderstorms occur an average of 45.6 days per year, with the incidence peaking in May (7.4 days).

Figure 1-4: Isohyet map illustrating average annual precipitation in the Fort Worth District.

Mean daily maximum temperature at DFW averages 76.3° F. on an annual basis, ranging from a high of 96.5° F. in July to a low of 54.1° F. in January. Annual mean daily minimum is 54.9°, ranging from a high of 74.7° F. in July to a low of 33.7° F. in January. Extremes range from a high of 113° to a low of -1°. There are, on average, 97 days a year with a high temperature of 90° or above, and 41 days with a minimum of 32° or below. Figure 1-5 illustrates climatic variability at Stephenville, in the southwestern part of the district. The upper graph illustrates the maximum recorded temperature range for each month, which varies from 32.5° C (52° F) in January, February, and March to 54.75° C (86° F) in June and July. The highest temperature ever recorded at Stephenville is 48.75° C (110° F), which occurred in September. The lowest is -21.25° C (-2° F), and occurred in January.

Figure 1-5: Illustration of variability in temperature and precipitation at Stephenville in Erath County, based on National Weather Service climate data.

Winds at DFW average 10.8 mph on an annual basis, and vary from a high of 12.7 mph in March to a low of 9.1 in August. Winds are typically out of the north in winter and the south in summer. The highest recorded sustained winds (minimum 2 minute duration) are only 47 mph, which occurred in June and again in August of 1996 (probably in connection with thunderstorm squall lines). However, much higher winds (up to 300 mph) are associated with tornadoes, which occur with regularity in the district during the spring and are known from all seasons, particularly in the more populous counties in proximity to Fort Worth (Figure 1–6).

Precipitation extremes at Stephenville are indicated by the lower graph in Figure 1–5, and are generally illustrative of variability across the district as a whole. The shaded portion of the graph indicates the variability of precipitation that can be expected to occur in eight

of every ten years on a month to month basis, while the upper and lower limits indicate maximum and minimum thresholds that are exceeded approximately one year in ten. Thus, the height of the shaded bar represents an approximation of the variability inherent in monthly precipitation. Examination of the graph reveals that low rainfall (<5 cm) can be expected to occur on occasion in every month throughout the year, but that high rainfall (>15 cm) is typical of only May (the Spring peak) and October (the Autumn peak), which reflect the influence of the frontal thunderstorm and hurricane seasons, respectively. The two months with the lowest variability are February and December. Relatively high variability is associated with the frontal/convectional storms of April through July and, particularly, the tropical storm season in September and October. The month of October is particularly striking; one year in ten can be expected to yield only a trace of precipitation, while one year in ten can be expected to yield more than 15 cm (6 inches), depending on the incidence of late season tropical storms.

Figure 1–6: Frequency and timing of tornadoes reported in the Fort Worth District between 1950 and 1995.

The line in the lower graph provides a measure of the record amount of precipitation for each month that has been received during a single day. This graph clearly indicates that while strong storms may occur at any time of year—even in February, more than 8 cm (3 inches) of precipitation has been recorded in a 24 hour period—the highest potential is associated with the collision of tropical moisture and continental air masses in the fall, when September storms have yielded up to 25 cm (10 inches) in a single day. Note that the record daily totals are of the same magnitude as the norms for the entire month. This similarity illustrates the importance that individual storm systems can have in influencing the monthly total. This is important because storms of this magnitude far outstrip the ability of the soil to take up the moisture, and can lead to devastating flooding. However, these totals pale in comparison to periodic events recorded along the Balcones escarpment to the south, where some of the highest hourly and daily rainfall totals in the world have been recorded in association with the influx of Gulf moisture (Kingston 1986; Bomar 1995).

Figure 1–7 illustrates the record of stream discharge collected by the United States Geological Survey for several of the moderate to large systems in the district. The average discharge over the period of record varies from approximately 14.5 cubic feet per second (cfs) on the North Bosque River at Stephenville to 1365 cfs on the Brazos River at Glen Rose. As might be expected, the larger streams such as the Brazos and Trinity rivers exhibit variable discharge with common large floods. Peak discharge over the period of record ranges from a relatively meager 4720 cfs in the North Bosque at Stephenville to quite impressive peaks, including 47,300 cfs

Figure 1-7: Plot of peak discharge (in cubic feet/second) on five different streams in the district during the period of record, based on USGS stream gage data.

in the West Fork of the Trinity at Fort Worth and 85,100 cfs in the Brazos River at the US 67 bridge east of Glen Rose.

When adjusted for the size of the contributing drainage basin, the average discharge of these very different rivers is much more comparable, ranging between 0.08 and 0.27 cfs per square mile of contributing basin. Using the same normalized measure, floods appear much more imposing in the smaller systems, where more of the drainage basin receives precipitation at the same time. For example, the largest flood recorded on the North Bosque at Stephenville appears much more imposing (49.17 cfs/mi²) than the largest flood on the Brazos at US 67 (5.24 cfs/mi²), while Big Sandy

Creek near Bridgeport is even more impressive, yielding a peak normalized discharge of approximately 71.5 cfs/mi².

One striking aspect of the record to those familiar with similar hydrological records in other parts of the state is the minimal influence that ongoing modifications to the water retention infrastructure over the course of the 20th century seems to have had on the magnitude of large floods. As dams and other flow control and retention structures are built in a watershed, they tend to alter the basic character of the hydrologic curve—floods have a lower magnitude and a longer duration, and base flow (the low water condition between floods) is often elevated as retained water is released. As Figure 1-7 illustrates, there is little evidence that this factor significantly decreased peak flow in the Brazos, even though two large reservoirs were installed during the period (Possum Kingdom in 1941 and Lake Granbury in 1969). However, while the magnitude of discharge was not strongly affected, there is clear evidence that modifications made to the Brazos and Trinity River channels in the urbanized settings of Glen Rose and Fort Worth, respectively, substantially changed the hydrology of the channels (Figure 1-8). Interestingly, the change apparent to the Brazos in Glen Rose (where the channel is apparently artificially confined between 1946 and 1956, thereby significantly increasing the elevation of the water surface at any given discharge) is diametrically opposed to the change apparent on the Trinity in Fort Worth (where the channel was enlarged, dramatically reducing the stage associated with any given flood discharge).

1.3 Geology and Physiography

Figure 1-9 illustrates the distribution of principal geologic units in the Fort Worth District, and Figure 1-10 illustrates a composite side-looking radar image illustrating its topography. The map is based on the most recent editions of the Geologic Atlas of Texas published by the University of Texas Bureau of Economic Geography (Barnes 1972; 1976; 1987; 1988; McGowen et al. 1991). Surface rocks in the district are dominated by Lower Cretaceous limestones, shales, and sandstones to the south and east, and diverse Pennsylvanian clastics and limestones to the northwest. The Pennsylvanian rocks include formations of the Cisco, Canyon, and Strawn Groups. They are exposed in Jack County, Palo Pinto County, western Wise County, extreme western Parker County, and northwestern Erath County. They represent areas where the Cretaceous beds that unconformably overlie the Pennsylvanian sequence have been stripped by stream erosion, exposing northeast-to-southwest trending outcrops of the older rocks. This area represents the eastern part of the Osage Plains or Low Rolling Plains, a subdivision of the Central Lowland physiographic region (Fenneman 1946). The rocks include a diverse suite of sandstones, shales, mudstones, limestones, and conglomerates, and dip relatively steeply to the

Figure 1-8: Plot of discharge (cfs) vs. stage height (ft) during peak events on four different streams during their respective periods of record. Note abrupt changes to this relationship at the West Fork Trinity and Brazos stations reflecting artificial channel modifications.

northwest. Differences in the hardness of these rocks has led to the formation of a series of *cuesta* landforms that range from subtle to relatively pronounced (see Figure 1-10). Economic deposits of importance include coal beds and clays, both of which tend to crop out in the valleys carved into the softer parts of the landscape.

The deposits of the Cisco, Canyon, and Strawn Groups were laid down on a low-gradient shelf between the Ouachita Mountains to the east and the Permian Basin to the west (Sellards 1932; Spearing 1991). Both the Ouachita mountains and the Permian Basin are relatively large structural features formed by tectonic processes and then largely obliterated by erosion and infilling during the Paleozoic. As the Ouachita

Mountains were gradually eroded from a massive range to a series of low, residual hills, streams carried the eroded material westward into the Permian Basin depocenter, depositing fluvial, deltaic, and marine sediments across the broad shelf under the influence of a constantly shifting shoreline. The oldest of these rocks exposed in the study area, the Strawn Group, consists of shale and sandstone with thin lentils of limestone and thin beds of coal, indicating an oscillating shoreline where rivers and deltas repeatedly yielded to the encroaching sea, only to build outward again. Organic beds that formed where thick vegetation was overwhelmed and buried by deltaic deposition gradually were converted to coal (such as the seams exploited at the historic community of Thurber) and to hydrocarbons.

Figure 1–9: *Geology of the Fort Worth District, adapted from the Geologic Atlas of Texas (Dallas, Sherman, Waco, Brownwood, Abilene, and Wichita Falls-Lawton sheets) (Bureau of Economic Geology, University of Texas).*

Figure 1-10: Surface texture map illustrating the Physiography of the Fort Worth District, developed from NASA composite Side-Looking Airborne Radar (SLAR) data.

The overlying Canyon Group is characterized by a more marine-dominated signature, including several thick limestones as well as interbedded shales. Sandstones and coal beds are rare, supporting the notion that marine conditions predominated during deposition of the group. With the subsequent Cisco Group, deposition again appears to have fluctuated repeatedly between marine and terrestrial as the shoreline oscillated. Rocks here range from muds and thin limestones to sandstones and conglomerates, with the deposits generally becoming finer-grained and less heterogeneous to the west. As a result of the frequent changes in the character of Pennsylvanian deposits, the character of soils and terrain also changes frequently. In such areas, the landscape varies from sandstones with deep soils to limestones with thin soils in areas far too small to capture effectively on geologic and

(to a lesser degree) soils maps, complicating the task of mapping the geoaerchological potential of the landscape.

The remainder of the district is overlain by a thick, unconformable suite of Cretaceous-age rocks, which were deposited on an erosional surface marking the top of the Pennsylvanian sequence and are associated with the proto-Gulf of Mexico to the southeast. Because these deposits dip gently east and have been laterally eroded from the west, they are exposed in a series of roughly north-south oriented bands that are the youngest (late Cretaceous) in eastern Johnson and Tarrant County and get progressively older to the west. Although this arrangement is less spatially variable than the underlying Paleozoic rocks, it also includes interdigitated limestones and sandstones that strongly influence the character of soils and vegetation, the rate and character of denudation processes, and the potential for site preservation. The southern part of the district, which is underlain primarily by Lower Cretaceous rocks, is mapped within the Central Texas Section of the Great Plains Province, while the extreme eastern edge is underlain by

upper Cretaceous rocks and mapped within the Western Gulf Coast Section of the Coastal Plain physiographic province (Fenneman 1946).

1.4 Soils

In general, soil properties reflect the interaction of five soil-forming factors: (1) climate; (2) organisms; (3) relief; (4) parent material; and (5) time (Jenny 1941). The spatial variability of soils in the Fort Worth District is primarily a function of the texture and chemical properties of the parent material, the length of the soil forming interval, and the nature of relief (slope and aspect), tempered by factors such as vegetation type, degree of bioturbation, depth to water table, surface drainage characteristics, and historic and modern land use. Although

changes in climate over the long term have strongly influenced the trajectory of pedogenesis, so that very old soils exhibit starkly different properties than are currently developing, the spatial influence of climate is secondary because the Fort Worth District is too small to exhibit strong climatic gradients. However, there are subtle differences in the soil system attributable to the general east–west moisture gradient.

In the United States, soils are typically classified according to the official USDA *Soil Taxonomy* (Soil Survey Staff 1975; 1999) classification system. *Soil Taxonomy* is a complex, hierarchical system based on interrelationships between soil properties. Although *Soil Taxonomy* is not a genetic classification *per se*, the relationship between soil properties and pedogenic processes is such that the classification of a soil is strongly related to its origin and history. Twelve soil orders (Alfisols, Andisols, Aridisols, Entisols, Histosols, Gelisols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols) are recognized in the most recent version of the system (Soil Survey Staff 1999), but only five (Entisols, Inceptisols, Mollisols, Alfisols, and Vertisols) are represented in the Fort Worth District. Soil orders are subdivided successively into Suborders, Great Groups, Subgroups, Families, and Soil Series, with each class representing soils grouped on more narrowly focused criteria than its parent class. The dynamic nature of the *Soil Taxonomy* is illustrated by increases in the total number of classifications at each level of the hierarchy between the 1975 and 1999 editions. For example, the 1975 edition recognized 185 Great Groups and approximately 10,500 Series, while the 1999 edition recognizes more than 300 Great Groups and 19,000 Series (Soil Survey Staff 1975; 1999).

Soil mapping in the United States is performed by the Natural Resource Conservation Service (formerly Soil Conservation Service), a division of the United States Department of Agriculture. Because soil classification involves imposing categories on a complex, gradational phenomenon, appropriate mapping resolution is scale-dependent, and

the USDA–NRCS has compiled soils data at three different levels of detail. These are, in order of increasing resolution, the National Soil Geographic (NATSGO) data base (mapped at 1:7,500,000) the State Soil Geographic (STATSGO) data base (mapped at 1:250,000, and the Soil Survey Geographic (SSURGO) database (mapping resolution varies between approximately 1:31,680 and 1:12,000). As of 2008, all of Texas has been mapped at the two coarser scales, and most of the state (and all of the Fort Worth District) is available in the most detailed format, which is comparable to the old county soil survey books produced by the Soil Conservation Service. Figure 1–11 illustrates the mapped distribution of soils in the Fort Worth District according to the Statewide (STATSGO) map. Table 1–1 lists pertinent data for each soil series reported in the district, including counties where

Figure 1–11: Generalized distribution of soils in the Fort Worth District, based on USDA STATSGO mapping data.

Table 1-1: Soils of the Fort Worth District, Compiled from Available USDA-SCS Soil Surveys

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Aledo	Mollisols	Lithic Calcistoll	X	X	X	X		X	X	upland	hard, fractured limestone	A1-Ak-R	8-20		low	low
Altoga	Inceptisols	Udic Haplustept	X		X		X			upland/high terrace	ancient alluvium	Ap-Bk1-Bk2-Bck	35-65		low-moderate	low-moderate
Anrocon	Mollisols	Udic Argiustoll	X	X					X	upland	loamy upland sediment	A-Bt1-Bt2-BCt	60-80	mottled subsoil	low-moderate	low
Apalo	Inceptisols	Udic Haplustept						X		high terrace	stratified alluvium	Ap-A-Bw1-Bw2-Bk	>60	stage I/II calcic horizon	high	high
Aquilla	Alfisols	Lamellic Paleustalf			X					upland/high terrace	ancient sandy alluvium	Ap-A-Bw-E&Bt1-E&Bt2-2Bt-2C	70-90+	lamellae; eolian colluvial reworking possible	moderate	moderate
Arenosa	Entisols	Typic Quartzipsamment					X			upland	loose sand	A-C1-C2-C3-C4	<10	eolian parent material?	high	high
Aubrey	Ultisols	Typic Haplustult			X					upland	acid shale w/ thin sandstone interbeds	A-Bt1-Bt2-Ck	20-40		low	low
Balsora	Entisols	Typic Ustifluvent		X						floodplain	recent loamy alluvium	Ap-C1-C2-Ab	12	buried soil common	very high	very high
Bastrop	Alfisols	Udic Paleustalf	X			X		X	X	high terrace	older loamy alluvium	A1-A2-Bt1-Bt2-Bt3-Bt4-Bck	60-80	upto 15% siliceous pebbles	moderate	moderate
Bastil	Alfisols	Udic Paleustalf		X	X				X	upland/high terrace	ancient loamy alluvium	A-E-Bt1-Bt2-Bt3-Bt/E	60-80+	gleyed/depleted ped faces at base of profile; possible eolian/colluvial component	moderate	low-moderate
Birome	Alfisols	Ultic Paleustalf	X		X					upland	weakly cemented sandstone	A-E-Bt1-Bt2-Bt3-Cr	20-40		low-moderate	low
Blanket	Mollisols	Pachic Argiustoll		X		X	X	X	X	upland/high terrace/toeslope	ancient alluvium or interbedded marls & clays	Ap-A-Bt1-Bt2-Bk-Bck	40-80	stage I or II calcic horizon	moderate	low
Bluegrove	Alfisols	Typic Haplustalfs							X	gently sloping to sloping uplands	sandstone and shale residuum	A-Bt1-Bt2-Cr	34		low	low
Bolar	Mollisols	Udic Calcistoll	X	X	X				X	upland	interbedded limestone and marl	Ap-A-Bk1-Bk2-Bk3	20-40	stage II or III calcic horizon	low	low
Bonti	Alfisols	Ultic Paleustalf		X		X	X	X	X	upland	sandstone	A-E-Bt1-Bt2-R	20-40	up to 15% sandstone fragments in epipedon	low-moderate	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Brackett	Vertisols	Typic Haplustert	X	X	X	X	X	X	X	upland	interbedded limestone and marl	A-Bw-Cr	10-20		low	low
Branyon	Vertisols	Udic Haplustert			X					upland/high terrace	clayey, alkaline alluvium	Ap-A-Bss1-Bss2-Bkss	66-100+	Gilgai	low	low
Bunyan	Entisols	Typic Ustifluvent				X	X	X	X	floodplain	stratified recent alluvium	Ap-A1-C1-C2-C3-C4	<20	expression of stratification varies	high	high
Burfeson	Vertisols	Udic Haplustert	X		X					upland/high terrace	ancient clayey alluvium	A1-A2-Bss1-Bss2-Bss3-Bss4-2BCKss	60+	soil cracks, gilgai	low	low
Callisburg	Alfisols	Udic Paleustalf	X							upland	clay or shale	Ap-B2t1-Bt1-B2-B3-Bw	60-80	stage II calcic horizon	low	low
Chaney	Alfisols	Oxyaquic Paleustalf		X		X	X	X	X	upland	sandy upland sediment	A-E-Bt1-Bt2-BC1-BC2-C	40-60	mottled subsoil-possible eolian/colluvial component	moderate	low
Chatt	Mollisols	Vertic Calcistoll			X					stream terrace	loamy, carbonate-rich alluvium	A1-A2-Bw1-Bw2-Bk1-Bk2	60+		moderate-high	moderate-high
Cisco	Alfisols	Typic Haplustalf		X						upland	loamy sediment	Ap-B1t-B2t-BC1-BCK	40-70	occasional siliceous pebbles	low-moderate	low
Cona	Alfisols	Udic Paleustalf		X		X			X	upland	shaly clay or weakly cemented sandstone	A-E-Bt1-Bt2-BC1-C	20-40	contains sandstone clasts-possible eolian/colluvial component	low-moderate	low
Coarsewood	Entisols	Udic Ustifluvent				X				level floodplain	loamy alluvium	Ap-Bw1-Bw2-C1-C2	40-60	faint stratification; occasional weak carbonate filaments	very high	very high
Coving	Alfisols	Aquic Arenic Paleustalf	X							upland	eoian sediment	Ap-A2-B2t1-B2t2-B3	60-80+		moderate-high	moderate-high
Crawford	Vertisols	Leptic Udic Haplustert					X			upland	limestone	Ap-A-Bss1-Bss2-R	30-33	gilgai; soil cracks	low	low
Crosstell	Alfisols	Udic Paleustalf	X		X					upland	shale/clay w/ thin sandstone interbeds	A-Bt1-Bt2-Bt3-BC1-C1-C2	40-60		low	low
Culp	Mollisols	Vertic Argistoll	X							upland	loamy and clayey sediments	Ap-Bt1-Bt2-Bw-Bk-C	50-80+		low	low
Damell	Inceptisols	Udic Haplustept		X					X	upland	thick-bedded sandstone	A-Bw-Cr	10-20		low-moderate	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Deleon*	Mollisols	Udentic Haplustoll	X							floodplain	recent alkaline, clayey alluvium	Ap-A1-A2-Ak-Ab	>60	soil cracks, buried soils, stage I/II calcic horizon	high	high
Demona*	Alfisols	Aquic Arenic Paleustalf				X	X	X	X	upland	sandy sediments	A-E-Bt1-Bt2-BC-C	56-64	siliceous pebbles; mottled subsoil; possible eolian/colluvial component	low-moderate	low
Denton	Mollisols	Udic Calcistoll	X		X	X	X	X	X	upland	clay colluvium over interbedded limestone & marl	Ap-A-Bw-2Bk-2CBk-2R	12-40	stage I calcic horizon	low-moderate	low-moderate
Duffau	Alfisols	Udic Paleustalf	X	X	X	X	X	X	X	upland	loamy sediment or weakly cemented sandstone	Ap-E-Bt1-Bt2-Bt3-BC	60-80+	sometimes gullied-possible eolian/colluvial component	low-moderate	low
Dugout	Inceptisols	Lithic Haplustept					X			upland	indurated limestone	A-Bk-R	18-20	may be stony	low	low
Eufaula	Alfisols	Psammentic Paleustalf					X	X		stream terrace	eolian sediment on terraces	Ap-E1-E2&Bt	80+	pronounced clay lamellae	high	high
Exray	Alfisols	Lithic Rhodustalf		X			X	X	X	upland	indurated sandstone	A-E-Bt-R	14-20	stony	low-moderate	low
Ferris	Vertisols	Udic Haplustert	X		X					upland	calcareous marine clays and shales	Ap-Bw-Bss-Ck	34-60		low	low
Frio	Mollisols	Cumulic Haplustoll	X	X	X	X	X	X	X	floodplain	recent calcareous alluvium	A1-A2-A3-A4-Bk	25-60		very high	very high
Gaddy	Entisols	Udic Ustifluent	X				X	X	X	floodplain	sandy alluvium	Ap-C1-C2	>20		high	high
Gasil	Alfisols	Ulitic Paleustalf	X	X	X					upland	interbedded sandstone and loamy strata	Ap-E-Bt1-Bt2-Bt3	60-100+	possible eolian/colluvial component	moderate	low
Gowen	Mollisols	Cumulic Haplustoll	X				X			floodplain	recent sandy to clayey alluvium	A1-A2-Bw	30		high	high
Harpersville	Entisols	Aridic Ustorthents				X				upland	upland ridges and slopes	A-Cd1-Cd2	3-14	dense subsoil; some gypsum may occur	low	low
Hassee	Alfisols	Aquic Paleustalf	X	X		X		X	X	upland	alkaline clays	Ap-A-E-Bt1-Bt2-Bt3-Bt4-Btk2-Bck1-Bck2	40-72	stage II calcic horizon; possible eolian/colluvial component	low-moderate	low-moderate
Heaton	Alfisols	Arenic Paleustalf		X		X				upland	loamy sediments on hard, fractured limestone	Ap-E-Bt1-Bt2-Bt3-Bt4	60-80+	E horizon; some siliceous and ironstone pebbles; potential for eolian reworking	moderate	moderate
Heiden	Vertisols	Udic Haplustert	X		X					upland	alkaline marine clay and weathered shale	Ap-A-Bssk1-Bssk2-C	55-70	gilgai, soil cracks	low	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Houston Black	Vertisols	Udic Haplustert	X		X					upland	alkaline marine clay and weathered shale	A1-A2-Bss-Bssk1-Bssk2	60-80+	gilgai, soil cracks	low	low
Jacksboro	Alfisols	Lithic Haplustalfs							X	gently sloping upland	indurated conglomerates and sandstones	A-E-Bt-R	18	E horizon contains 35% gravel	low-moderate	low
Justin	Mollisols	Udic Paleustoll		X						upland	clayey and loamy sediment	Ap-A1-Bt1-Bt2-Bt3	60-70+	gilgai, soil cracks	low	low
Kamay	Alfisols	Typic Paleustalfs							X	level upland	Permian redbeds	A-Bt1-Bt2-Btk-Bt1'-Bt2'	60-80+	stage II calcic horizon	low	low
Keeter	Alfisols	Udic Haplustalf		X					X	upland	stratified sandstone w/ loamy or shaly interbeds	A-E-Bt1-Bt2-Bt3-Bt3'-C1-C2	20-40		low-moderate	low
Konsil	Alfisols	Ultic Paleustalf			X					upland	unconsolidated loamy sediment	A1-A2-Bt1-Bt2-Bt3-Cr	60-100		moderate	moderate
Krum	Mollisols	Udertic Haplustoll				X			X	upland	alkaline shale and clay	Ap-A-Bw-Bk1-Bk2	49-70+	gilgai, soil cracks	moderate-high	moderate-high
Lamar	Inceptisols	Typic Haplustept				X				upland	loamy calcareous sediment	A-Bw-Bk-Ck	20-50	stage II calcic horizon	low-moderate	low
Leeray	Vertisols	Typic Haplustert					X			upland	calcareous clay	A1-A2-Bss1-Bss2-Bkss1-Bkss2-Bk1-Bk2-2BCKss	40-80+	gilgai, soil cracks	low	low
Leson	Vertisols	Udic Haplustert			X					upland	alkaline shale and clay	Ap-Bss-Bkss-Ck	49-70	gilgai, soil cracks	low	low
Lewisville	Mollisols	Udic Calcistoll					X			terrace and toeslope	loamy to clayey alluvium and colluvium	Ap-A-Bk1-Bk2	42	stage I calcic horizon	high	high
Lindale	Alfisols	Typic Haplustalf	X		X					upland	limestone rubble and marine clay	A-Bt1-Bt2-Bk-Ck1-Ck2	20-40	ironstone fragments	low	low
Lindy	Alfisols	Udic Haplustalf		X			X			upland	thick-bedded, indurated limestone	Ap-A-Bt1-Bt2-R	20-40		low	low
Lott	Mollisols	Udorthentic Haplustoll	X		X					upland	carbonate rich marly silty clay or chalky marl	Ap-A-Bw-Bk-Ck	40-44		low-moderate	low-moderate
Luckenbach	Mollisols	Typic Argiustoll	X		X					upland/high terrace	ancient alkaline loamy alluvium	Ap-A-Bt-Btk-Bk1-Bk2	44-60		moderate-high	low-moderate
Mabank	Alfisols	Oxyaquic Vertic Paleustalf			X					upland	clayey marine sediment	Ap-Btg-Btssg1-Btssg2-Btyg1-Btyg2	60-80	subsoil cracks	low	low
Malotierre	Entisols	Lithic Ustorthent			X				X	upland	indurated limestone	A-R	3-10		low	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Houston Black	Vertisols	Udic Haplustert	X		X		X			upland	alkaline marine clay and weathered shale	A1-A2-Bss-Bssk1-Bssk2	60-80+	gilgai, soil cracks	low	low
Jacksboro	Alfisols	Lithic Haplustalfs							X	gently sloping upland	indurated conglomerates and sandstones	A-E-Bt-R	18	E horizon contains 35% gravel	low-moderate	low
Justin	Mollisols	Udic Paleustoll			X					upland	clayey and loamy sediment	Ap-A1-Bt1-Bt2-Bt3	60-70+	gilgai, soil cracks	low	low
Kamay	Alfisols	Typic Paleustalfs							X	level upland	Permian redbeds	A-Bt1-Bt2-Bk-Bt1'-Bt2'	60-80+	stage II calcic horizon	low	low
Keeter	Alfisols	Udic Haplustalf	X					X		upland	stratified sandstone w/ loamy or shaly interbeds	A-E-Bt1-Bt2-Bt3-BC-C1-C2	20-40		low-moderate	low
Konsil	Alfisols	Utic Paleustalf			X					upland	unconsolidated loamy sediment	A1-A2-Bt1-Bt2-Bt3-Cr	60-100		moderate	moderate
Krum	Mollisols	Udertic Haplustoll	X		X	X			X	upland	alkaline shale and clay	Ap-A-Bw-Bk1-Bk2	49-70+	gilgai, soil cracks	moderate-high	moderate-high
Lamar	Inceptisols	Typic Haplustept			X	X	X			upland	loamy calcareous sediment	A-Bw-Bk-Ck	20-50	stage II calcic horizon	low-moderate	low
Leeray	Vertisols	Typic Haplustert					X			upland	calcareous clay	A1-A2-Bss1-Bss2-Bkss1-Bkss2-Bk1-Bk2-2BCKss	40-80+	gilgai, soil cracks	low	low
Leson	Vertisols	Udic Haplustert			X					upland	alkaline shale and clay	Ap-Bss-Bkss-Ck	49-70	gilgai, soil cracks	low	low
Lewisville	Mollisols	Udic Calcistoll	X				X			terrace and toeslope	loamy to clayey alluvium and colluvium	Ap-A-Bk1-Bk2	42	stage I calcic horizon	high	high
Lindale	Alfisols	Typic Haplustalf	X		X					upland	limestone rubble and marine clay	A-Bt1-Bt2-Bk-Ck1-Ck2	20-40	ironstone fragments	low	low
Lindy	Alfisols	Udic Haplustalf		X		X	X			upland	thick-bedded, indurated limestone	Ap-A-Bt1-Bt2-R	20-40		low	low
Lott	Mollisols	Udorthentic Haplustoll	X		X					upland	carbonate rich marly silty clay or chalky marl	Ap-A-Bw-Bk-Ck	40-44		low-moderate	low-moderate
Luckenbach	Mollisols	Typic Argiustoll	X		X					upland/high terrace	ancient alkaline loamy alluvium	Ap-A-Bt-Bk-Bk1-Bk2	44-60		moderate-high	low-moderate
Mabank	Alfisols	Oxyaquic Vertic Paleustalf			X					upland	clayey marine sediment	Ap-Btg-Btsg1-Btsg2-Btyg1-Btyg2	60-80	subsoil cracks	low	low
Malotierre	Entisols	Lithic Ustorthent			X	X	X		X	upland	indurated limestone	A-R	3-10		low	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Mingo	Mollisols	Pachic Argiustalf		X	X					upland	bedded platy limestone and marl	Ap-A-Bt1-Bt2	22-40		low	low
Minwells	Alfisols	Udic Paleustalf	X				X	X		high terrace	ancient loamy alluvium	Ap-Bt1-Bt2-Bt3-Bk1-Bk2-2Ck1-2Ck2	80+	stage II/III calcic horizon	low-moderate	low
Navo	Alfisols	Udertic Paleustalf	X		X					upland	alkaline clayey marine sediment	A-Bt1-Bt2-Bt3-Bt4-B3	60-80+	subsoil cracks	low	low
Nimrod	Alfisols	Aquic Arenic Paleustalf		X	X	X			X	upland	sandy and loamy sediment	A-E-Bt1-Bt2-Bt3-BC	60-80+	possible eolian/colluvial component; depth to Bt horizon 27 inches	moderate	low-moderate
Ovan	Vertisols	Udic Haplustert			X					floodplain	recent clayey alluvium	Ap-A-Bss-Bkss	60-80	soil cracks	moderate	low
Owens	Inceptisols	Typic Haplustept		X		X	X	X		upland	shale/clay	A-Bw-C	14-30	stony; stage II calcic horizon	low	low
Palopinto	Mollisols	Lithic Haplustoll		X			X	X		upland	limestone	A1-A2-R	6-20	very stony (35-85% limestone)	low	low
Paluxy	Inceptisols	Udic Ustochrept	X						X	stream terrace	loamy eolian or alluvial sediment	Ap-Bw1-Bw2-C	36-80	few siliceous pebbles	high	high
Patilo	Alfisols	Grossarenic Paleustalf		X		X	X		X	upland	thick, loamy and sandy sediment	A-E-Bt1-Bt2	>80	A-E sequence commonly >72 inches thick; probable eolian/colluvial component	high	high
Pedernales	Alfisols	Typic Paleustalf						X		upland	sandy loam, sandy clay loam, or clay	Ap-Bt1-Bt2-Btk-BCtk	35-60	stage II calcic horizon	low-moderate	low
Ponder	Alfisols	Vertic Haplustalf	X	X	X					upland	loamy, calcareous marine sediment	Ap-Bt1-Bt2-Bt3-Bck1-Bck2	60-80+	soil cracks; gilgai	low	low
Pulexas	Entisols	Typic Ustifluvent	X	X	X				X	floodplain	recent loamy alluvium	A-C1-C2-C3	>60	preserved stratification	very high	very high
Pursley	Mollisols	Fluventic Haplustoll	X							floodplain	recent loamy calcareous sediment	A-Bw-C-Ck-C'	<50	stage I/II calcic horizon	very high	very high
Purves*	Mollisols	Lithic Calciustoll	X	X	X	X			X	upland	interbedded marl and fractured limestone	A-Ak-Bk-R	8-20		low	low
Rader*	Alfisols	Aquic Paleustalf	X							upland/high terrace	older loamy and clayey alluvium	A-E1-E2-Bt/E-Bt1-Bt2-Bt3-BC	>60	common redox mottles	moderate	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/ Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Rowden	Mollisols	Typic Argiustolls								level upland	hard limestone	Ap-Bt1-Bt2-R	27	secondary carbonate common in fractures of R horizon	low	low
San Saba	Vertisols	Udic Haplustert		X						upland	clayey sediment over limestone	Ap-A-Bss-R	24-40	gilgai, soil cracks	low	low
Sanger	Vertisols	Udic Haplustert	X	X						upland	alkaline marine clay	Ap-A-Bkss-Bk-C	40-70	gilgai, soil cracks	low	low
Santo	Entisols	Typic Ustifluvent						X		floodplain	recent stratified, calcareous loamy alluvium	A-C1-C2-C3-C4-C5	<12		high	high
Seawillow	Inceptisols	Udic Haplustept	X						X	upland/minor drainage	calcareous loamy alluvium	Ap-Bk1-Bk2-Bk3-BkC	20-40	stage II calcic horizon	low-moderate	low-moderate
Selden	Alfisols	Aquic Paleustalf		X	X	X				upland	loamy sediment	Ap-E-Bt1-Bt2-Cr1-Cr2	60-80	redox mottles	low-moderate	low-moderate
Set	Mollisols	Typic Calcistoll		X				X		upland	clayey or loamy colluvium on clay or shale	A-B1k-B2k-Bk-C	40-60	stony, stage II calcic horizon	low	low
Shatruce	Alfisols	Typic Paleustalf						X		upland	shale regolith	A-E-Bt1-Bt2-BC-C	20-40	stony, stage II calcic horizon	low	low
Shavash	Alfisols	Lithic Haplustalf						X		upland	Pennsylvanian sandstone	A1-A2-Bt1-R	10-20	stony, stage II calcic horizon	low-moderate	low
Ships	Vertisols	Chromic Hapludert				X				floodplain	recent stratified clayey alluvium	Ap-A-Bss1-Bss2-Bkss	40-60+	gilgai	moderate	moderate
Silawa*	Alfisols	Ultic Haplustalf		X						upland/high terrace	ancient sandy/loamy alluvium	Ap-E-Bt-Bt-C	40-72+	common siliceous and ironstone pebbles	low-moderate	low
Silstid	Alfisols	Arenic Paleustalf	X		X					upland/high terrace	loamy sediment	A-E-Bt1-Bt2-Bt3	60-75+	mottled subsoil; relatively thick E horizon	moderate-high	low-moderate
Slidell	Vertisols	Udic Haplustert	X	X						upland	alkaline marine sediment	Ap-A-Bss-Bssk1-Bssk2-Bssk3	60-80+	gilgai, soil cracks	low	low
Somervell	Mollisols	Typic Calcistoll		X			X			upland	interbedded fossiliferous limestone & marl	A-Bk-R	20-40	stage II calcic horizon	low	low
Speck*	Mollisols	Lithic Argiustoll		X						upland	clay weathered from limestone	A-Bt-R	14-20		low	low
Stephenville*	Alfisols	Ultic Haplustalf							X	upland	weakly cemented sandstone	A-E-Bt1-Bt2-Cr1-Cr2	20-40	possible eolian/colluvial component	moderate	low
Sunev	Mollisols	Udic Calcistoll	X		X				X	upland	loamy colluvium and high terrace alluvium	Ap-A-Bk1-Bk2-Bk3	40-70	up to 15% siliceous and limestone pebbles	moderate	moderate
Tarrant	Mollisols	Lithic Calcistoll							X	upland	indurated, fractured limestone	A-Ak-R	6-20		low	low

Table 1-1: Continued...

Series	Soil Order	Subfamily	Johnson CO	Wise CO	Tarrant CO	Parker CO	Erath CO	Palo Pinto CO	Hood/ Sommervell CO	Topographic Position	Parent Material	Typical Profile	Thickness of Solum (in.)	Comments	Apparent Georcheological Potential (<1 m)	Apparent Georcheological Potential (>1 m)
Treadway	Inceptisols	Typic Haplustepts								toeslope	Permian redbeds	A-Bw-C	21	can contain buried A horizons	moderate	moderate
Trinity	Vertisols	Typic Hapludert		X			X			floodplain	recent clayey alluvium	Ap-A-Bss1- Bss2-Bss3	60-75	soil cracks, gilgai	moderate	moderate
Truce	Alfisols	Udic Paleustalf		X		X	X	X	X	upland	weathered shale and sandstone	A-E-Bt1-Bt2- Bt-Cd	40-60	sandstone fragments up to 25% in A	low-moderate	low
Vashti	Alfisols	Aquic Haplustalf					X	X		upland	sandstone	A1-A2-B2t1- B2t2-R	40	may be stony	low-moderate	low
Velow	Mollisols	Typic Haplustoll						X		upland	limestone regolith	A-Bw-Bk1- Bk2	40-70	stage I/II calcic horizon	moderate	moderate
Venus	Mollisols	Udic Calcistoll		X		X	X		X	floodplain	unconsolidated loamy upland sediment	Ap-A-Bk1- Bk2-Bk3	40-70	stage I/II calcic horizon	high	high
Vernon	Inceptisols	Typic Haplustepts		X						upland	calcareous clay loam	A-Bk-Cd-Cr	20-40	stage II calcic horizon	low	low
Waurika	Mollisols	Vertic Argioboll					X			upland	calcareous clay loam	Ap-A-E-Btss- Btk-C	50		low-moderate	low
Weatherford	Alfisols	Ultic Haplustalf		X		X				upland	weakly cemented to uncemented sandstone	A-E-Bt1- Bt2-C	40-60	possible eolian/ colluvial component	low-moderate	low
Westfork	Mollisols	Cumulic Haplustoll		X						floodplain	recent silty clay alluvium	A1-A2-A3- A4-Bk-Bk3	>60	buried soil; stage I calcic horizon	high	high
Weswood	Inceptisols	Udifuventic Haplustepts				X				floodplain	loamy alluvium	Ap-Bw1-Bw2- Bk2-2Bwb1- 2Bwb2- 2Bwb3-3Ab- 4Ab	60-80+	stratified; buried paleosol	very high	very high
Whitesboro	Mollisols	Cumulic Haplustoll				X				floodplain	loamy alluvium	A1-A2-Bw1- Bw2	40-60+		high	high
Wichita*	Alfisols	Typic Paleustalf					X			high terrace	ancient clayey or loamy alluvium	Ap-A-Bt1- Bt2-Btk-C	60+	stage II calcic horizon	low	low
Wilson	Alfisols	Oxyaquic Vertic Haplustalfs		X						upland	clay	Ap-Bt- Btssg1- Btssg2-Btkss	60+	soil cracks	low	low
Windthorst	Alfisols	Udic Paleustalf		X		X	X	X	X	upland	loamy and clayey material grading to packsand	A-E-Bt1-Bt2- BC-C1-C2	35-60	mottled subsoil; potential for eolian/colluvial component	low-moderate	low
Winters	Alfisols	Typic Paleustalfs							X	upland/high terrace	loamy to clayey ancient alluvium	Ap-Bt1-Bt2- Bt3-Btk-Bt	60+	stage II calcic horizon	low-moderate	low
Wise	Inceptisols	Udic Haplustepts		X						erosional upland	stratified loamy and shaly marine sediment	A-Bw-Bk-C	20-40	stage I/II calcic horizon	low-moderate	low
Yahola	Entisols	Typic Ustifluvent						X	X	floodplain	deep loamy alluvium	A-C1-C2-C3	<20	buried soils may occur below 30 inches	very high	very high

it is present, characteristic topographic position and parent material, typical profile, approximate solum thickness, and specific comments. These data are based on the SSURGO database. One hundred twenty-four (124) distinct series are mapped in the district. The classified soils represent six soil orders: Entisols (8%), Mollisols (25%), Vertisols (15%), Alfisols (41%), Ultisols (0.8%), and Inceptisols (10%). In very general terms, the Mollisols and Vertisols are typical of the Cretaceous limestones and marls (and older alluvium derived from them), while the Alfisols are typical of the Pennsylvanian rocks and Cretaceous sandstones (and older alluvial and eolian deposits derived from them), and the Entisols and Inceptisols represent soils developed on recent deposits or in eroding upland settings. The distribution of Vertisols is almost entirely dependent on parent lithology (i.e., limestone that weathers to produce smectitic clays). Although only sixteen of the soil series are classified as Vertisols, strong vertic properties are also indicated for seven Mollisol series and four Alfisol series.

1.5 Vegetation and Fauna

Modern vegetation and fauna in the Fort Worth District reflects the transition from the humid east to the semiarid west, tempered by edaphic conditions and the distribution of urban and agricultural areas, surface water, and patterns of artificial clearing and planting during the historic period. Important natural plant communities and their characteristic taxa are presented in Table 1–2, and the relationship between these natural “vegetation types” (after McMahan et al. 1984) and Texas natural regions (as mapped by the Texas Natural Resource Information System, or TNRIS) is presented in Table 1–3 and Figure 1–12. Important faunal species are listed in Table 1–4. The characteristics of important natural regions in the Fort Worth District are described in more detail below. The discussion is organized around the five natural regions represented in the district, as defined by Texas Parks and Wildlife’s GIS coverage of Texas natural regions, which is in turn adapted from a classification developed by

Table 1–2: Representative Vegetation of the Fort Worth District

Taxon	Common Name	Ashe Juniper Parks/ Woods	Live Oak–Ashe Juniper Parks	Live Oak–Mesquite–Ashe Juniper Parks	Mesquite–Lotebush Shrub	Oak–Mesquite–Juniper Parks/ Woods	Post Oak Parks/ Woods	Post Oak Woods, Forest, and Grassland Mosaic	Silver Bluestem–Texas Wintergrass Grassland
<i>Ambrosia cumanensis</i> (<i>A. psilostachya</i>)	western ragweed								
<i>Aristida purpurea</i> (<i>A. longisetata</i>)	purple three-awn								
<i>Aristida roemeriana</i>	Roemer three-awn								
<i>Aristida</i> spp.	red three-awn								
<i>Berchemia scandens</i>	supplejack								
<i>Bignonia</i> sp.	trumpet creeper								
<i>Bothriochloa barbinodis</i>	cane bluestem								
<i>Bothriochloa laguroides</i> ssp. <i>Torreyana</i> and <i>Bothriochloa longipaniculata</i> (<i>B. saccaroides</i>)	silver bluestem								
<i>Bouteloua curtipendula</i>	sideoats grama								
<i>Bouteloua hirsuta</i>	hairy grama								
<i>Bouteloua rigidiseta</i>	Texas grama								
<i>Bouteloua trifida</i>	red grama								
<i>Buchloe dactyloides</i>	buffalograss								
<i>Callicarpa americana</i>	American beautyberry								
<i>Carex planostachys</i>	cedar sedge								
<i>Carya texana</i>	black hickory								
<i>Celtis</i> spp.	hackberry								
<i>Chasmanthium sessiliflorum</i>	spranglegrass								
<i>Chloris verticillata</i>	windmillgrass								
<i>Crataegus</i> spp.	hawthorn								
<i>Desmodium</i> spp.	tickclover								
<i>Diospyros palmeri</i>	Mexican persimmon								
<i>Engelmannia pinnatifida</i>	Engelmann daisy								
<i>Eragrostis trichodes</i>	sand lovegrass								
<i>Erioneuron pilosum</i> (<i>Tridens pilosus</i>)	hairy tridens								

Table 1–2: Continued...

Taxon	Common Name	Ashe Juniper Parks/ Woods	Live Oak–Ashe Juniper Parks	Live Oak– Mesquite– Ashe Juniper Parks	Mesquite– Lotebush Shrub	Oak– Mesquite– Juniper Parks/ Woods	Post Oak Parks/ Woods	Post Oak Woods, Forest, and Grassland Mosaic	Silver Bluestem– Texas Wintergrass Grassland
<i>Forestiera pubescens</i>	elbowbush								
<i>Gutierrezia</i> spp. (<i>Xanthocephalum</i> spp.)	broom snakeweed								
<i>Hilaria mutica</i>	tobosa								
<i>Hymenoxys</i> spp.	bitterweed								
<i>Ilex vomitoria</i>	yaupon								
<i>Juniperus ashei</i>	Ashe juniper								
<i>Juniperus</i> spp.	juniper								
<i>Juniperus virginiana</i>	eastern redcedar								
<i>Lupinus texensis</i>	Texas bluebonnet								
<i>Mahonia trifoliolata</i> (<i>Berberis trifoliolata</i>)	agarito								
<i>Opuntia leptocaulis</i>	tasajillo								
<i>Opuntia lindheimeri</i> (<i>O. engelmanni</i>)	Texas pricklypear								
<i>Panicum hallii</i> var. <i>hallii</i>	Hall's panicum								
<i>Prosopis</i> spp.	mesquite								
<i>Psoralea</i> spp.	scurfpea								
<i>Quercus buckleyi</i> (<i>Q. texana</i>)	Texas oak								
<i>Quercus durandii</i> var. <i>breviloba</i>	shin oak								
<i>Quercus incana</i>	sandjack oak								
<i>Quercus marilandica</i>	blackjack oak								
<i>Quercus stellata</i>	post oak								
<i>Quercus virginiana</i>	live oak								
<i>Rhus aromatica</i> (<i>Rhus trilobata</i>)	skunkbush sumac								
<i>Rhus</i> spp.	sumacs								
<i>Rhus</i> spp.	sumac								
<i>Rubus trivialis</i>	dewberry								
<i>Sapinus saponaria</i> var. <i>drummondii</i>	western soapberry								
<i>Schedonnardus paniculatus</i>	tumblegrass								
<i>Schizachyrium scoparium</i> var. <i>frequens</i>	little bluestem								
<i>Senna roemeriana</i>	two-leaved senna								
<i>Smilax</i> spp.	greenbriar								
<i>Sporobolus aster</i> var. <i>aster</i>	tall dropseed								
<i>Sporobolus cryptandrus</i>	sand dropseed								
<i>Stipa leucotricha</i>	Texas wintergrass								
<i>Symphoricarpos orbiculatus</i>	coral-berry								
<i>Toxicodendron diversilobum</i>	poison oak								
<i>Ulmus crassifolia</i>	cedar elm								

an interdisciplinary conference held at Winedale, Texas, and published by the LBJ School of Public Affairs (1978). Principal resources used in this summary include McMahan et al. (1984), Bezanson (2000), Schmidly (2002), Vines (1982), and Bailey (1905; as reprinted in Schmidly 2002).

(1) *Blackland Prairies*. This natural region includes the Blackland Prairie proper, which lies to the east of the Eastern

Cross Timbers, and the slightly drier Grand Prairie, which lies between the Eastern and Western Cross Timbers. Both are dominated by rich grasslands underlain by dark, calcareous clay soils—often termed black “waxy” soils or black “gumbo” soils—developed primarily in upper Cretaceous marls and clays. The area of the Blackland Prairie subregion is limited in the Fort Worth District, but the Grand Prairie subregion occurs as a thick swath that cuts north–south through the east–central part of the district.

Table 1–3: Correlation between Mapped Vegetation Zones and Natural Regions

Vegetation Types (TPWD)	Natural Regions (TNRIS)					
	Blackland Prairie	Eastern Cross Timbers	Grand Prairie	Mesquite Plains	Western Cross Timbers	Total
	Ashe Juniper Parks/Woods			911 (18%)	22 (<1%)	933
	Live Oak – Ashe Juniper Parks			831 (17%)	211 (3%)	1042
	Live Oak – Mesquite – Ashe Juniper Parks			407 (8%)		407
	Mesquite – Lotebush Shrub			61 (1%)		61
	Oak – Mesquite – Juniper Parks/Woods		203 (5%)	714 (14%)	1744 (23%)	2660
	Other Native and/or Introduced Grasses	19 (6%)	12 (1%)			32
	Post Oak Parks/Woods			1625 (33%)	109 (1%)	1734
	Post Oak Woods, Forest, and Grassland Mosaic	47 (14%)	679 (47%)	849 (23%)	3 (<1%)	3303
	Silver Bluestem – Texas Wintergrass Grassland	1 (<1%)	180 (12%)	1635 (44%)	341 (7%)	5159
	Crops	259 (75%)	292 (20%)	613 (16%)	93 (2%)	1897
	Urban Land	18 (5%)	273 (19%)	427 (11%)		718
Total	344	1437	3727	4986	17947	

Values represent square kilometers of area within the Fort Worth District, and percentages represent contribution to the natural region

Native flora in the Blackland Prairies includes a number of tall grass prairie species, including big and little bluestem, indiangrass, switchgrass, tall dropseed, eastern gamagrass, interspersed with many species of composites and forbs (Bezanson 2000). In the original community, trees were almost exclusively limited to lowland settings along stream courses, but the abundant nutrients and high water–holding capacity of the clay soils resulted in lush grass cover in the uplands and on the hillslopes. Native fauna includes coyote, ringtail, collared peccary, plains pocket gopher, fulvous harvest mouse, and northern pygmy mouse. However, the dense clay soils limited the extent and number of burrowing rodents except in sandy deposits associated with through–flowing streams (Bailey 1905). Ocelots and bison were once common, but are now extirpated. Birds are typical of grass and shrublands; residents include many common species, such as turkey vulture, hairy woodpecker, cardinal, and yellow warbler. Smith’s longspur, a bird of the Arctic tundra, winters here. Amphibians and reptiles typical of this area include eastern spadefoot toad, Great Plains narrow–mouthed frog, green toad, Texas toad, Gulf Coast toad, yellow mud turtle, Texas horned lizard, Texas spiny lizard, and Texas blind snake (McNab and Avers 1994). Overall, Bailey (1905) noted that no species appeared limited to the Blackland Prairies in range, but that many species present in adjacent habitats were absent in the Blackland Prairie due to limitations imposed by the character of the habitat.

Because the landscape has been modified intensively by 150 years of agriculture and development, the modern environment bears little resemblance to the prehistoric

setting. Schmidly (2002:393–394) estimates that 98% of the Blackland Prairies were under cultivation by the earliest 20th century, and that vestiges of the original climax community have been all but eradicated. The intense cultivation of crops like cotton, sorghum, corn, and wheat, coupled with the planting of trees along fence rows and near settlements has profoundly changed the character of this former grassland and blurred the former abrupt demarcation between these prairies and the adjacent Cross Timbers woodlands and forests.

(2) *Oak Woods and Plains.* The Oak Woods and Plains natural region is also represented by two distinct subregions in the Fort Worth District: the Eastern and Western Cross Timbers (see Figure 1–12). The Eastern Cross Timbers consists of a dense, north–south oriented strip of relatively dense oak–hickory woodlands between the Blackland Prairie to the east and the Grand Prairie to the west. It extends from the Red River south to near Waco, and cuts through the Fort Worth District from the northeastern corner of Tarrant County to south–central Johnson County. Because it crosses the Dallas–Fort Worth metroplex, the northern part of the Eastern Cross Timbers has been very heavily impacted by urbanization, while agricultural development and the suburban sprawl has also impacted the southern part of the Eastern Cross Timbers in Johnson County.

The Western Cross Timbers also represents a wooded, north–south oriented strip of oak–dominated woodlands. In the study area, it runs from Wise County south through southeastern Jack County and western Parker County into

Figure 1–12: Distribution of vegetation types in the Fort Worth District, after data compiled and published by Texas Parks and Wildlife Department (McMahan et al. 1984), compared with the mapped distributions of natural regions.

Table 1–4: Fauna of the Fort Worth District

MAMMALS	SELECTED REPTILES AND AMPHIBIANS	SELECTED BIRDS	SELECTED FISH (Cont.)
<i>Didelphis virginiana</i> (Virginia opossum)	<i>Acris crepitans</i> (northern cricket frog)	<i>Aix sponsa</i> (wood duck)	Centrarchidae (Sunfishes)
<i>Antilocapra americana</i> (Pronghorn)	<i>Ambystoma maculatum</i> (spotted salamander)	<i>Anas acuta</i> (northern pintail)	Cupeiidae (Herrings)
<i>Bassariscus astutus</i> (Ringtail)	<i>Ambystoma opacum</i> (marbled salamander)	<i>Anas americana</i> (American wigeon)	Cyprinella lutrensis (Red shiner)
<i>Bison bison</i> (Bison)	<i>Ambystoma talpoidum</i> (mole salamander)	<i>Anas clypeata</i> (northern shoveler)	Cyprinella lutrensis (Red shiner)
<i>Canis latrans</i> (Coyote)	<i>Ambystoma texanum</i> (smallmouth salamander)	<i>Anas crecca</i> (green-winged teal)	Cyprinodon rubrolineatus (Red River pupfish)
<i>Canis lupus</i> (Gray wolf)	<i>Ambystoma texanum</i> (tiger salamander)	<i>Anas platyrhynchos</i> (mallard)	Cyprinodon rubrolineatus (Red River pupfish)
<i>Castor canadensis</i> (Beaver)	<i>Amphiuma triacanthum</i> (three-toed amphiuma)	<i>Anas strepera</i> (gadwall)	Cyprinus carpio (Common carp)
<i>Chaetodipus hispidus</i> (Hispid Pocket Mouse)	<i>Bufo americanus</i> (American toad)	<i>Anser albifrons</i> (greater white-fronted goose)	D. petenense (Threadfin shad)
<i>Cryptotis parva</i> (Least shrew)	<i>Bufo valliceps</i> (Gulf Coast toad)	<i>Aythya affinis</i> (lesser scaup)	Dorosoma cepedianum (Gizzard shad)
<i>Cynomys ludovicianus</i> (Black-tailed prairie dog)	<i>Bufo woodhousii</i> (Woodhouse's toad)	<i>Aythya americana</i> (redhead)	Etheostoma spectabile (Orangethroat darter)
<i>Dipodomys elator</i> (Texas kangaroo rat)	<i>Desmognathus auriculatus</i> (southern dusky salamander)	<i>Aythya valisineria</i> (caracasback)	Fundulus zebrinus (Plains killifish)
<i>Eptesicus fuscus</i> (Big brown bat)	<i>Gastrophyscus carolinensis</i> (eastern narrowmouth toad)	<i>Breita canadensis</i> (Canada goose)	Gambusia affinis (Western mosquitofish)
<i>Erethizon dorsatum</i> (Porcupine)	<i>Gastrophyscus olivaceus</i> (Great Plains narrowmouth toad)	<i>Bucephala albeola</i> (bufflehead)	Hybognathus nuchalis (Miss. silvery minnow)
<i>Felis concolor</i> (Mountain lion)	<i>Hyla chrysoscelis</i> (Cope's gray treefrog)	<i>Bucephala clangula</i> (common goldeneye)	Hybognathus placatus (Plains minnow)
<i>Geomys bursarius</i> (Plains pocket gopher)	<i>Hyla cinerea</i> (green treefrog)	<i>Buteo albicaudatus</i> (white-tailed hawk)	I. punctatus (Channel catfish)
<i>Geomys knoxi</i> (Jones' pocket gopher)	<i>Hyla squirella</i> (squirrel treefrog)	<i>Chen caerulescens</i> (snow goose)	Ictaluridae (Catfishes)
<i>Geomys texensis</i> (Llano pocket gopher)	<i>Hyla versicolor</i> (northern gray treefrog)	<i>Charadrius melodus</i> (piping plover)	Ictalurus furcatus (Blue catfish)
<i>Lasionycteris noctivagans</i> (Silver-haired bat)	<i>Notophthalmus viridescens</i> (eastern newt)	<i>Dendrocygna autumnalis</i> (black-bellied whistling-duck)	Ictalurus punctatus (Channel catfish)
<i>Lasius borealis</i> (Red bat)	<i>Pseudacris clarkii</i> (spotted chorus frog)	<i>Dendrocygna autumnalis</i> (black-bellied whistling-duck)	Ictiobus bubalus (Smallmouth buffalo)
<i>Lasius cinereus</i> (Hoary bat)	<i>Pseudacris streckeri</i> (Strecker's chorus frog)	<i>Dendroica pensylvanica</i> (magnolia warbler)	L. gulosus (Warmouth)
<i>Lepus californicus</i> (Black-tailed jack rabbit)	<i>Pseudacris triseriata</i> (striped chorus frog)	<i>Dendroica petechia</i> (yellow warbler)	L. humilis (Orangespotted sunfish)
<i>Lutra canadensis</i> (River otter)	<i>Rana blairi</i> (plains leopard frog)	<i>Egretta rufescens</i> (reddish egret)	L. macrochirus (Bluegill)
<i>Lynx rufus</i> (Bobcat)	<i>Rana catesbeiana</i> (bullfrog)	<i>Falco peregrinus</i> (peregrine falcon)	L. megalotis (Longear sunfish)
<i>Mephitis mephitis</i> (Striped skunk)	<i>Rana clamitans</i> (green frog)	<i>Falco peregrinus anatum</i> (American peregrine falcon)	L. microlophus (Redear sunfish)
<i>Microtus ochrogaster</i> [haydeni] (Prairie vole)	<i>Rana palustris</i> (pickerel frog)	<i>Falco peregrinus tundrius</i> (arctic peregrine falcon)	L. osseus (Longnose gar)
<i>Mustela frenata</i> (Long-tailed weasel)	<i>Scaphiopus couchii</i> (Couch's spadefoot)	<i>Grua americana</i> (whooping crane)	L. platostomus (Shorthorn gar)
<i>Neotoma albigula</i> (White-throated woodrat)	<i>Scaphiopus holbrookii</i> (eastern spadefoot)	<i>Haliaeetus leucocapillus</i> (bald eagle)	Labidesthes sicculus (Brook silverside)
<i>Neotoma micropus</i> (Southern plains woodrat)	<i>Siren intermedia</i> (lesser siren)	<i>Mergerus merganser</i> (common merganser)	Lepisosteidae (Gars)
<i>Odocoileus hemionus</i> (Mule deer)	<i>Agkistrodon contortrix</i> (copperhead)	<i>Mergerus serrator</i> (red-breasted merganser)	Lepisosteus oculatus (Spotted gar)
<i>Odocoileus virginianus</i> (White-tailed deer)	<i>Agkistrodon piscivorus</i> (cottonmouth)	<i>Numenius borealis</i> (Eskimo curlew)	Lepisosteus osseus (Longnose gar)
<i>Ondatra zibethicus</i> (Muskrat)	<i>Alligator mississippiensis</i> (American alligator)	<i>Oxyura jamaicensis</i> (ruddy duck)	Lepomis cyanellus (Green sunfish)
<i>Perognathus flavescens</i> (Plains pocket mouse)	<i>Chelydra serpentina</i> (snapping turtle)	<i>Parula americana</i> (northern parula)	M. salmoides (Largemouth bass)
<i>Perognathus flavius</i> (Slick pocket mouse)	<i>Deirochelys reticulata</i> (chicken turtle)	<i>Sterna antillarum</i> (athalassos (interior least tern))	M. storeriana (Silver chub)
<i>Peromyscus atwateri</i> (Texas mouse)	<i>Eumeces obsoletus</i> (Great Plains skink)		Macrhybopsis aestivalis (Speckled chub)
<i>Peromyscus leucopus</i> (White-footed mouse)	<i>Farancia abacura</i> (mud snake)	SELECTED BIVALVES	Menidia beryllina (Inland silverside)
<i>Peromyscus maniculatus</i> (Deer mouse)	<i>Graptierys pseudogeographica</i> (false map turtle)	<i>Cyrtodonta tampicoensis</i> (Tampico pearly mussel)	Micropterus punctulatus (Spotted bass)
	<i>Graptierys pseudogeographica</i> (false map turtle)	<i>Lampsilis teres</i> (Yellow sandshell)	Morone chrysops (White bass)
	<i>Kinosternon flavescens</i> (yellow mud turtle)		N. bairdi (Red River shiner)
	<i>Kinosternon subrubrum</i> (eastern mud turtle)		N. buchananii (Ghost shiner)
	<i>Nerodia erythrogaster</i> (plainbelly water snake)		N. oxyrinchus (Sharpnose shiner)
	<i>Nerodia fasciata</i> (southern water snake)		N. potteri (Chub shiner)
	<i>Nerodia harteri</i> (Brazos water snake)		N. stramineus (Sand shiner)
	<i>Nerodia rhombifer</i> (diamondback water snake)		Notemigonus crysoleucas (Golden shiner)
	<i>Nerodia sipedon</i> (northern water snake)		Notropis atherinoides (Emerald shiner)
	<i>Nerodia sipedon pleuralis</i> (Midland water snake)		Notropis buccula (Smalleye shiner)
	<i>Pseudemys concinna</i> (river cooter)		P. promelas (Fathead minnow)
	<i>Pseudemys texana</i> (Texas river cooter)	SELECTED FISH	P. vigilax (Bullhead minnow)
	<i>Regina grahamii</i> (Graham's crayfish snake)	<i>A. natalis</i> (Yellow bullhead)	Percichthyidae (Temperate Basses)
	<i>Sternotherus carinatus</i> (razorback musk turtle)	<i>Amelurus melas</i> (Black bullhead)	Percidae (Darters)
	<i>Sternotherus odoratus</i> (common musk turtle)	<i>Aplodinotus grunniens</i> (Freshwater drum)	Percina caprodes (Logperch)
	<i>Thamnophis proximus</i> (western ribbon snake)	<i>C. venustus</i> (Blacktail shiner)	Percina carbonaria (Texas logperch)
	<i>Thamnophis sirtalis</i> (common garter snake)	<i>Camptostoma anomalum</i> (Central stoneroller)	Phenacodus notatus (Suckermouth minnow)
	<i>Thamnophis sirtalis annexans</i> (Texas garter snake)	<i>Carpiodes carpio</i> (River carpsucker)	Pimephales notatus (Bluntnose minnow)
	<i>Trionyx muticus</i> (smooth softshell)		Pimephales vigilax (Bullhead minnow)
	<i>Trionyx spiniferus</i> (spiny softshell)		Poeciliidae (Livebearers)
			Pomoxis annularis (White crappie)
			Pomoxis nigromaculatus (Black crappie)
			Pygocentrus nattereri (Flathead catfish)
			Sciaenidae (Drums)

Compiled from a variety of references, including:

Albert El-Hage, Daniel W. Moulton, and Peter D. Sorensen

1999 Area Study: North-Central Texas Area: Evaluation of Selected Natural Resources in Part of the North-Central Texas Area.

Electronic Document, Resource Protection Division: Water Resources Team, Texas Parks and Wildlife Department. <http://www.tpwd.state.tx.us/texaswater/sb1/wildlife/pgmapdf/area11.pdf>

William B. Davis and David J. Schmidtly

Hood, Somervell, and Erath Counties (see Figure 1–12). While much less heavily urbanized than the eastern Cross Timbers, the Western Cross Timbers is nonetheless heavily altered by agriculture, and only a patchwork remnant approximating the original environment remains.

Both the Eastern and Western Cross Timbers reflect edaphic control on the biotic assemblage. The geography of the Eastern Cross Timbers corresponds roughly to the outcrop of the Cretaceous Woodbine Formation sandstones, which are relatively hard sandstones that support relatively acidic, sandy loam soils. The more open Western Cross Timbers corresponds to a variety of lower Cretaceous formations, including the sand-rich Paluxy, Antlers, and Twin Mountains Formations, as well as the limestone and marl-dominated Goodland Limestone and Glen Rose Formation. These limestone areas support an oak–juniper woodland reminiscent of the typical Edwards Plateau assemblage, while the sandy uplands support an oak-dominated assemblage.

Plant taxa typical of the uplands in the Eastern and Western Cross Timbers include post oak, blackjack oak, shin oak, Texas oak, live oak, cedar elm, sugarberry, eastern red cedar, sumac, hackberry. On limestone, Ashe juniper is also common. Shrubs include various sumacs, redbud, elbowbush, Texas persimmon, Mexican buckeye, coralberry, mesquite, and soapberry. Prickly pear is common, particularly in disturbed areas. Common grasses include sideoats grama, Texas grama, little bluestem, silver bluestem, hairy tridens, purple threeawn, tall dropseed, buffalograss, and windmillgrass. Common forbs include western ragweed, broom snakeweed, white prairie clover, and slender green thread. Mesquite and prickly pear are very common in disturbed areas, particularly in the western part of the Cross Timbers. Riparian corridors support woodlands to relatively dense forests dominated by American Elm, pecan, bur oak, hackberry, and western soapberry.

Among the mammals in the Cross Timbers are white-tailed deer, bobcat, gray fox, raccoon, cottontail rabbit, gray squirrel, fox squirrel, eastern chipmunk, white-footed mouse, short-tailed shrew, pine vole, and cotton mouse. Birds include turkey, bobwhite, cardinal, mourning dove, red-eyed vireo, tufted titmouse, wood thrush, summer tanager, blue-gray gnatcatcher, hooded warbler, and Carolina wren. Reptiles and amphibians include the box turtle, common garter snake and timber rattlesnake (McNab and Avers 1994; Davis and Schmidly 1994; see Table 4 for a more detailed list of fauna in the study area as a whole).

(5) *Rolling Plains*. The Mesquite Plains natural region, as defined by the LBJ School of Public Affairs (1978),

corresponds to the low Rolling Plains or Osage Plains physiographic region. It lies on the western side of the district, where precipitation is relatively low and the biota is increasingly adapted to semi-arid conditions, including sparser grasses and increased mesquite and prickly pear. However, as the similarity between the outcrop of Paleozoic rocks and the boundary of the natural region indicates (cf. Figures 1–2 and 1–9), edaphic factors have also profoundly influenced its definition. Other classifications of natural regions in Texas (e.g., McNab and Avers 1994; Gould et al. 1960; see also Bezanson 2000) do not map the Rolling Plains in the Fort Worth district; rather, the Cross Timbers extend past the western boundary of the district. Native vegetation in the Mesquite Plains is open parkland with occasional low trees and shrubs; however, agriculture, grazing (particularly overgrazing and seed dispersal by cattle), and fire suppression have resulted in a fundamental change in the biotic character of the region. As Figure 1–12 illustrates, oak (particularly live oak) and Ashe juniper are also common throughout this part of the Rolling Plains, demonstrating that the area is transitional between the oak-dominated Cross Timbers and the grass-dominated Rolling Plains.

Common plant taxa in the Rolling Plains include mesquite, Ashe juniper, lotebush, prickly pear, live oak, Texas oak, post oak, shin oak, soapberry, sumac, hackberry, and cedar elm. Shrubs and succulents include shin oak, agarito, prickly pear, tasajillo, Mexican persimmon, and narrow-leaf yucca. Grasses include little bluestem, sideoats grama, Texas wintergrass, silver bluestem, hairy tridens, and red three-awn. Forbs include broom snakeweed, bitterweed, Engelman daisy, and scurfpea. Floodplains may be grassy or support a relatively dense, low forest that includes mesquite, walnut, live oak, and catclaw acacia (McMahan et al. 1984; Gould 1975). Salt cedar is also present locally. In this, the most easterly and therefore the moistest part of the Rolling Plains, these assemblages are interdigitated on the landscape with stands typical of the Western Cross Timbers assemblage, and with areas cleared for agriculture.

The Rolling Plains faunal community is diverse. Large to medium-size mammals include white-tailed deer, coyote, ringtail, and collared peccary. Typical smaller herbivores include cottontail rabbits, pocket mice, and the Texas kangaroo rat. Bison and pronghorn were once common but have been extirpated. Birds include red-tailed hawk, wild turkey, yellowlegs, sandpiper, turkey vulture, sparrow, scaled quail, and woodpecker. Ducks and geese pass through regularly during their annual migration. Common reptiles and amphibians include a variety of toads, frogs, skinks and other lizards, and snakes.

1.6 Late Quaternary Paleoenvironments of North–Central Texas

1.6.1 The Nature of the Evidence

Like the weather, the climate of a given locality is not static. Unlike weather, however, changes in climate cannot be readily observed, but occur gradually over the long term in response to a variety of intrinsic and extrinsic controls. In order to study climate, such changes must be documented by repeated observations over many years. Because climate is by definition an abstract representation of diachronic atmospheric behavior, the interpretation of previous climates, and of the mechanisms and trajectories of climate change, are complex endeavors. Because past climatic conditions are not directly observable, paleoclimatic reconstruction involves inferences based on diverse lines of evidence. With a few exceptions (e.g., some types of isotopic evidence), this evidence does not directly document former climatic conditions at any given locality. Rather, paleoclimatic data provide information on other environmental parameters (e.g., fauna, flora, rates and trajectories of geomorphic change or soil development) that are to some degree contingent on climate and can be related to past climates using modern analogs. Such lines of evidence are referred to as proxy data (Lowe and Walker 1984; Bradley 1985; Smiley et al. 1991; Caran 1998).

While proxy data are vital to our understanding of previous climates and environments, the interpretation of such data is not a trivial exercise. Biotic conditions also change over time, responding not only to long-term climate change but also to competition between species, fire, disease, geological and cosmological catastrophes (e.g., volcanoes, asteroid impacts), and the intentional and unintentional impact of humans. Inherent differences in thresholds and temporal lags characteristic of different proxy indicators complicate the application of proxies (Bradley 1985; Ellis et al. 1995; Caran 1998), as do the assumptions necessary to their use. While paleoclimatic interpretation from biological proxies assumes that the indicator taxon (e.g., beech pollen; skeletal remains of a specific pocket gopher) and its modern analog (beech trees; living pocket gophers) both reflect environmental equilibrium, the distribution of any given taxon is actually conditioned not only by climate, but also by edaphic factors, competition between species, degree of tolerance to fluctuations in climate, the trajectory and rate of environmental change, and the previous distribution of the organism. Therefore, multiple lines of evidence must be employed, and care is required in their interpretation.

Caran (1998) provides an excellent summary of the complexities and potential pitfalls of paleoenvironmental reconstruction from proxy data. He identifies a number of

potential problems, including inadequate contextual control (e.g., stratigraphic problems, unrecognized intrusive or reworked materials), inadequate chronological control, inadequate proxies (e.g., mixed assemblages, inappropriate environmental comparisons) inappropriate or overly simplistic proxy functions/models, and inherent biases (e.g., differential preservation, atypical backgrounds, cultural/taphonomic biases in assemblages). He also stresses that interpretation of proxy indicators requires abstraction, and that the degree of abstraction necessary differs markedly between different types of proxy data.

Despite the potential for problems, proxy evidence is indispensable data. Lines of evidence that inform on past climatic conditions in north–central Texas include pollen data from bogs on the inner Texas coastal plain and Oklahoma, microfaunal data from caves in the Texas Hill Country, tree-ring data from eastern Texas, Oklahoma, and Arkansas, and isotopic and geomorphic data from a variety of localities in Texas and surrounding states. While all of these sources provide crucial information, apparent conflict between proxies is not unusual and the overall picture remains ambiguous in many respects.

1.6.1.1 Microscopic Evidence

Much of the available paleoclimatic information on Texas is derived from pollen data extracted from a small number of bogs that roughly parallel the Balcones fault system on the inner coastal plain (principal localities include Weakly Bog, Boriak Bog, Patsche Bog, Gause Bog, and Sofje Bog); from cave, rockshelter, and alluvial sites along the Balcones fault, in the lower Pecos, and on the High Plains; and from bogs, lakes, and alluvial settings in Oklahoma (e.g., Ferndale Bog, Natural Lake). (Albert 1981; Bryant and Holloway 1985; Baker and Waln 1985). Pollen consists of tiny reproductive cells of seed-bearing plants and exhibit complex structures that are diagnostic of the parent taxa. Pollen is typically produced in vast quantities and dispersed through the environment, where it falls as “pollen rain.” It forms a component of the sedimentary record where the physical and chemical environment is conducive to preservation. In paleoenvironmental studies, this pollen is recovered by stratigraphic sampling of suitable deposits, the sediment samples are processed to concentrate the pollen, and a slide is prepared for counting of different taxa using an optical microscope. The presence and proportion of various taxa represented by pollen grains on the slide is used to infer the character of the past biotic assemblage. Most pollen data in Texas comes from a small number of bogs that captured the pollen rain and sealed it within accumulation lacustrine/palustrine sediments. Attempts to obtain alluvial pollen in Texas have been spotty at best, and when pollen

has been obtained it is often uninterpretable (e.g., Weinstein and Bryant 1993), although there are reports of improved recovery in recent years (e.g., Albert 2007).

The process of interpreting a pollen spectrum requires careful consideration of a number of factors. First, the volume of pollen released by various plants varies considerably, so that the proportion of pollen grains in pollen rain is not directly reflective of the proportion of plants on the landscape. Second, dispersion methods differ, and plants that are primarily pollinated by insects (as opposed to simple aerosolic dispersion) are typically not represented or drastically underrepresented in the pollen rain. Third, the dispersion patterns of aerosolic grains are dramatically different depending on the size and buoyancy of pollen grains from different taxa; some types of aerosolic pollen will only be dispersed locally, while others may travel hundreds of miles. Fourth, the resistance to corrosion/environmental degradation of different pollen taxa also varies considerably, so that the relative frequency of distinct taxa in a fossil assemblage may be quite different than that of the original pollen rain. Finally, this differential resistance to corrosion may skew the preservation of different taxa during the rigorous processing that samples undergo in the laboratory as other organic remains are chemically destroyed to concentrate and prepare the pollen for counting. Interpretation of pollen data must consider these factors.

Pollen is not the only type of microscopic evidence available. *Phytoliths* are tiny (silt-sized) siliceous grains that form inside certain plant cells. These siliceous grains have characteristic shapes that reflect the shape of the cell. They are thus broadly diagnostic of plants with relatively simple structures, while the diversity of cell structures in more complex plants like trees makes identification more challenging. Phytoliths have proven particularly valuable for distinguishing between different broad families of grasses (e.g., Brown 1984; Piperno 1988), but the taxonomy is extremely complex and is far from fully understood. While several phytolith studies have been reported in Texas (e.g., Robinson 1982; Fredlund and Tieszen 1994; Jones 1997; Fredlund 1998), relatively little synthetic work has been reported south of the southern High Plains.

Diatoms are unicellular algae that secrete diagnostic siliceous structures called *frustules*. Because different diatoms inhabit a wide range of environments (ranging from dry soil to water of specific salinity, temperature, turbidity, depth, and velocity), they are valuable indicators of local environmental conditions, and can be extremely valuable in site-specific studies (Lowe and Walker 1984). Although the potential for substantial contribution is clearly there, the contribution of diatom analyses in Texas to this point (e.g., Winsborough 1995; 1998) has been limited. Similarly, *ostracodes* are

tiny aquatic bivalves that inhabit fresh to hypersaline environments, and are quite sensitive to local environmental conditions (Lowe and Walker 1984), but their use in the investigation of paleoenvironments in Texas (e.g., Henry et al. 1998) is very rare to this point. Other microfossils useful for paleoenvironmental reconstruction include *foraminifera*, *radiolarians*, *silicoflagellates*, and *coccolithophores* (Bradley 1985). These microorganisms produce distinctive calcareous shells, or tests, and are diagnostic of a wide variety of variations in temperature, salinity, water depth, and water chemistry. However, unlike ostracodes, they are largely limited to brackish to hypersaline marine environments.

1.6.1.2 Other Biological Evidence

Macrobotanical remains also provide direct evidence that a plant was present in the surrounding environment. Macrobotanical remains have proven quite valuable in relatively arid locales such as the Chihuahuan Desert, particularly where plant materials have been concentrated and preserved in packrat middens (e.g., Van Devender 1990). However, such records are subject to behavioral and taphonomic biases, and macrobotanical preservation is limited in exposed settings. Fossil insect records (e.g., Elias and Van Devender 1990) also have some potential to inform on aspects of the paleoenvironment, but are likewise subject to severe preservation biases.

Faunal data is another very valuable type of paleoenvironmental information that has seen considerable application in Texas. While some large animals are informative, by far the richest source of information is the rich microfaunal record recovered from central Texas caves (Lundelius 1967; Graham 1987; Toomey 1993). In general, microfauna (and particularly micromammals like mice and voles) are much more environmentally sensitive than larger fauna, in that they generally tolerate a narrower range of environmental conditions. Considered in aggregate, assemblages of penecontemporaneous species (*faunules*) provide powerful evidence of prevailing environmental conditions. However, faunal records are also subject to a number of factors that complicate interpretation. As in pollen analysis, it is necessary to assume that the modern baseline data and the fossil faunule both represent equilibrium with environmental constraints, and such an assumption may not always be valid. The distribution of animals on a landscape is also conditioned by interspecies competition, historical trends, sensitivity to environmental variables, and varying response times to environmental stimuli among different taxa. In many cases, older fossil assemblages include suites of taxa that inhabit differing environments today (disharmonious assemblages) and thus represent an environment with no modern analog, which requires more abstraction (and thus decreased confidence) in interpretation.

Another powerful data source is tree-rings, which provide an extremely sensitive, precise proxy record of climate. The annual growth rings of many tree taxa reflect environmental factors influencing growth. Analysis of tree rings is used for dating (*dendrochronology*) by counting the rings back from a known date of cutting, and for paleoclimatic inference (*dendroclimatology*) by examining the width and makeup of the rings, which is related to the supply of moisture during the growth period (as well as other climatic variables and a host of other factors, such as tree species, tree age, soil type, soil depth, nutrient availability, slope inclination, and slope aspect) (Fritts 1971; Bradley 1985). Climatically-sensitive characteristics of tree rings include width, density, vesicle structure, isotopic composition of the wood, frost damage, and false rings (e.g., Stahle 1990; Burke and Stuiver 1981; Dering 2002; Fraser et al. 1978). The major limitation of tree ring studies is the lack of time depth; individual trees typically live only a few hundred years or less (although there are exceptions). With intensive study, fossil trees with overlapping life spans can be correlated to create a master regional chronology. Such a tool has been extended back nearly 2,000 years in the Southwestern United States, but no such record exists for north-central Texas, where climate conditions make preservation of ancient trees far less likely. Nevertheless, the temporal resolution offered by tree ring analysis is unparalleled among lines of paleoenvironmental data, and the promise afforded by some types of long-lived trees and by stumps buried and preserved beneath the water table (e.g., Hall and Lintz 1984) remains to be fully exploited.

1.6.1.3 Isotopic Analysis

In addition to tree wood, isotopic analysis can be conducted of many other types of biotic remains and abiotic materials. In fact, isotopic analysis is an extremely powerful technique of paleoenvironmental reconstruction (van der Mewe 1982; Cerling 1984; De Niro 1987; Cerling et al. 1989; Hertz 1990; Nordt et al. 1994; Humphrey and Ferring 1994; Attendorf and Bowen 1997). Several types of isotopic evidence of paleoenvironmental conditions exist. The most common isotopes examined are carbon ($^{12}\text{C}/^{13}\text{C}$), oxygen ($^{16}\text{O}/^{18}\text{O}$), and nitrogen ($^{14}\text{N}/^{15}\text{N}$), although recent studies have also examined strontium ($^{87}\text{Sr}/^{86}\text{Sr}$). Stable carbon isotope analysis is based on metabolic fractionation of ^{12}C and ^{13}C by organisms. Three different metabolic pathways exist in modern plants: the Calvin-Benson pathway (CAL or C_3), which is typical of most plants; the Hatch-Slack pathway (HS or C_4 pathway), which is typical of tropical grasses; and the CAM (crassulacean acid metabolism) pathway, which is typical of succulents like cactus. Each of these pathways results in fractionation of the relative ^{13}C content of carbon fixed by organisms relative to the established standard (the Pee-Dee Belemnite standard, which is the same standard used for correcting fractionation effects in radiocarbon

dating). Because plants fix the most abundant isotope of carbon (^{12}C) more readily than its other isotopes (^{13}C and ^{14}C) by plants, all terrestrial biological materials tend to be isotopically light. The relative concentration of the stable carbon isotope ^{13}C , and indeed all stable isotopes, is typically expressed as parts per thousand (parts per mil or ‰). C_3 pathway plants exhibit typical fractionation values between -22‰ and -33‰ (usually -25‰ to -27‰), while C_4 plants typically range between -9‰ and -16‰ (usually -12‰ to -14‰) and CAM plants typically exhibit intermediate values. The isotopic character of consumer organisms is a function of the isotopic character of elements of the diet, additional fractionation effects by the organism, and trophic level (van der Mewe 1982; De Niro 1987).

The primary paleoclimatic information derived from the study of carbon isotopes is related to climate-driven variations in the relative proportion of C_3 (woody plants, forbs, and temperate grasses) and C_4 plants (primarily warm-season grasses) through the late Quaternary. As climate warms, warm season grasses expand at the expense of temperate grasses, only to be gradually replaced in response to cooling trends. The isotopic value of bulk sediments and paleosols, soil carbonates, animal and human skeletal material, and gastropod shell has been used to infer the relative proportion of C_3 and C_4 plants in the surrounding environment (e.g., Amundson et al. 1988; Nordt et al. 1994; Humphrey and Ferring 1994; Fredlund and Tieszen 1997; 1998; Brown 1998; Goodfriend and Ellis 2000) and the relative contribution of C_3 and C_4 plants, terrestrial animals, and marine resources in the diet of animals and humans (e.g., Huebner and Boutton 1990; Huebner 1991; Huebner and Comuzzie 1992). However, the use of bulk humates for estimating regional proportions of C_3 and C_4 plants from isotopic values is not a particularly straight-forward procedure, because there are several specific problems that complicate interpretation. First, the isotopic composition of C_3 and C_4 plants is somewhat variable due to differences in local environmental conditions (Buchmann et al. 1996). This variability is not extreme (no more than 1–2 ‰) and therefore does not preclude reconstruction of the relative percentage of C_3 and C_4 plants in general terms; however, it does caution against overly precise conclusions in the ratio between C_3 and C_4 plants. A second and potentially more severe problem is related to spatial variability in stable carbon isotopes in the soil system. In grassland settings, some researchers (e.g., Bird and Pousai 1997) have found differences in average $\delta^{13}\text{C}$ values of up to 6.6‰ in the span of a few meters, while others have found negligible variability (Nordt, personal communication, 2000). Because paleoenvironmental stable isotope studies typically assume that the measured ratio is representative of the regional vegetation (e.g., Cerling 1984; Cerling et al. 1989; Quade et al. 1989; Nordt et al. 1994; Monger et al. 1998), this variability has the potential to bias the data; in

other words, the isotopic character of local vegetation may sometimes override the regional signal (Fredlund and Tieszen 1998). This is particularly true in depositional settings like river floodplains, which often support a local flora markedly different than that in the surrounding uplands. It is likely that the heterogeneity of isotopic carbon in soil is relatively pronounced in some settings and negligible in others, but the degree of heterogeneity in all settings is likely to be enhanced during periods of vegetative response to environmental change, because the soil carbon will be influenced by previous conditions (Boutton et al. 1998). Finally, alluvial and lacustrine sediments often contain carbon fixed hundreds or thousands of years previously (Goh and Molloy 1978) and introduced by the erosion of soils in the catchment. This bias has been demonstrated repeatedly in radiocarbon studies of bulk humates in alluvium, which are often found to date considerably older than associated charcoal samples (e.g., Nordt 1992; Abbott 1994a). It follows that the stable carbon isotope signature of such sediments must also be influenced by the influx of old carbon.

While carbon isotopes represent fractionation by organisms, isotopes of oxygen (^{16}O and ^{18}O) are fractionated by physical processes, and are indicative of paleotemperatures (Bradley 1985; Lowe and Walker 1984). This fractionation occurs because the vapor pressure of the H_2^{16}O molecule is higher than that of H_2^{18}O . For this reason, water containing the lighter ^{16}O isotope is preferentially evaporated from a body of water, while heavier ^{18}O isotopic water preferentially condenses. Thus, water molecules containing ^{18}O are less likely to evaporate in the first place, and more likely to contribute to the first drops out of the cloud. Moreover, this tendency becomes increasingly marked as temperature drops. Thus, isotopically light water is far more likely to be evaporated, penetrate into a continental interior, and fall as snow. Therefore, as continental glaciers accumulate, ^{16}O is preferentially bound in the ice, enriching the oceans in ^{18}O . During interglacials, this light water is released by melting and returns to the oceans, reversing the trend. As a result, long-term oxygen isotope records from deep-sea sediments and ice cores record glacial–interglacial cycles at a global scale (Bradley 1985).

For the same basic reason, examination of the oxygen isotope record is potentially a valuable proxy of more localized trends in temperature, precipitation seasonality, and the source of precipitation—producing air masses through the Holocene period. Terrestrial oxygen isotope data are available from a variety of sources, including soil carbonates, molluscan shells, wood, and travertine. However, the interpretation of regional to local temperatures from isotope data is complex, because the signature is a composite function of the temperature and isotopic composition of the moisture source (which varies

slightly between sources and in response to large-scale oceanic circulation patterns, seasonality, and freshwater/meltwater influx), the seasonality of precipitation (e.g., warm summer rains versus winter snow), the latitude of the study site, the distance between the study site and the moisture source, and the elevation at which condensation occurs. The complexities introduced by these different factors are many, and few meaningful temperature/precipitation records have yet to emerge from terrestrial data, although attempts are being made (e.g., Dworkin et al. 2005).

Compared to carbon and oxygen, nitrogen isotopes are of relatively limited utility for paleoenvironmental studies, although they have proven extremely valuable in dietary analyses. However, nitrogen isotopes contained in paleosols, sediments, and bone do have the potential to provide proxy evidence of the abundance of nitrogen-fixing plants such as mesquite and acacia in the environment at different times in the past. As yet, however, there is relatively little baseline data to address this possibility.

Another line of evidence exploited in Texas is isotopes of strontium. Given that other types of data (e.g., Toomey et al. 1993) indicate that massive soil loss occurred across the Edwards Plateau during the Holocene, Cooke and her colleagues (Cooke et al. 2002; Cooke et al. 2003) hypothesized that the ratio between the strontium isotopes ^{87}Sr and ^{86}Sr in soils of the Texas Hill Country, and in plants and animals deriving nutrients from those soils, should reflect the changing thickness of the soil cover. The reason for this hypothesized trend is that the relative contribution from limestone (which has a low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio that reflects the strontium composition of Cretaceous seawater) increased as the older, siliceous soil components derived from insoluble limestone residues and aerosolic dust (which were ultimately derived from continental crusts and have higher strontium ratios) were eroded and removed. Subsequent analyses on floral and faunal remains interstratified in cave fill confirmed the relationship, supporting the hypothesis.

1.6.1.4 Speleothems

Growth rates and isotopic composition of cave speleothems (stalactites, stalagmites, and other forms of flowstone), and spring carbonates (tufa, travertine), are also dependent on climate (Bradley 1985; Musgrove et al. 1999; Musgrove et al. 2001). The deposits are also subject to dating by several methods (e.g., U/Th, ESR, radiocarbon on carbonate or occluded organic matter) (e.g., Ford and Hill 1999; Lutz et al. 2002; Caran et al. 1995). Travertines and tufas also frequently envelop and preserve pollen, macrobotanical remains, and other paleoenvironmental proxies (Caran et al. 1995; Hall and Abbott 1995). For these reasons, speleothems and related

forms of precipitated carbonates can record relatively high-precision, multifaceted records of climatic change. Although in relatively early stages, these methods have considerable potential to add resolution and time depth to the paleoclimatic record of Texas.

1.6.1.5 Geomorphic and Stratigraphic Evidence

It has long been recognized that climate exerts considerable influence on the character, trajectories, and speed of landscape evolution (Tricart & Cailleux 1972; Büdel 1982). However, the relationship between climatic changes and resulting landscape changes is complex, and the character of the changes that do occur is conditioned by a number of factors, including pre-existing system states, intrinsic geomorphic thresholds, and successive changes as geomorphic systems attempt to reestablish equilibrium conditions (Bull 1991).

Climate changes can have a powerful impact on landscapes. Among their potential impacts, climatic changes can stimulate episodes of erosion, deposition, or stability and soil formation. They can destabilize hillslopes, leading to increased erosion, gullying, and/or colluviation. They can stimulate upland soil erosion or promote upland soil formation. They can change the character of vegetation, leading to changes in the host landform. They can change the trajectory and/or rate of soil formation. They can affect the character of processes on hillslopes. They can turn springs on or off, resulting in slope retreat through sapping, or they can lead to clastic and/or chemical sediment deposition (e.g., tufa, travertine). They can lead to episodes of eolian accumulation and deflation. They can cause channel trenching or channel aggradation, alter the character of channels and floodplains, and speed the formation and destruction of terraces and floodplains. They may cause unique and often contradictory changes in different parts of a system at the same time, or set off a cascade of fundamental changes that play out over a span of decades or centuries. Or, they may do nothing at all.

In the absence of significant tectonic or anthropic influences, both of which can be ruled out as significant geomorphic triggers in the North-Central Texas region during the period of interest, it is likely that changes in the geomorphic systems were dictated by changes in climate. However, just as the universe of changes to the climate system is more complex than “cooler/moister-warmer/drier”, the universe of potential geomorphic responses to climate change is rich and varied. For this reason, it is far from trivial to interpret the climatic cause of a given event observed in the stratigraphic record. For example, an episode of channel entrenchment observed in the stratigraphic record may have resulted from an increase in precipitation the made for more powerful floods; or from a decrease in precipitation that led to a loss of stabilizing

vegetation; or from a change in the character and periodicity of precipitation that shifted the system from slow, soaking winter rains to rapid summer downpours; or even from a successive adjustment to a climate shift that occurred centuries earlier. For this reason, geomorphic information is best suited to providing corollary and supporting data for climate interpretation built on multiple lines of evidence.

1.6.1.6 Atmospheric Modeling

A final line of paleoenvironmental inquiry involves examination of the mechanisms of environmental change. Global Circulation Models (GCM's) are mathematic models of large scale circulation systems, which provide the driving mechanism of climate. GCM's such as CLIMAP and COHMAP (CLIMAP Project Members 1981; COHMAP Members 1988) provide insights into shifting patterns of global atmospheric circulation resulting from changes in insolation and surface ice volume. They are based on relatively coarse-grained approximations, however, and as yet do not provide data that is suitable for anything but heuristic analysis. When coupled with multiple lines of proxy data, however, they do provide for a powerful, albeit generalized, explanatory framework.

As the following summary indicates, these data only allow for a generalized reconstruction of the evolution of the environment, and more data is needed. Nevertheless, it is possible to outline broad trends in environmental change through the late Quaternary. The following synopsis is based on a wide range of data, but owes a great deal to previous summaries of paleoenvironments in the region (e.g., Bryant and Schafer 1977; Bryant and Holloway 1985; Smiley et al. 1991; Johnson and Goode 1994; Ferring 1994a; Collins 1995; Bousman 1998). Several of these summaries are presented in Figure 1–13.

1.6.2 Late Pleistocene Climates and Biota

Most evidence suggests that the late Pleistocene period (roughly 16–12 ka) was relatively cool and moist in north-central Texas compared to modern conditions. Most central Texas pollen records from the Full Glacial period (roughly 18 ka) exhibit a wide range of cold-tolerant deciduous and evergreen arboreal taxa, including *Picea* (spruce), *Populus* (poplar), *Betula* (birch), *Fraxinus* (ash), *Acer* (maple), *Cornus* (dogwood), *Carya* (hickory), *Tilia* (linden), *Quercus* (oak), *Alnus* (alder) and *Pinus* (pine) (Bryant and Holloway 1985). Data from the southern High Plains were long believed to indicate the area supported a Pleistocene boreal forest (Hafsten 1961; Oldfield and Schoenwetter 1975). However, Holliday (1987) and Hall and Valastro (1995) use soils data

Figure 1-13: Compendium of proxy climatic and environmental records of Texas compared with the cultural record.

and pollen data to dispute this interpretation. Based primarily on data from Friesenhahn Cave in Bexar County and White Lake on the southern High Plains, Hall and Valastro (1995) concluded that the Southern High Plains and Edwards Plateau were dominated by grassland assemblages with no good modern analog during the last Full Glacial. Arboreal assemblages are apparent in the southeastern U.S., where the Full Glacial period pollen record exhibits evidence of substantial populations of cold-tolerant taxa, particularly *Picea* and *Abies* (Delcourt and Delcourt 1977; 1985). Faunal evidence from central Texas also suggests that Full Glacial conditions were relatively cool and moist, but that both grassland and forested habitats were present (Graham 1987). Small mammal data also indicate a degree of warming from 15–13 ka (Toomey et al. 1993).

Based on detailed re-analysis of pollen data from several of the east-central Texas bogs, Bousman (1998) notes that while woodland communities with many boreal taxa are strongly represented, an apparent increase in grassland communities occurred about 16.5 ka and again around 12.5 ka. Bousman also notes that the percentage of oak pollen and pine pollen tends to increase in tandem with grass pollen during the late Pleistocene, while no such relationship is apparent in the Holocene record, and proposes that the structure of late Pleistocene communities has no modern analog. On the basis of faunal, pollen, and soils evidence, Graham (1987) suggests that the late Pleistocene environment east of the Balcones escarpment consisted of gallery forests that extended west from closed forests in the eastern part of the state, while the upland interfluvies were open parklands or lush grasslands.

Stratigraphic/geomorphic investigation of a number of Texas streams suggests that most large systems were characterized by relatively coarse-grained load, large meandering channels, and broad, low constructional floodplains dominated by lateral accretion deposits (e.g., Epps 1973; Ferring 1994a; Blum and Valastro 1994; Nordt 1992; 1994; Waters and Nordt 1995). Where preserved, meander radius far exceeds the modern systems. This evidence is typically taken as indicating that stream discharge was far greater than at present (e.g., Barton 1930; Alford and Holmes 1985; Sylvia 2002), although this view is not universally shared (e.g., Blum et al. 1995). In Central Texas, these large channel scars tended to rest on cut bedrock surfaces that were abandoned by continued incision of the streambed in the latest Pleistocene, and thus are frequently well-exposed in the valley systems, where they can be readily recognized by their red color and dense, nodular Bk horizon. This pattern probably extends into North Texas along the Brazos drainage (Mandel 1992) and is definitely apparent along the Brazos in northwest Texas (Blum et al. 1992). In the Trinity system, however, maximum incision occurred somewhat earlier, and the alluvium dating to the latest Pleistocene is typically deeply buried beneath the floodplain (Ferring 1994a). Consequently, the character of the

deposits is less clear, but they tend to be sandy and gravelly and are associated with scallops in the valley wall that document outsized meanders.

While the character of alluvial deposits suggests relatively high, sustained discharge, vegetation data do not suggest an environment that was significantly wetter than at present. Rather, the prevailing interpretation is that cooler temperatures promoted more effective precipitation, and thus more sustained discharge. Haynes (1991) interprets the late Glacial period (roughly 14–12 ka) climate as drier than the last Full Glacial (roughly 18 ka), although it apparently remained relatively cold. Based on stratigraphic data, Haynes identifies a period of drought during Clovis times, followed by a return to somewhat cooler, moister conditions during the subsequent Folsom period. Basing his interpretation on investigations of the Mississippi and St. Lawrence systems (e.g., Broecker et al. 1989; Overpeck et al. 1989; Fullerton 1986), Bousman (1998) presents a compelling model for the influence of glacial meltwater on the temperature of water in the Gulf of Mexico, and thus on terrestrial climate of the surrounding coastal plain. According to Bousman's model, as glacial meltwater from the Laurentide glacier began to flow down the Mississippi River in significant volumes by around 15 ka, the Gulf cooled and became a less efficient source for evaporative moisture and energy. This discharge reached a peak between 13–12 ka, but was sharply curtailed as the Laurentide ice-front withdrew across the St. Lawrence valley and meltwater was diverted to the North Atlantic. However, the Laurentide glacier re-advanced during a cold phase (the Valdres or Younger Dryas event, which may have been stimulated by the influx of meltwater into the north Atlantic), and glacial meltwater was again routed down the Mississippi from approximately 10 ka to 9 ka. Bousman believes that these two meltwater surges (and the earlier one in particular) promoted relatively cool, dry conditions along the Gulf coast, while the intervening period was moister and more temperate. Similarly, Toomey et al. (1993) use microfauna, soils, and geomorphic data to identify a shift to drier conditions beginning around 14 ka, followed by a return to somewhat moister conditions by 10.5 ka. Using growth data from speleothems obtained in central Texas caves, Musgrove and her colleagues (Musgrove et al. 1999; Musgrove et al. 2001) interpret the period between 15 and 12 ka as transitional between a cool, wet phase of rapid speleothem growth centered on the last Full Glacial and a much warmer and drier postglacial period when speleothem growth was severely limited.

Faunal evidence from the latest Pleistocene and the Pleistocene–Holocene transition suggest that temperatures were probably cooler than at present, particularly in summer, but that very cold winters were probably not common (Graham 1987). In the southeastern United States, the latest Pleistocene witnessed a gradual shift from forest dominated by boreal elements (e.g., spruce, fir, and *Diploxylon Pinus*) to cool temperate deciduous

elements, (Delcourt and Delcourt 1985). The late Pleistocene alluvial record in central Texas and on the inner coastal plain indicates that there was a shift from a phase of bedload-dominated aggradation during the full glacial to an interval of valley entrenchment during the terminal Pleistocene (Blum 1989b; Nordt 1992; Blum and Valastro 1992; 1994). In North Texas, where entrenchment of the Trinity system occurred somewhat earlier (22–15 ka), the same period witnessed slow aggradation of the coarse-grained Aubrey alluvium in the valley bottoms (Ferring 1994a; 2000).

1.6.3 Early Holocene Climates and Biota

Most lines of evidence suggest that the early Holocene (roughly 12 ka–8 ka) witnessed warming and, at least in central Texas, drying. However, some investigators have interpreted this transition as a relatively smooth trend, while others see relatively rapid changes and/or a great deal of fluctuation apparent in the record, and data from North Texas suggest that the early Holocene was probably wetter than both the preceding and succeeding periods. Pollen profiles from a variety of central Texas bogs exhibit marked declines in most types of arboreal pollen (*Quercus* is an exception) and concomitant increases in grass and herbaceous pollen during the early Holocene. Bryant and Holloway (1985) emphasize a steady, gradual warming and drying trend that resulted in incremental changes that only becomes apparent when viewed at a generalized level (1985). Isotopic evidence from Fort Hood in central Texas (Nordt et al. 1994) also indicates gradual warming and drying through a transition from approximately 45–50% warm season grasses in the late Pleistocene to 50–60% in the early Holocene, while soil isotope data from the Wilson Leonard site (Fredlund and Tieszen 1998) remain C₃ dominated throughout the entire record (this contrasts strongly with phytolith data from the same site; see below). While Bousman's (1998) re-analysis of the pollen data also supports warming and drying during the early Holocene, he sees evidence for marked fluctuations in canopy cover, including a short-term transition from woodland to grassland around 9 ka. Similarly, Holliday (2000) uses stratigraphic and isotopic evidence to argue that while the period from 10.9 ka to 8 ka was a period of overall drying on the Southern Plains, it witnessed relatively pronounced, short-term fluctuations between moist and very dry conditions. In contrast to the above studies, Humphrey and Ferring (1994) report increasing importance of C₃ grasses in the early Holocene (roughly 11–7.5 ka) in north Texas, which they interpret as a return to somewhat moister conditions following Haynes' Clovis-age drought. This change was presumably associated with a westward shift in the woodland-plains boundary. Fredlund (1998) uses phytolith data to suggest that woodlands surrounding the Wilson-Leonard site in central Texas were more closed, and that the species composition of interdigitated grasses was substantially different, than modern conditions from approximately 10 to 9.5 ka.

One of the most striking aspects of the late Pleistocene/Holocene transition is the relatively abrupt extinction of the megafauna. There is still no firm consensus on the relative importance of climate change and human predation in this process, but there is little doubt that the changing character of the environment did have an impact on the megafauna. Smaller animals were somewhat slower to adjust, with rodent taxa now found well to the north and/or east such as the eastern chipmunk (*Tamias striatus*) and the southern bog lemming (*Synaptomys cooperi*) persisting on the Edwards Plateau until at least 9 ka (Graham 1987). However, there is clear evidence that progressive soil loss from the Late Pleistocene through the mid Holocene resulted in the extirpation of a variety of fossorial rodents (e.g., *Cynomys* sp., *Geomys* sp.) (Toomey 1993; Toomey et al. 1993).

Alluvial records from Texas show many of the same trends during the latest Pleistocene and early Holocene, but differ somewhat in the details. On Fort Hood, Nordt (1992; 1994) identifies an alluvial unit (the Georgetown alluvium) that spans the period from approximately 11 to 8 ka. This fill, which occupies the bedrock incised valley formed by entrenchment during the late Glacial, is buried by subsequent deposits and capped by a relatively prominent paleosol. Nordt believes that this fill was abandoned by a relatively brief episode of alluvial incision around 8–7 ka, which removed much of the fill and truncated the soil on most of the preserved remnants, but did not incise appreciably into the bedrock. Blum (1989b; Blum and Valastro 1989) identifies an alluvial unit (Unit E) in a similar stratigraphic setting in the Pedernales River, but interprets the age range represented as roughly 11 ka to 6.5 ka, which overlaps Nordt's subsequent unit on Fort Hood (the Fort Hood alluvium) (Nordt 1992). Blum's work on the Colorado River in west-central Texas (Blum and Valastro 1992) also identified a unit in a comparable stratigraphic position (variously termed the "early Holocene alluvium" or "early-middle Holocene fill"), but dating suggests that it spanned the period from 10 to 5 ka. In the upper Trinity basin, Ferring (1994a; 2000) identifies an extended period of rapid valley aggradation that dates to roughly 11–7.5 ka. This episode, which resulted in the accumulation of up to 4 m of sediment in less than 4000 years, is interpreted by Ferring as the result of an increase in annual precipitation and/or the incidence of cyclonic storms. Because the unit is not well exposed, it is possible that there may have been a bracketing incision of the fill, but there is no evidence that such an event occurred; rather the system appears to have transitioned smoothly into the finer-grained aggradation.

1.6.4 Middle Holocene Climates and Biota

The middle Holocene (roughly 8–4 ka) witnessed continuation of the warming and drying trend begun in the early Holocene. However, opinion is divided on the severity of this trend relative to modern conditions; some authors see evidence of one or two pronounced periods where climate

was significantly warmer and drier than at present (the so-called Altithermal or Hypsithermal periods), while others do not. Delcourt and Delcourt (1985) suggest that the prairie/forest boundary shifted eastward significantly in the period between 8500 to 4000 BP, while Bryant and Holloway (1985) see little evidence of a pronounced drought in Texas pollen records. However, in his re-analysis of the same pollen data, Bousman (1998) notes a rapid shift from forest to grassland between approximately 8 and 7 ka, followed by a brief return to greater arboreal cover (and, by implication, more effective precipitation) around 6 ka, then a shift to the driest conditions of the Holocene between approximately 5.5 and 4.5 ka. One of the most important changes in the southeastern evergreen forest was a shift from oak and hickory to southern pine dominance (Delcourt and Delcourt 1985). Bryant and Holloway (1985) suggest that an essentially modern oak savanna was established in parts of central Texas by the middle Holocene, while other areas may have continued as oak woodlands until as late as 1500 BP; Bousman (1998), in contrast, suggests that grasslands dominated throughout much of the middle Holocene, and that oak woodlands were not established until the late Holocene. Phytolith data (Fredlund 1998) suggest that arboreal cover was declining and arid-adapted short grasses were expanding from 8.7 to 6 ka. Given the strong edaphic control on the distribution of prairies and forests in the Fort Worth district, it is unlikely that the region witnessed a simple east-west migration of the prairie-forest boundary; rather, it is likely that the type and density of arboreal species varied in response to climate change, particularly within the boundary of the modern Cross Timbers.

On the basis of faunal evidence, Graham (1987) concludes that the early-middle Holocene was warmer and drier than the previous period but still relatively mesic compared to modern conditions, while the latter middle Holocene continued the trend toward aridity. Lundelius (1967) also interprets the faunal record as indicating a gradual, smooth trend towards increasing aridity through the entire Holocene period, while Toomey (1993) interprets faunal and sedimentological data from Hall's Cave (southern Edwards Plateau) as indicating a long-term drying trend interrupted by brief, relatively mesic intervals 10,400 to 9000 BP and 2500 to 1000 BP. In contrast, Dillehay (1974) interprets apparent periods of bison absence as indicative of pronounced dry periods between 7500 and 4500 BP and 1500 to 750 BP.

Carbon isotopic data from north Texas (Humphrey and Ferring 1994) suggest that the period from approximately 7500 BP through 5000 BP was drier than at present, while Nordt et al. (1994) interpret carbon isotope data from central Texas as indicating substantially warmer and drier conditions (85–95% C_4 grasses, compared to a modern ratio of 65–70%

C_4) from approximately 6000 to 4000 BP. Radiocarbon ages on sediments from the lower Brazos River fill show relatively consistent apparent stratigraphic reversals between approximately 6 ka and 5 ka, suggesting that the system was being overloaded with old organic matter derived from soil erosion in the basin (Abbott 2001a; Abbott and Frederick 2003). In contrast, Goodfriend and Ellis (2000) use stable carbon isotope data from Hinds Cave (southwest Texas) snail shells to postulate that the peak expression of C_4 plants in snail diets occurred somewhat later (approximately 3.5 ka), and that middle Holocene conditions in the trans-Pecos were considerably more mesic.

Geomorphic data suggest that the early to middle Holocene may have experienced significant stripping of thick, reddish Pleistocene soils developed on the Cretaceous limestones of the Edwards Plateau, which is also interpreted as evidence of increasing aridity (Nordt 1992; Toomey et al. 1993). Roughly coincident with this stripping, a series of relatively fine grained fills accumulated in the stream valleys in central Texas, followed by a renewed period of incision between approximately 6500 and 4500 BP (Blum 1989b; Blum and Valastro 1992, 1994; Nordt, 1992; Thoms and Mandel 1992). East of the Balcones escarpment in the Eocene Sand belt, Bousman (1991) documents a series of stacked alluvial units on Buffalo Creek and its tributaries, in Freestone and Leon Counties. Here again, a depositional hiatus and/or pronounced erosional event appears to have occurred between approximately 6000 and 4000 BP. In contrast, Waters and Nordt (1995) identify a period of alluvial aggradation on the lower Brazos River that spans the period from approximately 8000 to 4000 BP; however, they argue that this aggradation is largely the result of increasing sediment yield during a middle Holocene warm period due to erosion upstream in the large Brazos basin.

1.6.5 Late Holocene Climates and Biota

The late Holocene pollen record is limited because many of the Central Texas bogs either lack sediments or pollen representing the last few thousand years (in some cases, as a result of mining of the upper part of the peat deposits). Nevertheless, data from Weakley Bog indicate that while oak was present for the entire period of record represented in the column (approximately the last 2500 years), a transition from an oak woodland to a more open oak savanna occurred approximately 1500 BP (Bryant and Holloway 1985). In Harris County, pollen data from Aronow Bog (Beck et al. 2001) document a transition from an open, grassy environment with very little arboreal pollen around 1 ka to an oak savanna and, ultimately, a pine-dominated environment within the last 200 years.

Faunal data from the Coastal Plain are somewhat equivocal, but in general indicate a continuation of the previous trend towards increasing aridity (Lundelius 1967; Graham 1987). Isotope and geomorphic data, in contrast, generally indicate more variable climatic conditions. Both Humphrey and Ferring (1994) and Nordt et al. (1994) interpret middle–late to late Holocene carbon isotope data (on soil carbonate and soil/sediment humates, respectively) as indicating a pronounced shift towards more effective moisture (i.e., moister, cooler, or both) following the middle Holocene dry interval. According to Humphrey and Ferring (1994), this moist interval was punctuated by a 1,000 year shift toward aridity between roughly 2000 and 1000 BP. Although the carbon isotope signatures were not as straightforward, Brown (1998) used oxygen isotopic data from mussel shell features to infer a period of relatively cool, moist climate between approximately 1500 and 2500 BP. Nordt et al. (1994) also see evidence of a brief shift towards drier and possibly warmer conditions, but this shift occurs slightly earlier (roughly 2500–1800 BP). In contrast, Goodfriend and Ellis (2000) see a peak abundance of C_4 vegetation around 3.5 ka, with increasingly depleted samples afterwards.

Geomorphic data also generally indicate fluctuating climate during the Late Holocene. Major alluvial fills spanning all or part of the period between approximately 4.5 ka and 1.5 ka are documented at several localities throughout Texas (Hall 1988; Blum and Valastro 1989; 1992; Blum 1992; Nordt 1992; Waters and Nordt 1995; Ferring 1994a; 2000). In many localities, aggradation appears to have slowed in the second millennium BP, allowing a widespread soil to form. Elsewhere, aggradation of a comparable late Holocene unit appears to have terminated by approximately 3 ka (Thoms and Mandel 1992). Approximately 1 ka, there was another regional episode of stream incision (Hall 1990), followed by aggradation of another unit in the last 1,000 years or so (Blum 1992; Nordt 1992). This episode is also apparent in areas east of the Balcones escarpment. At Jewett Mine in Freestone County, examination of floodplain deposits suggests that the alluvial fills of tributaries to Buffalo Creek were extensively eroded by approximately 1 ka, and that almost all deposits in the tributary valleys post-date this stripping (Abbott 1996a).

As the preceding summary demonstrates, while the broad trends in the paleoenvironment of Texas are relatively consistent, there are many subtle differences among different records of environmental change in Texas throughout the late Quaternary. Importantly, while results should be reviewed and integrated carefully and critically, there is little reason to expect different environmental/climatic proxies to correspond precisely. The various physical and biological components of ecosystems vary in spatially complex ways, and respond to climatic/environmental changes (if at all) according to differing thresholds and lag times. Characterization of the resources available to and

environmental constraints faced by prehistoric peoples in a given area requires an appreciation of spatial and temporal variability in Texas paleoenvironments, which remain poorly understood indeed. Much more data, of as many different types and from as many different contexts as possible, are needed to characterize the spatiotemporal environment through time in Texas.

1.7 Resource Distributions in the Fort Worth District

The distribution of resources in time and space throughout the Fort Worth District is of considerable interest to archeology. Because of the strong edaphic controls imposed by the regional geology, there was almost certainly a very diverse suite of biotic resources available in the district, and ecotonal settings from which inhabitants could effectively forage in a variety of very different environments were common. The following discussion addresses the suite of resources that would be used by prehistoric peoples, and their probable distribution within and around the Fort Worth district.

1.7.1 Plant Resources

Given the alternating prairie–woodland described above, the plant resources available for exploitation varied across the Fort Worth District. Several basic, functional classes of plant exploitation can be identified: use as a food resource, use as a fuel resource, use as a medicinal resource, and use as a construction/fabrication/decoration resource. In addition, plants were almost certainly collected and processed for ritual purposes, and the structure of extant vegetation was utilized to passive, ambient advantage for shade and protection from the elements. While no single publication provides a comprehensive accounting of prehistorically important north–central Texas plant taxa, a number of publications have presented a great deal of relevant ethnobotanical information, some of which applies to prehistoric Native Americans in general (e.g., Castetter 1935; Whitford 1943; Kirk 1970; Moerman 1986; Kindscher 1987) and some of which applies to specific Plains tribes (e.g., Carlson and Jones 1939; Vestal and Schultes 1939; Jordan 1965; Munson 1981; Perttula and Bruseth 1983). Despite their number, these studies provide an incomplete picture of the breadth and details of prehistoric plant use. In large part, this is because our ability to approach such a subject archeologically or deductively is constrained by a paucity of evidence, while ethnographic descriptions are limited in availability and scope, and at best apply to the Protohistoric and Historic periods.

Food is the most obvious, and the most critical, use of plants by prehistoric residents of the Fort Worth District. The edible

portion of a plant is typically a root structure (tubers and bulbs), a reproductive structure (fruits, nuts, or seeds), or foliage (greens), although other parts may also be edible (e.g., cactus pads, sotol hearts). In almost all cases, the availability of these resources varies both spatially and temporally (i.e., on a seasonal basis). However, individual plant taxa occasionally yield different edible structures at different times of the year. It is also unlikely that all potential vegetal foodstuffs were recognized, much less utilized. The desirability of plant foods varies considerably according to taste, availability, and cultural preference; many potential plant and animal foods were probably only exploited in times of severe food stress (Jochim 1981).

Despite the considerable uncertainty that remains about the universe of edible plant resources that was exploited, it is possible to outline their character and distribution in broad terms. The prairie grasslands are characterized by primarily non-woody grasses and forbs that would yield primarily greens, roots/tubers, and seeds, while the Cross Timbers would yield nuts and fruits in greater abundance. Gallery forests lining the floodplains of streams in the grassland were probably particularly rich, concentrated sources of plant resources, particularly in late summer and autumn when the production of fruits and nuts peaked. In terms of seasonality, spring and early summer represents the production peak for greens and many bulbs and tubers, while fruit, nut, and seed production peaks in late summer and autumn. Because winter is the season of lowest productivity, it may have seen comparatively intense exploitation of root resources, not because it represents the optimal time for them, but because other plant foods were relatively scarce.

Fuel is another fundamental requirement for people, who use it to feed fire that keeps them warm and cooks their food. In terms of fuel resources, there is a clear dichotomy between the Prairie grassland, where firewood would have been a relatively scarce and precious commodity, and the Cross Timbers and (to a lesser extent) Mesquite Plains, where fuel would have been relatively abundant. Of course, it is likely that non-woody fuel sources such as dried dung were routinely exploited in the grassland environment, particularly when bison were present in significant numbers. Nevertheless, it is likely that the need to procure wood for fuel was a much more important consideration in the decision to locate activities in the Black and Grand Prairies than it was in the wooded areas.

Our knowledge of medicinal and ritual plants in the district is equally limited, but generalized ethnographic data on hunter/gatherer bands suggest that they were an important resource. Wild plants were potentially used as astringents, tonics, diuretics, emetics, analgesics, stimulants, and as poultices for wound dressings, and there are a variety of native plants that could have fulfilled these functions (Kirk 1970). Given

that disease was often attributed to supernatural agencies, there was a great deal of crossover between medicinal and ritual applications of plants. Unlike food plants, knowledge of medicinal and ritual plants was often restricted (and closely guarded) to individuals, families, or other kinship groups within tribes (Jordan 1965). Although more information is necessary to assess the distribution of such resources, it is likely that those areas characterized by relatively diverse flora, such as the dense riparian corridors, were relatively important sources because they contain a heterogeneous, concentrated assemblage of available taxa.

Plants were also important as a source of raw materials for construction and fabrication. Although many types of plant resources were clearly used to manufacture implements and structures, the most notable include wood and grasses for construction and tool manufacture, and fiber for binding, fish nets, and basketry. While a variety of these resources were available, there were clear preferences of specific woods and fibers for specific uses, such as the use of bois d'arc wood for bow manufacture and willow for fabrication of frameworks and supports. The distribution of woods clearly favored the more heavily forested areas, although the riparian corridors probably contained a much more diverse set of useful woods than the more uniform upland forests and woodlands. Fibers would have been available from a variety of locales in both grassland and woodland settings. Other construction/fabrication uses include gourds for containers, a variety of plants for pigments and dyes, sap for binding agents, sources of tannin for curing hides, and sources of soap for cleaning. Table 1–5 presents a synopsis of plants identified in Jordan's (1965) thesis on the ethnobotany of the Kiowa Apache, and therefore illustrates a minimal suite of plant resources used by a single tribe. While the plants included in this study are limited to those growing in the vicinity of the former Comanche-Kiowa-Apache reservation in southwestern Oklahoma, many of the same plants are available in the Fort Worth district.

1.7.2 Faunal Resources

The fauna typical of the Fort Worth District has been listed previously (see Table 4). In large part, the suite of available faunal resources reflects the character of the habitat; while there was considerable overlap, the available fauna in the grasslands were very different than those in the adjacent woodlands. Although use as a food resource was probably paramount in the exploitation of most types of fauna, other animal parts—skin, bones, sinews, stomach, horns, etc.—were used extensively in the manufacture of tools, clothing, shelter, medicinal, and ritual implements. However, it is unlikely that most animals were procured for purposes other than consumption. Rather, uses were found for the inedible portions of game, which served to make the process

Table 1–5: Economic Plants of the Kiowa Apache, from Jordan (1965)

Scientific Name	Common Name	Uses		
		food	medicine	other uses
<i>Allium sp.</i>	wild onion	root, stem		
<i>Ambrosia sp.</i>	ragweed, bloodweed		screw worms (horses)	low windbreaks, thatch
<i>Andropogon sp.</i>	big bluestem, little bluestem		sweat lodge switch	bed pallets, brooms, thatch
<i>Artemesia filifolia</i>	silvery wormwood			bed pallets, toilet "paper"
<i>Artemesia ludoviciana</i>	sage		smoke (in sweat lodges and other ritual settings to promote "harmony")	
<i>Asclepias sp.</i>	milkweed	fruit (pod)	stomach medicine; snakebite medicine; chest medicine	
<i>Baptista sp.</i>	false indigo			rattles
<i>Bouteloua curtipendula</i>	sideoats grama		cataracts (surgical)	
<i>Bulelia lanuginosa</i>	wooly buckthorn	fruit		
<i>Callirhoe involucrata</i>	cowboy rose	roots		
<i>Carya illinoensis</i>	pecan	nut		wood for tent stakes, walking canes, hoe handles, etc. Not favored for fence posts and tipi poles due to quick onset of rot
<i>Celtis spp.</i>	pecan	fruit		tool handles (not a favored wood)
<i>Cocculus carolinus</i>	Carolina moonseed	fruit		
<i>Cornus drummondii</i>	western dogwood			arrow shafts, light bows, drumsticks
<i>Crataegus sp.</i>	hawthorne	fruits		
<i>Cucurbita foetidissima</i>	missouri melon		screw worms (horses); nausea; constipation	
<i>Cuscuta sp.</i>	dodder		shingles, thrush (mixed with clay and insect parts)	
<i>Cyperus setigerus</i>	sedge	stem (base)		
<i>Dalea laxiflora</i>	slender parosela		headache	
<i>Diospyros virginiana</i>	persimmon	fruit		
<i>Echinacea angustifolia</i>	purple coneflower		tooth and gum problems	
<i>Equisetum hyemale</i>	common scouring-rush			whistles
<i>Eriogonum longifolium</i>	long leaved eriogonum		unknown application	
<i>Fraxinus sp.</i>	ash			light bows, misc. wooden implements
<i>Gaura coccinea</i>	scarlet gaura			toy arrows
<i>Gutierrezia dracunculoides</i>	broomweed		skin ailments; lower respiratory ailments	brooms
<i>Gymnocladus dioica</i>	Kentucky coffee bean			game pieces
<i>Helianthus sp.</i>	sunflower			windbreaks
<i>Ipomoea leptophylla</i>	bush morning glory		"bone medicine" (pain relief for broken bones)	
<i>Juglans rupestris</i>	black walnut	fruit		pipe stems, drum sticks, walking sticks, and other decorated wooden implements; dye
<i>Juniperus virginiana</i>	red cedar		smoke (in sweat lodges and other ritual settings to promote "harmony")	tipi poles, fence posts, staffs, flutes

Table 1-5: Continued...

Scientific Name	Common Name	Uses		
		food	medicine	other uses
<i>Lithospermum incisum</i>			intestinal problems, diarrhea	
<i>Lygodesmia juncea</i>	skeleton weed		eye infections	
<i>Maclura pomifera</i>	bois d'Arc			strongly favored for bows, war clubs, drumsticks, pipetamps, and cradleboards
<i>Matelea biflora</i>	prairie anglepod	fruit (pod)	chest colds, pneumonia, pain, and swelling	
<i>Morus rubra</i>	red mulberry	fruit		light bows, war clubs, tool handles, fence posts
<i>Nasturtium officinale</i>	water cress	leaves (greens)		
<i>Nelumbo lutea</i>	water chinquapin	root (tuber)		
<i>Neobesseyia missouriensis</i>	hedgehog cactus	fruit		
<i>Opuntia sp.</i>	prickly pear	fruit, leaves (pads)	burns, sores	
<i>Paronychia lobata</i>	strict whitlow-wort			broom
<i>Phytolacca americana</i>	pokeweed	leaves, stems (greens)		dye (juice)
<i>Populus deltoides</i>	cottonwood			fuel (rarely)
<i>Proboscidea louisianica</i>	unicorn plant	seeds		
<i>Prosopis glandulosa</i>	mesquite	seeds & seed pods		
<i>Prunus sp.</i>	plum, choke cherry	fruit (important)		
<i>Psoralea esculenta</i>	indian turnip, prairie apple	root (tuber)		
<i>Psoralea tenuiflora</i>	pursh			marrow scoop
<i>Quercus sp.</i>	oak	nuts (rare)	cigarette papers	fence posts, arbor framework, drying racks, tent poles and stakes, bowls, pigment (charcoal)
<i>Rhus aromatica</i>	skunkberry	fruit		
<i>Rhus glabra</i>	smooth sumac		smoked with tobacco	
<i>Ribes odoratum</i>	currant	fruit		
<i>Robinia pseudoacacia</i>	black locust			fence posts
<i>Rubus sp.</i>	blackberry	fruit	diarrhea, stomachache	
<i>Salix nigra; Salix interior</i>	black willow, sandbar willow			arbor supports, sweat lodge supports, and other framework constructions; cordage & lashing material (green bark), windbreaks
<i>Sapindus drummondii</i>	chinaberry, soapberry		constipation, kidney trouble, and to start menstrual flow	tent poles and stakes, fence posts, arbors, drying racks, bows, tool handles
<i>Schrankia uncinata</i>	catclaw sensitivebrier, touch-me-not		stomach medicine, diarrhea	
<i>Silphium laciniatum</i>	compass plant	sap (gum)		
<i>Solidago sp.</i>	goldenrod		cold and fever medicine	

Table 1-5: Continued...

Scientific Name	Common Name	Uses		
		food	medicine	other uses
<i>Thelesperma intermedium</i>	--	seed pods		
<i>Typha</i> sp.	cattail	root	ritual use to improve temperament of children	
<i>Ulmus</i> sp.	elm	bark (tea, gum)		saddle frames, fence posts, arbor frames, bows (occasionally)
<i>Viburnum rufidulum</i>	black haw	fruit		
<i>Vitis</i> sp.	grape	fruit		wooden implements, handles

of acquiring the animal more efficient. Nevertheless, in some cases (e.g., small birds acquired to obtain feathers for fletching arrows or personal adornment; predators like black bear, gray wolf, mountain lion, and eagles), the primary motive may have been acquisition of raw materials, ritual objects, and/or status.

While large game were probably much preferred because of their caloric yield, it is likely that small game were relatively more important at many times due to their greater abundance. Faunal remains from sites in the region typically include a wide range of smaller terrestrial taxa, including small mammals, reptiles, birds, and amphibians. The largest animal in the district through the Holocene was the American bison (variously *Bison bison* or *Bos bison*; see Nowack 1991), but it is unlikely that it was continuously present (Dillehay 1974), and would have been largely restricted to the more open prairies and woodlands. When available, bison were hunted during the whole of the prehistoric period, and formed the most important resource for many Plains tribes. Pronghorn (*Antilocapra americanus*) would also have inhabited the prairies, while the most persistent and reliable large game in the wooded areas would have been white-tailed deer (*Odocoileus virginianus*). Both white-tailed deer and pronghorn were probably widely available in their respective habitats, but did not occur in the concentrations typical of bison. It is possible that pronghorn abundance, like bison abundance, varied systematically through time in response to climatic influences. The much larger mule deer (*Odocoileus hemionus*) may have occasionally been present in the district, but did not form a prominent component of the assemblage. Jackrabbit, cottontail rabbit, opossum, raccoon, beaver, and a variety of smaller rodents were probably common and relatively widespread. A variety of snakes, lizards, turtles, and birds were also common throughout the district on at least a seasonal basis. Acquisition of such species was probably conducted by both active hunting and by use of traps and snares. Riverine areas in the Fort Worth

district provided sources for a variety of marine resources, including freshwater mussels (e.g., *Amblema* sp., *Lampsilis* sp.) and freshwater fish such as gar (*Lepisosteus* sp.), and channel catfish (*Ictalurus punctatus*). Because preservation of fish bones is rare, it is likely that riverine resources were more important than their representation in the record would seem to suggest.

1.7.3 Fresh Water

Water for drinking and cooking is essential for humans, and is always a major consideration in the location of activity loci. Given the number of through-flowing streams, the availability of water in the Fort Worth district was probably not as serious a limiting factor on prehistoric settlement during most of prehistory as it was further west on the High Plains and western Rolling Plains. While the discharge of these streams varied seasonally and with longer term climate change, periods when the larger streams such as the Brazos and the West Fork of the Trinity supplied no water were almost certainly rare. Even though the quality of that water certainly varied across the district and through time due to stagnation, algal growth, saline discharge, and variations in suspended sediment, poor water was probably the exception rather than the rule. In fact, early descriptions of the area (e.g., de Mézières 1778, as quoted in Bolton 1914) remark on the quantity and quality of available surface water in the area.

Even more highly favored than surface streams are reliable springs. Because they frequently supply a clear, cold, and clean source, springs have long been a preferred source of water. Although not all of the district was examined, Brune did examine Tarrant, Wise, Parker, Jack, and Hood Counties in his landmark volume *Springs of Texas, Vol. 1* (2002); his more abbreviated *Major and Historic Springs of Texas* (1975) is missing Jack and Wise Counties, but includes Johnson County. Brune identifies more than 80 named springs in these six counties, including a number that include multiple

sources. Unsurprisingly, a large number of these springs are identified as having associated Native American campsites, some of which are clearly large, dense archeological sites that represent protracted, repeated occupation of the localities.

1.7.4 Lithic Resources

Lithic resources of the north Texas area have been summarized in detail by Banks (1990) and more briefly by Peter and McGregor (1988), Turner and Hester (1993) and Hofman (1989). This discussion focuses on knappable lithologies useful for making flaked stone tools, but also briefly touches on materials for ground stone tools and for battering tools like hammerstones and celts. Throughout the discussion the term *chert* is used in its most inclusive sense, encompassing related forms of microcrystalline and cryptocrystalline quartz, including flint, jasper, chalcedony, agate, and opal.

In general, there is relatively little knappable lithic material available in any of the Cretaceous and Paleozoic rocks that underlie the district. According to the various sheets of the Geologic Atlas of Texas covering the district (Barnes 1972; 1976; 1987; 1988; McGowen et al. 1991), chert is not a notable inclusion in the Cretaceous carbonate series (including the Edwards Limestone, which is well known for its diverse, rich chert in Central Texas and along the Callahan Divide). While the GAT sheets note that chert and quartz pebbles occur in conglomerate beds in the Cretaceous Twin Mountain Formation and a number of Paleozoic Formations (e.g., the Brazos River, Palo Pinto, Mineral Wells, Markley Formations) in most cases they tend to be small (pebble-sized) clasts and therefore unlikely to serve as a reliable lithic source (although they were almost certainly utilized at times). According to the Abilene sheet of the Geologic Atlas (Barnes 1972), there is primary chert associated with some of the Paleozoic limestones in western Palo Pinto County (e.g., Ranger Limestone, Winchell Limestone), but this material is not mentioned in the descriptions of these same units in the adjacent Wichita Falls–Lawton sheet (Barnes 1987). In addition, while it is not mentioned as a characteristic of the formation on the Sherman Sheet of the GAT (McGowen et al. 1991), Banks (1990) describes chert from the Pennsylvanian Chico Ridge Limestone in Wise and Jack counties. While these various bedrock materials were almost certainly exploited prehistorically to some degree, the relative scarcity of the material suggests that most lithic material was probably obtained from Quaternary sources or obtained (e.g., through trade or through embedded procurement during seasonal rounds) from surrounding areas such as the Arbuckle Mountains, Edwards Plateau, and Callahan Divide.

Quaternary sources of knappable material in the Fort Worth district include the channels and terraces of through-flowing

streams and gravels strewn somewhat unpredictably across the upland surfaces. These latter materials include a variety of discontinuous, siliceous upland gravels of probable Pliocene and/or early–mid Pleistocene age. Banks (1990) equates these deposits to the similar Uvalde gravels of central and south Texas. The Uvalde gravels (Hill 1891; Byrd 1971) consist of a lithologically–diverse suite of stream rounded gravels that mantle upland surfaces and are apparently unrelated to the modern drainage net. In the Fort Worth district, such deposits are present but not in sufficient concentrations to warrant mapping on the geological atlas. They are apparently dominated by cherts and quartzites of unknown provenance (Banks 1990), although it is likely that they are related to reworked vestiges of material related to the Ogallala Fm. underlying the High Plains surface (similar to the Seymour Formation, mapped farther to the west). Chert and quartzite gravels are also present in Quaternary terraces of the Brazos River, but should be relatively limited in the Trinity system, which does not encompass a terrain rich in either bedrock sources or residual lag gravels.

Stone provided raw material for more than flaked stone tools, such as groundstone implements (e.g., manos, metates, celts, abraders, etc.), battering implements, weights, and materials for stone boiling and related forms of thermal storage. Many localized, silica- and iron-cemented sandstones suitable for the manufacture of groundstone artifacts are present in the various Paleozoic rocks in the northern and western part of the district. Banks (1990) notes that the Woodbine Formation sandstones, which underlie the eastern Cross Timbers, were commonly used for abraded stone implements. In contrast, the Cretaceous sandstones such as the Antlers, Twin Mountain, and Paluxy Formations are typically too soft to yield durable groundstone material, although all may contain localized lentils suitable for use.

1.7.5 Other Resources

Clays for ceramic use became an important resource during the Late Prehistoric period, but was less important to the relatively mobile groups typical of the Fort Worth district than it was to the more settled Caddo to the east. To the author's knowledge, no prehistoric clay quarries have been identified in the Fort Worth district. Nevertheless, ceramic-quality clay is available, and it is likely that it was obtained and used during the Late Prehistoric period. Exploitable clay deposits are present in the district as soils and alluvial deposits (although these are frequently problematic for ceramic manufacture due to expansive mineralogy and inclusions of mineral salts such as calcite and gypsum) and as bedrock clays. Sufficient clay resources were present in Pennsylvanian rocks at the now-vanished town of Thurber to supply a thriving brick-making industry from 1897–1930 (Maroney 2002).

Salt is an essential dietary supplement for humans, and is extremely valuable for curing food to preserve it for long periods. While the author knows of no prehistoric salt processing sites identified in the district, salt-making was a small-scale industry practiced by the Caddo to the north and east during Late Prehistoric times (e.g., Early 1993; Kenmotsu 2005), and was traded widely.

Inorganic pigments, particularly iron oxides (e.g., hematite, limonite), were also commonly available in the district. Iron oxide concretions, which produce various shades of red, orange, and yellow, are common in upland soils and in the

Paleozoic and (to a lesser extent) Cretaceous rocks. Various manganese oxides (e.g., hausmanite, braunite) are also common in soils and produce brown and black pigments. Copper oxides, which supply bluish and greenish pigments, were reported by a number of early surveys of the mineral resources of the North Texas Paleozoic rocks (Sellards et al. 1932). While small-scale copper production was undertaken in adjacent Archer County (in the Wichita Falls District) during the 1860s (Anderson and Kleiner 2002), copper ores were never found in sufficient concentrations for economic exploitation during the historic period in the Fort Worth District, and there is little evidence that they were exploited by prehistoric peoples.

Part II:
Late Quaternary
Stratigraphy and Geoarcheology
of the Fort Worth District

PART II: Late Quaternary Stratigraphy and Geoarcheology of the Fort Worth District

2.1 Introduction

This part of the report integrates available stratigraphic and geoarcheological data from the Fort Worth District. It begins with a discussion of relevant geomorphic and pedogenic processes. This discussion is framed with consideration of the range of landscape settings in the district from a genetic, process-oriented perspective. This discussion is then followed with an examination of more detailed stratigraphic issues and historical models for a variety of environments in the district.

2.2 Landforms of the Fort Worth District and the Processes that Shaped Them

The landforms in the Fort Worth district can be divided into two principal classes and a number of distinctly subordinate ones. The two primary classes consist of upland/hillslope landforms, which form the overwhelming majority of the district; and alluvial landforms, which are widespread and have relatively high archeological relevance due to their aggradational nature. Subordinate classes include less common natural landforms and landforms made by humans; most (but not all) of the latter date to the past hundred years. Among the subordinate natural landforms are eolian dunes and sheets, karstic caves and sinkholes, and rockshelters. Manmade landforms are abundant and of great variety, ranging from enormous artificial building pads and levee systems designed to hold back large rivers at full flood to small but locally ubiquitous roadcuts, stock tanks, and areas of localized filling and leveling. Somewhere in between the natural and the manmade are landforms that developed through natural processes under the direct influence of human activity, such as stream channels choked with sediment liberated by agriculture and beaches built by wave activity along the shorelines of reservoirs.

In addition to the depositional and erosional processes that sculpted the landforms, soil processes shape the biotic character of the landscape, in part controlling and in part controlled by the universe of associated flora and fauna. The classification of soils in the district was previously described in Part I. The relatively brief summary that follows outlines landforms in the Fort Worth district and provides an overview of the suite of natural processes that molded them into their current form, including processes of deposition, erosion, and weathering and soil formation. The emphasis is on contemporary processes rather than long-term landscape

genesis. A more focused discussion of the geoarcheological potential of the district's landforms is presented in Part III of this document.

2.2.1 Weathering and Pedogenesis

Weathering and soil formation are processes that gradually break down and alter geological media—bedrock and sediments—to form the material we know as soil. While Webster's Ninth New Collegiate Dictionary (Mish 1987) defines soil as "the upper layer of earth that may be dug or plowed and within which plants grow", soil scientists typically define soil more narrowly (Rowell 1994; McRae 1988; Gerrard 1981; Birkeland 1984). While such definitions differ in detail, the unifying concepts are that soil (1) occurs at the earth's surface, (2) supports plants, and (3) has been altered from the parent material (typically bedrock or clastic sediments) through the combined action of a suite of interrelated physical, chemical, and biological mechanisms. The mechanisms that convert solid rock to soil are commonly divided into two classes: *weathering*, which breaks rock down into sediment, and *pedogenesis*, which reorganizes and transforms sediment to form soil. Each of these is discussed below.

2.2.1.1 Physical and Chemical Weathering

Weathering refers to the suite of *in situ* physical and chemical processes that occur in the near-surface environment and act to gradually convert solid rock to unconsolidated material (Selby 1993; Chorley et al. 1984; Birkeland 1984; Ritter 1978). The mechanisms of weathering can be further subdivided by process (*physical weathering* vs. *chemical weathering*) or by agent (*biological weathering* vs. *abiotic weathering*). Soil formation, or *pedogenesis*, acts to progressively reorganize and convert these materials to soil. It is important to note that the distinction drawn between weathering (particularly chemical weathering) and pedogenesis is artificial. Various forms of weathering are always operating in intimate concert with pedogenic processes. From a conceptual standpoint, however, it is useful to distinguish between the two suites of processes.

Physical weathering (*disintegration*) processes act to break rock up into smaller components without changing their essential chemical makeup. Commonly cited forms of physical weathering include physical stresses imposed by unloading of overburden, thermal stress, hydration of expansive minerals, crystal growth, frost wedging, and the action of organisms. *Unloading* refers to the release of stresses

in rock formed under intense pressure when it is exposed at the surface by erosion. This pressure release is believed to be responsible for the formation of joints, sheeting, and other fractures in the rock surface. While these fractures can break rock into smaller fragments, they also serve as conduits that allow water access into the rock, and thereby enhance chemical weathering. *Thermal stress* refers to fracturing of rock in response to heating and cooling. Because rock is generally a poor conductor of heat, thermal expansion of mineral constituents adjacent to the heat source sets up internal stresses that can cause failure, particularly along grain contacts. Intense thermal stresses from fire have long been recognized as a mechanism to break rock (Blackwelder 1927), but initial experiments on heating and cooling typical by solar radiation suggested that thermal stress produced by ambient temperature changes alone was an ineffective form of physical weathering (Blackwelder 1933; Griggs 1936). However, more recent experiments (e.g., Aires-Barros et al. 1975) have demonstrated that the presence of water and lateral confinement, neither of which was adequately considered in the early experiments, can significantly enhance the effect of diurnal heating and cooling on rock weathering. The mechanics of these processes are complex and imperfectly understood, but it is clear that rock breakdown by ambient temperature fluctuation is far more efficient in the presence of water.

Hydration refers to the alteration of a mineral through the incorporation of water, such as the conversion of anhydrite to gypsum or the uptake of water by expandable clays. Because it changes the chemical properties of the mineral, hydration is normally considered a mechanism of chemical weathering. However, the uptake of water into the structure of a rock can cause component minerals to swell, shattering parent rock and increasing porosity. While hydration is not a particularly pervasive form of physical weathering, it is very important in certain situations such as weathering of clay stones to form badland topography (Torri and Bryan 1997). Expansion of biotite-derived clay minerals in weathered granite also appears to contribute significantly to its breakdown into grus (Ritter 1978).

Salt weathering results from the growth of salt crystals within rock as brine solutions evaporate. Such crystals, representing a wide variety of sulfate, carbonate, and chloride salts, can impart significant pressure when they grow within cracks or other voids in rock. Chorley et al. (1984) note that 1% supersaturated calcite may crystallize against a pressure of 10 atmospheres, which is comparable to the tensile strength of most rocks. They note that permeable rocks are particularly susceptible to such forms of weathering, while dense, impermeable rocks are not. Birkeland (1984) points out that the dispersive power of carbonate precipitation is readily

apparent in soil calcretes, which through time develop a matrix where the original matrix grains have been forced apart by the growth of interstitial carbonate. Salt crystals are also capable of producing physical weathering due to a relatively high coefficient of thermal expansion and a tendency to swell upon hydration.

Ice crystallization, like salt crystallization, can impose severe pressures on surrounding rock. This process is typically termed *frost weathering*. Water expands approximately 9% on freezing, and under the proper conditions can exert stresses exceeding 2,000 lbs/cm² in a closed system (Chorley et al. 1984). Because freezing begins at the surface and proceeds inward, confining pressures are common, increasing the internal stresses. Unlike salt crystallization, which occurs gradually, ice can form repeatedly over a short timeframe, resulting in repeated stresses that wedge the rock apart. For this reason, frost weathering is probably more efficient in the high temperate latitudes, where a number of freezes can be expected every year, than in the polar latitudes, where the freeze cycles are harder but far less frequent.

The final class of physical weathering is caused by organisms, which can break rock by burrowing and root growth. Burrowing insects, annelids, reptiles and mammals can all penetrate through the soil cover and attack bedrock. Root growth is an even more pervasive phenomenon that can reduce rock to rubble. These mechanisms are discussed in greater detail below in regard to the effect of such processes on disturbance of unconsolidated sediments and soils.

While physical weathering processes are common and begin the process of breaking down rock, chemical weathering processes are far more efficient agents in the reduction of solid rock to unconsolidated material. Chemical weathering (*decomposition*) processes represent a complex series of interrelated and often interdependent chemical reactions. The reactions are complex because (1) reactions occur in stages, gradually altering rock composition through a series of intermediate stages; (2) rocks and sediments are seldom homogeneous, and thus have differing resistance to chemical attack; (3) removal of weathering products (i.e., erosion, translocation) is often needed for weathering to proceed; (4) the availability of moisture and ambient heat to drive chemical reactions varies seasonally; and (5) the character of reactions and weathering products being produced conditions the environment and thus the range of complimentary reactions that can occur (Selby 1993). While there are a great many reactions that break down minerals, most can be subsumed under a few broad classes: solution, hydrolysis, hydration, carbonation, oxidation, reduction, and chelation (Selby 1993; Chorley et al. 1984; Birkeland 1984; Ritter 1978).

In general terms, *solution* refers to a process or state where one substance (typically a solid, but also sometimes a gas) is disaggregated and evenly dispersed within a liquid *solvent*. In weathering processes, the solvent consists of water containing free H^+ and OH^- ions and/or acidic or basic compounds such as H_2CO_3 (carbonic acid) or (particularly since the advent of fossil fuels) H_2SO_4 (sulfuric acid). The effectiveness of solution is dependent on the solubility of the material, the amount of the solvent passing in contact with it, and the pH of the solution, which is a measure of the concentration of H^+ ions. Birkeland (1984) distinguishes between minerals that dissolve completely (congruent dissolution) and those that result in the precipitation of new compounds or the creation of residual insoluble material (incongruent dissolution). While solution is not particularly important compared to other forms of chemical weathering (except in the weathering of carbonates; see below), it is typically the first mechanism of chemical weathering to attack freshly exposed rock. Ritter (1978) points out that solution of individual minerals in a rock causes instability of its crystalline structure, hastening its overall decomposition.

The concentration of hydrogen ions, or pH, of natural waters dictates its role in the process of solution. While silica is slightly soluble across a broad range of pH values, the solubility of carbonates and iron and aluminum oxides is strongly dependent on pH. In addition to controlling solubility, the concentration of free hydrogen ions (H^+ and OH^-) also affects the reactivity of a solution. *Hydrolysis* represents a chemical reaction between the hydrogen ions in water and minerals. Simply put, the hydrogen ions enter the crystalline lattice of minerals and substitute for existing cations (e.g., Ca^{+2} , K^+ , Na^+ , Mg^{+2} , Fe^{+2} , Fe^{+3} , Al^{+3}), which then go into solution and are removed by circulating water. Hydrolysis also produces reactive compounds like silicic acid (H_2SiO_4), hydrocarbonate radicals (HCO_3^-), and hydroxyls (OH^-) which can then react with other minerals. While other reactions contribute, hydrolysis is the most important reaction in the conversion of silicate minerals to clay minerals (Birkeland 1984; Selby 1993).

As discussed above, *hydration* refers to the *adsorption* of water to a mineral's crystal structure. It is typically a reversible process, but imposes both physical and chemical changes on a mineral's structure. *Carbonation* represents the action of carbonic acid, which primarily attacks limestone and other calcareous rocks. Carbonic acid (H_2CO_3) results from the dissolution of carbon dioxide in water. *Oxidation* and *reduction* reactions represent the loss and gain of electrons to ions in solution, respectively, and are dependent on the availability of free oxygen. Thus, oxidation is common above the water table and reduction is common below it, although high concentrations of organic matter can exhaust

free oxygen and create reducing conditions above the water table. Like most chemical reactions, oxidation and reduction change the chemical properties of the affected minerals, often reducing the integrity of the parent rock's structure and increasing their susceptibility to further attack.

A final important mechanism of chemical weathering, *chelation*, is dependant on the presence of organic matter. Chelation represents the formation of chemical complexes between mineral ions and organic molecules, and is important because it can dramatically change the solubility of normally insoluble ions, particularly ions of iron and aluminum, allowing them to be mobilized and leached out of the system. Chelation is also important because the chelating reactions are an important source of hydrogen ions to drive the hydrolysis reaction (Ritter 1978).

2.2.1.2 Soil Morphology and Soil Forming Factors

The term 'soil' is often equated with any matrix containing and enveloping the artifacts at an archeological site. However, in earth science terms, the definition of soil is much more restricted. For purposes of this discussion, soil is defined as *a naturally occurring thin layer at the earth's surface that has been acted on by the soil forming factors to produce a material that differs from its parent material*. In other words, soils are dynamic entities produced by the action of a number of interrelated processes on a parent sediment (deposited by one or more of the mechanisms outlined in the previous section) or on weathered bedrock. By definition, sedimentary deposits are not soils unless soil forming processes have acted to transform them from their original character in some manner. By the same token, the soil horizons developed through the action of these processes are not strata because they represent differences that developed through time after deposition of the sediment.

Pedogenesis refers to the action of a suite of processes on a parent material, and serves to convert that parent material into a soil. The character of any given soil is conditioned by the interaction of five *soil forming factors*. The five soil forming factors are: climate, organisms, relief, parent material, and time (Jenny 1941). The climate factor refers to the sum total of ambient environmental factors acting on a sediment, including trends in temperature, solar radiation, precipitation, and groundwater. The organisms factor refers to the cumulative effect of biological agents (i.e., animals, plants, bacteria, fungi, etc.) on soil, and is itself strongly conditioned by ambient environmental factors. The influence of these two factors is regulated by relief (primarily slope and aspect), which controls the incidence of radiation and the potential for moisture to penetrate, and the character of the parent material, which controls the chemical and physical

nature of the raw material and thus limits the range of potential processes affecting the soil. Finally, the time factor exercises control by dictating the duration of pedogenesis, and thus the potential for progressive pedogenic alteration of the parent material. Collectively, these factors affect not only soils but the archeological record contained within them (Schiffer 1987; Holliday 1990; 1994).

All pedogenic processes are time-dependent to some degree, but the rate of different suites of processes varies considerably. Some processes, like the accumulation of organic matter or soluble salts in specific horizons of a soil, can occur relatively quickly (e.g., 10^{-1} to 10^3 years), while other processes like accumulation of secondary clays and dissolution and leaching of siliceous minerals occur over much longer periods (10^4 to 10^7 years). If conditions remain constant, all pedogenic processes will eventually reach a state of equilibrium where change is not apparent, but the time required for differing processes to achieve equilibrium varies by several orders of magnitude (Birkeland 1984). Moreover, because the physical environment is in a constant state of flux, true equilibrium conditions are rarely if ever achieved (however, quasi-equilibrium, where changes are relatively minor, does occur with regularity).

The morphology of a given soil is frequently indicative of the cumulative effect of changing pedogenic factors over time. The terminology used to describe such soils is complex and contradictory, and little consensus has been reached, particularly regarding the thresholds necessary to merit use of a given term (Fenwick 1985; Holliday and Goldberg 1992; Johnson and Hole 1994). The issue of threshold is very relevant, because the physical environment is not static, and all soils exhibit the influence of former environments to some degree. However, it is unclear whether such an identification would be useful in broadly applicable terms, and application of terminology continues to be governed by qualitative assessment.

One important construct is the distinction drawn between soils developed under a single, stable soil-forming regime (*monogenetic soils*) or a succession of different regimes resulting from climate change or topographic evolution (*polygenetic soils*) (Bryan and Albritton 1943). Polygenetic soils exhibit juxtaposition or overprinting of morphological features or other characteristics that suggest a significant change in pedogenic pathways during its development. Such soils have also been termed *relict soils*, but the normal usage of that term has changed somewhat in recent years (Johnson and Hole 1994; see below). Another related term is *fossil soil*, which has also been used in a number of different ways, but typically refers to a soil that does not reflect the modern

pedologic environment, usually because it was buried and pedogenesis was arrested (Butzer 1971).

Probably the most commonly used term is *paleosol*. Like most of these terms, it has been defined in a number of different ways (see Johnson and Hole 1994; Holliday and Goldberg 1992). While there are a number of subtle distinctions between definitions, the most significant difference is that some authors restrict the term *paleosol* to buried soils (e.g., Thorp 1949; Fenwick 1985) while others include both buried soils and active soils that exhibit morphological properties related to previous (and often very different) environments (e.g., Hunt and Sokoloff 1950; Morrison 1967; Butzer 1971). In geoarcheological usage, the term *paleosol* is usually used as a synonym for a buried soil. If a soil is buried by a thick packet of fresh sediment, pedogenesis will be arrested, preserving the results of soil formation over a specific period of time in the past (Fenwick 1985). However, if the depth of burial is insufficient to take the soil out of the zone of pedogenic alteration, then the buried soil may exhibit properties or overprinted features characteristic of different parts of an intact profile (e.g., a buried A horizon that also contains more recent illuvial material such as secondary carbonate). Such a soil is also generally considered a paleosol, but is less representative of the past character of pedogenesis (i.e., a true *fossil soil*) because soil processes continued to progressively modify the soil after burial. If a buried soil is subsequently exposed through erosion, it can be termed an *exhumed soil* (Ruhe and Daniels 1958). If an extant surface soil exhibits properties characteristic of a significantly different pedogenic trajectory than currently exists, and it can be demonstrated that the soil was not buried and isolated, then that soil can be termed a *relict soil* (Ruhe 1965). Note that while the definition differs in emphasis from the polygenetic context used above, it is difficult to envision a relict soil that is not also polygenetic.

Several basic reorganizational processes operate in conjunction with chemical weathering to affect a wide variety of soil components. The term *eluviation* refers to the mobilization and removal of (typically weathered) soil components from their original location by infiltrating soil water. As defined here, this process may occur either in suspension or in solution, although the term is sometimes limited to the former process. Eluviation is most prominent in the upper horizons (the A and, particularly, E horizons) of a soil, and affects constituents like clay particles and nutrients like calcium and potassium. *Illuviation* refers to the accumulation of material derived from elsewhere in the profile by precipitation from soil water solution or movement of finely-divided particles, and is characteristic of lower soil horizons (B, C, and K). However, these characterizations are generalizations, as eluviation and illuviation can occur in any

soil horizon. In fact, individual horizons are often illuvial and eluvial at the same time—for example, a horizon may be enriched in illuvial clay and have lost carbonate to eluviation.

The process of downward movement of constituents through a soil is termed *translocation*. If the constituents enter the water table and are removed from the pedon, they are said to be *leached* (however, this term is sometimes used as a synonym for solution-based mobilization and removal, particularly where the term eluviation is limited to suspended particles). *Mineralization* refers to the conversion of soil constituents from organic forms to inorganic forms through microbial decomposition. *Humification* refers to the process of recombination of soluble acids produced in the soil during decomposition, and produces a suite of black or dark brown substances collectively termed *humus*. As discussed above, *Chelation* refers to a chemical process where metal ions (e.g., iron, aluminum) combine with organic molecules to form a complex that is much more soluble than the metals are alone, and is primarily responsible for eluviation of such metallic compounds in a soil.

There are a variety of processes and influences that affect soil color. There are a number of generalized terms that refer to processes that change the color of a soil horizon as a whole or cause differentiation of color within a horizon. *Melanization* refers to the darkening of a soil A horizon, usually due to organic matter accumulation and humification. The process of *oxidation*, described above in the section on chemical weathering, produces oxides and hydroxides that typically exhibit reddish, orange, yellowish and/or brown coloration. *Rubifaction* (or *rubification*) refers to the gradual reddening of a soil B horizon through oxidation of *in situ* constituents and illuviation of oxidized constituents. *Gleyzation* (or *reduction*) refers to the reduction and mobilization of free iron and manganese in a soil through intermittent or prolonged saturation by anaerobic waters, and produces characteristic bluish, greenish, and gray colors. In addition to color, iron state is important because reduced hydroxides of iron and manganese are mobile and tend to move in the profile, while oxidized compounds are relatively immobile. In intermittently saturated soils, color variation is frequently produced by the interdigitation of oxidized and reduced or depleted zones resulting from this mobility.

The accumulation of coatings and precipitates can also introduce differences in hue and chroma. Mottling (variegation) of soil color may also be produced by other processes, including infilling of burrows produced by vertebrates and insects (*krotovina*), infiltration of material into soil cracks, root decay, differential weathering of parent material, and inherited differences in the color of parent

material. While most of these features have long been termed *mottles* by soil scientists, the most recent comprehensive USDA–NRCS guide to soil description (Schoenberger et al 2002) strongly restricts the use of this term, limiting it to non–matrix colors that are not associated with a coat/stain, concentration, or depletion.

In most cases, the result of pedogenesis on a uniform parent material is the development of a series of soil zones, or *horizons*, that are subparallel to the ground surface and exhibit differing properties (although in some cases pedogenic processes may lead to homogenization of a lithologically–diverse profile) (Johnson et al. 1987). The principal master soil horizons include the O horizon, A horizon, E horizon, B horizon, C horizon, and R horizon (Soil Survey Staff 1990). Recent additions include the L (limnic) horizon and W (water) horizon (Schoenberger et al. 2002). Although unrecognized by the USDA–NRCS, many geomorphologists working in arid and semi–arid regions (e.g. Birkeland 1984) prefer the designation of a K horizon, as proposed by Gile et al. (1965), to the more prosaic Bkm horizon of the USDA system. Lowercase suffixes are used to clarify horizon properties; for example, the designation Bt denotes a B horizon enriched in illuvial clay and the designation Bk denotes one enriched in secondary (i.e., pedogenic) calcium carbonate. Transitional horizons are designated by combining horizon designations, with the dominant characteristics determining the order of listing (e.g., an AB horizon represents a lower A horizon with clear subordinate properties of the underlying B, while a BA horizon represents an upper B horizon with clear subordinate properties of the overlying A). In some cases, a transitional horizon may have distinct, separate zones that are clearly related to underlying and overlying horizons. In these cases, the dominant horizon is listed first, and a vigule (/) is used to separate the horizon designations (e.g., an A/R horizon) (Soil Survey Staff 1990; Schoenberger et al. 2002; Table 2–1).

2.2.1.3 Organic Matter in Soils

The accumulation of organic matter in the surficial horizons of a soil is one of the most conspicuous aspects of soil formation. Organic matter accumulates as plants and animals living on the surface or colonizing the soil die, decompose, and are incorporated into the soil matrix. The archeological implications of organic matter accumulation in soil have rarely been addressed in detail (although there are exceptions, e.g., Carr 1982; Stein 1995), which is unfortunate because the accumulation of organic debris is one of the most important physical consequences of cultural occupation at any given locality. However, spatial and stratigraphic patterning in soil chemistry and magnetic characteristics produced by

Table 2–1: Master and Subordinate Horizon Designators in the USDA Soil Taxonomic System

Master	Criteria
O	Organic soil materials (not limnic)
A	Mineral; organic matter (humus) accumulation, loss of Fe, Al, clay
AB (or AE)	Dominantly A horizon characteristics but also contains some characteristics of the B (or E) horizon
A/B (or A/E)	Discrete, intermingled bodies of A and B (or E, or C)(or A/C) material; majority of horizon is A material
AC	Dominantly A horizon characteristics but also contains some characteristics of C horizon
E	Mineral; loss of Fe, Al, clay, or organic matter
EA (or EB)	Dominantly E horizon characteristics but also contains some attributes of the A (or B) horizon
E/A (or E/B)	Discrete, intermingled bodies of E and A horizon(or E and B) material; majority of horizon is E material
E and Bt (or B and E)	Thin lamellae (Bt) within a dominantly E horizon (or thin E within dominantly B horizon)
BA (or BE)	Dominantly B characteristics but also contains some attributes of A (or E) horizon
B/A (or B/E)	Discrete, intermingled bodies of B and A (or E) material; majority of horizon is B material
B	Subsurface accumulation of clay, Fe, Al, Si, humus, CaCO ₃ , CaSO ₄ ; or loss of CaCO ₃ ; or accumulation of sesquioxides; or subsurface soil structure
BC	Dominantly B horizon characteristics but also contains some characteristics of the C horizon
B/C	Discrete, intermingled bodies of B and C material; majority of horizon is B material
CB (or CA)	Dominantly C horizon characteristics but also contains some characteristics of the B (or A) horizon
C/B (or C/A)	Discrete, intermingled bodies of C and B (or A) material; majority of horizon is C material
C	Little or no pedogenic alteration, unconsolidated earth material, soft bedrock
L	Limnic soil materials
R	Bedrock, Strongly Cemented to Indurated
W	A layer of liquid water (W) or permanently frozen water (Wf) within the soil (excludes water/ice above soil)
K*	Indurated by soil carbonates; (not in standard USDA classification)
Suffix	Criteria
a	Highly decomposed organic matter
b	Buried genetic horizon (not used with C horizons)
c	Concretions or nodules
co	Coprogenous earth (Used only with L)
d	Densic layer (physically root restrictive)
di	Diatomaceous earth (Used only with L)
e	Moderately decomposed organic matter
f	Permanently frozen soil or ice (permafrost); continuous, subsurface ice; not seasonal ice
ff	Permanently frozen soil ("Dry" permafrost); no continuous ice; not seasonal ice
g	Strong gley
h	Illuvial organic matter accumulation
i	Slightly decomposed organic matter
j	Jarosite accumulation
jj	Evidence of cryoturbation
k	Pedogenic carbonate accumulation
m	Strong cementation (pedogenic, massive)
ma	Marl (Used only with L)
n	Pedogenic, exchangeable sodium accumulation
o	Residual sesquioxide accumulation (pedogenic)
p	Plow layer or other artificial disturbance
q	Secondary (pedogenic) silica accumulation
r	Weathered or soft bedrock
s	Illuvial sesquioxide accumulation
ss	Slickensides
t	Illuvial accumulation of silicate clay
v	Plinthite
w	Weak color or structure within B (used only with B)
x	Fragipan characteristics
y	Pedogenic accumulation of gypsum
z	Pedogenic accumulation of salt more soluble than gypsum

SOURCE: Schoeneberger et al. 2002; * K horizon after Gile et al 1966

the decomposition of cultural organics have proven to be valuable lines of archeological evidence in certain settings (e.g. Carr 1982; Eidt 1977; 1984).

The process of organic decay is complex, and produces a number of substances and compounds with differing levels of stability. Typically, organic matter accumulated in soils includes a wide range of decay products, as organic matter is simultaneously accumulating through the death of organisms and being removed through progressive decay and leaching. Common decomposition products include finely divided plant and animal tissue; proteins, carbohydrates, tannins, fats, lignins, and other complex organic compounds; organic acids such as humin, humic acid, and fulvic acid; and molecular and elemental constituents such as carbon, nitrogen, phosphate, and calcium complexes. Undecomposed and partially decomposed organic matter forms the principal component of soil O horizons and the principal minor constituent of most soil A horizons. As organic matter accumulates, the surface horizon darkens in a process termed *melanization*, which is frequently the first macroscopic indication of incipient pedogenic alteration.

During the early stages of pedogenesis, organic matter tends to accumulate relatively rapidly in the upper horizons of a soil profile. As soil development progresses, the rate of accumulation slows as older organic material is broken down and translocated or lost through leaching. Provided that ambient conditions do not change, eventually the rate of organic loss reaches rough equilibrium with the rate of organic addition. This quasi-equilibrium is typically reached in a few hundred to a few thousand years (Birkeland 1984), although much longer periods sometimes may be required, particularly in soils formed under strongly arid regimes (e.g., Wang et al. 1996). Consequently, radiocarbon determinations on bulk organic matter in active A horizons tend to yield ages no greater than a few thousand years regardless of the true age of the soil. Such ages reflect the equilibrium between organic gains and losses, termed the *apparent mean-residence time* (AMRT) of the soil (Wang et al. 1996). Because organic matter tends to be translocated, and more stable (and, hence, older) organic compounds are more common at depth in an active soil, the AMRT tends to increase with depth in most soils. In all moderately to strongly developed soils, the oldest ages obtained are generally still younger than the true age of the soil, although it is possible to increase the precision of the estimate by dating only the most stable fractions (e.g., pretreated charcoal, humin) (Goh and Moloy 1978; Matthews 1985).

When renewed deposition buries a soil, forming a buried paleosol, most active organic accumulation ceases. In these cases, the youngest ages generally provide the best estimate

for termination of pedogenesis. However, if the depth of burial is not particularly great, the former A horizon may not be removed from the zone of active pedogenesis, and soluble organic acids (e.g., fulvic acid) and organic solids may continue to accumulate through turbation, eluviation of the active A horizon developing in the new sediment packet, and deep rooting. Consequently, buried soils can produce ages younger than the true age of burial.

In addition to *in situ* accumulation, organic matter may also be introduced into a soil environment from elsewhere as a component of the sediment load. This material may be either contemporary (derived from decomposing organics such as leaf litter in the basin) or older than the period of deposition (derived from erosion of organic soils). In cases where appreciable organic matter is introduced both as sediment and through the decomposition of animals and plants that died locally (so-called *cumulic* soils), radiocarbon ages on bulk organics may be either younger or older than the true age of deposition. The results of such assays depend on the ratio between authigenic organic production and allogenic organic delivery, the true age of the soil, and the rate of microbial decomposition through time. Thin alluvial soils intercalated in terrace deposits are particularly likely to exhibit cumulic properties, and dates from them must be interpreted cautiously (Abbott 1997b; Abbott and Frederick 2003).

In addition to the importance of organic accumulation on soil character, the decomposition products produced by the decay of organic matter play important roles in the weathering and translocation of mineral components of the soil. Organic acids are capable of combining with metallic ions to form chelating complexes that are soluble in pH ranges far wider than the metal ions alone. These complexes are commonly interpreted as a principal mechanism of iron and aluminum translocation in soils, particularly in the process known as *podsolization*, where iron, aluminum, and organic matter accumulate in the B horizon below an E horizon dominated by residual silica (Birkeland 1984). Maintenance of organic matter in a soil is also largely a function of various types of chemical bonding with mineral constituents, particularly clays, although other mechanisms (particularly nutrient cycling and re-synthesis) also play important roles.

2.2.1.4 Soil Calcification

In common usage, the term calcification refers to a soil-forming regime typified by the accumulation of carbonate minerals in a soil under the influence of pedogenic processes (Birkeland 1984; Strahler and Strahler 1992). Soil carbonates are dominated by calcium carbonate (CaCO_3), but may also include magnesian calcites with up to 20% MgCO_3 and dolomite ($\text{CaMg}(\text{CO}_3)_2$) (Rowell 1994). Calcification is

typical of subhumid to arid settings, where precipitation influx is insufficient to leach these soluble minerals completely out of the soil. Rather, the calcification process represents incomplete leaching of carbonates, which are translocated from the upper soil horizons to the lower horizons, where they precipitate as secondary carbonates with distinctive morphologic characteristics.

While this general concept is a valuable heuristic device that allows for the development of basic, generalized linkages between climate and soil dynamics, it is too restrictive a model to encompass all mechanisms of carbonate precipitation and enrichment that occur in soils. For purposes of this discussion, calcification is defined here as *the suite of processes that result in the accumulation of secondary carbonate in soils*. The key difference in this definition is that the notion of a requisite climatic regime is removed, for various forms of carbonate can accumulate under a wide range of environmental conditions. In fact, five different mechanisms exist that can account for the occurrence of carbonate in soils, whether alone or in combination. These mechanisms are:

1. carbonate accumulation by pedogenic translocation, as described above;
2. carbonate accumulation under the influence of intermittent saturation or capillary rise from the water table;
3. carbonate accumulation as a result of continuous or periodic saturation with calcium-enriched groundwater;
4. carbonate occurrence in the form of residual parent material; and
5. biogenic carbonate accumulation; for example, synthesis by earthworms (e.g. Canti 1998).

All soil scientists and Quaternary scientists would accept the first mechanism listed above as a pedogenic process, and most would probably accept the last mechanism (although it is rarely considered in soil textbooks). However, some would exclude the second and/or third mechanisms, and no one would accept the fourth mechanism as pedogenic unless the material has been dissolved and reprecipitated (Birkeland 1984:144). While papers and other treatments dealing with the arid/semi arid model of carbonate accumulation are extremely common (e.g., Bretz and Horberg 1949; Brown 1956; Gile et al. 1966; Rightmire 1967; Reeves 1970; Goudie 1973; 1983; Bachman and Machette 1977; Gile et al. 1981; McFadden 1982; Birkeland 1984; Machette 1985; McFadden and Tinsley 1985; Harden et al. 1991; Dixon 1994), discussion of soil carbonate resulting from fluctuating

vadose/phreatic conditions (e.g., Freytag and Plaziat 1978; 1982), phreatic influx (Netterberg 1978; Mann and Horwitz 1979; Slate 1998), parent material (West et al. 1988), and biogenic sources (Canti 1998; 2007) is relatively limited, and the concepts are not widely accepted.

All carbonate accumulation is a function of equilibrium reactions between carbonate and bicarbonate, as shown by the following reversible reactions:

and

In normal equilibrium conditions, water in equilibrium with calcite and the soil atmosphere has a pH of 8.4, although the solubility of soil carbonate (and thus pH) is affected by coatings and impurities and generally has a lower pH. A decrease in pH, an increase in CO₂ content in soil, or an increase in soil moisture will drive the reaction in equation (2) to the right, dissolving carbonate to yield aqueous calcium and bicarbonate ions. Precipitation is promoted by increased pH, decreased soil CO₂, evapotranspiration of water, or saturation of the soil water by calcium or bicarbonate ions. In addition, bacterial metabolic processes can promote the precipitation of calcite in settings that would otherwise not be conducive, and accelerate it in others (Berner 1971), and most earthworms produce and excrete carbonate synthesized from organic matter, either as micron-sized spherules or as larger aggregates termed granules (Morgan 1981; Canti 2007).

The most widely recognized mechanism of carbonate enrichment in soils is translocation and precipitation of carbonate in percolating soil water. Detrital calcium carbonate in the upper profile, aerosolic carbonate dust in the atmosphere, and calcium ions dissolved in rainwater are all gradually translocated through the profile, precipitating at depth and eventually forming a calcic (Bk) horizon. The latter sources appear particularly important in relatively dry regimes, where the accumulation of pedogenic carbonate in the lower profile can greatly exceed the amount of detrital carbonate parent material that could have been present in overlying horizons (Yaalon and Ganor 1973; Bachman and Machette 1977; Gile et al. 1981; Birkeland 1984). In arid settings, the depth of the calcic horizon in an untruncated and

unburied soil is a function of the average depth of wetting during formation of the horizon. However, precipitation of carbonate can be stimulated by any mechanism that serves to slow percolation, such as the presence of a textural boundary or a zone of saturation.

As secondary carbonate accumulates in a soil, it typically goes through a series of morphologic stages. Progressions of four (Gile et al. 1966) to six (Machette 1985) stages of pedogenic carbonate accumulation are recognized in soils, with differences evident in soils of relatively coarse and relatively fine texture during early stages of accumulation (Table 2–2). Early stages of carbonate accumulation, which occur over Holocene time scales, consist of filamental (mycellial or pseudomycellial) carbonate accumulation that typically represent carbonate precipitation in the vicinity of fine roots (Stage I), followed by formation of small masses that are typically termed nodules (Stage II). In gravelly parent materials, early stages are represented by the formation of thin carbonate pendants on the undersides of the gravelly clasts (Stage I), which thicken and begin to engulf the matrix (Stage II). It is frequently useful to further characterize Stage I and Stage II as “early” or “late” to describe the thickness and density of filaments and films and the size and frequency of nodules. Over longer (10^5 – 10^6 years) time periods, the surface horizons are progressively decalcified and the amount of carbonate in the subsoil matrix increases to the point that it becomes increasingly plugged (impermeable) (Stage III), and a laminar cap develops and thickens (Stage IV–V). These latter stages represent true calcretes, and merit the master soil horizon designation of a K horizon (Birkeland 1984), or Bkm horizon of the USDA taxonomy. Occasionally, a well developed calcrete will be exposed to increased attack and fracture, typically as a result of a shift towards a moister climate or erosion of overlying horizons. Such a horizon, if re–cemented, forms a thick, brecciated calcrete that Machette (1985) terms Stage VI.

Correlation between deposits of known age and the morphology of secondary carbonates in the soils they support (e.g., Blum and Valastro 1989; 1992; Abbott 1990a; 1994a; Nordt 1992; 1994; Frederick 1993) has demonstrated that carbonate development is a valuable diagnostic feature for estimating the age of alluvial paleosols and alluvial deposits in Texas. The morphology of secondary carbonate segregations in soil is variable and reflects the mode of accretion. Similar complexity is apparent in concretions and masses formed in other environment, such as pelagic and benthic marine settings (Sellés–Martínez 1996). The reasons for the complexity and genesis of secondary carbonate segregations is also far from fully understood, and the terminology used to describe such segregations is often used inconsistently. Nevertheless, eight classes of secondary carbonate accumulation can be recognized: filaments, films, crystallaria, nodules, concretions, septaria, rhizoconcretions, and matrix accumulations.

Filaments (also termed mycellial or pseudomycellial carbonate), are typically the first stage of pedogenic carbonate accumulation in fine–grained sediments. They consist of subvertically–oriented dendritic threads of fine calcite that are typically concentrated on ped faces in soils with marked pedality and distributed through the matrix in apedal soils. The number of filaments, and the thickness of individual threads, tends to increase with time, although thick filaments may develop relatively rapidly in particularly conducive situations. In most cases, carbonate filaments appear to be associated with fine roots, and frequently appear as accumulations of fine–sparry to micritic calcite surrounding fine open channels (i.e., root traces) in thin section. The mechanism of filament formation is poorly understood. Carbonate solubility is strongly affected by the partial pressure of atmospheric CO_2 , which can be 10 to 100 times the concentration in soil air as in the surrounding atmosphere due to root and microbial respiration (Birkeland 1984). In CO_2 –rich conditions, carbonate solubility is dramatically elevated.

Table 2–2: Stages of Carbonate Accumulation, after Machette (1985)

	Gravelly Parent Material	Non–Gravelly Parent Material
Stage I	thin, discontinuous carbonate pendants	films and thin filaments on ped faces and in matrix
Stage II	thicker, more continuous carbonate pendants and localized matrix enrichment	thick filaments and/or nodules or other masses
Stage III	continuous pebble pendants and interclast matrix cementation	coalesced nodules and matrix cementation
Stage IV	plugged matrix; incipient laminar cap	
Stage V	thick laminar cap, strongly cemented	
Stage VI	massive, strongly cemented, multilaminar, brecciated with pisoliths	

For this reason, carbonate precipitation is normally inhibited in the shallow root zone, where the high partial pressure of CO_2 promotes solubility (Birkeland 1984). However, the formation of filaments in association with roots is somewhat problematic, because solubility should be particularly high in direct proximity to respiring roots. The precipitation of carbonates in association with roots suggests that this tendency is probably counterbalanced by withdrawal of water by transpiration, which elevates the local concentration of solute calcium and bicarbonate ions sufficiently to promote precipitation, forming the characteristic filaments and, ultimately, calcic rhizoconcretions.

Films (calcans) are also common in the early stages of carbonate accumulation in fine-grained soils with developed pedality. Films are thin, discontinuous, two-dimensional coats of fine calcite on ped faces and fissures in the soil matrix. In some cases, such films may form through the infiltration and subsequent evaporation of water along voids between peds, but most probably represent precipitation of carbonate from solute calcium and bicarbonate ions in the matrix due to preferential evaporation at ped faces. Films may also be composed of sparry or micritic calcite, sometimes interdigitated with more soluble salts (e.g., gypsum, halite).

Crystallaria are isolated crystalline aggregates or similar bodies formed in association with other secondary carbonate masses in the soil. They may exhibit radial, concentric, or irregular crystalline patterns, and the size of crystals commonly increases or decreases from the center to the periphery. Crystallaria probably form most commonly where crystalline calcite develops around the margins of a void (growing inward) or around a skeletal clast (growing outward) in a zone of intermittent saturation.

Nodules consist of soft to relatively hard microcrystalline calcite (micrite and/or microspar) masses that lack a concentric internal fabric. Elementary carbonate nodules generally range in size from less than 100 microns to several millimeters. However, larger complex nodules also occur frequently; these generally represent fusion of elementary nodules and may exhibit irregular, knobby shapes. The fabric of complex nodules is rarely homogeneous, and may exhibit internal joints, curved contact planes, and ferruginous inclusions. The character of nodules varies from relatively porous, chalky calcite that is typically white or light brown to denser, gray calcite. Sparry calcite (crystallaria) is often associated with nodular development, where it may occur at the core of nodules or along planes and fissures in complex nodules. In advanced development, nodular zones may coalesce to the extent that drainage is restricted, forming a K (Bkm) horizon.

Concretions have a concentric internal laminar fabric indicating that they accreted in stages. They may also be relatively small and simple or exhibit complex internal structure. Patches of sparry calcite, ferruginous concretions, and internal cracks and voids may occur. In some cases, nodules and concretions may develop a concentric system of radial cracks intersected with a second system of cracks parallel to the surface of the mass. Often, these features (septaria) have open or sparry calcite-filled voids associated with radial or concentric structures in the nodules. The origin of septaria is poorly understood, but it appears related to shrinking and swelling (usually of the surrounding matrix, although some septaria may engulf and incorporate expandable clays) associated with variations in moisture content of the soil.

One relatively common form of nodule or concretion is a vertically elongate concentric cement that presumably forms around roots (this explanation is not universally accepted, but few viable alternatives have been proposed). These features, which may be quite thin or large and massive, are termed subcutanic features or rhizoconcretions. In some cases, concentric structure is very apparent, while in others coalescent nodules are clearly indicated. Fractures and cracking structures also frequently develop in rhizoconcretions. Vertically-oriented axial canals, either open or filled with dissimilar sediment or sparry calcite, are typically present. In many cases, the character of calcite morphology varies systematically through the cross-section, with dense, crystalline calcite in the interior and more porous, chalky calcite on the outer portion of the rhizolith.

Matrix accumulations represent diffuse-edged zones of micrite or, more rarely, sparry calcite that forms in association with other soil constituents. As such, they do not represent calcite-dominated segregations in a soil, but rather zones where precipitated calcite remains a subdominant constituent but is noticeably concentrated in relation to other parts of the matrix. Macroscopically, matrix accumulations tend to result in relatively large (typically 2–10 cm), diffuse “clouds” that whiten (i.e., reduce the chroma and increase the value) localized areas in comparison to the surrounding matrix. Sometimes, matrix accumulations are associated with specific strata in a stratified profile, suggesting that they may sometimes be related to preferential zones of throughflow. They also sometimes occur as low-value “halos” around nodular accumulations. Matrix accumulations are typical of loamy soils that have abundant pore space, and appear to represent precipitation of substantial quantities of dispersed microcrystalline calcite in existing voids, usually without significant displacement of existing constituents or disruption of primary fabric. They are less commonly observed in dense clayey matrices.

2.2.1.5 Iron and Manganese in Soils

Iron and manganese pedofeatures are typical of acidic soils and soils with poor drainage. They reflect chemical transformations and movement of iron and manganese compounds in the soil profile, particularly under the influence of a seasonally or permanently high water table. In some cases, iron has been mobilized and translocated down through the profile, while in other cases it represents local reorganization within peds or introduction of solutes by throughflow or groundwater. The morphology of ferric pedofeatures are similar to the range of calcic pedofeatures, including concretions, rhizoliths, pore coatings, filaments and films on ped faces, and ferric hardpans. Oxidation–reduction reactions, such as the conversion between ferric iron (e.g., Fe_2O_3) and ferrous iron (e.g., FeO) occur on a regular basis in soils that experience fluctuating moisture conditions brought on by flooding or seasonal changes in the position of the water table. These reactions affect the state and solubility of ferric and manganese compounds in soil, and typically impart characteristic hues to the soil matrix (Van Wallenburg 1973; Birkeland 1984). Reducing conditions are initiated as soil microbes exhaust free oxygen in saturating water and initiate anaerobic respiration. Anaerobic respiration results in the sequential reduction of a variety of compounds, the severity of which is measured by the soil's *redox potential*. In addition to reduction of iron and manganese oxides and hydroxides, reduction results in denitrification, production of organic compounds like ethylene and acetic acid, and conversion of sulfates to sulfide compounds such as hydrogen sulfide gas (which causes the rotten–egg smell commonly noted when marshy sediments are disturbed) and iron sulfide (pyrite) precipitates (Rowell 1994). The redox state of iron in the system also influences matrix color. The presence of reduced iron (gley) is indicated by bluish gray or greenish gray colors, while neutral gray colors often indicate that mobile iron compounds been leached. Intermittent saturation tends to produce mottled coloring, where gleyed colors (blues, greens, and grays) and oxidized colors (browns, oranges, yellows, blacks, and reds) interdigitate in complex arrangements within a horizon. Patterns of oxidation and gleying in a profile are indicative of soil drainage conditions, and oxidized, reduced, and mottled sediments and soils are commonly patterned on the landscape in complex ways that reflect spatial patterns of soil water and groundwater delivery, retention, and throughflow. Iron mobility and pedogenic accumulation is facilitated by anaerobic water and relatively acidic pH.

In some cases, the arrangement of mottling in the matrix may be indicative of saturation history; peds characterized by oxidized exteriors and gleyed interiors may indicate a shift towards more freely drained conditions, while oxidized interiors and gleyed exteriors may indicate a shift towards more restricted drainage. In other cases, the same patterning may reflect soils that are saturated from the bottom up and

from the top down, respectively (Veneman et al. 1998). However, such patterns may also result from other factors, such as the formation of coatings on ped faces by infiltrating material (Brammer 1971; Greenburg and Wilding 1998) or maintenance of color inherited from the parent material in the ped interior. Moreover, many redoximorphic features appear remarkably stable long after drainage conditions change, and observed patterns may therefore not reflect extant conditions (Greenburg and Wilding 1998). In fact, in many cases iron features occurring in a soil may represent inheritance from bedrock parent material (e.g. ferruginous sandstones) or concretions and nodules reworked from older soils.

Although gley is usually the most obvious consequence of soil saturation, other soil characteristics also arise from seasonally wet conditions. They are mentioned here because they often occur in conjunction with ferric mottling and staining. One consequence of repeated wetting and drying in expansive clay soils is the formation of pressure faces, or slickensides, where the expanding peds come into contact. Another consequence, particularly in alluvial settings, is the development of silty ped coats and caps. As an expansive soil shrinks upon drying, a pattern of subvertical cracks forms in a roughly hexagonal pattern. These cracks are responsible for the formation of both silt coats and slickensides. Silt coats occur when floodwaters containing suspended silts and/or fine sands infiltrate into the open cracks of a dry expansive soil. As the surface is flooded, silt is carried down into the cracks until the soil takes up enough moisture to swell and close them. As the soil expands upon wetting, the faces of opposing peds meet and press into each other, forming slickensides as clays at the ped surfaces are compressed by the expansive pressure (see the discussion of argilliturbation).

Anaerobic conditions resulting from continuous saturation typically results in relatively uniform bluish gray or greenish gray soil colors. Such conditions can promote spectacular organic preservation, as witnessed by the succession of “bog people” recovered over the past centuries in Europe. However, soil moisture conditions that alternate between saturated and freely drained on a regular basis, as most of the wet areas in the Fort Worth district do, are extremely harsh on organic matter and tend to rapidly degrade plant and animal remains.

2.2.1.6 Clay Formation and Translocation

The formation of argillic horizons is one of the most commonly cited time–dependent soil processes. Argillic horizons form as clay originally dispersed throughout a deposited sediment is translocated from the A and E horizons into the B horizon. Clay can also be introduced through eolian processes, or created through *in situ* weathering of

silicate minerals over the long term. Infiltrating water carries this clay deeper in the profile, where it accumulates in the B horizon, forming a characteristic “clay bulge” in the textural profile. Illuvial clay accumulates as coatings on coarser particles, bridges between particles, laminated fillings within voids, and aligned coats on ped faces. These latter features, commonly termed clay films, clay skins, or clay cutans, are typically visible in hand section, particularly with a 10x hand lens. They are probably the most diagnostic macroscopic feature of clay translocation, although care must be taken to avoid confusing them with pressure faces and slickensides resulting from expansion and contraction of clayey materials.

Development of an argillic (Bt) horizon through the action of pedogenesis on a loamy sediment is usually a long-term process. Birkeland (1984) notes that the rate of argillic horizon development varies widely (10^2 to 10^5 years) depending on many factors, including the abundance, character, and timing of precipitation, parent sediment character and texture, rates of eolian influx, and the influence of other soil constituents (such as the dispersive influence of sodium ions). In most cases, incipient argillic horizons will develop within Holocene time scales, although significantly arid conditions may lengthen this process, while high magnitude dust delivery may shorten it considerably. In contrast, argillic horizon development resulting from the neoformation of clay minerals in the profile through weathering of feldspars and other siliceous minerals requires considerably longer time spans in most environments (although the warmer and moister the environment is, the more rapid that weathering will occur).

Although the importance of clay translocation for pedogenesis is almost universally recognized, one recent synthetic work (Paton et al. 1995) argues that the process is not demonstrable and that alternate models such as bioturbation mantles and textural heterogeneity of complex parent materials provide more compelling explanations of the observed morphologies. While the overall argument is not persuasive, Paton et al. (1995) do make the valid point that soil scientists tend to assume that textural contrasts between the upper and lower horizons are the result of eluviation/illuviation, and therefore often fail to consider other possibilities. The same is true of another assumption that can sometimes be seen in soil surveys: that sandy materials occupying the position of an E horizon are in fact the product of pronounced pedogenesis on a single deposit, rather than the result of multiple phases of depositional activity. Indeed, many texture contrast soils are clearly the result of changes in primary texture (due to facies changes or depositional unconformities) or the influence of biological activity (cf. Johnson et al. 1987; Johnson and Watson–Stegner 1990). Nevertheless, micromorphological data indicate that considerable clay translocation does take

place in most soils over the long term, and dismissing the process entirely as Paton et al. do is an untenable argument.

Unlike most soil processes, the process of clay translocation has very little direct relevance for archeology because it does not directly affect the context or condition of archeological remains in the matrix (although water infiltration, which drives clay translocation, does affect the chemistry and stability of perishable remains). Clay accumulation in the B horizon is primarily an indicator of relative soil age, and is often used together with other indicators such as degree of rubifaction, carbonate morphology, and structural development to assess the relative age of deposits and to determine when deposits too old to be of cultural relevance are encountered. However, the rate at which an argillic horizon forms is strongly dependent on many factors, and very rapid formation due to aerosolic influx has been documented.

2.2.2 Process of Erosion, Deposition, and Disturbance

As outlined above, weathering processes convert rock into unconsolidated material, and soil processes reorganize the constituents of that material into soil. The suite of processes that move that unconsolidated material are termed erosional and depositional processes. Erosional processes consist of those processes that mobilize, entrain, and remove sediment, while depositional processes consist of those natural mechanisms capable of introducing sediment into any given setting. Together, these suites of processes are responsible for the destruction, or the burial and preservation, of archeological sites. While there are a limited number of basic processes, each subsumes a large number of permutations dictated by variations in the character of sediments and the strength and periodicity of depositional energy. The following discussion focuses on depositional processes, because they are responsible for the preservation of sites. However, the discussion also touches on erosional processes that destroy archeological sites and, paradoxically, also supply the sediment needed to seal and preserve them.

There are three basic classes of deposited sediments. *Clastic* sediments represent solid particles—clasts—derived directly or indirectly from weathering of a parent rock. Such clasts may be of any size, ranging from submicroscopic (clays) to massive (boulders). *Organic* sediments represent remains of organisms and decomposition products derived from them. They also include inorganic remains such as calcareous or siliceous deposits derived from the shells of organisms. Such remains can also be considered clastic if they are moved from the location of the organism’s death by natural processes. *Chemical* sediments represent deposits precipitated from

solution, such as gypsum and halite. They are relatively unimportant in archeological settings, although they do occur as minor components in site sediments.

The mechanisms of sediment transport and deposition are also readily divided into three classes by transport medium, which may be liquid (e.g., fluvial, littoral, lacustrine, estuarine, and benthic processes), gaseous (e.g., eolian processes), or a plastic solid (e.g., glacial processes). Of these, transport by fluid medium is by far the most pervasive and efficient mechanism in the Fort Worth district, which is the focus of this discussion. Although they may be very important elsewhere, processes that are not significant to geoaerchological questions in the study area (such as glacial transport, lacustrine processes, and marine processes) are not addressed except where needed to place the discussion in theoretical context.

In addition to fluid transport, sediment transport is also accomplished under the primary influence of gravity, and as a result of intentional or incidental movement by organisms (of which humans are by far the most efficient). In practice, the separation between these three basic classes of transport is far from clear cut; fluid movement is itself strongly influenced by gravity, most gravity movements are facilitated at least in part by fluid media, and deposits resulting from biotic transport are often syn-depositionally and post-depositionally modified by fluid- and/or gravity-driven processes. Nevertheless, the processes themselves are quite distinct, and affect archeological materials in different ways.

2.2.2.1 Fluvial Processes, Deposits, and Landforms

Rivers are extremely efficient sediment conduits, and are the primary mechanism responsible for transporting the weathered material from the land surface to the ocean basins. No other physical process, save the action of continental-scale ice sheets, is as effective in moving large quantities of sediments over extremely long distances. For example, minimal sediment yield from the Brazos River basin (as measured at Richmond, some 80 kilometers upstream of the mouth in Fort Bend County) has been measured at more than 97 million metric tons per year, equivalent to roughly 1080 metric tons per square kilometer of drainage area (in 1942), and averaged 24,871,000 tons per year (276 tons/km²/yr) between 1924 and 1973 (Mirabal 1974). Consequently, knowledge of fluvial processes and alluvial deposits is critical to an understanding of the mechanics of landscape evolution. The following summary is drawn and simplified from a number of sources, but key references include Leopold et al. (1963), Schumm (1977), Reineck and Singh (1980), Howard (1992), and Brown and Keough (1992).

The amount of water moving through any given point on a river at any particular time is termed its *discharge*, or Q . Discharge is a function of its cross-sectional area of the stream channel, a , and the velocity of the stream, v , according to the formula:

$$Q = av$$

The amount and constancy of discharge, in turn, profoundly affects the morphology of the fluvial system, affecting variables such as channel width, channel depth, and meander radius. Fluvial transport is accomplished because flowing water exerts a tractive force on sediments in the bed and on the banks of the channel (Sabersky et al. 1971; Julien 1998). Entrainment of clasts occurs when this force exceeds the resistance to movement imparted by friction and interparticle attraction. The magnitude of the tractive force is primarily a function of velocity, but is also affected by the degree of turbulence, water depth, bed roughness, and fluid density (which is affected in turn by temperature and the amount of sediment already in suspension). The inherent erodability of alluvial sediments is related to particle size, particle shape, and degree of interparticle cementation or, for clay-sized particles, molecular attraction. In unconsolidated sediments, sand-sized grains are the most readily eroded. Larger clasts (gravels) are more resistant to erosion due to their greater mass and interparticle friction, while smaller particles (fine silts and clays) are increasingly resistant to erosion due to electrostatic bonding between particles. However, once entrained, gravels and coarse sands will rapidly settle out with minor decreases in flow competence, while turbulence will keep finer sands and coarse silts entrained even after flow competence drops dramatically, and entrained fine silts and clays will remain suspended for a period even after the velocity of flow drops off completely (Figure 2-1).

The amount of sediment carried by a stream is referred to as its *sediment load*. Fluvial processes transport sediment in a number of different ways, and the relative importance of these various modes of transport differs based on many factors, including stream size and gradient, character of the source rock, and flow conditions at any particular time. There are three different modes of sediment transport typically recognized: *traction*, *suspension*, and *solution*. Traction is responsible for moving larger clasts, either in the *bed load*, which rolls or slides along the bed of the stream, or in the *saltation load*, where clasts are lifted off the bed and quickly settle as they move downstream, essentially bouncing along in the water column. Bed load transport may involve clasts of any size larger than silt,

Figure 2-1: Generalized relationship between particle size and velocity in determining thresholds of fluvial erosion, transport, and deposition.

while saltation tends to affect sand-sized and, in conditions of extremely powerful flow, smaller gravel-sized clasts. Finer materials are also frequently transported in traction as aggregates, which behave more or less as comparably-sized individual clasts until they are disaggregated. *Suspended load* transport primarily involves silts and clays, although high velocity flow may involve very fine sands. Clasts in suspension are held in the water column by turbulence, and only settle out gradually as the water slows and loses competence. Collectively, the traction and suspension loads are termed the *solid load*. In contrast, *dissolved load* sediments are those that travel in solution, and typically are not held in storage along the stream in any quantity, but instead pass directly to the sea (the exception is arid settings where flow is ephemeral and evaporation of water ponded in depressions in the channel common). Finally, organic materials (and occasionally some unusual inorganic materials such as pumice) may be transported at the water surface as the *floating load*.

Alluvial deposits are primarily composed of traction and suspended load sediments laid down in a variety of channel and floodplain environments. The resulting sediment bodies differ in terms of sediment texture, internal structure, soil process overprinting, and bounding relationships with related deposits, and are termed *facies*. The geometric relationships among fluvial deposits

(including penecontemporaneous facies and depositional units of different ages) and with the confining valley is referred to as the streams *alluvial architecture*.

The characteristics of a given stream are largely a function of the spatial structure of these specific depositional environments, which is controlled in turn by a number of interrelated factors, including discharge characteristics (mean and variability), volume and character of the sediment load, gradient, structure and erosion-resistance of bedrock, degree of valley incision, valley size, and character and density of vegetation on the floodplain and in the basin. While many different types of natural channel pattern can be recognized (Chorley 1969), most can be subsumed under five basic types: meandering channels, anastomosing channels, distributary channels, braided channels, and straight channels. Meandering and anastomosing channels are typical of finer-grained, relatively low gradient, and relatively low sediment yield systems, while straight and braided channels tend to develop in settings that are more coarse-grained, sediment-rich and high gradient. Distributary channels are characteristic of deltaic systems, and represent the response of a sediment-laden system to a complete loss of gradient.

Stream behavior is not constant. Over the short term (days to years), discharge reflects the influence of seasonal cycles,

individual storm events, and variations in groundwater input. This can vary tremendously between streams, with humid systems tending to exhibit respectable discharge under normal flow conditions, and more arid systems tend to exhibit much flashier flow, with much more of their annual discharge occurring immediately after storm events. In all systems, however, this variability tends to average out into a dynamic equilibrium that results in a relatively consistent mode of stream behavior (and, therefore, in the character of resulting deposits). Periodically, however, in response to more significant changes in one or more systemic variables (e.g., climate, sediment availability), this equilibrium is upset, and the basic mode of systemic behavior changes. This change may be manifest, for example, by a shift from floodplain aggradation to channel incision, or from a coarse-grained braided system to a finer-grained meandering system. Such changes result in packets of sediment delimited by changes in innate character, soils, and/or definable bounding surfaces that mark vertical and lateral boundaries. These packets are termed alluvial stratigraphic *units*, and preserve the evidence for the behavior of the stream during a given time period.

The vast majority of streams in the Fort Worth district exhibit a distinct meandering channel pattern, although in many cases the meandering pattern is “fossilized” by bedrock incision. Meandering streams are characterized by a single, sinuous channel that migrates laterally, eroding sediments on the concave exterior banks and depositing them on the convex interior banks. Actively meandering systems are typical of fine-grained to mixed-load systems that have low to moderate gradients, and are characterized by channels with sequences of well-defined pools and bars separated by relatively shallow riffles. The character of meandering stream deposits varies according to the size and gradient of the stream, the textural character of the sediment load, the magnitude and variability of stream discharge resulting from precipitation events and groundwater discharge, the position of the water table, and the degree of bedrock confinement. Meandering streams have been studied extensively (Harms et al. 1963; Leopold et al. 1963; McGowan and Garner 1970; Reineck and Singh 1980), and exhibit a variety of depositional facies that are characteristic of specific sub-environments within the overall system (Reineck and Singh 1980; Walker and Cant 1980). These facies can be divided into three classes characterized by increasingly fine-grained deposits: channel lag deposits, which are laid down in the bottom and on the sides of the channel; point bar deposits, which accrete as a series of off-lapping wedges on the streamward margin of a migrating point bar; and overbank deposits, which are deposited across the floodplain during flood stage. Overbank deposits include natural levee deposits, which are typically sandy or silty strata deposited on the margin of the channel as the stream overtops its bank and velocity drops off; flood basin deposits, which are typically muddy strata deposited on the floodplain from short-term standing water as the flood recedes; backswamp deposits, which are typically fine-grained, organic-rich strata laid down

in semi-permanent ponds on the floodplain; crevasse splay deposits, which are wedges of sandy sediment laid down in the flood basin when natural levees are breached during flood stage; and channel plug (oxbow lake) deposits, which infill abandoned channels. The degree to which backswamps develop is largely a function of gradient and development of channel-margin levees, while the frequency of oxbows and abandoned channels reflects the frequency of avulsion and meander cut-off; neither is particularly common in the Fort Worth area.

Active meandering streams are not particularly stable, although some are more stable than others and most are much slower to exhibit changes in channel pattern than braided systems. The rapidity of meander development results from the interplay of many factors, including the magnitude and variability of discharge, channel gradient, sediment character, degree of channel entrenchment/aggradation, and resistance of bedrock to lateral migration. In addition to gradual migration of the channel, meandering streams often undergo several different types of sudden shifts in channel position. The most common type is meander cutoff, which results when the channel shifts to occupy a chute or swale on the point bar (chute cut-off) or a meander develops to such an extent that a flood is able to breach the neck of the meander, abandoning a single loop of the sinuous channel (neck cut-off). When such a cut-off event occurs, the ends of the old channel are quickly filled with sediment and an oxbow lake develops along the old channel course. Gradually, the oxbow lake fills with overbank muds, finally resulting in a gentle swale on the floodplain underlain by a *channel plug*. The second type of rapid channel shift is *avulsion*, where a significant length of channel relocates within the valley system. Avulsion generally occurs when aggradation of the channel raises the stream bed to within a few feet of the floodplain surface, allowing the principal axis of flow to break out of the channel during a flood event and establish an entirely new channel elsewhere in the valley. Avulsion events are most common in large, low gradient streams with broad aggrading floodplains. In some cases, channels abandoned by avulsion can quickly infill, while in other cases they may persist as tributary drainages. Finally, the third type of channel shift is termed *stream piracy*, which occurs when a headward-cutting stream encounters and diverts the channel. While this may be initiated by a floodplain-confined tributary, most stream piracy events involve streams in two different drainage basins, and are therefore a characteristic of long-term landscape evolution. For example, basing his argument on valley size and architecture, Lewand (1969) argues that the ancestral Brazos flowed along what is now the Leon River before being captured and diverted at several points as the landscape evolved.

As Brown (1997) points out, it is difficult to generalize about the character of meandering systems because the sedimentology and architecture of streams reflects both the character of the myriad factors affecting their current

behavior and influences imposed by their long-term history. In particular, the relative importance of channel, point bar, and overbank facies within a given valley segment varies considerably from stream to stream. In relatively small streams, channel migration frequently involves the entire floodplain surface, so that long-term storage of valley sediments is limited. However, lateral migration can also be inhibited, particularly if the stream is incising into bedrock, which is a common occurrence in the Fort Worth district. In many larger systems, lateral migration is limited to one or more relatively well-defined meander belts within the alluvial valley, and overbank deposits can frequently be preserved for long periods in other parts of the valley. Tectonic influences and base-level adjustments can also strongly affect the relative proportions of channel, point bar, and overbank facies, while differences in discharge and sediment load can also profoundly affect the configuration of the system. In all cases, the character and configuration of fluvial deposits reflects the environment of deposition, and the deposits can thus provide a proxy record of environmental change. Unfortunately, this record is rarely complete or unambiguous.

Although three-dimensional alluvial architecture can vary in many ways, in a simplified, two-dimensional profile a meandering stream's unit architecture falls somewhere between two end members. On the one extreme, aggradational units may develop one on top of the other, like the layers of a cake, in an arrangement referred to here as *stacked architecture*. Such arrangements are typical of punctuated aggradation that is not interspersed with periods of significant downcutting and lateral planation, and units are

typically demarcated by buried soils. At the opposite end of the spectrum, aggradational units may be laterally associated, forming *inset architecture*.

Deposits making up the floodplain of a stream are in temporary storage, destined to be re-entrained and moved further toward the sea by the stream. Occasionally, intrinsic adjustments or extrinsic factors can cause a stream to cut down, abandoning former floodplain surfaces and decreasing the probability that the sediments will be re-entrained. Landforms created by such incision are termed *alluvial terraces*, and the contacts between major fill episodes are termed *bounding surfaces*. In its simplest form, each fill underlies a distinct terrace surface. However, the relationship between terrace surfaces and the number of discrete alluvial fills present is not particularly straight-forward because (1) incision or the influence of more than one flow regime can result in the development of more than one terrace surface in a single fill, and (2) overtopping of an older fill by a subsequent one can create a single surface underlain by multiple fills (Figure 2–2).

Occasionally, multiple episodes of valley incision can create benches termed *bedrock straths* that are eroded into the valley wall. Strath surfaces underlain by alluvium (*alluvial straths*) can also be created by multiple episodes of incision. Prolonged or rapid incision of bedrock by a meandering stream can result in the formation of entrenched meanders, where the original meander pattern is entrenched into solid rock, restricting the stream's ability to meander freely and preserving a snapshot of

Figure 2–2: Illustration of idealized relationships between alluvial terraces and fill units.

the stream's history. In the Fort Worth District, this is a common situation, particularly in the Brazos drainage.

The potential for alluvial deposits to preserve archeological materials is dependent on a number of factors, including (1) character and depositional energy represented by the deposits, (2) rate of burial, (3) the chemical and biotic environment, and (4) susceptibility to post-depositional disturbance. Conversely, the potential for a given behavioral episode to be preserved as an archeological site depends both on the environmental characteristics outlined above and on the vagaries of timing. Relatively high-energy fluvial deposits, including channel lag, lower point bar, and chute bar deposits in meandering stream systems, have relatively low potential to contain cultural materials in good context. This is true because (1) the energy conditions that prevailed during deposition were generally high enough that cultural material would have been reworked, and (2) the depositional environments represented are not particularly attractive for occupation. Thus, sites are relatively unlikely to have formed in these environments in the first place, and any that did form would probably not have survived burial in reasonable context. In addition to high energy deposits, which are characteristically coarse-grained, care should be exercised to identify truncation surfaces resulting from erosion during high magnitude flow. In many cases, such scour surfaces may not be associated with coarse clastic deposits, but the context of any archeological materials resting on such surfaces must still be considered highly suspect.

Moderate energy environments, in contrast, can provide the best potential for site preservation in meandering stream settings. These environments, including upper point bar, levee, crevasse splay, and some proximal flood basin settings, represent relatively well-drained, stream proximal settings that were frequently attractive localities for prehistoric peoples. They are also characterized by deposits that were often laid down under fairly energetic conditions, and archeological materials stratified in such deposits can often exhibit moderate to severe taphonomic modifications that alter or disrupt their spatial integrity (e.g., size sorting, removal of small and light materials, reworking of heavier materials through limited transport). In other cases, energy conditions were not as extreme and their disruptive effects were more limited. Moreover, in many cases high rates of sediment supply in these settings can quickly bury occupations, minimizing the potential for destructive reworking during burial. Thus, evaluation of such settings requires detailed investigations of each site, with particular focus on the character of its matrix.

Certain bedforms, such as climbing ripple laminations, are indicative of high rates of sediment delivery, which can

indicate that an assemblage was buried rapidly and therefore had relatively little opportunity for pre-burial disturbance. However, in many (if not most) cases, such bedforms are poorly preserved. Spatial patterning in the distribution of archeological materials is frequently taken as evidence of integrity, but care must be exercised as apparent patterning can arise from a number of mechanisms. For example, transport of artifacts on vegetated surfaces can result in deposition of diverse materials in the lee of flow restrictions such as trees and clumps of grass, and size sorting is not always apparent, particularly if the materials are being exhumed by flood-induced erosion upstream (Lintz et al. 1992). Similarly, the stratigraphic concentration of materials in discrete strata or on presumed paleosurfaces is also frequently cited as evidence of integrity, but similar relationships can develop through erosional stripping or intensive bioturbation (e.g., Johnson 1989; 1990). For these reasons, care must be exercised in the interpretation of the integrity of archeological sites sealed in alluvial deposits.

From the perspective of burial energy, environments away from the channel, including distal floodbasins and channel plugs, represent the settings where the original spatial relationships between artifacts is least likely to be altered by the tractive power of floodwater. However, because burial occurs so slowly, and because the rates of pedogenic and biotic alteration of the deposits are correspondingly higher (sometimes dramatically so), the overall preservation potential of such deposits is frequently lower than it is in moderate energy settings. Moreover, in many systems, such settings are distinctly less attractive for habitation because they are often wet and muddy and/or too far from a ready source of water. On the other hand, where chemical conditions are right, fine-grained matrices (particularly dense clay) can enhance preservation of fragile or chemically-susceptible artifacts like bone and other organic materials. Therefore, while these settings have somewhat lower potential than the stream-proximal settings, they do have substantial archeological potential and should not be ignored during survey.

In general, alluvial deposits have high potential to contain archeological sites in good, interpretable context. However, finding and investigating sites in such settings requires a considerable investment of time and resources. While exceptions can be cited, surface survey and shovel testing is generally not an effective mechanism to locate sites in such settings. Rather, identification of buried alluvial sites requires detailed cutbank examination and an intensive program of machine-aided subsurface prospection. Such a program is best accomplished if the investigator possesses a good working understanding of the architecture and stratigraphy of deposits underlying the floodplain and terraces in the particular system of interest. While much work remains to be

done, Section 2.3 outlines preliminary stratigraphic models for a variety of the streams in the Fort Worth District.

2.2.2.2 Eolian Processes, Deposits, and Landforms

Eolian processes involve the action of wind as an agent of transport. Wind primarily affects clasts ranging from coarse sand-sized to clay-sized; gravels (and gravel-sized clasts such as artifacts) are not entrained, but may be concentrated as a residual lag as fines are removed. As with water transport, eolian clasts are transported in the bed load (termed *surface creep* in eolian processes), saltation load, and suspended load. Many authors (e.g., Pye 1987; Lancaster 1995) draw a distinction between the load in short-term suspension, which is held in the air column by turbulence at low altitude and typically travels tens to hundreds of meters, and the load in long-term suspension, which is lofted high in the air column and can be held in suspension for hundreds or thousands of kilometers.

Both wind and water are fluid mediums, albeit fluids with very different density characteristics. The size grades comprising the suspended, saltating, and surface creep fractions are finer and narrower than in fluvial processes due to the lower density of air, and sorting of eolian deposits is typically much better than it is in even well-sorted alluvial deposits. One distinction between eolian and fluvial transport is that there is no dissolved load associated with the former. Another key difference between eolian processes and fluvial processes is that while flow vectors in a stream are highly constrained by gravity and topography, wind direction (and thus the vector of eolian sediment transport) can (and commonly does) change radically in a short span of time. Consequently, while alluvium is either moving towards the sediment sink at the stream's mouth or in temporary storage, eolian deposits can move across the landscape in a variety of directions, often changing direction radically or reversing course. This is important because it means that eolian sediments, unlike alluvial sediments, can move perpendicular to or against the prevailing slope. As a result of multiple vectors of transport, eolian deposits frequently develop complex internal architecture and a wide variety of cross-cutting strata.

Eolian deposits can be conveniently divided into those dominated by sands (dunes and sand sheets), which are formed primarily by localized transport of the traction load and often develop distinctive bedforms, and those dominated by silts (loess), which are formed by long-distance transport of the suspended load and typically settle out of the air column gradually, forming massive, uniform blankets across the landscape. In both cases, eolian transport and deposition requires two key variables: (1) winds of sufficient power to entrain and transport sediment; and (2) a source of erodable

sediment to entrain. Eolian entrainment occurs because wind exerts a tractive force on the ground surface, much as moving water exerts a tractive force on the bed of a stream. This force has two components: a lateral (translational) force and a vertical (lifting) force. The magnitude of this lifting force is a function of wind velocity, air density, and the degree of surface roughness. No matter what the ambient wind velocity, wind speed falls off to zero at some small height above the surface due to friction effects. Bagnold (1941) demonstrated that this height is approximately 1/30 of the mean diameter of the largest particles resting on that surface. Vegetation also disrupts wind in the near-surface layer, breaking the vector of flow into a series of eddies and vortexes and diminishing the shearing and lifting forces necessary for entrainment. Thus, continuous vegetative cover effectively eliminates the potential for eolian entrainment, and surfaces mantled with a discontinuous cover of large clasts or discontinuous clumps of vegetation can still be effectively armored against eolian deflation. On the other hand, partial vegetative cover is no guarantee that eolian transport will not occur; Wasson and Nanninga (1986) demonstrate that effective eolian entrainment and transport can occur in areas with up to 45% ground cover.

In addition to an absence of ground cover, soil moisture conditions must be low for transport to be initiated. Eolian deflation requires that the exposed sediments are nearly or completely dry. Because of the attractive force imparted by surface tension, moisture content increases interparticulate attraction considerably. For example, medium sands with a moisture content of 0.6% require winds of twice the velocity to be entrained as dry sands of the same size, while sands with a moisture content of more than 5% are essentially immune to entrainment by natural winds (Lancaster 1995). Therefore, in order for appreciable eolian activity to occur, the landscape must include a significant number of patches of bare, dry ground. However, even if soil moisture is abundant, sustained wind across a bare surface will tend to desiccate and erode the upper few millimeters of the surface.

Sand transport by wind is dominated by saltation, which accounts for more than 80% of sediment movement in a sandy system. Surface creep, a concept that includes grains moved directly by the wind and those moved as a result of impacts imparted by saltating grains (*reptation*), accounts for less than 20% of movement. As with fluvial processes, grains in the very fine sand range are the most readily entrained by eolian processes. As grain size increases, increased mass and friction require increasing wind speed for entrainment, until the resistance of the grains exceeds the force imparted by natural winds in the fine gravel size range. As grain size decreases, the cohesive properties of the sediments make entrainment increasingly difficult. However, because saltating grains impart considerable energy as they return to the surface,

abrasion by saltating sand grains is one of the most important mechanisms for breaking down and entraining eolian dust. In fact, it is difficult to entrain fine silts and clays at all unless sand-size clasts (or aggregates) are also present at the source to break the cohesive bonds through abrasion (Paton et al. 1995). The energy imparted by saltating grains is also commonly transferred to other sand grains, causing them to saltate or reptate in turn. For this reason, the threshold velocity necessary to initiate eolian transport (the *fluid threshold*) is greater than the velocity necessary to maintain transport once it has begun (the *impact threshold*) (Figure 2–3).

The extent of recognized eolian deposits in the Fort Worth district is limited. No eolian deposits are mapped in the district on the relevant Geologic Atlas of Texas sheets (Barnes 1972; 1976; 1987; 1988; McGowen et al. 1991). However, active deflation and small dune formation is apparent around agricultural fields in some parts of the district, and geographically-limited areas of substantial prehistoric eolian deposition have been noted in Wise County (Ferring 1994a; 2000). These include both upland (the George King site) and stream-proximal (the Dodd Pit site) deposits. While neither of these localities has apparently been reported in any detail, they do represent thick accumulations of eolian sand burying and/or encapsulating cultural material. In addition, thick accumulations of what appears to be eolian sand heavily infiltrated with silts and clays was noted on a meander bend of the Brazos River in Somervell County during the current study (see Section 2.3.5).

Figure 2–3: Generalized relationship between particle size and wind velocity in determining thresholds of eolian erosion, transport, and deposition. Note the difference between the wind velocity needed to initiate transport (*fluid threshold*) and to sustain transport (*impact threshold*).

The most obvious sources for high volumes of fine sands and silts in the Fort Worth district are the siliciclastic formations such as the Paluxy and Antlers Sandstones, the streams that drain these formations, and major through-flowing streams such as the Brazos and Trinity. However, little eolian activity is currently observable in these systems except where the groundcover has been destroyed by agriculture. While it is likely that the extent of prehistoric eolian activity was strongly limited by vegetation, even during the driest portions of the Holocene, there clearly were localized episodes of sand accumulation that probably represent climatically-driven devegetation. Large, intense wildfires could have had the same effect locally, allowing eolian processes to operate on the exposed substrate for short periods before the burned areas were able to “heal.”

Because they represent a relatively weak transport medium, sandy eolian deposits have strong potential to contain archeological sites in reasonably good context. Reworking of artifacts occurs primarily through erosion of the surrounding matrix, leaving the relatively large and heavy cultural material to settle. Although this deflation can result in changes to the planimetric distribution of artifacts, these changes are typically relatively minor compared to the movements that can occur with even relatively gentle flows of water. The primary problem with eolian deflation is that it destroys stratigraphic relations between artifacts. Therefore, a single component site that has been severely deflated and then reburied still has considerable archeological potential, but a stratified multicomponent site that is deflated can contain commingled artifacts of several different periods on a single paleosurface. Such mixed assemblages can often be very difficult to identify, particularly if the frequency of time-diagnostic artifacts is low, and almost impossible to interpret with confidence.

One approach to the assessment of site integrity in sandy eolian settings is to pay attention to the hierarchy of bounding surfaces (*sensu* Kocurek 1981) in the matrix, if evidence of such surfaces is preserved. Eolian deposition results in the formation of laminae and beds through three primary mechanisms: (1) *climbing translant strata*, which are relatively low-angle laminae and ripple beds that form on the stoss (windward) face as sand migrates up a dune or in areas where dunes do not develop; (2) *grainfall laminae*, which are more steeply inclined and form as sand drops out of the air column on the lee of a dune crest; and (3) *grainflow cross-strata*, which form as the lee face of a dune oversteepens and avalanching occurs (Lancaster 1995). Because climbing translant strata and grainfall strata are typically destroyed as a dune migrates, grainflow cross-strata are by far the dominant type of bedding preserved in dune deposits. Figure 2–4 illustrates a cross-section of an idealized barchan dune, including the hierarchy of eolian bounding surfaces. Individual eolian beds are

Figure 2-4: Idealized cross-section of a generic unidirectional migrating dune (e.g., a barchan), illustrating terminology used in describing dune morphology and the generalized distribution of climbing translantent strata, grainfall strata, and grainflow strata in the bedform. Numbers represent bounding surface hierarchy.

composed of packets of subparallel laminae that form during relatively constant conditions. Third order bounding surfaces represent reactivation surfaces representing relatively minor discontinuities in depositional conditions, usually reflecting short-term changes in wind strength or direction, and define the boundary between *bedding sets*. Second order bounding surfaces represent more protracted periods of local erosion and renewed deposition within an accreting bedform, and mark the boundary between *bedding cosets*. First order bounding surfaces are major discontinuities that represent the passage of migrating bedforms; they tend to be relatively parallel to the ground surface and are often overlain by interdune deposits (Kocurek 1981). Because this hierarchy of bounding surfaces reflect varying intervals of time, it follows that archeological materials contained within sets or resting on third-order and second-order bounding surfaces have higher potential to represent materials in primary or semi-primary context, while materials resting on first-order bounding surfaces are likely to represent redeposited lag material, and should be carefully examined for evidence of assemblage mixing. Unfortunately, second- and third-order bounding surfaces are rarely preserved in semi-arid settings like the Fort Worth district, probably as a result of deposition on vegetated surfaces and/or pervasive, small-scale turbation by insects and other organisms.

2.2.2.3 Hillslope Processes, Deposits, and Landforms

By far the most spatially ubiquitous suite of processes affecting the Fort Worth district are the mass movement and wash processes that affect the hillslopes and uplands (Selby 1993; Heimsath et al. 2002; . Mass movement processes are those physical mechanisms where sediment is moved downslope under the primary influence of gravity, and wash processes are those driven by the initial stages of stormwater run-off, before the water is concentrated in defined channels. Mass movement processes are differentiated according to speed of movement, integrity of the moving mass, and degree of lubrication

involved. Wash processes include those processes where sediment is transported downslope by sheet flow and rill flow. In practice, sheetwash and mass movement processes occur in tandem, and their relative contribution to slope deposits is often difficult to gauge. Similarly, the distinction between wash processes and fluvial processes used here is somewhat arbitrary, as water tends to concentrate into lines of flow due to internal friction and the influence of surface roughness characteristics, and these small, ephemeral concentrations of flow share many physical similarities with their larger cousin, the stream, including the ability to erode definable

(albeit often ephemeral) networks of channels called *rills*. It is also worth noting that subsurface runoff or *throughflow* is an important process. While this usually involves movement through the network of pores and voids present in soil, in some cases erosion of complex networks of subterranean channels occurs in a process called piping.

Table 2-3 lists the major categories of mass movements, their integrity, speed, and lubrication characteristics, and a generalized assessment of the potential for the preservation of archeological integrity within resultant deposits. Slope failures such as rockfall, block topple, block glide, spreading, and cambering are typical of relatively steep, consolidated bedrock slopes. Block glide, spreading, and cambering are particularly common where inclined bedding is present, such as the Paleozoic rocks in the western part of the district. Debris topple is similar to block topple, in that a block of cohesive material detaches from the face of a steep slope and cants slowly outward until a sudden, catastrophic failure occurs. However, the material involved in a debris topple is unconsolidated sediment that has typically been undercut, as in alluvium on the outside of a meander bend. Rotational failures or slumps are extremely common mass movements that occur at a variety of scales in unconsolidated sediments and, occasionally, in weakly lithified and poorly bedded bedrock. They involve one or more failures along a curved cleavage plane, causing the upper surface to tilt down and back away from the scarp, while the lower part rotates out and up. Often, the lower part of a rotational failure loses integrity and converts to a slide or flow.

Speed is an important characteristic of mass movements, and affects the potential for archeological preservation in the resulting deposits. While some mass movements are rapid, others occur over protracted periods and are nearly imperceptible on the ground except through their cumulative effects. Rapid mass movements may be instantaneous (e.g., a vertical rock

Table 2-3: Generalized Classification of Mass Movements and Their Geoarcheological Potential

Type of Movement		Speed of Movement	Lubrication	Integrity of moving mass	Geoarcheological Potential of Deposits
rock fall		very rapid	none	high	low
block topple		very rapid	none	high	very low
debris topple		rapid to very rapid	none	high	low; may rework material
landslide		rapid to very rapid	air cushion	low	low to moderate
mudslide		rapid to very rapid	water	very low	low to moderate
earthflow		moderately rapid to rapid	some water	very low	low to moderate
mudflow		moderately rapid to rapid	water	very low	low to moderate
debris flow		moderately rapid to rapid	water	very low	low
block glide		moderately slow to rapid	frequently none; facilitated by water	high	low
rotational failure		moderately slow to moderately rapid	frequently facilitated by water	moderately high to high	low to moderate
spreading, cambering, sacking		slow	frequently none; facilitated by water	high	very low
soil creep	shrink/swell	very slow	water	moderate	low to moderate
	rainsplash	slow	water; raindrop impacts	low	moderate
	bioturbation	very slow	none; may be reworked by other processes	low	moderately high to high
	viscous flow	very slow to slow	some water	moderate to high	moderate to moderately high

fall) or occur over periods of a few minutes to a few hours (e.g., landslides, debris flows, rotational failures). Incremental processes (e.g., soil creep, solifluction) may occur relatively continuously or discontinuously, but require long periods before the effects can be noticed. In some cases, rapid mass movements can be preceded by protracted periods of incremental movement that gradually shift the mass to a point where catastrophic failure occurs. One well-documented example is the gradual movement of Threatening Rock, which collapsed onto Pueblo Bonito in Chaco Canyon National Monument in January, 1941. Concerned that the rock would fall and damage the monument, the park caretaker collected data that demonstrates an exponential increase in the rate of movement for eight years before the rock fell. Significantly, the rock was perceived as a threat and braced by the original inhabitants approximately 1,000 years ago, suggesting that the fall of threatening rock was preceded by at least 2,000 years of slow movement as it gradually detached from the cliff face and canted outward (Chorley et al. 1984). Other types of catastrophic slope failure are also frequently preceded by incremental movements, such as the bulging of hillslopes before rotational failures and flows (Selby 1993).

The integrity of the moving mass is another key variable that differentiates various types of mass movement. At one extreme, failure and detachment of individual rock masses in rock fall, block glides, and similar events represent movements with a high degree of internal integrity. Unconsolidated sediments can also move as integrated masses, particularly in block topples and rotational failures, but this integrity tends to break down as the failure progresses. Mass movements that behave like plastic solids (some flows, solifluction, some types of soil creep) can also maintain a degree of integrity, while mass movements that act as viscous liquids (e.g., debris and mud flows) or as collections of independently-moving solids (e.g., landslides, creep by individual particles on hillslopes) have very low integrity.

The type and degree of lubrication involved also serves to differentiate types of mass movement. The most common lubricating agent is water, which is why so many mass failures occur during or after heavy storms. Water permeating into sediment or along fissures and bedding planes in a rock tends to create hydrostatic pressure that decreases the frictional

resistance to movement (the *shear strength*). At the same time, water also imparts considerable weight to sediment, increasing the impetus for movement (the *shear stress*). If the content of water is high, then frictional resistance tends to break down entirely and the movement behaves as a flow (albeit with somewhat higher viscosity than pure water). Although water is the most common lubricant, some mass movements (e.g., rock glaciers) are facilitated by the presence of ice, while other rapid mass movements (e.g., landslides) may be buoyed by a cushion of air, decreasing frictional resistance and increasing their speed dramatically (Selby 1993).

Although geomorphic texts often focus on the more awe-inspiring rapid mass movements (e.g., rockfall, landslide), slow, incremental processes play a more important role on the evolution of most landscapes and in the preservation and destruction of most archeological sites. These processes occur gradually over periods that are too long to be directly observed, but affect much broader portions of the landscape. While the effect of rapid processes on archeological sites can be considerable, they tend to be highly localized, while almost all sites are affected to some degree by incremental processes.

Incremental mass movement processes in unconsolidated sediments and soils are generally termed *soil creep*. Soil creep, in turn, can be divided into processes that affect individual grains, and those that affect the soil mass as a unit (Paton et al. 1995). The mechanisms and impact of those processes that affect individual particles are relatively well-established. Rain splash, for example, is a very important process on exposed hillslopes. Falling raindrops can impart considerable energy, particularly if they are large, and are capable of detaching particles and splashing them into the air. Rain splash erosion can move considerable amounts of sediment on susceptible hillslopes; Chorley et al. (1984) report a maximum rate of $2.6 \text{ cm}^3 \text{ per cm}^{-1} \text{ year}^{-1}$ in the American southwest. The evidence of rain splash erosion is often easy to see, both in the form of mineral particles adhering to plants, rocks, or buildings well above the ground surface, and in the formation of small “pillars” of sediment capped by resistant clasts. Rain splash results in net downslope movement because detached particles follow a parabolic arc returning to earth, and those moving downslope tend to travel farther than those moving upslope. The degree of slope is also important; Mosley (1973) performed experiments that showed that on a 5° slope, 60% of the material moved by a simulated 30 minute rainstorm traveled downslope, while on a 25° slope, a similar storm resulted in 95% of the material moving downslope. Therefore, over time, raindrop impacts alone can have a considerable cumulative effect. However, raindrop impacts do not occur in isolation, because at least some of the incident water is quickly converted to runoff (unconfined surface wash/rill flow), which can result in substantial erosion. Chorley

et al. (1984) argue that, because overland flow alone quickly loses effectiveness as the loose surface particles are removed, raindrop impacts play a major role in detaching grains and making them available for transport.

Another process responsible for soil creep is *heave*, which can operate either on individual grains or on consolidated masses of sediment. Heave is the result of small-scale expansion/contraction processes resulting from freeze/thaw cycles or hydration and dehydration of expansive clays (Ritter 1978). In the expansion phase, particles are lifted roughly perpendicular with a surface, while in contraction they settle more or less vertically. If the surface is inclined, this process results in a small net movement downslope. The effectiveness of heave remains somewhat controversial, largely because it is difficult to isolate from the effects of granular creep and bioturbation so that meaningful observations and measurements can be made. Still, the contribution of heave processes to overall soil creep will clearly vary with climate (the frequency of freeze-thaw cycles) and with the mineralogical composition (i.e., the amount and type of expansive clays) of the soil.

A final and even more controversial component of soil creep is the slow downslope movement of the entire soil mass, sometimes termed *continuous creep* (Ritter 1978). Early investigators (e.g., Sharpe 1938) argued that evidence of continuous creep was abundant (e.g., displaced and curved trees, displaced posts, downslope bending of bedded rock, etc.), but alternative explanations have since been proposed for almost all of these phenomena (Finlayson 1985) and recent researchers tend to downplay its importance (e.g., Heimsath et al. 2002). Continuous creep is typically ascribed to slow plastic deformation resulting from loading pressures (i.e., weight of overburden) and some authors have argued that it does not truly reflect a form of gravity-driven mass movement (Paton et al. 1995). Nevertheless, these processes may result in plastic deformation within the soil, and can affect the spatial and stratigraphic relationships between artifacts.

It is also important to acknowledge the role of bioturbation, particularly in incremental processes. Although many investigators draw a theoretical distinction between biotic and abiotic processes, most acknowledge (either explicitly or tacitly) that bioturbation and mass movement operate in tandem to transport soil materials downslope, and some argue that it is impossible to separate bioturbation processes from slope processes because they are so intimately interrelated (e.g., Gabet et al. 2003; Johnson et al. 2005).

Mass movements, and particularly the various forms of soil creep, are very important geoarcheological considerations because they affect most parts of the landscape, albeit at often

imperceptible rates. Although the energy available for mass movement is determined by the gradient of the slope, colluvial processes are not limited to steep parts of the landscape. Creep processes, in particular, can affect surfaces with very minor inclinations. However, the rates of such processes are so slow that the potential for such deposits to envelop and preserve archeological materials in reasonable context is very low. In contrast, areas characterized by moderate to steep slopes are characterized by rates of mass movement that may lead to archeological preservation. On moderate slopes, particularly where the soil cover is readily erodable, sites may be preserved anywhere, while in steeper settings deposits likely to preserve sites are typically restricted to the *footslope* and *toeslope*.

Colluvium is the generalized term for hillslope deposits produced by mass movement processes, although in practice more specific terms are frequently used when deposits related to specific types of mass movement, and particularly to individual events, are recognized (e.g., landslide deposits). Most definitions (e.g., Whittow 1984; Bates and Jackson 1984) restrict the term colluvium to the product of gravity-driven processes, but in practice gravity and surface wash processes operate in such intimate concert that distinguishing between colluvium and *slopewash* is usually problematic. Therefore, the following discussion uses the terms colluvial processes and colluvium to refer to both gravity-driven and surface wash processes and the deposits formed by their combined action.

The potential for archeological preservation by colluvial processes varies depending upon the position of the archeological site on the hillslope. Hillslopes have characteristic forms, and different segments (or *facets*) of a hillslope have varying potential to encase and preserve archeological materials. Figure 2-5 illustrates terminology commonly used to describe hillslopes. As the figure indicates, the upper portions of hillslopes are predominantly erosional, midslopes are characterized by sediment transport, and the footslope and toeslope is characterized by sediment accumulation. Colluvial deposits tend to accrete on the lower portion of hillslopes as a wedge that thickens towards the base of the slope and then thins away from it. The geometry of these wedges varies with the three-dimensional configuration of the *slope*

break, the angle of the slope, the textural characteristics of the colluvial deposits, and the character of vegetation. The preservation potential of colluvial deposits depends upon the original position of archeological materials on the hillslope, the type of mass movement involved, the relative influence of wash processes, the age of mass movement events relative to the age of the archeological materials, and the degree of post-depositional alteration. Artifacts deposited at the base of a hillslope may be covered with colluvium laid down at a later point in time, incorporated into penecontemporaneous deposits, or rest on older colluvial deposits. The integrity of such archeological materials depends upon the rate of colluviation. Very rapid mass movements impart considerable energy and are likely to disrupt cultural patterning severely, while very slow colluviation allows an artifact assemblage to remain exposed and subject to disturbance for a long time. Thus, the highest potential for preservation exists in areas where the rate of colluvial deposition is moderate.

In some situations, artifacts originally deposited on the hillslope are transported downslope as individual clasts and

Figure 2-5: Illustration of terminology used to describe slopes.

incorporated into colluvium at the toeslope. In these cases, the artifacts are in secondary context and (usually) have little research potential. However, it is possible for artifacts to be displaced downslope by mass movements with relative integrity, so that the spatial arrangement between a suite of artifacts and features is preserved (albeit at a position on the slope other than where they were originally deposited). In these rare cases, the research potential of such deposits may remain high, even though they have been subjected to significant displacement.

Hillslope processes and the resulting deposits vary considerably in response to a wide variety of localized controls on sediment mobilization, transport, and deposition. These controls are imposed by the configuration and orientation of a slope, character and spatial pattern of slope materials, and the character and spatial patterning of slope vegetation through time. As a consequence, hillslope deposits are often far more locally heterogeneous than fluvial and eolian deposits.

After burial, colluvial deposits are subject to the same types of post-depositional alteration that affect other deposits. For this reason, and because the style of colluviation affects the potential for preservation, it is important to assess that context carefully and critically. Therefore, while colluvial deposits have good potential to contain archeological materials in a reasonable context, archeological materials contained therein must be carefully evaluated to assure that the integrity of deposits is adequate to support any conclusions that are drawn. Archeologists dealing with the colluvial environment must keep the depositional context in mind at all times, because the internal architecture of colluvial deposits is inconsistent with standard archeological practice. Because colluvial sediment accretes on hillslopes, excavation of artificial levels is almost guaranteed to cut across internal time horizons and result in the recovery of mixed assemblages. Accordingly, it is critical that considerable attention be paid to the stratigraphy early in the excavation to facilitate investigation by natural levels. Unfortunately, in many cases, internal stratigraphy in such deposits is subtle or lacking, making excavation by natural levels impossible. In such cases, minimizing the length of slope spanned by individual excavation units will help to minimize the potential for cutting across multiple occupations.

2.2.2.4 Miscellaneous Deposits and Landforms

Other landforms of potential significant, albeit geographically limited, archeological relevance in the Fort Worth District include rockshelters, springs/seeps, and caves and sinkholes. Rockshelters are essentially open-air caves; areas where bedrock

overhangs have developed in a cliff face. They are unique local environments where depositional and site preservation conditions are quite different than anywhere else on the surrounding landscape. Moreover, because of their ability to provide shelter from the elements, rockshelters were prime localities for habitation during the prehistoric period, both in Texas (e.g. Trierweiler 1994) and throughout the world (e.g., Laville et al. 1980; Farrand 1985; Barton and Clark 1993). While north-central Texas is not particularly known for rockshelter sites (unlike other areas of Texas, such as the Edwards Plateau and the Lower Pecos region), there are occasional shelters present, particularly in the western and southern part of the study area. A brief review of the Texas Historic Sites Atlas revealed twenty-nine recorded rockshelter sites in the Fort Worth district. These shelters are primarily associated with the Brazos and its tributaries, and concentrated in Palo Pinto and Somervell Counties (Figure 2–6). The absence of recorded shelter sites in Tarrant, Johnson, and Wise Counties is almost certainly attributable to a marked paucity of habitable shelters, while in Jack County it likely reflects the limited amount of archeological work that has been done.

Rockshelters usually form in calcareous terrain, although they may also occur in sandstone, or in other locations where hard, resistant beds overlie softer, readily erodable rocks. Mechanisms of shelter formation are varied and complex, but all involve physical and/or chemical weathering to weaken and

Figure 2–6: Distribution of recorded rockshelter sites and sites with associated rockshelters noted in the Fort Worth District, according to the Texas Historic Sites Atlas.

break down the rock. Cryoprocesses break rock up by freeze–thaw cycles (cryoclasticism) and mix rockshelter sediments (cryoturbation); they are considered particularly important in the formation of many European rockshelters (Laville et al. 1980), but are probably of relatively minor importance in Texas where winters are comparatively mild. Lateral erosion by streams can play an important role in shelter formation in some situations, but has probably been overemphasized as a formation mechanism in central Texas (Abbott 1994b). The single most important suite of mechanisms in Texas is chemical weathering, which attacks a shelter’s walls and roof, resulting in dissolution, granular disintegration, spalling of coarse fragments, and roof collapse. Typically, the rate of weathering is greatest at the back wall, causing the shelter walls to retreat and increasing the size of the overhang through time. This is counterbalanced by retreat of the free face (see Figure 2–5) as weathering weakens the rock, leading to spalling and collapse of slabs and blocks from the cliff face and the shelter roof.

A variety of deposits are associated with shelters. Farrand (1985) recognizes endogenous sediments derived from the ceiling and walls by dissolution (chemical weathering), frost weathering, and collapse, and exogenous sediments carried in by water from the exterior or from karstic drainage, blown in by wind, and carried in by mass movements or people. To this list can be added organic sediment carried in or produced in situ by animals or plants (e.g., dung, algae) and mineral sediments precipitated from water (e.g., tufa, travertine, ferromanganese concretions). The coarse fraction of shelter fill, which is derived primarily from collapse and spalling of the roof and walls, is termed *éboulis*, and consists of lightly to moderately weathered, angular fragments of the parent rock. It is typically contained within a fine matrix, although on occasion erosion will have flushed all fine materials out of a shelter, leaving only a lag of the coarse material behind. The character of the fine matrix varies considerably, but usually falls into one of two classes depending on whether the shelter is wet (due either to water discharged from springs or seeps, or surface water draining into the shelter from cracks or fissures in the overhang) or dry. In the former case, shelter fills tend to resemble soils outside the shelter, while dry shelters developed in limestone are typically dominated by a loose, silty fill that is relatively easily disturbed. At Fort Hood in Central Texas, Abbott (1994b; 1995a; Abbott and Quigg 1996) synthesized geomorphic evaluations of more than 150 rockshelters and sinkholes developed in lower Cretaceous carbonates, and identified six distinct classes of shelter fill. These included (1) dry silts; (2) silts with light to moderate diagenetic alteration due to intermittent saturation; (3) dark gray clays derived from erosion of A horizons on surrounding uplands and from weathering of continuously wetted shelter sediments; (4) dark red clays derived primarily from erosion of upland argillic horizons and often delivered through karstic drainage into the back of the shelter; (5) chemical

precipitates (tufa and travertine); and (6) lag deposits of coarse clasts produced by erosion of shelter fill. Each of these types of deposits have differing physical and chemical characteristics that affect the visibility and preservation potential of incorporated archeological materials.

In dealing with rockshelters as archeological phenomena, it is important to recognize that shelters are not static landscape features. Rather, they are dynamic entities that evolve with the parent slope and ultimately die, merging back into the parent slope as the overhang is buried or destroyed (Collins 1991; Waters 1992). The rate at which this occurs is quite variable, depending upon the size of the shelter; the thickness and resistance to weathering and erosion of the overhang, backwall, and floor; the types and rates of shelter formation processes; and the relative rate of sediment influx (endogenous and exogenous) vs. shelter fill erosion. However, in many settings sediment influx is rapid enough that archeological deposits laid down in a shelter during the Late Pleistocene or Early Holocene, if preserved at all, will lie beneath the talus well outside and downslope of the shelter. A second aspect of shelters is that bedrock encountered in test pits does not necessarily signal the bottom of archeological deposits. Many shelters incorporate multi-ton slabs shed from the shelter roof, while others host seeps that produce prodigious amounts of tufa and travertine that form beds within the shelter fill. While such large fragments of *éboulis* clearly complicate investigations, they can also seal and protect underlying deposits.

Springs and seeps are landscape features that contribute to the configuration of the surrounding landscape and provide foci for human activity. As mentioned above, seeps and springs are often associated with rockshelters, and spring sapping at the base of a cliff is a major mechanism of shelter formation. Sapping can also occur around springs and seeps in open environments. Springs can also produce limited amounts of clastic sedimentation and copious amounts of chemical sediments. These deposits can envelop and seal a variety of archeological and biotic remains (Hall and Abbott 1995; Caran 2001), and therefore have considerable, and largely untapped, potential for paleoenvironmental research.

Caves consist of large voids in bedrock, and may or may not be open to the surface. Sinkholes (or *dolines*) are a particular type of cave formed when the roof of a subterranean void collapses, creating an opening that is a vertical shaft. Most caves and sinkholes are formed through the solution of carbonate rocks such as limestone and dolomite. The suite of processes associated with carbonate dissolution are termed *karstic processes*, and the landscape that results from the long-term operation of such processes is termed *karst* or *karstic terrain*. Utilization of deep caves by prehistoric people

was usually limited to the areas near the cave mouth where light was able to penetrate. Rarely are substantial prehistoric remains detected from deep within caves in North America (they are more common in other parts of the world, including Europe and Central America). However, where remains are noted, preservation is often spectacular due to the constancy and isolation of the environment.

Sinkholes have proven particularly informative from an archeological and paleoenvironmental perspective because they preserve detailed fossil records of fauna that entered and were unable to escape, and because they often were used as a convenient place for human burials. Sedimentation patterns in caves are similar to that in rockshelters: spalling, granular disintegration, and periodic collapse of the walls and roof, coupled with deposition of travertine and flowstone. While the mapped extent of karstic terrain in Texas extends into the southern part of the district (Erath and Somervell Counties; see Reddell 2001), the frequency of caves and sinkholes is limited in the district. Only two caves, Eagle Creek Cave and Manley's Water Hole, are identified in the district in *The Caves and Karst of Texas* (Elliot and Veni 1994). Both caves are associated with Paleozoic limestones in Palo Pinto County.

2.2.2.5 Nonbiological Turbation Processes

We now turn from physical processes of sedimentation to physical processes of turbation, or mixing, of those sediments. There are many mechanisms capable of disrupting and mixing soils and sediments. This summary addresses physical turbation mechanisms—those abiotic processes that churn and mix soils and sedimentary deposits—typical of the Fort Worth district. Three important processes can be identified in the Fort Worth District: argilliturbation, salt growth, and cultural disturbance. Biological processes are addressed in Section 2.2.2.6.

Argilliturbation

Argilliturbation refers to soil mixing resulting from the expansion and contraction of clays in the solum and subsoil with repeated wetting and drying. It is typical of the Vertisol soil order, although soils belonging to other soil orders may also exhibit vertic properties. Clay minerals of the smectite family are able to readily take up and lose water molecules in their crystalline lattice, which causes them to swell when wetted and shrink again upon drying, and all clays (particularly fine clays) tend to expand and contract somewhat during wet-dry cycles due to interparticular phenomena. Wilding and Tessier (1988) identify a number of factors influencing shrink-swell phenomena, including soil fabric,

mineralogy, the character of the saturating cation, electrolyte concentration and speciation, clay content, surface area, antecedent soil moisture content, frequency of desiccation/rewetting cycles, confining pressures, soil thickness, macro- and microclimate, slope, topography, vegetation, cropping patterns, and soil management practices. As a result of these factors, deep soil cracks typically develop as the soil shrinks and the peds separate. These cracks, which can be up to 10 cm in width and over 1.5 m deep in extreme cases (Gustavson 1975), provide avenues for fragments of soil material and artifacts to fall deeper into the profile, where they are incorporated in the next phase of wetting. During expansive phases, the margins of adjacent peds exert pressures that result in soil failure and the development of compressed, striated surfaces termed slickensides. Larger, curved slickensides develop at depth as a result of shear forces arising from differential rates of expansion. There is some evidence that these phases of expansion and contraction tend to gradually force large objects such as artifacts to the surface, potentially destroying archeological integrity (Duffield 1970; Limbrey 1975; Schiffer 1987; Johnson et al. 1987).

Vertisols have been referred to as “self-mulching” or “self swallowing” soils (Buol et al. 1980; Ahmad 1983). Vertic pedoturbation is itself a function of two related processes, upward movement of large objects by incremental heave processes, and infilling of cracks by loose soil material during dry seasons. However, the development of horizonation and clear trends in physical and chemical parameters with depth in many Vertisols suggests that the role of self mulching is exaggerated (Wilding and Tessier 1988). Nevertheless, vertical displacement of artifacts, stones, and other large objects contained in vertic clays is a common occurrence (Johnson et al. 1987; Schiffer 1987; Waters 1992), and archeological integrity must always be considered suspect in Vertisols.

Pronounced vertic activity frequently leads to the development of unusual soil features termed gilgai. Gilgai consist of a form of patterned ground associated with, and usually attributed to, the cumulative effect of long-term shrink-swell processes. Where not disturbed by agriculture, gilgai are characterized by a pronounced surface topography of regular, small-scale humps and depressions. Relief between microhighs and microlows is commonly on the order of 10–30 cm, and the depressions are typically 4–6 m in diameter (Gustavson 1975). On level surfaces, gilgai tend to occur in relatively random patterns that show no preferred orientation, but on low slopes they appear as relatively continuous, subparallel ridges and depressions oriented downslope. In vertical section, gilgai are characterized by highly variable soil profiles. The microhighs are underlain by areas where the lower soil and subsoil rises towards the surface, while

the depressions are underlain by thicker A horizons and one or more B horizons. The elevation of the subsoil commonly varies by a meter or more between the ridges and depressions. Slickensides are commonly well-developed at depth beneath the depressions.

Several explanations have been proposed for the formation of gilgai structures. Paton (1974; Paton et al. 1995) favors an explanation involving plastic deformation of the subsoil due to differential loading. In this model, the subsoil highs represent diapir-type structures formed as plastic subsoil is deformed. There are a number of sedimentary structures on a variety of scales that clearly do represent plastic deformation due to loading (e.g., ball and pillow structures, salt diapirs; see Reineck and Singh 1980), but the argument advanced by Paton that such loading also causes gilgai is not convincing for several reasons. First, density differences between the subsoil (which theoretically flows in response to loading) and the soil (which theoretically supplies the load) are not great (Gustavson 1975). Second, the regularity with which most gilgai occur, particularly on hillslopes, is not consistent with loading structures. Finally, loading of plastic material on slopes would stimulate flow in a downslope direction, resulting in structures oriented perpendicular to the slope, not parallel with it (Wilding and Tessier 1988).

The self mulching model (Figure 2-7) attributes formation to forces associated with expansion and contraction of the clays and with redistribution of material through crack filling. Because the deep, wide soil cracks developed during the dry season commonly fill somewhat with dry surface material, when they are rehydrated volume increases in the soil, resulting in lateral pressures that force surrounding sediment, including soil and subsoil, upward and outward. This creates small surface variations that favor the formation and rehydration of cracks in the depressions, accentuating the process. While this model, first proposed nearly a hundred years ago (Hilgard 1906), appears to play a role in gilgai formation, other factors are also involved.

The most comprehensive model to explain the formation of gilgai is the soil dynamics model, proposed by Wilding and Tessier (1988) (see Figure 2-7). As in the self-mulching model, the formation and infilling of soil cracks plays an important role. However, the role played by cracks in transmitting water rapidly to the subsurface is much more important. The cracks facilitate preferential rewetting, and thus preferential expansion, of the lower soil and subsoil during the early part of the wet season. This results in the formation of cones of force in the sediment that not only force surrounding sediment up and out, but also cause shearing and the formation of large, inclined slickensides that dip toward the center of the depression.

As a result of topographic variability at the surface and slickenside inclination in the subsurface, the rate of chemical weathering beneath depressions is accelerated relative to the rate beneath adjacent highs. Variability in the depth of the subsoil is therefore a function of both lateral forces that physically deform the sediment and different rates of weathering beneath the small rises and depressions. Because weathering of the subsoil removes carbonate salts and enhances chemical weathering of clays, readily expandable clay, moisture, and soil cracks are more common in depressions, resulting in a positive feedback that promotes continued gilgai development. In contrast, topographic variability promotes sheet erosion of surficial sediment from the microhighs and deposition in microlows. This is probably the reason that most gilgai surface expression is on the order of 10–30 cm of relief, while depth to subsoil commonly varies by a meter or more.

The implications of Vertisols and gilgai for archeologists have been touched on previously, but bear repeating here. Vertisolic expansion and contraction results in the formation of deep soil cracks. These cracks provide conduits for artifacts to move deep into the profile, while associated heave processes can move artifacts upward through the soil to the surface (Johnson et al. 1987; Schiffer 1987). Although sheet erosion from ridges and sheet deposition in depressions is probably common in gilgai terrain, and may sometimes bury artifacts, the self-mulching tendency of the sediments makes the potential for contextual integrity limited.

Salt Growth

The growth of salt crystals, or crystallurbation (Waters 1992) is another mechanism capable of disrupting sediments. The accumulation of soluble salts in soils, particularly in conjunction with irrigation in semi-arid and arid landscapes, is a major agricultural problem of intense interest to soil scientists (Rowell 1994). However, the disruptive influence of salt growth on soil matrices, and particularly on archeological matrices, has rarely been examined in any detail.

Salt accumulation is typical of areas where salts in solution are concentrated as the water evaporates or is used by plants. In natural settings, salt accumulation is typical of coastlines and of internally-drained basins, and salt deposits (evaporites) make up a relatively small but important part of the sedimentary geologic record. Humans have changed that. The widespread practice of irrigation has made the accumulation of soluble salts in the upper horizons of soils, a process termed *salinization*, a problem of considerable practical interest. Salinization results in drastic reductions in effective fertility and can ultimately make fields unsuitable for crops.

Example of gilgai (source: United States Dept. of Agriculture)

Pedoturbation Model

Soil Dynamics Model

Figure 2–7: Two different models of soil gilgai formation. The pedoturbation model is adapted from Gustavson (1975) and Buol et al. (1980). The soil dynamics model is adapted from Wilding and Tessier (1988).

Salt crystallization occurs when dissolved salts become supersaturated as water evaporates. In soils, salt crystallization is particularly pronounced at the surface and within the capillary fringe. Common salts include calcite, gypsum, anhydrite, and halite. As evaporation progresses and these salts

are concentrated into a brine, the first salt to be precipitated is calcite, followed by gypsum and halite. Salts more soluble than halite (table salt), such as epsomite, sylvite, and bischofite are extremely ephemeral in open environments, although they do occur in association with halite in evaporation pans. With the exception of calcite and (to a lesser extent) gypsum, which are relatively insoluble, evaporitic minerals will readily re-enter solution in the opposite order that they are precipitated.

As the brine evaporates, salt crystals begin to form on the soil surface, in the interstices between peds, and ultimately in the sediment matrix. The formation of these crystals exerts tremendous force on the surrounding sediment and on any fragile or permeable artifacts contained within the matrix. This force causes the sediment to expand and can destroy artifacts by crushing, wedging, and exfoliation. Permeable artifacts like bone and ceramic can literally be pulverized by crystal growth in the artifact and the surrounding matrix. Salt crystals can also form preferentially beneath anomalously large clasts (e.g., artifacts) causing them to be moved. Repeated wetting and drying, and the accompanying expansion and contraction of the soil as salts form and dissolve, can result in slow heaving of the soil, displacing artifacts vertically and laterally within the sediment matrix.

2.2.2.6 Processes of Biotic Sedimentation and Bioturbation

Organisms have two distinct roles in the accumulation of sediments making up the matrix of a site. The first, most widely recognized role is the suite of processes responsible for altering or disturbing site sediments. Collectively termed *bioturbation*, it includes *faunalturbation* and *floralturbation*. Faunalturbation refers to the mixing of sediments by the action of animals. It occurs primarily through burrowing, although several other processes (e.g., digging by predators, trampling, wallowing) may also contribute to such mixing (Hole 1981; Butler 1995). Floralturbation refers to disruption of sediment

through the action of plants, primarily by stresses imposed by root growth and root movements and the process of tree throw. The second, generally less appreciated role of organisms is the physical introduction of sediments, termed *biotic sedimentation*. This section summarizes these related suites of processes. While the focus is on animals and plants, the discussion concludes with a brief consideration of the role of people on sedimentation and disturbance.

There are a number of types of biotic sedimentation with strong potential relevance to archeology. The most obvious form of biotic sedimentation is the contribution made by organisms as they die and decompose. Although animals do add some material to the system, here the contribution of plants is far more important. This phenomenon is all too familiar to any archeologist who has attempted to perform surface survey in a forested area, where a cover of leaf litter and *mull* (partially decomposed organic matter) commonly obscures the ground surface. As discussed in more detail below, organic decay results in a wide number of early-stage, intermediate-stage, and late-stage products. The rate of accumulation of these products in the soil is a function of the rate of organic production versus the rate of physical and microbial decomposition. While the rate of production increases in the tropics, the rate of microbial decomposition has a concomitantly greater increase, so that organic matter does not tend to accumulate. In the subtropical zone, organic production is somewhat lower, but the rate of decomposition is markedly lower, and organic accumulation is much more rapid. These organics represent a type of sediment, and are capable of progressively burying archeological materials. However, with the exception of permanently wet locations like peat bogs and marshes, where anaerobic conditions tend to limit bacterial action, the accumulation of the organically-dominated O horizon is limited because a variety of biotic and abiotic pedogenic processes tend to gradually break down and mix accumulated organics into the underlying, mineral-dominated A horizon.

In addition to providing organic sediments through their death and decay, organisms are also capable of introducing mineral sediments which can bury occupation surfaces. The role of plants in this regard is relatively minor, because the only effective mechanism is tree throw (see below).

In contrast, there are many mechanisms of terrestrial sedimentation by animals, including digging for burrowing prey, rooting for buried vegetal foods, transport of sediment matted or caked on the hide and in the fur; concentration and decay of the remains of prey in a den; the concentration of grasses, leaves, or other vegetal matter for bedding in a den; routine defecation in a limited area such as a den or a corral;

and ejection of sediment on the surface in association with burrowing. Of these, burrowing behavior is the most important mechanism of mineral sedimentation in the context of the overall landscape, although other mechanisms may be much more important at individual localities. In the process of excavating a burrow, many animals eject subsurface sediment around the entry point, where it is then reworked by a number of mechanisms, including gravity, raindrop impact, overland flow, flooding, and eolian processes. In most instances, reworking of this material results in some sediment re-entering the burrow (where it may again be ejected if the burrow is still occupied) and some being dispersed across the ground surface surrounding the burrow. The volume of sediment affected by any individual animal is a function its size, life span, and the intensity of its burrowing behavior, while the overall effect of burrowing on any given landscape segment is a function of the type of burrowing animals involved, their population density, and the longevity of surface occupation.

The most important classes of burrowing animals in the Fort Worth District include insects and arachnids, annelids, reptiles, crayfish, and small mammals. Although there are many types of burrowing insects (and other burrowing invertebrates, such as arachnids), appreciable surface modification is primarily limited to social insects like ants and termites, who can collectively create significant subsurface alterations and surface modifications in a brief span of time. The ability of ant colonies to move sediment is readily apparent to anyone who has dealt with fire ant (*Solenopsis* spp.) colonies, which can riddle open fields with closely-spaced mounds that can reach heights greater than 2 feet. Although the fire ant is a recent immigrant from South America (it was introduced through the port at Mobile, Alabama, in the 1920's), other mound-building species like the western harvester ant (*Pogonomyrmex occidentalis*) and various species of the genus *Formica* were probably common in the prehistoric past (Mandel and Sorensen 1982; Paton et al. 1995). Many of these ants, as well as a variety of other invertebrate and vertebrate species (including, mercifully, ticks and chiggers), are suffering before the onslaught of the fire ant invasion, and non-fire ant mounds are much less common today than they were only a few decades ago.

The amount of sediment ejected from an ant burrow represents only a fraction of the volume of earth affected, because much more sediment is reworked beneath the surface. Nevertheless, the amount of sediment brought to the surface by ants can be considerable. In a review of literature on ant mounding, Paton et al. (1995) found reported rates worldwide range from a low of less than 0.003 t ha⁻¹ yr⁻¹

to a high of approximately $10 \text{ t ha}^{-1} \text{ yr}^{-1}$, with the higher rates occurring in relatively moist subtropical and temperate environments. As a result, burial of the surface can occur relatively quickly where rates of mound construction are high. For example, in a study in southwestern Wisconsin, Baxter and Hole (1967) estimated that the entire study area surface would be occupied with mounds formed by *Formica cinerea Montana* in 700 years time.

These rates of sediment turnover become even more impressive when one considers that much of the sediment reworked in the subsurface is not ejected on the surface, but rather rearranged in the subsurface by compaction of burrow walls and backfilling of passages. Over a span of thousands of years, the density of these infilled burrows can approach total reworking of the soil matrix. Moreover, these small krotovina can be extremely difficult to discern unless they are infilled with dissimilar sediment. In west Texas, for example, eolian coppice dunes frequently appear to be featureless masses of fine sand when they are first trenched, but several days of weathering reveal complexes of dense, multigenerational insect krotovina that completely occupy the shallow subsurface (Abbott 1996b). Similarly, observations of silty Holocene alluvium made by the author during testing of site 41WB437 in Laredo, Texas, revealed a dense network of small krotovina and open ant and termite burrows extending to more than 1 m below the surface and infilled with a variety of similarly-colored sediments, most prominently laminae of silty clay introduced during flooding (Abbott 1997a). Such dense networks of burrows and krotovina, introduced by many generations of ant and termite activity in the subsurface, may completely rework the fine-grained matrix of a site and significantly alter its chemical composition. In some cases, textural and chemical data has been used to postulate bioturbation as a site burial mechanism where no visual evidence is apparent (e.g., Leigh 1998). In this report, Leigh does not speculate on the agent of bioturbation, although insecturbation is more likely than large animalurbation where macroscopic evidence of burrowing is absent. However, because of their body size and because the volume of burrows active at any particular point in time is relatively small, ants and termites are unlikely to affect any but the smallest of buried, non-perishable artifacts. Thus, archeological remains like burned rock features and lithic scatters may be maintained with a high degree of subsurface integrity even while the encompassing matrix and associated organic remains are gradually reworked and destroyed.

The distribution, size, and density of ant mounds clearly exercise considerable control on patterns of surface sedimentation. Because they are cooperative social animals, ant mounds develop as a series of sediment point sources

that are readily identifiable when active. Patterns of surface sedimentation as a mound breaks down and is dispersed are controlled by a number of factors, including the size and shape of the mound, slope inclination and microtopography surrounding the mound, character of surface vegetation, and the character of mound sediment. The size and shape of the mound reflects a combination of behavioral and physical variables, while the character of mound sediment is constrained by the character of underlying soils and sediments, supplemented by behavioral sorting. Some mounds (such as the prominent fire ant mounds common in the modern Houston-area landscape) are relatively tall and irregular with a relatively small base. Such mounds are inherently unstable, and thus highly subject to rapid dispersal by natural processes such as intense rains or flooding. Other mounds, such as those formed by the western harvester ant, are low, broad-based cones with much lower potential to be rapidly redistributed. Coupled with the textural characteristics and friability of the sediments and the character of erosive energy, the slope, vegetation assemblage, and microtopography of the landscape surrounding an ant mound control the vectors and distances of dispersive transport. In some cases, the presence of a surface armor can inhibit breakdown and dispersion of mound sediments. Some ant species, including the western harvester ant, construct mounds characterized by a surface armor of relatively large granules that serve to protect finer-grained sediments below. While in some cases this armor may represent a lag produced by winnowing of fine particles, some species clearly collect coarse clasts (including bits of glass and other items) from the surrounding surface to intentionally armor the mound against erosion (Cowan et al. 1985).

Although the effect of ants can be considerable, it pales in comparison to the potential for soil turnover and surface sedimentation caused by annelids (earthworms). While ants and other burrowing insects (e.g., ground wasps, cicadas, and beetles) do so primarily for shelter, earthworms burrow for sustenance, ingesting soil and sediment to extract their nutritive requirements and excreting the residua (Stein 1983). Unlike ants, termites, and other organized social insects, earthworms operate individually, riddling the subsurface with a constantly changing network of pathways. While ants initially strive to create a burrow network, the bulk of an ant colony's life cycle is primarily concerned with burrow maintenance while they forage elsewhere for sustenance. Earthworms, in contrast, spend their entire life cycle burrowing because burrowing and eating are essentially the same activity. As a result, they are quite prodigious burrowers. In fact, earthworms appear responsible for the formation of the granular structure typical of many surface horizons, which indicates that the upper 25 to 75 cm of many soils has been completely and repeatedly passed through the gut of the worms that live in it. As with ants, the body size

of earthworms makes it unlikely that large non-perishable artifacts in the subsurface will be substantially affected, while the surrounding matrix may be completely altered.

The production of surface sediment by earthworms was first described more than a century ago by Charles Darwin (1881), who attributed the development of fine-grained “vegetable mould” in the upper part of soils to the action of earthworms. Since that time, a number of researchers have quantified the rate of surface casting by earthworms, with values ranging from less than 0.06 tons per hectare per year to more than 250 $\text{tha}^{-1}\text{yr}^{-1}$ (Paton et al. 1995). In central Texas, Frederick (1996) found that earthworm casting had buried a pre-existing upland surface with up to 6.3 cm of fresh sediment in a span of 40 years. As a result, archeological assemblages may be gradually buried in a few decades, sometimes without pronounced internal disruption (Van Nest 1998).

The effects of solitary burrowing insects are more difficult to assess because they affect significant changes only gradually. As with ants and other burrowing social insects, the most intense modifications occur in the upper part of the soil, decreasing markedly below a depth of 1–1.5 m. However, certain species of insects, such as cicadas, may burrow quite deeply (> 2 m), disrupting the sediment matrix well below the active soil zone. Overall, the impact of burrowing insects and annelids on archeological deposits is a function of (1) the intensity and character of burrowing activity, which reflects both the number of individuals and their habits; (2) the age of the deposits (and thus the longevity of burrowing); and (3) the depth of the archeological remains.

Insects and earthworms typically occupy freely drained soils, and do not tolerate saturated soil conditions well. However, such soils are colonized by crayfish, which build pronounced burrow entries termed chimneys that also represent large quantities of sediment brought to the surface. The rate of surface sedimentation by crayfish has not been studied in a manner similar to the action of ants and earthworms, but some observations suggest that it too may be considerable in certain settings (Stone 1993; Butler 1995).

Vertebrates also affect sediment/soil integrity by a variety of mechanisms. The most obvious here is also burrowing, which is practiced by a variety of small to medium-sized mammals, a number of reptiles and amphibians, and a few birds. Burrowing is conducted for a variety of reasons, including denning, rearing of young, shelter from predators and the elements, access to below ground resources, caching of food, and protection during hibernation (Butler 1995). Many other animals, including various taxa of reptiles and birds in particular, do not actively burrow but

routinely occupy burrows dug by other animals. Burrowing mammals range from relatively small (e.g., shrews, voles) to relatively large (e.g., canids like coyotes and foxes, bears), but the most common are small to moderately sized rodents (e.g., ground squirrels, rabbits, prairie dogs, and pocket gophers) (Bocek 1986).

Burrowing by vertebrate species also can result in the accumulation of significant quantities of surficial sediments (Johnson 1989; 1990; Johnson and Watson-Stegner 1990; Butler 1995; Reichman et al. 2001). Mammals are probably the most common class of burrowing vertebrates, although some species of reptiles, amphibians, and birds may also burrow. Burrowing mammals include those that burrow for shelter but feed at the surface (e.g., pocket gophers, prairie dogs) and true fossorial mammals, that live and feed underground (e.g., moles, shrews). Like insects and annelids, these small animals can displace and exhume considerable quantities of earth. For example, Buechner (1942) estimated rates of surficial mounding by pocket gophers in Texas between 0.81 and 15.87 $\text{t ha}^{-1}\text{yr}^{-1}$, while Thorn (1978) estimated rates of mounding by a different taxon of pocket gophers in the Colorado Rockies at 3.9 to 5.8 $\text{t ha}^{-1}\text{yr}^{-1}$. Notably, the action of burrowing mammals is one of the mechanisms cited for the formation of pimple mounds (Cox 1984). While insects and annelids will generally not move subsurface artifacts because of their small body size, crayfish may move small artifacts, and burrowing vertebrates may affect artifacts up to 7–8 cm in size. Even where the artifacts themselves are not moved, removal of the surrounding matrix can result in the concentration of larger stones and artifacts into discrete (and archeologically misleading) subsurface stone lines (Johnson 1990).

The size of vertebrate burrows ranges from small, shallow depressions to deep and extensive networks of passages and tunnels. Size is dictated by both the body size of the animal and its behavioral characteristics. In some cases, burrows may be quite lengthy but of a diameter only large enough to accommodate the animal's body, while other animals may create burrows that expand into relatively large subterranean living chambers that several animals can inhabit comfortably. Some of the larger documented burrows include prairie dog dens, which average 10–13 cm in diameter, and may be 30 m or more long and extend up to 5 m below the surface, and alligator dens, which may be up to 20 m long with diameters in excess of 75 cm (Sheets et al. 1971; Butler 1995). The net effect of burrowing on the integrity of the soil matrix is considerably enhanced when the animals involved live in large social groups. A prime example is the prairie dog colony, where hundreds of animals live in close proximity and active burrow entrances can number as high as 300 per hectare (Whicker and Detling 1988).

The archeological consequences of burrowing include disturbance of subsurface remains and introduction of sediment at the surface, which can bury surficial materials and archeological materials exhumed as part of the spoil (Bocek 1986). Because of their larger body size, burrowing vertebrates are capable of disrupting much larger artifacts and features than are impacted by insect burrowers, and relatively large burrowers are capable of completely destroying the context of even moderately large subsurface features, such as wall segments and burned rock clusters. Artifacts in matrices impacted by burrowers may be exhumed and reburied in surficial spoil, or they may fall or slide down the burrow and be incorporated deeper in the profile. If individual krotovina are apparent, the interstices between burrows may contain material in primary context, but intense, long-term burrowing by vertebrates can completely destroy the spatial and stratigraphic relationships between elements of an archeological component.

In addition to burrowing, vertebrates can affect archeological sediment matrices in several other ways. One common mechanism of disturbance is trampling. The efficacy of trampling as a mixing mechanism is a function of animal mass and foot size, sediment texture, and moisture content. Intense mixing typically only occurs where relatively large animals routinely walk through wet sediments. Ungulates, in particular, are capable of thoroughly mixing the upper half meter of muddy sediments simply by hoof penetration. In contrast, low-moisture sediments (with occasional exceptions like dry rockshelter silts and eolian sands) are usually not mixed appreciably by trampling. However, they can be significantly compacted and devegetated, resulting in increased susceptibility to reworking by sheet erosion, gullyng, and/or eolian deflation (Alderfer and Robinson 1974; York and Dick-Peddie 1969). In addition, trampling on hillslopes can lead to formation of terracettes and to chipping and calving of banks and slope breaks (Butler 1995).

Wallowing provides another mechanism where soil material can be mixed, compacted, and ultimately mobilized and removed. It represents activity designed to provide protection from heat, insects, or parasites, and can involve either wet (muddy) or dry (dusty) sediments. Wallowing is a common behavior among medium to large mammals (particularly bison), but is also noted in small rodents (Butler 1995). The degree of mixing caused by wallowing behavior depends on the textural character of the sediments, the size of the animal and the intensity of its behavior, and the moisture content of the sediment. Wallowing also leads to removal of sediments from the wallow, either caked and matted into the fur or on the skin, or through eolian deflation of the devegetated wallow surface.

A final mechanism of faunal turbation consists of rooting and digging activity by animals in search of food. This activity is performed by fossorial mammals in the process of burrowing, but it is also practiced by larger animals for the sole purpose of obtaining plant or animal food resources. Rooting and digging for food is practiced by herbivores in search of root foods and fungi, carnivores in pursuit of burrowing prey, and omnivores in search of practically everything. Pigs, in particular, have a strong tendency to dig extensively, but the trait is also apparent in raccoons, canids, bears, and porcupines (Butler 1995).

In addition to mixing near-surface sediments, devegetation and compaction resulting from overgrazing can render segments of the landscape very susceptible to sheet erosion and wind deflation. This tendency is particularly pronounced in domestic livestock, which is often forced by human containment to continue grazing areas that would have otherwise been abandoned in favor of other areas with more luxuriant growth. However, devegetation by wild grazing and browsing vertebrates can also lead to severe sheet and rill erosion (Selby 1993).

In comparison with the diverse turbation mechanisms attributable to animals, floral turbation is of distinctly secondary importance in most environments. Two basic floristic mechanisms exist that are capable of disrupting sediments to an appreciable degree. The first mechanism is stress imposed by root growth and root movements, and the second mechanism is tree throw.

Root growth exerts slow but incredibly powerful stresses on encasing sediment, as any observation of the cracked and buckled sidewalks typical of many older neighborhoods will demonstrate. The growth of woody roots, in particular, exerts force powerful enough to fracture bedrock. In unconsolidated sediment, increases in the diameter of woody roots results in compaction and displacement of surrounding sediments (and artifacts), and often raises the ground surface around the trunks of larger trees into hummocks. If a root penetrates a fragile artifact contained in the matrix, such as a ceramic vessel or a porous sandstone clast, the increase in diameter resulting from subsequent growth will easily shatter the artifact. Elongation of roots during growth also displaces sediment, and provides conduits for water and gasses that can accelerate weathering. Even fine, hair-like roots can displace sediment during growth, and are frequently responsible for the destruction of bedding planes in single-grain structured sediments like eolian deposits. When a root dies and decays, it leaves a void that can become filled with loose sediment (and artifacts) from higher in the profile, or it may collapse, displacing overlying strata (Waters 1992).

Roots can also exert stresses on the host sediment as the plant is buffeted by the wind. These stresses can result in minor adjustments of unconsolidated sediment surrounding the root network, but the effect on the integrity of archeological materials encased in the matrix is typically negligible. However, the uprooting of trees can result in massive disruption of the subsurface matrix (“*tree throw*”) as sediment encased in the root mass is torn free and gradually distributed across the ground surface by rain wash and root decay (Lutz and Griswold 1939). Tree throw is a relatively common occurrence, and leads to a characteristic pit and mound topography in areas where it is the dominant process over relatively long periods of time (Paton et al. 1995). Large tree throws can uproot hundreds of kilograms of sediment, leaving a hole several meters in diameter and up to a meter deep. However, the amount of sediment affected by an individual tree throw depends on the size of the tree, the density and morphology of the root system, characteristics of the soil and substrate, and whether the tree is alive or not at the time of uprooting. Moreover, the expression and persistence of pit and mound topography resulting from tree throws is dependent on the characteristics of the soil, the size of the throws, the effectiveness of other processes acting on the surface, and the direction that the tree falls. If the tree falls upslope, the bulk of the soil will tend to wash back into the hole, whereas trees that fall downslope tend to distribute the sediment in a thin wedge downslope.

2.2.2.7 Anthropogenic Disturbance and Sedimentation

A final category of biotic disturbance and sedimentation processes is cultural activity, which is the most rapid and ubiquitous cause of sediment disruption in the modern era. Although culturally-driven sedimentation and disturbance processes are certainly not limited to the past few hundred years, it is likely that when considered on the basis of sheer volume of disturbed sediments, the amount of cultural disturbance generated in the study area during the entire prehistoric period is exceeded on a daily basis in the modern Dallas/Fort Worth Metroplex. This turbation arises from a wide variety of activities, including building construction, installation and maintenance of utilities, roads, and other infrastructure, flood control, waste disposal, mining and other types of mineral extraction, timbering, and agriculture. Given our ability to shape the environment we live in, humans are truly geomorphic agents of a type that the world has never before seen (Nir 1983).

Although a detailed examination of culturally-driven sedimentation and disturbance practices and their consequences is beyond the scope of this study (see, for example, Goudie 1986 and Redman 1999), it is important to briefly address the role of people on the preservation

or destruction of archeological sites. Because of their magnitude and ubiquity, modern practices will be addressed first. The section concludes with a brief discussion of prehistoric disturbance.

Four principal classes of modern cultural disturbance can be identified: (1) building construction, (2) infrastructure construction and maintenance, (3) extraction and processing of natural resources, and (4) agricultural practices. Building construction introduces disturbance through a number of mechanisms, including excavation of foundations, land leveling and blading, cutting, filling, borrowing of fill material, and vegetation clearance. Modern construction practices are such that the potential for preservation of any shallowly buried sites in the area of construction is extremely low. Topsoil is routinely removed from entire lots during construction. Base material consisting of sands, loams, clays, and/or gravels from elsewhere is often spread, particularly in areas underlain by expansive materials. With the exception of utility installation, deep disturbance is relatively rare in conjunction with the construction of residences and smaller commercial establishments because basements are not particularly common in the Fort Worth region. Larger buildings, however, frequently involve deep excavations to provide a secure foundation.

Infrastructure construction and maintenance includes activities such as utility construction, road construction, floodwater detention structure construction and stream channelization, dam construction, waste disposal (landfill operation), and the construction and maintenance of air, rail, and shipping facilities. Delivery of electrical, natural gas, water, cable, and telephone services to end users involves complex dendritic delivery systems, many of which require extensive linear excavations. Wastewater and stormwater networks represent gathering systems, often of considerable size, that collect effluents from a large number of point sources. Their installation involves considerable subsurface disturbance. Pipelines for the transfer of water, petroleum, natural gas, and a variety of petrochemicals from production areas and rail heads to processing plants, and from plants to distribution sites are also common. Road and highway construction often results in wholesale disruption of near-surface sediments, and may affect deeply buried sediments at bridges, overpasses, and in areas where the terrain is modified to accommodate smoother traffic flow or greater speed. Landfill construction impacts areas beneath and around the fill itself, as well as areas used to obtain fill material. Channelization and straightening of stream courses and levee construction is relatively rare except on the Trinity and in urban Fort Worth, but construction of stock dams and rural flood control structures is very common, and has impacted a great deal of alluvial bottom land (primarily on low order

tributaries) through seasonal or permanent inundation. Large reservoirs in the district include Lake Worth, Eagle Mountain Lake, Benbrook Lake, Lake Joe Pool, Lake Arlington, Lake Granbury, Lake Weatherford, Squaw Creek Reservoir, Lake Pat Cleburn, Lake Palo Pinto, Possum Kingdom Reservoir, and Lake Bridgeport, which together occupy 118.9 square miles (74,324 acres) of alluvial lowlands (Kingston 1986).

Extraction and processing of natural resources is another important source of disturbance. Mining, in particular, results in severe disturbances due to excavation for ore and disposal of waste tailings. Minerals extracted commercially in the Fort Worth District today or in the past include bituminous coal; clay; gravel, sand and loam from alluvial deposits; sand from Cretaceous formations; crushed stone, lime, and limestone from the Paleozoic and Mesozoic; petroleum, and natural gas. Of these, those activities with the greatest consequence for cultural materials include the extraction of water and hydrocarbons, which produces disturbance through the preparation of well pads, storage facilities, access roads, and pipelines, and the extraction of coal and clay resources, which also have similar infrastructural requirements. However, unlike the extensive lignite resources further east, extraction of coal in the Fort Worth district never involved strip mining, limiting the wholesale destruction of landscapes.

Agriculture, including plant cultivation and stock raising, also significantly impacts the landscape. In general, cultivation involves destruction of existing vegetation and disruption of the soil, and can lead to pronounced soil erosion when not controlled (Morgan 1985). Plowing has a number of effects, including the breakdown of soil structure and corresponding loss of aggregate strength and stability in the plow zone; eventual increase in bulk density and decrease in porosity/permeability as the plow zone settles and compacts; and the formation of a mechanically compacted, impermeable “pan” at the base of the plow zone. The depth of the plow zone differs considerably depending on the equipment used, ranging from a few centimeters of disturbance by the animal-drawn plows of the historic period to depths of up to a meter by root plows used to prepare forested lands for agriculture. In most cases, modern plows and disks drawn by large tractors result in the complete disruption of the upper 25–40 cm of the soil.

In addition to the gradual autocompaction of plowed earth, soil compaction also results from the weight of machinery used to cultivate. This load compaction often results in less water infiltration and greater erosive runoff. The fertilization and harvesting of crops on a given tract of land typically results in changes in soil chemistry (particularly increases in nitrates and phosphates) and organic content. While cultivation may lead to organic enrichment if the land is initially poor, more often repeated cropping results in gradual

decreases in organic content because the resulting biomass is repeatedly removed during the harvest, rather than allowed to decompose and be reincorporated as soil organic matter (Ross 1989).

Plowing of an archeological site clearly affects integrity by mixing the sediments and altering the spatial relationships between artifacts (Lewarch and O’Brien 1981; Schiffer 1987; Navazo and Díez 2008). Artifacts contained within the plow zone are displaced vertically and, on hillslopes and where repeated plowing is oriented in a consistent direction, tend to migrate laterally across the landscape. Observations also suggest that plowing also tends to bring larger objects to the surface, and is less likely to rebury them, resulting in size-sorting of the assemblage through the plow zone. In addition, plowing can lead to sheet and rill erosion which can remove the artifacts and the site matrix. Accelerated erosion of hillslopes can lead to burial of surface artifacts as the eroded sediment accretes on the lower hillslopes in the form of colluvium and slopewash, and as valley systems aggrade in response to sediment influxes that exceed the capacity of the streams. While such burial can lead to spectacular preservation, the sediments themselves can contain artifacts in secondary context, complicating archeological interpretation.

Agricultural impacts include not only the direct impacts caused by cultivation, but also those caused by field preparation and maintenance, such as initial clearing, contour terracing, and establishment of drainage or irrigation systems. While many field preparation activities may be beneficial for stemming surface erosion, they can have devastating effects on buried archeological sites, particularly in the shallow subsurface. Raising stock also can have marked effects on the condition of the landscape and the rate of soil erosion (Alderfer and Robinson 1974; Warren et al. 1986). Adverse effects are largely the result of overgrazing, or grazing more animals than the landscape can support, although grazing strategies (e.g., pasture rotation frequency) and the characteristics of landscape impacts imparted by different animals (e.g., cattle vs. goats) can also affect the degree of impact.

Grazing results in land degradation by two basic mechanisms: (1) removal of vegetative cover, which increases susceptibility to wind and water erosion (Nir 1983; Warren et al. 1986; Belnap et al. 2007) and (2) compaction of the ground surface, which reduces infiltration and increases erosive surface runoff (Warren et al. 1986). Removal of vegetative cover is primarily a result of consumption by the animals, although trampling also has an effect. The degree to which vegetation is cropped varies among different animals, with sheep and goats tending to crop vegetation much shorter (and kill it more frequently) than do cattle and horses. However, when

confined to insufficient pasture, cattle and horses are also capable of eating grasses and other plants down to ground level, stunting regrowth and increasing susceptibility to erosion. Trampling results in compaction and vegetation loss, and tends to be localized unless the animals are densely confined (e.g., a corral or pen). Although erosion is strongly stimulated by vegetation loss, significant increases in sediment yield can occur before any change in vegetation density is apparent (Nir 1983). Another potential impact of grazing is the disturbance of sites by mechanisms of faunal disturbance discussed previously: trampling, wallowing, and rooting.

In comparison to modern impacts, the role of prehistoric peoples in shaping the Fort Worth District landscape was clearly of minor importance at best. However, any time people occupy a landscape, some impact is unavoidable. Moreover, because those areas of impact are by definition archeological sites, the impact of such activities on the archeological record is much greater than the overall level of impact on the landscape would suggest. In fact, it can be argued that the formation of an archeological site, no matter how sparse or ephemeral, is by definition an impact on the landscape. Nevertheless, the scale of prehistoric impact was clearly limited by the relatively low number of prehistoric people and their limited technological capabilities (and, debatably, their cultural predilections).

Prehistoric impacts can be divided into two categories: intentional impacts and unintentional impacts. Intentional impacts include excavations (e.g., burials, storage cists, fire pits), and vegetation clearing (by cutting, burning, and/or fuel gathering). Other possible impacts that do not appear to have played much of a role in the study area include planting, stream/runoff diversion and redirection, quarrying and rock clearing, and structure construction. Intentional excavations, while limited in size and number, are notable precisely because they provide opportunity for preservation where it is otherwise lacking. The excavation of pit provides the potential for preservation in the excavated hollow, whether it is intentionally backfilled or allowed to gradually accumulate sediment, and in areas where the excavation spoil is discarded. Vegetation clearing might be practiced to open areas for habitation or agriculture, although there is little evidence that appreciable agriculture was practiced within the district. Elsewhere on the Plains, it has been suggested (although not established archeologically) that grass fires were intentionally set to drive game (Wedel 1961), and such a hunting technique may have been employed in the grassy parts of the study area as well. The possibility that intentional fires were also used to kill invading shrubs and improve pasture has also been proposed (e.g., Lintz 1993:334).

Unintentional impacts by nonagricultural prehistoric people should be concentrated at habitation sites, with the severity of the impact related to the duration of occupation (or successive occupations). These impacts include trampling, organic concentration and depletion, soil chemical alteration, and the creation of anthropic deposits and sediment traps. Trampling by humans does not generally result in the same degree of mixing as is often caused by large, hoofed animals like bovids because the ratio between body mass and foot surface area is lower and because humans tend to avoid soft, saturated areas when possible. Nevertheless, trampling by humans results in ground compaction, vegetation loss, breakage of artifacts, and limited soil mixing, and can stimulate granular creep on hillslopes and subsequent water and wind erosion. The organic content of soils at an archeological site can be depleted as a result of trampling and degradation of the A horizon, or can be enhanced by the addition and decomposition of organic materials gathered and processed or produced (i.e., excreted) by the inhabitants. Typically, some areas of the site will experience organic depletion, while other areas will exhibit organic enrichment, reflecting the spatial patterning of activities. This patterning results in spatial variations in organic matter content, as well as related chemical constituents like phosphorous and calcium (Eidt 1977; 1984; Carr 1982). If refuse disposal is intense or prolonged, anthropic deposits such as middens may develop. Such deposits often cause significant changes in the chemical composition of surrounding and subjacent soils, and may create microtopographic features that trap and retain sediments from the surrounding landscape.

2.3 Discussion and Geoarcheological Significance of Regional Stratigraphic Models

This section addresses what is known and what can be deduced about the stratigraphy and architecture of a variety of depositional systems in the Fort Worth District. It draws heavily on the work of previous researchers, but also presents some new data. Although only a few localities in the district were examined in detail during this study, many more were examined on a limited basis, and several previous stratigraphic studies are available. However, the extant geoarcheological and stratigraphic investigations vary considerably in focus, scope, and detail, and therefore have very different levels of utility for synthetic discussions of the type attempted here. With a few notable exceptions, geoarcheological investigations in the Fort Worth district reside in the archeological "gray literature", and often these are simply compilations of soil descriptions from trenches and test pits that provide little pertinent data for this type of synthesis. While work conducted during this study attempted to discern more broadly applicable stratigraphic and architectural data, most fieldwork was essentially confined to the network of

current and proposed highway and county road right of ways. Although necessary for logistical reasons, this had the effect of constraining the stratigraphic picture that could be obtained. Because stratigraphic architecture is three-dimensional, and because roads are rarely situated to optimize cross-sectional stratigraphy, the stratigraphic sequences investigated during this study represent simplified (and possibly incomplete) two-dimensional generalizations of complex three-dimensional phenomena. Nevertheless, they provide for relatively clear insight into the general character of the stratigraphic sequences that are likely to host cultural remains.

As a quick review of the references cited in the following sections will illustrate, a disproportionate amount of the synthetic stratigraphic and geoarcheological research in the Fort Worth District has been conducted by a single individual, Dr. Reid Ferring of the University of North Texas at Denton. Ferring's work, which has concentrated almost exclusively on the Trinity basin, provides a very detailed and robust stratigraphic framework for this drainage. Quaternary studies of the Brazos drainage have been far more limited in the district, although relatively detailed studies have been conducted upstream and downstream. Besides Ferring, geomorphologists, alluvial stratigraphers, and geoarcheologists who have worked in the district and surrounding counties (often in close collaboration with archeologists) include Caran (1990; 2000; Skinner et al. 1999), Hall (Lintz et al. 2008), Gustavson (Brownlow et al. 1999), Collins (1988; Brownlow et al. 1999), Epps (1973), Stricklin (1961), Hendricks (1957), Matthes (1941), Lewand (1969), Plummer and Hornberger (1935), Kibler (2003), Patton and Watson (in Brown 1987), Abbott (Turpin 1994), Autin (Cliff et al. 1998), Nordt (1997), Crawford (1999), Mandel (1992; 1994) and Shanabrook (Cliff et al. 1999; Peter et al. 2001; Burson 2000; Burson et al. 2000; Huhnke and Wurtz 2004). The following sections present the results of stratigraphic studies conducted by these individuals and in conjunction with the current investigation. A map of the principal localities described in this section is presented in Figure 2–8. Terminology used in the following sections typically reflects its usage by the original author. Where reporting original research conducted as part of this study, the term “unit” refers to an informal allostratigraphic unit identified only within the specific locality and defined on the basis of bounding unconformities. Although tentative regional correlations are explored and the alluvial sequence developed by Ferring is employed, no formal stratigraphic units are defined here.

2.3.1 The Brazos River Basin

The Brazos River is a large fluvial system that traverses much of Texas and crosses a number of diverse environments. Although it is exceeded in length and drainage area by the Red River and the Rio Grande, the Brazos is the largest fluvial

network contained primarily in the state of Texas (Figure 2–9). The upper basin of the Brazos is divided into three forks, termed the Salt Fork, the Clear Fork, and the Double Mountain Fork. The Salt Fork and the Double Mountain Fork proper rise on the eastern margin of the Llano Estacado (Southern High Plains), where they are fed by High Plains arroyo systems, including Yellowhouse Draw, Blackwater Draw, Running Water Draw, and the White River. The Salt Fork and Double Mountain Fork meet in Stonewall County, forming the Brazos River proper. The Clear Fork, which heads on the southern Rolling Plains in Scurry County, joins with the Brazos proper in Young County, a short distance upstream from the district. The length of the Brazos, from the source of the High Plains draws feeding the Double Mountain Fork (the longest of the upstream feeder tributaries) to the Gulf of Mexico, is roughly 1350 km (840 miles), and its drainage basin encompasses approximately 110,850 km² (42,800 mi²). Annual discharge typically exceeds five million acre–feet (6.1 trillion m³).

In the Fort Worth District, the modern Brazos River is an entrenched, mixed load meandering stream that carries a moderate to high load of suspended sediment and a gravel load composed primarily of Paleozoic limestones and diverse siliceous rocks derived from Mesozoic and Cenozoic sources (e.g., the Triassic Dockum Formation and the Tertiary Ogallala Formation). The sediment gives the stream and its fine-grained deposits a distinct reddish-brown color, reflecting the contribution of the extensive Permian and Triassic redbeds in the upper basin. The stream is deeply incised into bedrock through most of the district (Stricklin 1961), fossilizing a long wavelength, high amplitude meander pattern that most investigators believe represents a much larger discharge regime than at present (Epps 1973; see discussion below). During most of the culturally-relevant period, rapid meandering of the channel has been severely limited to eliminated by this bedrock confinement. Instead, the stream has been slowly but inexorably eroding down into the encasing bedrock. Where bends in the stream focus the angular momentum against the bedrock walls, the Brazos has also been eroding laterally. Because such erosive energies are focused on the concave exteriors of bends in the channel, the size of the meanders has slowly increased and the valleys have developed a characteristic asymmetric profile characterized by a more gentle slip-off slope on the interior of meander bends and a steep cut slope on the opposing concave bank. As the meander gradually incises and cuts laterally into the bedrock, alluvium is deposited on the convex bank, so that the terrace surface slopes toward the stream, lateral accretion deposits predominate, and the age of the alluvium increases with the elevation of overlying surface and distance from the stream. Such a pattern is termed *ingrown meandering* (Hendricks 1957; Stricklin 1961; Chorley et al. 1984), and is clear evidence that the stream continued to cut laterally

1. Double Mountain Fork of the Brazos (Blum et. al 1992)	A. West Fork Trinity
2. Brazos River (Waters and Nordt 1995)	B. Brazos at US67
3. Lower Brazos (Abbott 2001, Sylvia 2002)	C. East Sanchez Creek
4. South Bend Reservoir (Mandel 1992)	D. Willow Creek
5. Aquilla Lake (Patton 1987; Watson 1987)	E. Denton Creek at US380
6. Joe Poole Reservoir (Collins 1988)	F. North Bosque River at SH 6
7. Lake Ray Roberts (Ferring 2001)	G. Big Sandy Creek/ Watson's Branch at FM1810
8. Upper Trinity (generalized)(Ferring 1994)	H. Big Sandy Creek at Wise County Road 1790
9. Lake Whitney (Stephenson 1970)	I. Rippy Branch, Fort Wolters
10. Cleburne State Park (Nordt 1997)	J. Hunt Creek at Wise County Road 3701
11. Nolan Creek (Crawford 1999)	K. Brazos at SH16
12. West Fork of the Trinity (Hall 2006)	L. Ash Creek at Newsome Mound Rd.
13. Rowlett Creek (Frederick 2009)	M. Watson Creek at Erath CR 109
	N. Wise County RR Section
	O. South Fork Chambers Creek

Figure 2–8: Map illustrating the location of studies cited in the text.

Figure 2–9: Extent of the Brazos River drainage basin.

as it incised its bed. Because bedrock is typically much harder and thus much more resistant to fluvial erosion than unconsolidated sediment, the rate of meander development is much slower. While available chronometric information is minimal, it does suggest that the channel was probably confined within a relatively narrow bedrock trench within the broader valley system throughout the culturally-relevant period. Consequently, the extent of Late Pleistocene–Holocene fluvial deposits is far more limited than an uncritical examination of the meander pattern would suggest, and erosion and/or reworking of Holocene deposits was probably quite common in the incised channel trench.

The outsized meanders of the Brazos River are usually considered to be a result of flow conditions considerably higher than modern levels. Based on the size of the meander pattern, Matthes (1941) interpreted this stretch of the Brazos as a classic underfit stream, occupying a valley cut by an ancestral system with substantially greater discharge than at present. Stricklin (1961:22) disagreed, pointing out the ingrown character of the meanders and arguing that this process, rather than a former, larger channel, was responsible for the preserved meander morphology. This view has seen little subsequent support, however. The outsized fossil meander scars seen not only in this incised reach but also on the margins to the broad Coastal Plain valley are typically presented as evidence that former flow conditions were substantially greater than they have been during the historic period. Epps (1973), for example, used the meander scar radii on the Coastal Plain to estimate that bank full discharge of

the ancestral Brazos was 5 to 9 times greater than at present. In his study of the Leon River system, Lewand (1969) concluded that the Leon River system was a former Brazos course abandoned when the channel was pirated in the middle Pleistocene (see below), and that the ancestral valley preserves a meandering pattern that reflects a discharge ten times the current Leon River discharge. More recently, Sylvia (2002) used three different morphometric methods to retrodict discharge of the Brazos during the Late Pleistocene on the Coastal Plain. Although the results of these methods (based, respectively, on paleomeander radii, paleomeander wavelength, and paleochannel width and depth) varied considerably, all supported the proposition that discharge was substantially greater during the Late Pleistocene than in the modern system. In contrast, Blum et al. (1995) argue that the similar scale of meanders on the coastal reach of the Late Pleistocene Colorado River reflects differences in the character of runoff, with higher sustained discharge but significantly lower peak discharges than at present.

The mechanics of meander incision are also problematic. Early models of incised meanders simply assumed that the meandering stream entrenched uniformly as the surrounding landscape was uplifted by crustal warping, fossilizing a morphology developed as a freely meandering system. However, two problems with this model are identified by Schumm (1977). First, a high proportion of incised meanders are noticeably compressed and deformed, exhibiting channel patterns that are noticeably more tortuous than most freely meandering systems. Second, attempts to simulate such behavior on flume studies have been unsuccessful, as uplift causes the channel to metamorphose into a straight pattern before incising. For these reasons, Schumm does not believe that uniform entrenchment is common. Instead, he argues that meanders are fossilized as incision, stimulated by either base level change or uplift, is transmitted upstream over time. This headward cutting process explains the deformation of meanders, as the lower limb of a meander is fixed by incising into bedrock while the upper limb is still freely meandering in alluvium, and continues to translate (migrate) downstream, compressing the meander.

While this model does fit some aspects of the incised reach of the Brazos, it does a poor job of explaining other aspects. Given the length of the incised segment (> 100 river miles), headward-cutting incision of the channel trench would be a slow process. Because lateral erosion would have considerably longer to operate at the downstream end of the incised reach than at the comparatively recent upstream end, the size of the incised valley and the size, valley cross-section, and gradient of the feeder tributaries should look considerably different

downstream than they do upstream. Examination of the incised Brazos valley in the upstream and downstream part of the district does reveal some noticeable morphological differences (Figure 2–10). The valley downstream of Lake Granbury exhibits large compressed meanders with amplitudes several times their wavelength. The meanders upstream are generally smaller and

less compressed, although there are exceptions (i.e., Village Bend). While these compressed meanders are consistent with Schumm’s model, differences in bedrock hardness and structure make such a judgment far from straightforward. The large meanders downstream of Lake Granbury are cut into the soft Paluxy Sandstone, which is readily eroded, while the Palo Pinto

Figure 2–10: Illustration of Brazos River channel patterns in the upstream and downstream segments, with examples of meanders and channel traces incised into bedrock.

County meanders are cut into harder rocks. Another problem is the presence (in Palo Pinto County) of abandoned channel traces and cutoff meander loops that are incised into hard bedrock, but lie far (50 ft +) above the elevation of current channel (see Figure 2–10). These features are difficult to reconcile with Schumm's headward-cutting model unless several successive episodes are invoked, but seems relatively unlikely given the distances involved and the time available. A more likely scenario is that the stream has alternately downcut into bedrock and aggraded its valley over the long-term, allowing the channel to migrate laterally in alluvium over the intervening bedrock "humps" before carving new channel loops into the bedrock. In order for this model to work, incision cannot be strictly a function of tectonic uplift; variation in the balance between sediment supply and transport efficiency is also necessary.

As the preceding discussion shows, there are many unresolved questions about the basic mechanism of Brazos channel incision in the Fort Worth district. Nevertheless, it is clear that the planiform pattern of large, incised meanders represents complex behavior by the Brazos over the long-term. It is likely that the overall channel pattern represents meander geometry imposed by a stream with considerably higher discharge than the modern Brazos, and modified considerably by "ingrown" meander erosion and deposition since the middle to late Pleistocene. Such a model is broadly consistent with observations at the studied cross-sections described below. The archeological consequences of this behavior are that the confined channel trench has limited the stream's ability to meander freely, and therefore limited the amount of sediment deposition, and increased the likelihood of erosional reworking of those sediments that were deposited (and any intercalated archeological sites).

2.3.1.1 Stratigraphic and Geomorphic Studies of the Brazos River

Very little detailed geomorphic and alluvial stratigraphic work has been conducted in the Brazos River drainage within the boundary of the Fort Worth district. No systematic alluvial stratigraphy was conducted in association with the construction of either Possum Kingdom Reservoir, DeCordova Bend Reservoir, or Lake Whitney, which are the reservoirs on the Brazos in the Fort Worth district (although Lake Whitney is primarily downstream of the district, the flood pool borders Johnson County). However, there are a number of pertinent studies of broader geological scope. An early geological synthesis of the western Texas Coastal Plain by Deussen (1924) includes a discussion of the Brazos River as far upstream as Johnson County. The entrenched portion of the Brazos, from the western Low Rolling Plains near Knox City to the margin of the Coastal Plain near Waco, was examined from a broad geomorphic perspective by Stricklin (1961), and a more

generalized geomorphic study of the drainage as a whole was conducted by Epps (1973). Brief geological and geomorphic observations of the Brazos within the Fort Worth district were also made in conjunction with archeological work at Lake Whitney (Stephenson 1970) and with county geological surveys of Palo Pinto and Parker Counties ((Plummer and Hornberger 1935; Hendricks 1957). Finally, number of pertinent geomorphic and stratigraphic studies have been conducted on the Brazos both upstream (e.g., Blum et al. 1992; Mandel 1992) and downstream (e.g., Bronaugh 1950; Waters and Nordt 1995; Abbott 2001a; Sylvia 2002) of the district boundary.

In Texas, most early observations on Quaternary deposits were made by geologists that were either producing broad syntheses in which the Quaternary was essentially an afterthought, or working in tandem with archeologists and/or paleontologists. These observations were typically reported relatively tersely, sometimes second hand, and were hampered by a lack of reliable chronometric data. Nevertheless, several provide valuable insights. In his early synthetic study of the geology of the Gulf Coastal Plain west of the Brazos, Deussen (1924) examined the Brazos valley from the vicinity of Cleburne to the coast. He identified two paired terraces in a cross-valley transect between Cleburne and Morgan (in Bosque County), crossing the Brazos valley near Lake Whitney. Terrace 1 is described as a flat-lying surface approximately 50 feet above the stream and a mile wide on each bank, underlain by red to brown silt or loam derived from the red beds upstream. A second, discontinuous terrace is noted at 70 feet (its fill is not described), and a possible high strath terrace is noted 270 feet above the stream. In contrast, Deussen notes six terraces near Waco at elevations between 30 and 250 ft above the river, and suggests that many of these surfaces can be traced downstream onto the outer Coastal Plain. Also near Waco, Bronaugh (1950) identified two groups of terraces in McLennan County, a low (presumably Holocene) group of continuous terraces lying twenty to fifty feet above the channel, and a high (presumably Pleistocene) group of discontinuous remnants lying seventy to two hundred feet above the channel. These age estimates were supported by archeological and Pleistocene faunal inclusions, respectively.

Farther upstream, brief observation on the Brazos terrace system were made in Palo Pinto County by Plummer and Hornberger (1935), while somewhat more in-depth observations were made in Parker County by Hendricks (1957). The former study is heavily focused on economic aspects of Palo Pinto County geology, but it does note the presence of three terraces along the Brazos River. The highest is reported at approximately 210 ft above the valley bottom, and is described as more gravelly than the lower terraces, with quartz and chert predominating. It is interpreted as early Pleistocene or pre-Pleistocene in age. An intermediate terrace, 90 to 120 ft above the river, is also noted as being underlain

by gravels and sands, and having yielded Pleistocene faunal remains. The lowest terrace, noted at 50 ft above the river, is described as primarily sandy, and is interpreted as of post-Pleistocene age. Hendricks (1957) includes a much more thorough summary of many non-economic aspects of Parker County's geology, including structure, geomorphology, and soils and vegetation. He remarks on the ingrown character of the meanders and identifies three terraces, including a nearly continuous "flood-plain terrace" approximately 23 ft above the river, discontinuous terraces at elevations of 40 and 60 ft, which are confined to the slip-off slopes on the interior meander bends, and vestiges of terraces at elevations up to 120 ft, where the meander bend alluvium pinches out. All of the described terrace surfaces are essentially restricted to the interior of meander bends; there is no discussion of any possible higher surfaces.

Reporting on work performed more than twenty years earlier, and paraphrasing observations made by geologists Glen L. Evans and Theodore White, Stephenson (1970) describes the alluvial setting at Lake Whitney. This sequence includes two well-preserved alluvial terraces termed the "twenty foot terrace" and the "forty foot terrace" and remnants of poorly preserved and uncorrelated terraces at higher elevations. Stephenson notes that both of the distinct terrace surfaces are prone to inundation by floodwaters, although only the lower typically floods on an annual basis. The lower terrace, therefore, represents the active floodplain while the higher terrace conforms to the typical definition of a flood terrace. The fill underlying the upper surface is described as "stratified deposits of sand, silt, clay, and gravels" that "constitutes the major alluvial fill in the valley" (Stephenson 1970:50). Stephenson notes that the (presumably basal) gravels are frequently cemented with calcium carbonate (which probably represents phreatic cementation rather than soil development). Overall thickness of the 40-foot terrace fill is described as 25–30 ft, thickening to 60 ft in an old channel facies exposed at the dam site. The lower terrace is described as a narrow shelf of sandy clays and silts inset against the upper terrace. Thickness is on the order of 18–22 ft. Neither terrace fill is dated, although Stephenson tentatively correlates the deposits with Middle to Late Holocene (4000 BC to AD 1000) and recent (AD 1200 to 1800) deposits, respectively, that had been described at a variety of localities in the southwestern United States.

Epps (1973) examined the Brazos as a whole, focusing on evidence for its long-term evolution and periods of significantly higher discharge in the past. Epps uses meander geometry, hydraulic geometry (channel cross-section), and transport competency to retrodict discharge, and concludes that the ancestral Brazos exhibited a discharge up to 9 times greater than the modern system. He identifies several stages

of river evolution, beginning with the deposition of complex regional aprons of alluvium, including the Ogallala and Uvalde gravels, that bury the pre-existing topography downslope of the Rocky Mountains and Balcones escarpment, respectively, during the Neogene (Miocene–Pliocene). This early phase of coalescent alluviation is followed by successive periods of downcutting through the Pleistocene, ultimately forming a modern floodplain underlain by a coastward-thickening wedge of alluvium and a series of at least three terraces. The first terrace is relatively undissected and lies approximately 30 ft above the floodplain on the Coastal Plain. Epps correlates the terrace with the Beaumont Formation on the outer coast, and notes that it is dominated by gravels and gravelly sands capped with thick sandy to clayey alluvial soils. The second and third terraces are poorly preserved due to dissection, but the fills rest on cut surfaces lying between 45–120 ft and 90–180 ft, respectively. This variability is potentially attributable to a number of factors, including changes in downstream gradient, local tectonism (associated with salt dome growth), and uncertainty in correlation. Epps correlates the second terrace with the Lissie coastal terrace (and fill), but draws a distinction between the third terrace deposits and the Willis coastal terrace. He also notes that there are still higher gravel lags that suggest a fourth terrace may have been present at one time.

Epps (1973) also speculated on the development of the tortuous, deeply-incised bedrock meanders in Palo Pinto County. He believed that their development clearly represents some type of rejuvenation, but discounted uplift as a viable mechanism because the effect is not apparent in the upper basin. Rather, he argued that the most likely explanation is changes in flow regime resulting from stream piracy in the upper basin, which contributed additional discharge from the Clear Fork and Double Mountain Fork basins, and thereby stimulated the incision. Based on extrapolations from calculated sediment yields, Epps suggests that the average rate of denudation for the basin as a whole (i.e., mean surface downwearing due to erosion of the bedrock and transport of the liberated sediment) is on the staggering order of a one foot per 1,000 years. This rate of denudation, equivalent to more than a mile of sediment every 5 million years, seems unsustainably high, and it is likely that Epp's data reflects drastic increases in sediment yield resulting from historic landscape impacts.

Other research provides more detail about the more recent part of the sequence. On the inner Coastal Plain, Waters and Nordt (1995) document a 75 kilometer segment of the Brazos Valley from Hearne to Navasota, in Robertson, Milam, Washington, Brazos, Burleson, and Grimes Counties, Texas. Here, the two terraces noted at Lake Whitney have merged into a single, broad terrace (or, more accurately, flood

terrace) that is up to 12.8 km wide. Although the presence of higher Pleistocene terraces is acknowledged, they are not addressed in the study, which utilized existing exposures to identify, characterize, and date five stacked allostratigraphic units (designated I–V) lying beneath the floodplain, each with preserved channel and floodplain facies (Figure 2–11). This sequence includes a relatively coarse-grained, basal Late Pleistocene to Early Holocene unit capped with a soil dating to approximately 9000–8500 BP, and a series of silt- and clay-dominated Holocene units with intercalated paleosols dating to approximately 4200–3000 BP, 800–500 BP, and 200–300 BP. Waters and Nordt interpret the basal unit as the product of a coarse-grained, competent stream that probably exhibited a braided channel pattern, while the remaining units are interpreted as the product of point bar and overbank deposition by a meandering stream. As indicated in the cross-section, active lateral migration of the stream was limited to distinct meander belts throughout most of the Holocene. Consequently, much of the sequence is stacked units composed of overbank muds and levee and splay sands separated by alluvial soils. Boundaries between units appear to represent episodes of sudden channel avulsion, and reworking of older deposits is typically limited to relatively narrow (typically < 1 km) meanderbelts within the overall floodplain.

Still farther downstream, both Abbott (2001a) and Sylvia (2002) examined the lower Brazos Valley. Abbott's investigation, conducted as part of a Houston District geoarcheological study, focused on the form, age and character of sediments filling the late

Pleistocene Brazos valley (post-Deweyville sequence). Based on a limited number of cutbank exposures near Richmond and a series of dated cores from the lower Brazos River only a few kilometers inland from the delta apex, Abbott found that over 100 feet of alluvium had aggraded across the broad (up to 18 km) valley in the last 12–14,000 years, and that the vast majority of that sediment (all but the upper 15–20 ft) accumulated relatively quickly between about 14 ka and 6 ka. Rather than exhibiting a uniform fining-upward pattern, the sequence was characterized by a number of thin, interdigitated and stacked loamy, clayey and sandy units that are interpreted as evidence of pronounced instability in channel pattern, with common channel avulsions that shifted depositional loci and created complex juxtaposed facies and sequences of stacked weak soils characteristic of the rapidly aggrading system. A lack of identifiable estuarine muds in the sequence suggested that aggradation kept pace with sea-level rise, and prevented a significant estuary from backing up into the deep Pleistocene valley.

Sylvia's study focused on the earlier Late Pleistocene degradational (falling sea level) sequence—typically termed the Deweyville sequence—as a means to investigate the “liberation, transport, and deposition of sediment within the latest Pleistocene Brazos system.” This sophisticated, multifaceted study combined a great deal of direct and inferential onshore and offshore stratigraphic and climatic data to reconstruct the form and processes driving stepwise incision of the Brazos valley system through the latest Pleistocene. Sylvia concluded that the Deweyville sequence formed as a

Figure 2–11: Generalized stratigraphy of the Brazos River between Hearne and Navasota, after Waters and Nordt (1995). The letter *c* represents channel facies, and *f* represents floodplain facies. Triangles represent artifact-bearing strata, and the bone symbol represents megafauna remains.

result of a series of incision–aggradation events driven by climatic and eustatic factors from roughly 50–20 ka, during which time the Brazos’ discharge was several times its modern value. Sylvia also examined the late Pleistocene sediment budget, and concluded that the vast majority of sediment liberated and transmitted through the system originated inland of the Coastal Plain, and that the rate of basin–wide erosion was considerable during the late Pleistocene.

The most extensive study of the Brazos drainage in proximity to the Fort Worth District was conducted by Rolfe Mandel at the site of planned (and as yet unbuilt) South Bend Reservoir in Young, Stephens, and Throckmorton Counties (Mandel 1992). This large study site is situated in the Rolling Plains upstream of Possum Kingdom reservoir (see Figure 2–8), and extends more than 30 kilometers upstream from the confluence of the Brazos River and the Clear Fork of the Brazos. Mandel examined ten discrete study areas within the planned reservoir and used this information, dated using 25 uncorrected radiocarbon ages on alluvial soil organics and intercalated charcoal, to develop generalized stratigraphic models of the Brazos proper, the lower Clear Fork of the Brazos, and several tributaries. Figure 2–12 illustrates several of these models, which represent very different sequences.

In the South Bend Reservoir study area, both the Brazos and the Clear Fork underwent a significant episode of bedrock incision in the latest Pleistocene, abandoning their late

Pleistocene floodplains and forming terraces. This event is not dated, and Mandel merely notes that it is bracketed by the age of the T_2 fill (which is undetermined) and the age of the fill inset against the incised scarp (which is poorly resolved, but demonstrably predates 7.5 ka). Although Mandel does not speculate further, this event probably occurred sometime between approximately 20 and 12 ka, based on similar episodes of valley incision that have been noted during this general timeframe in a number of localities throughout the southern Plains and surrounding regions (e.g., Nordt 1992; 1994; Blum and Valastro 1989; 1992; 1994; Ferring 1994a; 2001). This incision event was followed by a long sequence of punctuated aggradation from the late Pleistocene to the late Holocene, until another regional incision event abandoned the floodplains around 1.5 ka, forming the T_1 terrace and initiating aggradation of the modern floodplain. Again, there are clear analogs of this event at a number of other localities throughout the southern Plains (Hall 1990).

The period between these two principal episodes of valley incision witnessed the accumulation of the majority of the Holocene fill. Mandel interprets this interval as a period of penecontemporaneous meander migration, gradual incision of the meandering channel, and point bar/overbank deposition that resulted in an ingrown meander sequence and a sloping, time-transgressive T_1 terrace surface. While available dates are minimal, Mandel notes that the degree of soil development supports the idea that the upper parts of the ramped surface are considerably older than its lower

Figure 2–12: Generalized stratigraphy of the planned South Bend Reservoir on the Brazos River; after Mandel (1992).

parts, and the terrace reflects lateral accretion by an actively migrating and incising channel. In the Brazos valley proper, the sedimentary sequence underlying his T_1 surface is relatively undifferentiated, grading upward from sands to loamy and silty alluvium with few internal divisions (e.g., erosional surfaces and buried soils). Direct ages on the T_1 Brazos fill are limited to the upper part of the sequence, where soil development complicates the picture, and indicate only that the fill exceeds 1 ka. However, constraining ages on inset tributary alluvium extend this constraining age to approximately 4 ka, and it is likely that the fill began to accumulate considerably earlier than that.

While the fill underlying the Brazos T_1 is largely devoid of soils and truncation surfaces, the Clear Fork exhibits a complex sequence of intercalated soils and bounding surfaces that attest to a complex aggradation history, with at least three cut-and-fill events not mirrored in the Brazos valley proper. Mandel defines three distinct T_1 terrace surfaces (designated T_{1a} , T_{1b} , and T_{1c}) separated by subtle scarps. These surfaces represent inset fills resulting from successive periods of incision, aggradation, and floodplain stability and soil formation. Periods of stability defined by unconformities and buried paleosols in the Clear fork sequence are noted at 7.5 ka, 5 ka, 2.3–2.0 ka, and 1.7–1.3 ka. Tributary fills associated with both systems suggest that the early to middle Holocene was characterized by incision and lengthening of the smaller streams feeding into the system, while the late Holocene witnessed punctuated floodplain aggradation, followed by incision around 1.5 ka. Alluvial fans were accumulating at the mouths of some of these tributaries slightly after 5 ka, but the rate of accumulation appear to have slowed in the late Holocene.

Collectively, the stratigraphic picture assembled by Mandel at South Bend Reservoir is that of a complex system with spatially and temporally disjunct behavior. Many cut-and-fill cycles apparent in the Clear Fork valley are not apparent in the Brazos valley proper. In the latter, ongoing, penecontemporaneous lateral cutting, incision, and deposition appear to have created time-transgressive ingrown meanders without clear internal bounding surfaces. While he clearly prefers the preceding explanation, Mandel also suggests a second possibility: that the morphology of the Brazos terrace and spatial variability of soil development is a function of changes in deposition rate and style resulting from changes in channel location, coupled with sheet erosion of the surface.

Farther upstream, a series of investigations at the planned site of Justiceburg Reservoir (now Lake Allen Henry) on the south fork of the Double Mountain Fork of the Brazos have revealed a detailed sequence on the western Rolling Plains (Blum 1989a; Abbott 1990a; Bousman 1992; Blum et al. 1992; Boyd 1997). Justiceburg is situated at a lithological contact

between relatively hard sandstones and conglomerates of the Triassic Dockum Group and softer shales and mudstones of the underlying Permian Quartermaster formation. This lithologic break strongly influenced the character of landscape evolution during the late Quaternary. Three distinct, lithologically-controlled stream segments were identified in the study area: a broad, braided system in the upper reaches where the channel flows in a shallow valley developed on hard sandstones and conglomerates of the Dockum Group; a narrow, canyon-confined system where the channel has breached the Dockum relatively recently (in a geological sense) and cut a deep, narrow canyon into the softer muds of the Permian Quartermaster Formation; and a broader, incised valley in the lower reaches where the stream has had more time for lateral erosion of the Permian muds (Figure 2–13). Stratigraphic investigations backed by over 100 uncorrected (for the most part) radiocarbon ages on sediments, soils, and charcoal inclusions reveal that the majority of deposits in the system date to less than 3 ka. This is because most older deposits were flushed out of the system during an intense erosional period in the Middle Holocene or early part of the Late Holocene; however, buried older deposits do exist in

Figure 2–13: Generalized stratigraphy of the Double Mountain Fork of the Brazos at Justiceburg Reservoir (Lake Allen Henry).

some localized parts of the study area, both at depth in the valley fill and preserved as insets on the valley margin. There are localized deposits dating to the latest Pleistocene or early Holocene in the upper and lower segment of the study area, but Middle Holocene deposits are almost entirely absent in the project area, and all sediment appears to have been eroded from the narrow canyon system prior to around 3 ka. Again, the sequence of deposits in tributaries differs somewhat; while the main tributary investigated (Grape Creek) is also dominated by late Holocene alluvium, there are localized, massive alluvial fans that cap and preserve remnants of Late Pleistocene alluvium. The few radiocarbon ages available from these contexts suggest that the alluvial fans probably accumulated episodically beginning in the Late Pleistocene or Early Holocene.

Stratigraphy of the SH16 Crossing

Although a number of accessible crossings were examined at a reconnaissance level, only two localities were studied in any detail on the Brazos proper during this study. The first locality examined is situated in the northwestern part of Palo Pinto County, at the point where SH 16 crosses the Brazos River immediately southeast of Possum Kingdom reservoir (see Figure 2–8). This investigation accompanied a mechanical archeological survey conducted by Prewitt & Associates (Kibler 2004), and is based on a series of eleven trenches excavated into a complex of three surfaces developed within the confined valley system (Figure 2–14; see also Figure 2–10). This site is typical of the deeply-incised bedrock meanders that the Brazos occupies as it traverses Palo Pinto County. The trenches were excavated parallel to the alignment of SH16 on the north side of the stream in anticipation of planned improvements to the roadway. No archeological sites were identified during the survey.

In this reach, bedrock consists of Pennsylvanian carbonates and clastics, including the Winchell Limestone, which forms the majority of the surrounding landscape, and the underlying Wolf Mountains Shale, which is exposed only at the bottom of the canyon. The incised meander bend is typical of the complex topography that develops in this setting as the Brazos traverses the district. The modern channel segment is relatively straight, flowing from the Possum Kingdom dam southwest to Flint Bend. It is flanked by two large, offset semicircular meander scars cut deeply into the limestone valley walls, which form amphitheater valleys floored with expanses of low terrace that rise gradually to meet the valley walls. The more southerly of these, which extends in an arc from Flint Bend to just north of the SH16 crossing, forms a semicircular amphitheater floored with the gently sloping T₁ terrace. The northern meander bend, which extends from halfway between Flint Bend and SH16 to just downstream

of the Possum Kingdom (Morris Sheppard) dam site and hosts the associated fish hatchery, is more complex. The northern valley amphitheater is intersected by a tributary (Loving Creek) that flows in from the north. It also hosts an isolated bedrock remnant in the form of a large limestone hill, presumably left when the channel avulsed (see Figure 2–10). Finally, there is a preserved, arcuate remnant of a beveled late Pleistocene (T₂) terrace that flanks the valley wall (Figure 2–15). It was across this latter amphitheater that the series of trenches was excavated.

A minimum of three informal allostratigraphic units were identified in the study area (see Figure 2–14). However, the precise timing of deposition is relatively poorly constrained because few clear, datable bounding surfaces were found, and because dating was primarily based on low precision bulk sediment ages. Like all Brazos River deposits examined during this study, the alluvium is quite red, with sands ranging from 7.5 YR to 5YR hues and finer deposits ranging from 5YR to 2.5YR. The youngest deposits encountered (Unit 3) underlie the lowest alluvial surface above the discontinuous floodplain. This surface, designated as T1B here, lies 5–7 m above the modern channel. It may represent the active floodplain of the Brazos prior to damming of the river or a narrow terrace created by renewed downcutting in the last few centuries. Three trenches were excavated into the T1B surface, and all revealed a sequence of distinctly stratified reddish brown sands, loams, and thin muds typical of relatively recent deposits. Two radiocarbon ages were obtained from the unit (Appendix II). The first age was obtained on bulk organics from a mud at a depth of approximately 205 cmbs in BT 2, and yielded a corrected age of 1990 ± 40 BP. The second, on dispersed charcoal, was obtained from a depth of approximately 160 cmbs in BT7, and yielded an age of 1340 BP. Because these both represent ages on detrital material, and the older of the two is on alluvial muds with negligible soil development, these ages should be considered as maximum ages only. Nevertheless, despite the absence of appreciable soil development, the data suggest that Unit 3 represents deposition spanning approximately the last 1,500–2,000 years.

Six trenches were excavated into the T1A surface, which is separated from the T1B by a distinct scarp approximately 1–1.5 m high, and spans the majority of the amphitheater valley. This surface rises from approximately 8 m at the lip of the gentle scarp to 15 m above the stream at the toe of the riser to the higher T2 terrace. The average gradient of the gently sloping surface is less than 1%, but increases noticeably in the transition to the T2 toeslope.

The first trench cut into the T1A surface (BT3) was excavated at the edge of the scarp between the T1A and T1B terraces.

Figure 2-14: Layout and stratigraphy of the Brazos River at State Highway 16, based on backhoe investigations. Schematic profiles of BT 6 and BT 8 were omitted due to their similarity to BT 5 and the upper part of BT 4, respectively.

Figure 2–15: Photograph from near BT10 looking south at the T_1 terrace, SH16 at the Brazos River.

Surprisingly, it revealed bedrock shallowly buried by less than 50 cm of alluvium. The remainder of the trenches excavated into the T1A surface (BT 4, BT5, BT6, BT8, and BT9) each revealed thick deposits of Holocene age (Unit 2), indicating that the modern scarp between the T1A and T1B is coincident with the margin of the older valley that occupied the incised meander. Although additional work outside the ROW would be needed to settle the question, this is believed to be a coincidence within the ROW rather than a consistent relationship. The most likely explanation is that the buried bedrock high exposed in BT3 is an extension of the outlying bedrock hill to the north, and it was overlapped by alluvium during the last phases of Unit 2 deposition.

The deep deposits underlying the remainder of trenches excavated into the T1A surface (Unit 2) were broadly similar, but exhibited some important differences. In general, these deposits are at least 3 m thick and exhibit an Ap–A–Bw–Bk soil profile. Pedogenic alteration of the deposit is limited to accumulation of the secondary carbonates, weak structural development, and the formation of the A horizon. This profile is slightly truncated and overlain by up to 25 cm of gravelly construction spoil within the ROW of SH 16. Below the construction spoil, the typical section exhibits a thin (30–50

cm), subangular blocky structured, dark grayish brown (10YR 4/2) clay loam A horizon that grades into a dark brown (7.5YR 3/4) to reddish brown (5YR 4/4), moderate medium blocky structured silty loam Bw horizon. This horizon varies from less than 50 cm to more than 1 m in thickness, and contains colluvial limestone clasts near the bedrock outlier (see Figure 2–14). The Bw horizon grades down into a massive, reddish brown (5YR 4/4 to 5YR 4/6) silt loam Bk horizon containing less than 2% carbonate filaments by volume. One radiocarbon age of 3980 BP was obtained on sediments from a depth of 180 cmbs in BT 5 (Appendix II).

This thick, loamy to sandy silt Bk horizon extends to the base of all but one trench, where an older deposit capped with a truncated soil was noted in BT 4 at a depth of approximately 3 m bgs. This deposit consisted of a blocky structured, reddish brown (5YR 4/4) sandy clay 2Btk horizon. Both soft CaCO_3 masses and iron–manganese staining are apparent in the horizon, indicating a deposit with a complex geochemical history. One radiocarbon age of 6280 BP was obtained from this deposit (Appendix II). Because it was obtained from a relatively well-developed soil formed in the alluvial deposit, and is overlain by younger deposits, this age should be considered a minimum age only and could

be significantly too young. Because this deposit was only encountered in one trench, it is not formally distinguished as a separate stratigraphic unit at this time, although it is likely that additional deep trenches would reveal that it is more widespread and merits such a description.

The majority of trenches excavated into the T1A surface clearly represent sediments deposited by the Brazos River. However, in BT9, situated at the base of the T2 terrace scarp, the sequence interfingers with colluvial deposits shed off the beveled T2 terrace. The profile exhibits an A–Bw1–Bw2 profile that is at least 2.5 m thick. Discrete, interdigitated wedges of colluvial and alluvial deposits are not apparent, but the deposits are noticeably sandier and small, matrix-supported siliceous gravels are dispersed throughout the profile. The degree of redness of the profile increases noticeably below approximately 2 m bgs, possibly representing introduction of detrital material from an eroding soil upslope or a shift in the ratio of alluvial and colluvial sediments. In BT10, situated high on the beveled T2 riser (see Figure 2–15), two colluvial units are present. The upper deposits here consist of moderately structured, brown (7.5YR 4/4) gravelly sandy loam supporting an A–Bw profile approximately 1 m thick. These deposits represent colluvium shed off a higher surface, as indicated by the number of rounded siliceous pebbles dispersed throughout the matrix. They correlate with the thicker colluvial deposits exposed downslope in BT9. At approximately 110 cmbs, these deposits grade into a moderately structured 2Btk horizon composed of reddish brown to yellowish red gravelly sandy loam. The presence of dispersed, matrix-supported siliceous pebbles indicates that the sequence also represents colluvial material eroded from a higher alluvial surface, but the remnant soil suggests that it is a considerably older deposit. One conventional radiocarbon age of 9390 BP was obtained on sediment from the lower part of the truncated soil at a depth of approximately 150 cmbs (Appendix II). Because more detailed chronometric data is lacking, the upper deposit in BT10, and the entire sequence exposed in BT9, is considered a colluvial or mixed alluvial/colluvial facies of Unit 2 (respectively), while the lower deposit in BT10 is considered a colluvial facies of Unit 1, which describes undifferentiated and undated deposits of Late Pleistocene age. However, because these colluvial sediments appear to be derived from Pleistocene alluvial gravels upslope, they therefore represent a phase of activity that postdates abandonment of the T2 surface. Therefore, the decision to conflate the alluvial sediments underlying the T2 surface upslope and the colluvial deposits in BT10 into a single allostratigraphic unit is recognized as a convenient simplification of reality.

Finally, relatively undisturbed, albeit erosionally truncated, deposits of probable Late Pleistocene alluvium (Unit 1) were exposed in BT11, situated near the crest of the beveled

terrace at an elevation of roughly 25 m above the modern stream. This deposit consisted of a reddish brown (5YR 4/4), clayey fine sand 2Bt horizon underlain by a reddish brown (5YR 4/4) silty fine sand 2BC horizon. This sequence is interpreted as a truncated Pleistocene alluvial terrace. It is capped by a thin, weakly stratified sandy loam that appears to be mechanically compacted (AC horizon) and a thin veneer of construction spoil.

In summary, the SH16 crossing preserves at least three complex allostratigraphic units of Brazos River deposits dating back to the Late Pleistocene. These deposits are contained within an incised valley that represents a succession of degradational and aggradational phases of fluvial activity over a considerably longer span of time. Although the configuration of the sculpted valley and the presence of preserved bedrock outliers indicates a considerably longer and more complex sequence of punctuated incision and aggradation, a minimum of three allostratigraphic units dating from the Late Pleistocene through the Late Holocene were documented at the SH16 crossing. The oldest unit noted during the survey consists of reddish brown sandy to silty alluvium deposited at the rear of the large amphitheater valley carved over millennia by the meandering stream. This surface, which supports a soil with a decalcified Bt horizon, lies at an approximate elevation of 25 m above the modern stream. No ages are available from the alluvium, but the elevation, degree of soil development, similarity to dated deposits elsewhere in Texas suggest that this deposit is of Late Pleistocene age. This interpretation is supported by a constraining age of 9390 BP (Appendix II) from a soil developed in colluvium that mantles the terrace scarp. Because the age is from the lower part of a relatively well-developed soil, it is likely that incision of the stream occurred substantially earlier than the date indicates. The alluvial unit and subsequent colluvial deposit are collectively considered Unit 1. Because of its age, the potential for this unit to contain intercalated cultural material with reasonable stratigraphic or behavioral integrity is probably relatively low, but the possibility cannot be discounted.

Sometime before (and possibly well before) 6–7 ka, incision of the stream again gave way to aggradation of Unit 2, which continued to aggrade until approximately 2–3 ka, ultimately forming the T1A terrace. Penecontemporaneously, renewed degradation of the T2 terrace resulted in the gradual accumulation of a wedge of colluvium at the rear of the aggrading terrace and on the beveled T2 terrace riser. The overall sequence includes at least one episode of stability responsible for formation of a truncated soil detected at 3 m bgs in one trench, which dated to 6280 BP (Appendix II). A second age of 3980 BP was obtained from alluvium with relatively minor pedogenic overprinting at a depth of approximately 2 m bgs. Sometime after this date, most likely

between 3 ka and 2 ka, the stream again incised, abandoning the T1A terrace and terminating deposition of Unit 2. Since that time, soil development has resulted in the formation of a moderately developed soil with an A–Bw–Bk profile. All of Unit 2 appears to be of culturally-relevant age, and, with the exception of channel facies, has high potential to contain Archaic and possibly Paleoindian cultural material in reasonable context.

For approximately the last 2 ka, Unit 3 has been aggrading as a suite of distinctly stratified sands, silts, and muds. Ages of 1990 BP and 1380 BP were obtained from interbedded muds in the sequence (Appendix II), but it is likely that these ages are somewhat too old due to the presence of detrital organics. From a sedimentological perspective, the deposits of Unit 3 retain far more primary sedimentary structure than those of Unit 2. While this is probably partly due to Unit 2's longer exposure to entropy-inducing pedogenic processes, it appears that the initial character of Unit 3 deposits was more heterogeneous than Unit 2. Unit 3 also appears to have aggraded in a flashier manner than Unit 2, resulting in the juxtaposition of deposits with more textural heterogeneity (e.g., coarse sands, mud drapes) throughout the sequence. It is unclear whether this contrast reflects morphological differences in the system (e.g., width and/or depth of the active channel/floodplain complex), differences in independent environmental variables (e.g., rainfall frequency, duration, and seasonality), or simply inadequacy of the sample (lack of exposure of a representative cross-section of facies). In any case, the deposits of Unit 3 are distinctly stratified, and soil development in this unit is weak to negligible. Nevertheless, they have high potential to contain Late Archaic and Late Prehistoric cultural material with reasonable integrity.

Stratigraphy of the US 67 Crossing

The second Brazos River stratigraphic study conducted as part of this project was located at the opposite end of the district, where US 67 crosses the Brazos in Somervell County. This study locality was examined with a series of hollow auger cores extracted from a large point bar/meander bend on the west side of the stream (Figure 2–16). As such, the investigation is qualitatively different than that conducted at SH16. Although the amount of exposure of near-surface deposits is miniscule in comparison to trenches, making them unsuitable to reliably identify buried archeological sites, hollow auger cores provide a window through a much greater thickness of valley-fill deposits, and therefore are more suitable for assessing the entire suite of deposits in a given setting. The hollow auger core rig used on this study (and on the study of the West Fork of the Brazos at US 281 discussed later) retrieves a core approximately 2 ½ inches in diameter that is segmented into 5 ft lengths. Because the core barrel does not rotate inside the auger bit, the integrity

of the recovered core is typically high unless the deposits are sandy to gravelly and either very loose or saturated. Although up to 120 feet of deposits could be addressed with the available core barrel segments, complete sequences were rarely recovered. Thick gravels often “refused” the core, and saturated sands tended to flow out the bottom of the barrel as the core was driven in and withdrawn—this despite the use of a catcher sleeve device. Nevertheless, the technique provides a far more complete picture of the overall stratigraphy of the Brazos system than is possible with a backhoe.

At the study locality, the river is incised into Glen Rose limestone, and outcrops of the Paluxy Sand cap the surrounding uplands. As in much of the district, the Brazos makes a series of large, looping meanders that were fixed long ago by incision into the underlying bedrock. These bends typically exhibit an amplitude of five or more kilometers, and include DeCordova Bend, Abby Bend, Mitchell Bend, Cox Bend, and Turner Bend. The modern river is considerably underfit and has continued to enlarge the amplitude of the meanders without a great deal of downstream translation (see Figure 2–10). US 67 crosses the Brazos at the apex of one of these elongate meander loops, Turner Bend, providing the opportunity for a cross-section of the meander architecture. This locality is situated in east-central Somervell County immediately upstream from the confluence of Squaw Creek and the Paluxy River, which all converge at a spot a few kilometers east of the town of Glen Rose. Turner Bend is roughly 4 kilometers long and 2.5 kilometers wide, and lies on the west side of the Brazos. The elevation varies from roughly 570 to 700 ft above msl. There is a relatively narrow, level terrace/floodplain (T_0 surface) adjacent to the active channel at an elevation of approximately 8–10 m above the water on both sides of the stream. This quasi-continuous surface is 50–100 m wide and vegetated with mature riparian taxa. Although it is the lowest consistent alluvial surface (discontinuous bars and vegetated flats are present 1–4 m above the water), discharge data suggests that this surface rarely floods. Examination of data from a USGS gauging station at the locality (Figure 2–17) indicates that floods rarely exceed a stage of thirty feet, which is approximately the depth at which the bank would be overtopped. Interestingly, however, there is a distinct shift in the relationship between peak discharge and gage height around the mid-20th century, indicating that the cross-sectional morphology of the channel was narrowed so that flood peaks became higher. Comparison of the average discharge of the Brazos by decade shows essentially no relationship with trends in precipitation (see Figure 2–17), indicating that other factors (e.g., construction and management of drainage control structures) have played the major role in dictating flow characteristics in the Brazos, and that the historical record is a poor analog for its prehistoric behavior.

ELEVATION

meters feet

BRAZOS RIVER AT U.S. 67, SOMERVELL COUNTY

Figure 2-16: Layout and stratigraphy of the Brazos River at US 67, based on hollow auger core investigations. Radiocarbon ages shown are conventional ages (age before 1950, or age BP, corrected for $\delta^{13}\text{C}$).

Figure 2-17: Illustration of relationship between peak discharge, average discharge, annual precipitation, and reservoir closures in the Brazos basin.

At the rear of the T_0 terrace, there is a relatively steep riser to a narrow remnant of a level to gently sloping T_1 terrace. This surface, at a local elevation between approximately 615 and 625 ft above msl, is only present on the convex bank of the bend, as the concave bank floodplain abuts the limestone valley wall. The T_1 terrace in turn grades into a long, relatively gentle sloping surface that rises to an elevation of approximately 670 ft above msl before dropping more than 6 m into a well-defined, ancient paleochannel that cuts across the meander. The slope is a gentle, slightly irregular sandy surface. The paleochannel lies approximately 30 m above the

active channel, and while its age is unknown, almost certainly predates the culturally-relevant period.

A series of six cores were extracted from the lower part of the meander bend, from surface elevations between approximately 600 and 650 ft above msl (see Figure 2-16). Core 1 and Core 2 were extracted from the proximal and distal portions of the T_0 flood terrace, at roughly 183 m (600 ft) above msl, Core 3 was extracted from the narrow T_1 surface at roughly 190 m (623 ft) above msl, and Cores 4-6 were extracted from between roughly 195 and 198 m (640 to

650 ft) above msl on the irregular sloping surface above the T_1 terrace. No cores were taken from the crest of the slope or from the ancient channel, which were both beyond the geographic extent of the highway project that precipitated the investigation.

Cores 1 and 2 both revealed deposits quite similar to the stratified deposits of Unit 3 at the SH16 crossing. Both sequences consist of distinctly stratified, reddish brown sands, silts, and muds deposited relatively recently by the Brazos River, and support an A–C profile. Despite this similarity in appearance and the lack of a topographic indication of a boundary, the radiocarbon data from the cores strongly suggest that the two cores represent different allostratigraphic units separated by an intervening unconformity. Core 1, situated on the proximal part of the floodplain, was driven to a depth of approximately 6 m (20 ft) before refusal. It yielded a series of brown to reddish brown (7.5 YR 5/4 to 5YR 3/3), predominantly thin-bedded sands and silty sands that graded into gravelly coarse sands near the base. Two radiocarbon ages were obtained from the core. A radiocarbon age of 370 BP was obtained on a dark reddish brown, organic-rich stratum at a depth of 1.4 m bgs, and an age of 210 BP was obtained from a much deeper sample of interbedded charred organic detritus at a depth of 5.2 m (Appendix II). Because bulk sediment ages often tend to be too old due to the incorporation of reworked soil organics (Abbott 1997b; Nordt 1992), the latter age is considered a more reliable estimate for the sequence, suggesting that in excess of five meters of stratified sediments have accreted as a local inset in the last few centuries.

Two ages were also obtained from Core 2, which was similar to Core 1 in character. Minor differences noted between the cores include a tendency for the sands to be slightly redder in Core 2, which is not believed to be significant because the color is almost surely inherited from the parent material; the presence of some subtle diagenetic features attributable to intermittent saturation, including carbonate filaments in a few interbedded mud beds; and subtle redoximorphic features below approximately 3 m bgs (e.g., pale mottles, small dark mottles believed to represent incipient manganese concretions). The ages obtained from the sequence were both on interbedded fine-grained sediments. The upper of these ages was obtained from a bed at a depth of approximately 2.8 m bgs, and yielded an age of 1190 BP, while the lower was from approximately 5.7 m bgs and yielded an age of 1380 BP. Although both of these “humate” ages may be up to several hundred years too old, they are in stratigraphic order and clearly do not represent the same sequence exposed in BT1. While they are somewhat younger than the ages obtained from the comparable deposits at SH16 (Unit 3), it is likely that they represent the same basic suite of deposits.

Because it exhibits a very small tread, only one core was sunk into the T_1 terrace. It extended to a depth of approximately 8.2 m (27 feet) below surface before refusal, and revealed a thick, relatively homogeneous alluvial sequence characterized by reddish brown (5YR 3/4 to 5YR 4/6) sandy to silty loam supporting an A–AB–Bk1–Bk2–BC soil profile. Secondary carbonate was largely limited to relatively sparse filaments and films, but there were also a few small, hard carbonate masses that exhibited etched surfaces indicative of chemical attack. Although it is considered likely that these features do represent soil nodules, it is also possible that they are small limestone pebbles that have been subjected to surface dissolution and reprecipitation in the soil column. However, because they occur only in the upper Bk horizon (where nodules would be expected to form), are dispersed throughout the matrix in a manner consistent with secondary carbonate accumulation, and are not accompanied by any siliceous pebbles (which would be expected if they were of detrital origin), they probably represent in situ carbonate precipitation.

Two radiocarbon ages were obtained on organic matter in the sediment column. The upper of these ages, obtained from the lower Bk2 horizon at a depth of approximately 2 m bgs, is 5710 BP, while the lower, from a depth of approximately 5.2 m, is 13,010 BP (Appendix II). These ages suggest that the unit began to accumulate during the Late Pleistocene, and continued to aggrade until at least the middle to late Holocene. Soil development in the unit is exemplified by limited structural development, obliteration of primary sedimentary structures, and secondary carbonate accumulation and dissolution. Detailed granulometric and chemical analysis conducted on samples from the column (Figure 2–18) are consistent with a moderate amount of soil development in a relatively uniform sedimentary body. Significant leaching of carbonate is limited to the A horizon, and despite the presence of common filaments, little volumetric carbonate accumulation is apparent in the Bk. Similarly, no evidence of a clay “bulge” indicative of an argillic horizon is present. Trends in organic matter and magnetic susceptibility are consistent with a soil of Holocene age. There is no indication of any buried unconformities in the sequence, but otherwise these deposits are broadly consistent with those underlying the T_1 terraces at SH 16. As at the SH 16 locality, the contrast between the highly stratified deposits underlying the T_0 terrace and the relatively homogenous deposits underlying the T_1 terrace is striking.

The three cores placed upslope of the T_1 terrace revealed thick sequences capped by sediments interpreted as eolian sands. The deepest core extracted was Core 4 (Figure 2–19), which was driven to a depth of approximately 12.8 m (42 ft) bgs. The upper 8 m of this core consists of strongly rubified,

Figure 2-18: Results of textural, chemical, and magnetic analyses of Core 3, Brazos River at US 67.

noncalcareous, silty to clayey fine sand supporting an A-Bw-Bw&Bt-BC profile. The A horizon consists of up to a meter of yellowish brown (10YR 5/4) massive fine sand, while the underlying Bw horizon consists of a more consolidated, massive to weakly structured, olive brown (2.5 Y 4/5) loamy to silty fine sand approximately 1.5 m thick. Based on its texture, topographic position, lack of consolidation, lack of carbonate, and degree of soil development, these upper zones are interpreted as relatively recent (probably <3 ka) eolian sands.

At roughly 2 m bgs, the core grades into a much redder (5YR 4/5 to 5YR 5/6), loamy to silty fine sand Bw&Bt horizon exhibiting a weak coarse subangular blocky structure. A number of localized increases in silt and clay content are apparent in poorly bounded bands 5–10 cm thick. Although the small size of the core does introduce some uncertainty, these features are

probably soil lamellae, which form through the infiltration of silt and clay into existing deposits and are common in, but not exclusive to, eolian deposits (Djikerman et al. 1967; Gile 1979; Rawling 2000). Faint lamellae are apparent in a borrow pit along the existing road at approximately the same elevation. While the lamellae are distinct and clearly demonstrate the infiltration and translocation of silt, there is considerable silt content throughout the horizon as a whole (typically up to 20–40%; see Figure 2-19), which serves to weakly consolidate the sands. As a result of cohesion provided by this silt component, the sand tends to break down into large angular peds that do not bear much handling without disaggregating. These large peds were not visible in the extracted core, which instead exhibited a number of brittle fractures resulting from the coring process, but are inferred based on their presence in the adjacent borrow pit exposure. Pale silt coats are common on the ped faces in the

Figure 2-19: Results of textural, chemical, and magnetic analyses of the upper 11 m of Core 4, Brazos River at US 67.

upper part of the Bw&Bt horizon, while the red color of the matrix is imparted by the substantial silt component that coats the primary grains. Based on its low degree of compaction, high degree of sorting in the sand fraction, and lack of carbonate throughout, this deposit is also believed to be of eolian origin. Examination of cumulative texture curves from the sequence (Figure 2-20) indicate that the eolian deposits are dominated by very fine and fine sand, but that most samples also include significant (25–50%) silt content. Although the majority of this fine fraction is coarse silt, and therefore could have been introduced through eolian processes, the sheer volume of silt in the sequence is unusual, and would have served to inhibit re-entrainment and transport of the deposit. No radiocarbon ages are available from the deposit, but based on its appearance and stratigraphic relationship with the adjacent and subjacent alluvium it is likely of Late Pleistocene to Early Holocene age.

At a depth of approximately 7.6 m bgs (roughly 188 m above msl), the core grades into a much denser, redder (2.5YR 3/6), and more cohesive deposit of muddy fine sand that is believed to represent a soil developed in graded alluvium. A radiocarbon sample of sediment from this muddy sand yielded an uncorrected age of 19,770 BP (Appendix II). Examination of the cumulative texture curves (see Figure 2-20) indicates that this material is noticeably more poorly

Figure 2-20: Cumulative frequency curves of grain size analyses from Core 4, US 67 at the Brazos River, illustrating the difference between the texture of the eolian deposits and the underlying alluvium (including both fine-grained & gravelly facies).

sorted than the overlying (presumably eolian) material, with clay contents up to 7–8%, silt contents of 25–60%, and medium sand contents of 10–40%. Because the silts and clays could have been introduced through infiltration, and because the material is also noncalcareous, the medium sand component provides the strongest support for the interpretation that the upper part of this zone represents an

alluvial unit. Significantly, medium sand is entirely absent in the overlying (presumably) eolian sequence.

Whatever its origin, this intermediate material represents a soil that caps an underlying alluvial deposit. No A horizon is preserved, and no macroscopic evidence of clay translocation was noted, but the sediments are noticeably rubified relative to fresh alluvium in the system and the textural analysis (see Figures 2–19 and 2–20) does indicate a systematic increase in fine silt and clay content that probably represents an incipient Bt horizon. This soil grades rapidly down into a bedded sequence of gravelly coarse sand and sandy gravel exhibiting variable carbonate cementation in some beds and redox features (e.g., manganese staining, iron–depletion mottling) in others. Refusal occurred in strongly–cemented gravel, so the depth to bedrock is not known, but the gravels and sands are at least 6 m thick.

Slightly farther upslope, Core 6 was driven to a depth of approximately 6.4 m (21 ft). It revealed a thick sequence of silty fine sands interpreted as multistoried eolian deposits resting on marl. The deposits consisted of massive, noncalcareous, brown to reddish brown loamy fine sand to silty sand supporting an A–AB–Bw–BC–2Bw–2BC profile. One apparent erosional disconformity within the sand sequence was noted at a depth of approximately 1.5 m (5 ft). No A horizon is preserved at this contact, so it is unclear whether this truly represents a temporal unconformity or a localized reactivation surface in a single sequence of eolian sands. No radiocarbon ages are available from this sequence, but its character also suggests Late Pleistocene to Early Holocene age.

Core 5 was the highest core in the sequence, and was driven to an approximate depth of 8.7 m (28.6 ft) bgs. Although no reliable chronometric data is available, the upper two meters of the sequence is tentatively interpreted as Holocene eolian deposits, while the lower 6+ meters are interpreted as Pleistocene alluvium. The eolian sequence consists of a massive, noncalcareous, brown (7.5YR 4/4) to strong brown (7.5YR 4/6) fine sand to loamy fine sand A horizon that grades down into a weakly structured, brittle, noncalcareous, dark reddish brown (5YR 3/4) to reddish brown (5YR 4/4) loamy fine sand Bw horizon. This deposit rests unconformably on the alluvial sequence, which is capped by a subangular blocky structured, noncalcareous, dark red (2.5YR 3/6), slightly gravelly sandy clay Bt horizon more than a meter thick. Below this truncated soil, the core grades through a sequence of more than 4 m of bedded pebbly fine sands, loamy sands, and bedded gravelly coarse sands. The color of these bedded deposits alternates irregularly between strong brown (7.5YR 3/6 to 7.5YR 5/6), reddish brown (5YR 4/4), light reddish brown (5YR 6/3), and light yellowish brown (10YR 6/3). This suggests that the color

is due to inheritance from the parent material and alteration and winnowing of fines by groundwater throughflow. Near the base of the core, the deposit grades abruptly into a heavily mottled dense clay zone nearly two feet (60 cm) thick. This stiff clay is intensely mottled with red, brown, and gray, and contains large masses of calcium carbonate. It is underlain by a saturated, brown (7.5YR 4/4) fine sand that flowed up into the core barrel once the core was withdrawn. This suggests that the dense clay is a local aquaclude that is confining the underlying aquifer. One radiocarbon age from the dense clay returned an age of 5260 BP (Appendix II). Given the stratigraphic context, this age is clearly thousands of years too young, and is rejected. The most likely explanation for the error is contamination of a low–organic sample by groundwater throughflow.

In summary, a minimum of five apparently distinct alluvial fills, most of which are delimited by episodes of bedrock incision, and a poorly–defined sequence of associated eolian deposits were identified in the sequence of cores at US 67 and the Brazos River. The oldest alluvial unit (based on stratigraphic position, as it is undated), informally termed Unit 1, was identified in Core 5. It is preserved beneath a thick eolian veneer at an elevation approximately 21 m (70 ft) above the modern stream, and rests on a strath that is no more than 15 m (50 ft) above the modern stream. Although termed Unit 1 for discussion purposes here, this designation should remain informal because older deposits associated with the ancestral Brazos are clearly present in the area, as indicated by an ancient channel swale cutting across the meander upslope.

Unit 1 supports a well–developed, albeit truncated, soil with a prominent Bt horizon more than a meter thick, and has been decalcified to a depth of more than 3 m bgs. The lower profile consists of gravelly to pebbly sands indicative of channel and channel–proximal deposits. The age of this unit is unknown, but available ages and stratigraphic relationships indicate that it is considerably older than 20 ka, and the elevation and degree of soil development suggest that it probably dates to sometime in the early–middle part of the Late Pleistocene (i.e., >30 ka). As such, its potential to contain archeological sites dating to the generally–accepted span of human occupation in North America is negligible.

The second fill, Unit 2, was identified in the lower part of Core 4. Like Unit 1, it is an apparent Late Pleistocene alluvial fill overlain by eolian sand. It was encountered in the core at an elevation of approximately 14 m (47 ft) above the modern stream, and rests on a strath no more than 8.5 m above it, indicating in excess of 7 m of bedrock incision occurred following abandonment of the older unit. As with Unit 1, Unit 2 consists of a graded sequence representing the transition from channel to overbank facies. The soil developed in the

unit is composed of decalcified and rubified silty sands with little apparent structure. No clay cutans were observed, but textural analysis suggests that the soil may represent a weak Bt horizon. Bulk humates from the soil capping the unit were dated to approximately 20 ka, while the oldest age from the subsequent unit is approximately 14 ka. Accordingly, the potential for Unit 2 to contain archeological sites dating to the generally-accepted span of human occupation in North America is limited.

The subsequent fill, Unit 3, forms an alluvial surface (the T_1 terrace) at roughly 15–17 m (48–55 ft) above the modern stream and rests on a bedrock strath no higher than 8 m (27 ft) above it. The unit consists of a calcareous silty to fine sandy loam, and is characterized by a thick Bk horizon and the reddish brown hues typical of Brazos River deposits. Unlike the older units, Unit 3 is not mantled with eolian deposits at the core locality, although it is likely that such deposits overly or interfinger with distal parts of the terrace. Although the surface soil mantling Unit 2 is clearly truncated into the lower soil horizons, making its original elevation difficult to gauge, it is noteworthy that the preserved soil is lower in elevation than the T_1 surface. Although a definitive statement is not possible because neither core was able to penetrate to bedrock, it is likely that bedrock incision following abandonment of Unit 2 was no more than a few meters. Because the surface of Unit 3 is higher than that of Unit 2, the older unit had been truncated and at least part of the eolian deposition that caps it was in place before the last few meters of Unit 3 aggraded. Geometric relationships suggest that Unit 3 is laterally inset into Unit 2, while ages from Core 3 suggest that abandonment of the Unit 2 surface occurred sometime after 20 ka, while aggradation of the Unit 3 surface occurred between approximately 15–13 ka and 4–2 ka. Alternatively, it is possible that the two units are endpoints in the evolution of a single complex surface by long-term meandering—the “ingrown meander” process described previously. If so, aggradation of the surface accompanied gradual eastward translation of the channel over a period of up to 20,000 years, and Units 2 and 3 are not discrete fills. In any case, it appears that Unit 3 accreted episodically over most of the demonstrated span of human occupation of the region, and therefore has strong potential to contain prehistoric archeological sites with good integrity.

Sometime after approximately 4 ka, the stream abandoned the T_1 surface and incised into bedrock again, ultimately downcutting up to 8 m. This incision was completed and aggradation of Unit 4 was ongoing by approximately 1.4 ka, continuing until sometime after 1.1 ka and forming the T_0 surface. Unit 4 deposits are very different in character than the previous fills, exhibiting distinctly bedded, texturally and chromatically heterogeneous packets of sands, silts and

muds typical of deposits formed by episodic high-energy overbank flooding. Soil development in the units is minimal. A similar series of deposits are represented by Unit 5, which underlies the same surface closer to the channel. Reliable radiocarbon ages from organic matter interbedded in this sequence suggest that it has aggraded in the last few hundred years. Although the depositional energy represented by the coarser packets in these two fill units may have disrupted the spatial integrity of any intercalated archeological sites to some degree, the deposits represent periods of rapid aggradation with strong potential to isolate and preserve behaviorally-relevant artifact assemblages.

In addition to the alluvial units, a sequence of eolian deposits mantle the US 67 meander bend, achieving maximum depths in excess of six meters. While dominated by fine to very fine quartz sands, the older sands include a substantial component of dispersed, oxidized silt that gives them a bright red color. Although broader exposures would be needed to confirm this conclusion, initial examination of the cores and exposures provided in a series of borrow pits flanking the road indicate that these sands retain little to no primary structure, and probably accreted gradually as sheet deposits of fine to very fine sands and coarse silts derived from the stream and deposited on the vegetated meander bend surface. The presence of lamellae indicates that infiltration of the silt is ongoing, but it appears likely that much of the silt was delivered at the same time as the sand. These deposits appear to be localized on the meander bend, suggesting that they are derived from deflation of adjacent alluvium. Similar thick, localized eolian deposits are known from stream-proximal environments other parts of the state, such as O. H. Ivie Reservoir on the Colorado River (e.g., Abbott 1989; Blum and Lintz 1993) and the Dodd Pit site on Denton Creek (Ferring 1994a; 2000; see discussion below). No chronometric data is available directly from the Turner Bend sand sheet, but their character and available bracketing ages from alluvium indicate that there are sands of at least two ages in the sand sheet, including a long-term accumulation that may date back as far as 20 ka, and another cycle that probably dates to the past few thousand years. No preserved paleosol was noted separating these two presumed units, indicating an episode of deflation preceded renewed aggradation. Given the energy involved and the apparent age range of the deposits, the upper few meters of deposits have excellent potential to preserve cultural material in reasonable context.

2.3.1.2 Stratigraphy and Geomorphology of Brazos Tributaries

Relatively little stratigraphic work has been conducted on tributaries of the Brazos in the vicinity of the Fort Worth District. Small-scale investigations in the district

include Nordt's investigation of alluvial deposits of Camp Creek in Cleburn State Park (Nordt 1997) and Crawford's study of Nolan Creek (Crawford 1999), both in southern Johnson County, Abbott's investigation of the confluence of the Paluxy River and Denio Branch in Somervell County (Turpin 1994), and Carlson's (1999) broader consideration of the Paluxy River in the same locality (Dinosaur State Park). Outside the district boundary, investigations in the proposed flood pool for Aquilla Reservoir in Hill County (Brown 1987 and references therein) also provides a good descriptive, albeit chronometrically limited, treatment of a moderately sized system on the Blackland Prairie. Additional investigations conducted in conjunction with this study include examinations of the North Bosque River, the Paluxy River, Sanchez Creek, and Rippy Branch.

Camp Creek

Nordt (1997) examined the alluvial record of Camp Creek, a tributary of the Nolan River, within the boundary of Cleburne State Park in Johnson County (see Figure 2–8). He recognized two alluvial surfaces, a terrace surface 4.5 m to 5 m above the modern stream, and a narrow floodplain surface approximately 3 m above the stream. He also recognized colluvial wedges grading into both surfaces, although the floodplain-associated colluvium is apparently much more widespread.

Deposits underlying the terrace consist of sediments grading up from subrounded, relatively well sorted pebbles into loams, silt loams and clay loams containing dispersed pebbles. These sediments support a generalized A–Bw–Bk–C profile containing somewhat decalcified A horizons and accumulations of 5–10% carbonate nodules in the Bk horizons. Although no chronometric data were obtained during the study, Nordt interprets the terrace fill as early to middle Holocene in age, based primarily on correlation of the stratigraphic and pedologic character of the fill with his work in the Fort Hood area (e.g., Nordt 1992; 1994). Soils developed in the terrace vary from approximately one to more than two meters thick, with very dark gray to black structured A horizons up to 50 cm thick.

The floodplain surface of Camp Creek is underlain by somewhat gravelly clay loam alluvium that appears to date from Late Holocene to historic age. Again, these ages are estimates, and are based on cultural inclusions and correlation of stratigraphic setting and soil development with other sequences. Although both are capped with a thin veneer of historic alluvium, there are marked differences in the two trenches excavated in the floodplain setting. In one case (BT1), a relatively strongly-developed, truncated calcic soil containing large (up to 1 cm) brecciated nodules was encountered at approximately 90 cmbs, while in the

other trench (BT3), two much more weakly developed buried soils were encountered at approximately 140 cm and 240 cmbs. Although Nordt does not discuss the buried calcic soil in detail, the development of the calcic nodules is unusually advanced for a late Holocene fill, and it seems likely that the buried soil represents an alluvial strath cut into an older fill and then buried by subsequent fluvial activity.

In any case, the defined alluvial sequence of Camp Creek consists of two discrete alluvial surfaces. Although undated, Nordt's interpretation of the sequence is informed by the Fort Hood alluvial sequence. The higher surface is underlain by deposits interpreted as early to middle Holocene in age, or roughly equivalent to Nordt's (1992) Fort Hood fill. This unit was terminated by incision (arguably in the middle Holocene), after which time the subsequent fill began to aggrade. The floodplain surface is underlain by these subsequent deposits, which Nordt believes are of Late Holocene to historic age. Several buried soils were noted in the two trenches excavated in this floodplain, indicating that there were at least two localized depositional hiatuses during the aggradation of the Late Holocene unit. However, Nordt's data was insufficient to allow correlation between trenches, and the character of the respective soils suggests that they may not be age-equivalent. Significant colluvial deposition is also apparent, particularly during the Late Holocene, but more information is needed to understand its temporal context.

Nolan River

The Nolan heads in northwestern Johnson County and flows south to its confluence with the Brazos in northwestern Hill County. Crawford (1999) examined the stratigraphy of the Nolan River, situated a few miles southeast of Nordt's study of Camp Creek in Johnson County. All investigations were focused on alluvial units underlying the principal flood-terrace, which lies between 3 and 4 m above the low-water channel. Because the study was conducted along a pipeline route that ran subparallel to the stream, the trenches do not provide a good, integrated cross-sectional view of the stream's architecture. However, the twenty two trenches excavated during the project do provide valuable snapshots of the terrace fill.

Three alluvial stratigraphic units were identified beneath the terrace surface. Unit I forms the core of the terrace and is capped by a truncated soil that exhibits a Bw–BC–C or Bw–C profile. This soil is developed in loamy to clayey alluvial sediments that grade down relatively abruptly into clast-supported gravels with depth. Unit 1 was identified in 10 of 22 trenches (45%) excavated during the project. Depth of the Unit 1 paleosol varied from exposure at the surface to 237 cmbs. Trenches where Unit 1 was not encountered

ranged in depth from 180 to 275 cm, so it is possible that Unit 1 was present beneath the excavated depth of other trenches. Although it was not dated, Crawford interprets the fill to be point bar and channel deposits of late Pleistocene to early Holocene age, based on stratigraphic position, character of soil development, and correlation with Nordt's Fort Hood sequence.

Unit II was observed in all but two of the 22 trenches, but varied considerably in thickness (11 cm to 275 cm). In some cases, it was the only unit exposed in the trench, while in others, it capped Unit I and/or was capped in turn by Unit III. Unit II is composed of yellowish to dark grayish brown clay loam, and is interpreted as representing predominantly floodplain facies of the Nolan River. Soil development consists of an A-Bk or A-Bss-Bk profile with weak slickensides and carbonate filaments or fine nodules in the Bk horizon. Crawford correlates the fill with Nordt's early-middle Holocene fill at Fort Hood (the Fort Hood alluvium). Four bulk humate ages from the unit range from 6380 to 2020 BP; two of these ages postdate 4 ka, and are rejected by Crawford as biased by soil organic matter.

Unit III consists of a veneer of dark grayish brown to black clay and clay loam that was noted in nine trenches. The unit was never more than about 65 cm thick (in most cases, it was less than 40 cm thick), and exhibited an Ap-AB-C profile. No ages are available from this veneer, but Crawford infers an age of less than 3 ka based on the ages from Unit II and correlation with the Fort Hood sequence.

Paluxy River

The Paluxy River originates in north-central Erath County, and flows southeast through Hood and Somervell Counties to its confluence with the Brazos near the town of Glen Rose. Two stratigraphic studies have been conducted in Dinosaur Valley State Park, which occupies a large meander of the Paluxy River and adjacent tributaries and uplands in Somervell County. The first study was conducted by Abbott at archeological site 41SV56, and is reported in Turpin (1994). Site 41SV56 is situated at the confluence of the Paluxy River and Denio Branch, a relatively steep, gravelly tributary that enters the valley from the east. Bedrock in the area is the Glen Rose limestone, which forms the bed of the stream and preserves the dinosaur tracks that are the park's *raison d'être*. As the tributary enters the main valley, it meanders around a terrace complex formed of sandy alluvium associated with the Paluxy River and gravelly alluvium associated with the tributary (Figure 2-21). Site 41SV56 is contained in this terrace, and exposed in an extensive cutbank just upstream of the confluence. Based on a brief inspection of existing exposures, Abbott identified a sequence of three discrete

alluvial units at the locality. Two of these units, informally termed the "older sandy fill" and "younger sandy fill" consist of 1–2 m of basal gravels overlain by up to seven meters of fine-grained deposits laid down by the Paluxy River, while the third consists of gravelly clay deposited by Denio Branch. The younger sandy fill exhibits a relatively weak A-Bw profile, and was dated by three radiocarbon ages on cultural charcoal. The distribution of these ages (see Figure 2-21), which were obtained from features buried between approximately 1.5 and 4 m bgs, suggest that the younger fill accumulated very rapidly between approximately 1.5 ka and 1 ka. The older fill was exposed in an inaccessible cutbank, and was therefore not described in detail. Based on remote examination, it consists of a structured, oxidized sandy loam. No evidence of soil carbonate was noted in the profile, but the lack of close inspection means it is not precluded. Up to a meter of the younger sandy fill drapes this older fill, and the soil capping this younger unit has welded the drape to the surface. The gravelly Denio branch is inset into and lower than both of these fills, and probably represents relatively recent aggradation. Although this brief study was quite spatially restricted, it did serve to identify the presence of two discrete alluvial fills associated with the Paluxy River, including an undated older fill of probable Holocene age and a younger sandy fill that overrides and buries the older fill and apparently accumulated rapidly between 1500 and 1000 years ago.

Carlson (1999) examined the geomorphic context of Dinosaur Valley State Park as a whole in conjunction with a comprehensive archeological survey of the park by the Texas Parks and Wildlife department. He identifies three principal terrace surfaces in the park boundary: a narrow discontinuous alluvial strath terrace (Terrace 1) approximately 3–4 m above the stream, a principal terrace surface (Terrace 2) approximately 4.5–6 m above the stream, and an aerially-restricted high terrace approximately 14 to 17 m above the stream. He subdivides the second terrace into two sub-terraces: an "older" terrace (T2b) with a gently sloping morphology that is underlain by Udic Calciustolls of the Venus series, and a "younger" terrace (T2a) with a ridge and swale topography that is underlain by Cumulic Haplustolls of the Bosque series. As at Denio Branch, the T2a terrace surface is underlain by a younger fill unit that is inset into and overrides an older unit. (Figure 2-22). The younger unit consists of calcareous sands and loams that are cut with stringers of lag gravel, undulating reactivation surfaces, and thin interbedded soils (presumably weak cumulic A horizons). Overall soil development in the unit, as expressed by the development of a color or structure-differentiated B horizon, development of a melanized surface A horizon, or development of carbonate pedofeatures, is extremely limited. By contrast, the older unit exhibits noticeable blocky structure, oxidation that gives the B horizon an orange-brown color, and a thin but noticeable A horizon. Both of these units are capped by a veneer of recent (historic?) alluvium. Terrace 2b

Figure 2-21: Stratigraphy of the confluence of Denio Branch and the Paluxy River in Dinosaur Valley State Park.

is underlain by material similar in character (primarily color and structural development) to the older unit beneath the T2a surface, suggesting that the older of the two T2a fills may be an alluvial strath cut from the slightly higher T2b surface. Finally, the T3 surface is characterized by a lag of gravel and sand that supports Paleustalfs of the Pedernales series.

Correlation of the description and geometry of the units identified by Carlson (1999) and Abbott (Turpin 1994)

suggests that the two units attributed to the Paluxy River in the Denio Branch study are probably equivalent to Carlson's older and younger T2a fills. This correlation is strengthened by the one radiocarbon age was obtained during Carlson's study of Dinosaur Valley State Park, which is consistent with the three ages from the Denio Branch study. Carlson attributes the older unit to the Middle Holocene, but this estimate is based on the degree of soil development only, and requires verification with future work.

Figure 2-22: Stratigraphy of the Paluxy River at Dinosaur Valley State Park.

Another limited examination of the stratigraphy of the Paluxy River was conducted at the crossing of US 67, on the western side of the town of Glen Rose. This locality is approximately 3 km downstream of Dinosaur Valley State Park. This examination was undertaken as part of the current study, and occurred in conjunction with a mechanical survey of a planned bridge replacement by Prewitt & Associates (Griffith 2005). Three alluvial surfaces are present in the immediate vicinity of the US 67 study area, and each is directly correlatable with the major terraces identified by Carlson upstream. The lowest (T_0) surface is a narrow, discontinuous floodplain that flanks the channel on alternating sides of the channel trench, and varies from 3–4 m above the channel, which locally rests at an elevation of approximately 186–187 m (610–615 feet) above msl. This surface is broadly analogous to Carlson's T1 surface in landscape position, although it is clearly a fill terrace rather than the strath surface reported upstream. Yahola–Gaddy complex soils are mapped on the surface. Both of these soils are characterized by a very weak Ap–C profile (Udic Ustifluvents) developed in recent sandy alluvium, and are differentiated primarily by the coarseness of the sand.

The second surface (T_1 terrace) is analogous to Carlson's T2a and T2b terraces. This broad, level to gently sloping terrace is preserved as discontinuous segments on alternating sides of the stream. It rests at an elevation between approximately 194.5 and 196.5 m (635 and 645 ft). Like Carlson's study area upstream, soils mapped on the surface are predominantly Bosque loams and Venus loams. However, Frio clay loams are also present, occurring in channel fills inset into the surface. All three of these soils are classified as Mollisols; the Venus series is classified as Udic Calciustolls, while the Bosque and Frio series are both Cumulic Haplustolls. Bosque soils are particularly interesting because the type description includes a buried A horizon at a depth of 50 inches (127 cm). Finally, there are also remnants of a high, relatively level Pleistocene terrace (T_2) preserved intermittently on both sides of the

stream. It is analogous to Carlson's T3 surface upstream, and occurs at approximately 200–205 m (655 to 675 ft) above msl. Mapped soils on this surface include Paleustalfs of the Pedernales series, which are consistent with the landform, and Mollisols of the Sunev and Krum series, which are more often found on Holocene age alluvial surfaces. Because these surfaces were well outside the area of project impact, they were not examined. Rather, investigations at the US 67 locality focused on the T_0 and T_1 surfaces.

Six trenches were excavated in the vicinity of the crossing, exposing sediments correlated to four different alluvial fill events (Figure 2-23). The T_0 surface was underlain by thick, fine to medium sands with two interbedded A horizons, resulting in three stacked, A–C profiles. Consolidation of the material was very poor, and the trench collapsed repeatedly as it was excavated. Trenching was discontinued at approximately 150 cmbs. The accumulation of sediments underlying the T_0 surface is undated, but the character of the fill suggests that it has aggraded in the very recent past, possibly as a result of historic disturbance of the landscape.

Three additional stratigraphic units were identified beneath the gently sloping T_1 terrace. The most recent of these units occurs as a streamward-thickening wedge that was observed on both sides of the stream. On the northeast bank, it was relatively thin and fined upward rapidly from bedded gravels and sands to loams; while on the southwest bank the fill was much thicker, consisting of a wedge of organic loams with negligible pedogenic overprinting more than 2 m thick. Based on stratigraphic position and the very weak degree of soil development, this fill is believed to represent a very late Holocene unit. On both sides of the river, this unit overlies an older unit believed to date to the Middle- to Late Holocene based on its typical A–Bk profile. In BT1, the unit was capped by a dark brown buried A horizon and graded into a gleyed

Figure 2-23: Stratigraphy of the Paluxy River at the US 67 crossing.

sandy loam with ferrous staining, indicating periodic saturation of the unit in proximity to the river. In BT3, situated beyond the wedge of overlying very Late Holocene alluvium, this saturation effect is not in evidence, and the unit exhibits an A–Bk–C profile developed in a well-drained fining-upward depositional sequence that grades from fine sandy loam at the surface to gravelly sands two meters below the surface. This Middle-to-Late Holocene unit is also equated to the sequence exposed in BT6, where a thick deposit of sandy loam is differentiated only by the appearance of carbonate filaments at approximately 1.5 m bgs. Finally, BT2 exposed an erosional remnant of a much older fill with a strong, laminar to massive K (or Bkm) horizon developed in sandy loam. This unit was preserved as an isolated erosional remnant beneath a veneer of recent alluvium in the middle of the terrace, and, based on the degree of pedogenic development, represents a Late Pleistocene fill.

Aquila Reservoir

Although it is outside the district boundary, a study by Brown (1987) addresses the stratigraphy and architecture of streams inundated by Aquilla Reservoir, a moderately-sized reservoir (roughly 3,100 acres) in adjacent Hill County. Aquilla Creek and its tributary Hackberry Creek drain southward across the Grand Prairie to an eventual confluence with the Brazos upstream of Waco in McLennan County. In separate contributions contained in the same publication, Patton (1987) and Watson (1987) briefly consider the geomorphology and geoarcheology of the Aquilla Lake basin in connection with the archeological investigation. While they do impart some valuable information, the paucity of stratigraphic detail and poor integration of chronometric information limits the utility of the studies.

Patton (1987) identifies four alluvial surfaces, including the floodplain and three alluvial terraces, at elevations between 3 and 35 m above the modern stream. Watson (1987) places the first terrace at 28 ft (8.5 m) above the modern stream, the second terrace at 38–58 ft (11.5–17.7 m) above the modern stream, and the third terrace at 120–170 ft (36.5–52 m) above the modern stream. Associated mapping (see Figure 3–1 in Patton) clearly indicates that the third terrace is the upland, and that the three surfaces together cover the entirety of the basin. Tentative ages are proposed by the authors based primarily on soil development criteria, archeological associations, and correlations with adjacent areas (primarily Lake Whitney). Although Brown (1987) reports approximately 20 radiocarbon ages obtained from floodplain sites in the project area, these ages are not integrated into the broader geomorphic/geoarcheological discussions.

Both Watson and Patton identify the third terrace as a dissected cut surface mantled with siliceous alluvial gravel,

and interpret it as a Pleistocene (or older) surface with negligible potential to contain buried archeological sites in reasonable context. Terrace 2, which represents the highest inset surface, is also considered to have formed during the Pleistocene by Patton (1987). Terrace 2 is mantled with a variable, but generally downslope-thickening, veneer of sediment that supports a weak soil. Patton (1987:3–4) believes that this deposit is “most likely related to post-depositional modification of the alluvium” and may have “accumulated in historic times”. This colluvial veneer overlies a relatively strongly developed, albeit truncated, soil developed in sandy alluvium. Archeological sites associated with this surface are generally superficial (Brown 1987), suggesting that abandonment of the surface by the entrenching stream probably predates the culturally-relevant period.

The low (first) terrace lies a meter or less above the floodplain, and merges with it in many places. This suggests that the floodplain surface is overtopping the low terrace in places, but the authors also suggest that ongoing agricultural practices may have obliterated low scarps separating the two surfaces in other places. Although several large and culturally rich sites, including the Brazil Site and the Sullivan Site, were investigated in this setting, none were particularly well-preserved. Rather, they consisted of artifacts and a few poorly defined features distributed throughout the shallow surface horizons, most buried 50 cmbs or less below the modern ground surface. This suggests that the major episode of aggradation predated the succession of occupations, which span the Paleoindian and Archaic periods according to the large and diverse projectile point collection secured by the respective landowners.

The floodplain (T0), in contrast, consists of a thick sequence of alluvium with intercalated archeological deposits. It lies approximately 5–7 m above the channel and consists of stratified sands, loams, and clays with relatively subtle preserved stratigraphy. A series of twelve samples on charcoal, bulk soil, and mussel shell from a 3.5 m sequence at the McDonald Site yielded a largely ordered sequence of radiocarbon ages ranging from approximately 2880 to 780 BP. These samples suggest that the floodplain was aggrading relatively rapidly prior to 2.5 ka, and that deposition had slowed markedly by approximately 1.5 ka. However, there is some evidence of renewed aggradation during the historic period. Historic artifacts were recovered from the upper 30 cm of the sequence, and the character of the upper sequence suggests that up to 60–80 cm of aggradation occurred following Anglo-American settlement of the region, burying and preserving the relatively stable surface as a paleosol. It is this buried soil, which is 50–100 cm thick, which yielded the Late Prehistoric remains, while the Late to Transitional Archaic remains were recovered from the more rapidly accreted deposits beneath the buried soil.

Radiocarbon data from the other sites in the floodplain context are consistent with a late Holocene age for the overall fill, but do not present a uniform picture. At the Reps Davis site, cultural material was concentrated at a shallow contact and is believed by the original investigators to be disturbed and reworked (Skinner et al. 1978), but radiocarbon data is consistent with marked decrease in aggradation during the latter Late Prehistoric. At the McKensie site, in contrast, cultural materials are buried at a depth of approximately 2.5 m in association with the lower of two alluvial paleosols. Radiocarbon ages on bulk sediment and shell from within, immediately above, and immediately below this paleosol range from 1.07 ka to 2.3 ka. The higher of the two paleosols, which lies roughly 80–100 cmbs, is undated.

In summary, investigations of Aquilla and Hackberry Creeks in the flood pool of Aquilla Reservoir identified a modern floodplain and a series of three alluvial terraces at elevations up to 50–60 m above the stream. Although chronometric information is minimal, artifact recovery patterns suggest that the terraces are all relatively old, with the low first terrace stabilizing in the latest Pleistocene or early Holocene. Since that time, the surfaces have been relatively stable, although low order colluviation and erosion have probably affected the two lower terraces episodically, potentially burying cultural remains in the upper 50–100 cm of sediment. The floodplain, in contrast, appears to have aggraded relatively recently, with up to 4 m aggrading since approximately 3 ka. There is a locally preserved paleosol at depth, documenting a short period of relative stability, and a more widespread phase of stability during the latter part of the Late Prehistoric. Finally, there is some evidence of a brief period of renewed aggradation of the floodplain and on the colluvial slopes and terraces that is possibly related to historic disturbance of the landscape.

The North Bosque River

The North Bosque River originates in northern Erath County and flows south and southeast through a shallowly incised valley to its eventual confluence with the Brazos River on the northeastern outskirts of Waco in McLennan County. It drains an area of approximately 350 square miles in the southwestern part of the Fort Worth District, primarily within the boundary of the Western Cross Timbers natural region. In Erath County, the North Bosque occupies a broad, shallow valley incised into the Cretaceous Glen Rose Limestone. Sandstones and clays of the Cretaceous Paluxy Formation form the upper hillslopes and low interfluvies, and remnants of the bedded limestones and claystones of the Walnut Formation cap the highest parts of the surrounding landscape. The North Bosque River is a perennial system with a relatively deep, narrow channel and wide, nearly level floodplain. Recent (i.e. latest

Pleistocene/Holocene) alluvium is mapped in the bottom of the broad meandering valley excavated by the stream (Barnes 1972). Although much smaller than their counterparts on the Brazos, channel meanders on the North Bosque are also far larger than would be produced by hydraulic processes of the modern stream (meander amplitudes are up to 1 km). Like the Brazos, much of the interior meander bends consist of exposed bedrock, indicating that the system entrenched long ago. Small remnants of possible older terraces are preserved at intervals on the margins of the valley, but the topographic expression of these features in the project area is subtle, and they may instead represent accumulations of colluvial and/or fan deposits. On the other hand, alluvial lag gravels are present in small amounts on the upland divides, and have been correlated with the Uvalde Gravel Formation and interpreted as remnants of the formerly extensive Ogallala Formation (Byrd 1971). Mapped Pleistocene terrace deposits above the valley fill are very rare, occurring in only four small locations of between 60 and 130 acres each along more than 40 kilometers of the stream in Erath County. One of those mapped localities is in the city of Stephenville, where a crescent of Pleistocene terrace is mapped above the recent alluvium on the interior meander bend. Observations made during a pedestrian survey of this bend for a hike and bike trail (TxDOT Staff 2002) confirm that Holocene alluvium is restricted to the low terrace/floodplain in this area. Therefore, archeological sites on higher terraces should be either exposed at the surface or shallowly buried by colluvial and biotic processes.

Nearly fifty years of streamflow data from a gauging station at Hico, situated just outside the district in Hamilton County, suggest that overbank flood events are relatively rare on the North Bosque (Figure 2–24; see Figure 1–8 for a similar plot from upstream at Stephenville), probably because the extensive sandy soils developed on the Paluxy formation buffer the rate of runoff during strong storms. Again, however, contemporary flow conditions are mitigated by drainage control structures constructed in the last century, and therefore not necessarily a viable proxy for prehistoric behavior of the system. While no large dams have been constructed on the North Bosque, there are a multitude of small to moderately-sized earthen dams, check dams, and erosion control structures on the tributary network that serve to slow runoff, and limit the usefulness of recent flood records for understanding prehistoric flooding patterns. If this network of stock tanks and flow-retarding structures was not present, runoff in the catchment would be more rapid. As a result, the incidence of overbank flooding would be greater and flood crests would be higher, possibly significantly so.

Stratigraphic observations on the North Bosque were made during a mechanically-assisted archeological survey across

Figure 2-24: Relationship between discharge and gauge height of the North Bosque River over the period of record at Hico, TX.

the valley conducted by TxDOT in advance of improvements to SH 6. This locality is situated in southern Erath County, and lies near the stream's confluence with Round Hole Branch, approximately 37 kilometers south of the stream's headwaters. Despite the extensive sandy soils in the uplands, the entirety of the floodplain is mapped as Frio clay loam, occasionally flooded (Wagner et al. 1973). Although mechanical trenches were excavated at intervals across the whole valley, trenches on the distal alluvial surface were typically only excavated to a depth of less than 2 m, while deep trenching (3 m+) was conducted in the central part of the valley where deep impacts were anticipated. Consequently, the stratigraphic investigations in the North Bosque valley do not provide information about deeply buried sediments in the margins of the valley.

A total of twenty trenches were excavated across the North Bosque valley at SH6 (Figure 2-25). A minimum of three distinct allostratigraphic units were identified in the trenches. The oldest fill (Unit 1) was identified in one trench (GT14) on the margin of the valley. This fill is interpreted as probable Pleistocene alluvium, and was overlain with approximately 50 cm of colluvium and alluvium supporting a relatively weak Ap-Bw soil. Although undated here, the character of the soil suggests that colluviation and slopewash was probably a late Holocene phenomenon. The underlying Pleistocene deposits consist of silty loams supporting a former Stage IV calcrete whose surface has been attacked and brecciated by erosion and weathering. The former laminar cap now consists of a series of stacked, subhorizontal calcrete slabs surrounded by relatively unstructured clay loam. It is underlain by a massive, carbonate-infused silt loam K horizon. No remnants of the

presumed former soil that would have been present above the laminar calcrete horizon were preserved, suggesting that the surface was intensely eroded before the alluvial/colluvial unit began to accumulate. Similar landforms were noted upstream and downstream, and it appears likely that remnants of this unit may be preserved at intervals on the margin of the valley, where they are typically overridden with Holocene colluvium.

Unit 2 consists of loamy to clayey deposits with moderately strong soil development (typically A-Bk or A-Bt-Bk profiles), and represent the principal fill episode in the valley. Several localized buried soils and erosional surfaces were noted in the central valley (see Figure 2-25), suggesting that additional work might be able to further subdivide Unit 2. Deposits representing Unit 2 were encountered in every trench except GT3. Radiocarbon data obtained on bulk humates suggest that aggradation of

Unit 2 was ongoing by 5.5 ka and was terminated by incision of the channel sometime after 1.5 ka. Possible internal subdivisions include a weak buried A horizon dated to 3.1 ka in GT1 and apparent erosional surfaces noted in several trenches; however, these surfaces could not be traced between trenches and their significance to the broader sequence remains undetermined.

With the exception of GT14, which exposed Unit 1, the trenches excavated away from the valley axis (i.e., east of Round Hole Branch and west of the North Bosque) were dominated by clays representing distal overbank facies (floodbasin muds) of Unit 2. These trenches are represented by profiles GT7 and GT15 in Figure 2-21. These deposits support soils that exhibit vertic features like slickensides and prominent soil cracks. Many of these profiles also exposed thin veneers of probable recent deposits (i.e., Unit 3), but the lack of chronometric ages and prevalence of plow disturbance make this identification tentative.

Between Round Hole Branch and the current Bosque channel, the deeper trenches revealed a thick, heterogeneous sequence of lateral and vertical accretion deposits bounded by scoured surfaces and relatively prominent cumelic soils, suggesting that meander migration, point bar accretion, and (possibly) channel avulsion were dominant between the two channels for much of the Holocene. While this sequence is almost certainly complicated locally by the influence of Green Creek and Round Hole Branch, which both join with the North Bosque channel in the immediate vicinity, it suggests that the primary stream was both actively meandering and slowly aggrading during the Late

Figure 2-25: Layout and stratigraphy of the North Bosque River at SH6, based on trench investigations. Radiocarbon ages shown are conventional ages (age before 1950, or age BP, corrected for $\delta^{13}C$). Schematic cross-section is not to scale.

Holocene. The fine-grained sediments and vertic soils exposed in the trenches away from the valley axis suggest that this cutting and filling has been restricted to the central part of the valley for the last few millennia. Colluvial-alluvial deposits on the valley margin consist of clay loam containing a number of small, angular limestone gravels, and appear to interfinger with the floodplain suite. Given the apparent age range of Unit 2 and the

architectural relationship between the floodplain and hillslope sequence, these colluvial deposits are tentatively correlated with Unit 2, but may have continued during aggradation of Unit 3.

Unit 3 consists of a relatively distinctive sequence of recent deposits that are exposed in GT 3 and in the upper portion of GT 1, 2, 4, 5, and 6 (see Figure 2-25). Radiocarbon ages

on charcoal indicate that aggradation of this unit was ongoing by approximately 280 BP and continued to at least 80 BP. The sequence exposed in this series of trenches includes facies that primarily represent floodbasin deposition of clays and clay loams (GT 1, 2, and 4), proximal overbank (i.e., levee) deposition of loams, silts, and fine sands (GT 1, 2, 3, and 4), and crossbedded sands, loams, and fine gravels representing channel/point bar deposition (GT 3). Despite the recent age of the cut and fill sequence exposed by GT3, no evidence of this channel was apparent at the surface. Overall, Unit 3 also appears to represent lateral and vertical accretion in the axial valley and vertical accretion and splay deposition on the floodplain. The basic character of depositional activity is therefore similar to the preceding unit, but it is markedly sandier and therefore readily differentiated from the more clay-rich deposits of Unit 2. Given the age of the unit, it is likely that the sandier texture of the fill reflects anthropically-stimulated erosion of sandy soils in the catchment during the historic period.

In summary, three unconformity-bounded stratigraphic units were identified in the North Bosque River valley at the SH6 crossing. The oldest unit is undated, but is believed to be older than 12–15 ka based on the degree of soil development (in particular, the presence of a laminar-capped Stage IV calcrete). This soil indicates that the unit stabilized and was subjected to a protracted period of pedogenesis, ultimately developing a soil with a strong calcic horizon. At some point, incision and lateral erosion of the North Bosque flushed the majority of this unit from the valley, leaving truncated remnants of the fill clinging to the hillslope at intervals in the valley. This extensive erosion event is not dated, but it predates the onset of Unit 2 aggradation, which was ongoing by 5.5 ka. Unit 2 is dominated by dark grayish brown clay loam and clay that tends to fine laterally toward the margin of the valley. It supports a calcic soil with a strong blocky to prismatic structure, and represents a period of protracted valley filling in the Middle- to Late Holocene. Constraining ages indicate that this unit had aggraded to within 2.5 m of the surface by 5.5 ka, and that the surface soil was still forming around 1.5 ka. Aggradation probably occurred in a punctuated manner, as evinced by common, localized truncation surfaces and one localized buried soil present in the fill body. On the valley margins, colluvial and slopewash shed off the adjacent hillslopes overrode and buried the remnants of Unit 1 during this same period. Finally, localized channel cutting and alluviation that occurred in the axial valley resulted in the deposition of Unit 3 during the last few hundred years.

Sanchez Creek

Sanchez Creek is a relatively short tributary that flows into the Brazos from the north. Investigations on Sanchez Creek were conducted in conjunction with a proposed bridge replacement project at Thompson Road. The study area is

situated in southern Parker County a few kilometers upstream from the confluence of Sanchez Creek and the Brazos River, and immediately downstream of the confluence of Sanchez and East Sanchez Creeks. Bedrock in the area consists of Lower Cretaceous rocks, with sandstones and claystones of the Twin Mountains Formation forming the valley floor and lower hillslopes, and limestones and marls of the Glen Rose Formation forming the upper hillslopes and surrounding uplands. Relief is moderate; the elevation of the stream is approximately 750 ft amsl, while surrounding upland summits are roughly 840–950 ft amsl. The valley is locally asymmetric with a single sloping alluvial surface that merges with the colluvial slopes. This surface is roughly 5–7 m above the water next to the channel trench, but rises gradually to more than 10 m above the stream before merging with the colluvial slope on the broader eastern side of the valley. The western side of the valley is narrower, and the investigations there extended into the colluvial environment, while only the more proximal part of the broader eastern terrace was trenched. A series of gradall trenches (numbered GT1 through GT11) was excavated in a cross-valley transect in the study area, while four additional trenches (GT 12–15) were used to investigate archeological site 41PR99, discovered at the west end of the project during trenching (Figure 2–26).

For safety reasons and because deep impacts across the terrace surface were not anticipated in conjunction with the bridge realignment, trenches were restricted to a depth of approximately 1.5 m. Two alluvial units and one colluvial unit were identified in the trenches. The older of the two alluvial units was situated on the eastern side of the valley, and was exposed in trenches 1–6. It consisted of structured clay loams with variable amount of incorporated and interbedded alluvial and colluvial gravel. In the most distal investigated part of the floodplain (GT1), the gravel consists of poorly rounded to angular, matrix-supported limestone pebbles and cobbles. These clasts are believed to represent colluvial input from the colluvial slope. GT2, situated only a short distance further downslope, graded from a slightly gravelly clay loam into a bedded deposit of gravelly sands and loams representing a channel deposit underlying the terrace surface. Erosional truncation surfaces mantled with relatively coarse limestone gravels were also noted in GT4 and GT5, but these much thinner deposits clearly represent chutes or lags rather than channel deposits *per se*. The remaining trenches exposed dense, structured clay loam. Soil development in Unit 1 is relatively well expressed, with a typical profile consisting of an Ap–A–AB–Bk sequence. The Ap/A horizon and transitional AB horizon varies from less than 50 cm to more than 120 cm in thickness, exhibits a blocky structure that generally coarsens and becomes weaker with depth, and is very dark grayish brown (10YR 3/2) to black (10YR 2/1). The underlying Bk horizon consists of dark grayish brown to brown (10YR 4/2 to 10YR 5/3), very weakly structured to

Figure 2-26: Stratigraphy of Sanchez Creek at Thompson Road, Parker County.

massive sandy clay loam or sandy to silty loam. Subangular to subrounded limestone gravels, sometimes exhibiting evidence of surface etching (dissolution), are common throughout the matrix and in stringers and beds. Carbonate is present as prominent films, filaments, grain coats, and gravel pendants. Localized small carbonate masses were also noted in the trench nearest the stream. It was unclear from the field inspection whether these latter features were primary components of the deposit—that is, dissolving limestone clasts—or secondary carbonate nodules.

Six radiocarbon ages on bulk matrix carbon are available from Unit 1. Four of these ages are from the lower part of the soil, well into the Bk horizon, at depths between 120 cm and 150 cm. These samples yielded radiocarbon ages ranging between 4680 BP and 4110 BP. Although their conventional ($\delta^{13}\text{C}$ corrected) age centroids differ by less than 600 years, when calibrated, the samples span a period of almost 1200 years at the 2 sigma confidence interval (3640 BC and 2470 BC) and overlap between samples is limited. A major exception is the two samples from GT1 and GT3, which yielded exactly the same age. Interestingly, the oldest ages were obtained closest to the modern channel, which is not what one would normally expect from a migrating system. Additional ages of 3100 BP and 2100 BP were obtained from the upper part of the Bk horizon in GT4 (80–90 cmbs) and the A–AB interface in GT1 (60–70 cmbs), respectively (Appendix II). Both of these latter ages are probably influenced by soil organic matter, and may postdate the actual age of deposition by up to a millennium. It is possible that the four older ages were also influenced to some degree by soil organics, but their broad penecontemporaneity suggests that they are probably relatively accurate estimates of the age of deposition.

Unit 2 was exposed on the opposite (western) side of the stream in GT 7, GT8, and GT9. It was very different from the Unit 1 deposits in terms of sedimentary character and soil development. Texturally, the deposit grades from a relatively light sandy loam near the stream (GT7, GT8) to a much denser clay loam near the transition to the colluvial slope (GT9). This textural shift is accompanied by a significant change in the character and degree of soil development. Trench GT7, situated closest to the stream, is composed of very dark to dark grayish brown (10YR 3/2 to 10YR 4/2), granular to massive sandy loam. It is overlain by approximately 20 cm of weakly bedded loamy sands that may represent surface wash from the agricultural field upslope. Overall, the trench exhibits a relatively weak A(p)–2A–2Bk profile. Carbonate occurs as flecks, many of which appear to represent sand-sized primary limestone grains undergoing dissolution, and a few fine films and filaments that are clearly secondary precipitates. There are also a number small, angular fragments

of yellowish limestone that are believed to represent colluvial input. GT8 is similar, except that the surface (A1) horizon consists of weak blocky to granular structured sandy loam. GT9, in contrast, exposed finer sediments with more prominent soil development. The profile exhibits an Ap–A–AB–Bk profile dominated by a thick, prismatic clay loam A horizon. The structure is pronounced, and the ped faces are darker (10YR2/1) than the interiors (10YR 3/2). It grades into a moderately prismatic, very dark grayish brown (10YR 3/2) AB horizon. Carbonate filaments appear in the lower AB horizon, and become thick and prominent with depth. The underlying Bk horizon consists of a blocky structured, grayish brown (10YR 4/2 to 5/2) silt loam. It is similar to deposits upslope, and may represent older alluvial or colluvial material overlapped by alluvium; however, if so, soil development has obscured the contact.

Comparable ages were obtained from each trench exposing Unit 2. As is the case with Unit 1, all radiocarbon ages are on bulk organic matter in sediments, and therefore may include some soil material that could bias the ages. However, the samples were collected from depths between 125 and 140 cmbs, below the principal zone of organic enrichment, and are believed to be broadly accurate. The three ages from Unit 2 ranged from 2590 to 2150 BP, with a two sigma calibrated range of BC 830 to AD 60 (see Appendix II).

Upslope of this area, investigations on the colluvial slope revealed loamy deposits containing archeological remains (site 41PR99). These deposits exhibited an A1–A2–AB–Bk1–Bk2 profile developed in sandy to silty loam. A small feature of clustered burned rock was found at a depth of approximately 60–70 cm in GT10, and localized clusters of a few burned rocks each were discovered between 10 cm and 60 cmbs in several additional trenches. Although no charcoal or other cultural materials were associated with these rocks, a radiocarbon age of 1430 BP was obtained on sediment from the presumed hearth. Again, this age may have been influenced by soil organic matter, but it is stratigraphically consistent and is believed to be broadly accurate.

In summary, the deposits in the Sanchez Creek valley represent a minimum of two discrete periods of aggradation, the older of which was initiated sometime before 5 ka, and the younger of which aggraded primarily between 3 and 2 ka. This material accumulated in a valley that was at least partially flushed of alluvial deposits sometime prior to 6 ka. Colluvial deposition was also common as the alluvial sequence aggraded through the middle to late Holocene, interfingering with the alluvial units and overriding the terrace between approximately 2 and 1 ka. It is unclear whether Unit 1 and Unit 2 were separated by an incision event or simply represent a time-transgressive deposit formed as the stream

reached the western valley wall and then began to migrate back eastward, eroding the youngest deposits of Unit 1 and laying down Unit 2 in the process.

Rippy Branch

Fort Wolters is a Texas Army National Guard Facility located east of Mineral Wells in Palo Pinto and Parker Counties, Texas. It is drained by Rock Creek and its tributaries. Rock Creek heads in southeastern Jack County, and flows south to its confluence with the Brazos River in southwestern Parker County. Rippy Branch, one of the larger tributaries of Rock Creek, heads in northern Parker County, and flows south to its confluence near Mineral Wells in western Parker County. Bedrock in the vicinity of the study area consists of sandstones, shales, limestones, and conglomerates of the Pennsylvanian Mineral Wells formation, which are some of the oldest rocks exposed in the entire Fort Worth district. Like much of the Paleozoic sequence, these rocks have weathered to form a series of large cuesta landforms with resistant faces trending northeast–southwest and concordant surfaces dipping to the northwest. Brownlow et al. (1999) addressed the archeological geology of the base as a whole. They identified four principal landform/sediment assemblages in the facility's approximately 3,500 acres: erosional scarps and uplands (map unit P(B)); undifferentiated alluvium/colluvium deposited at the foot of retreating erosional scarps (map unit Qm (A/C)); terraces (map unit Qt(T)); and alluvial valley bottoms and terraces undifferentiated (Qal(A/T)). Examination of these settings was somewhat opportunistic, but still resulted in the identification of several archeological sites associated with the terraces and alluvium. Interestingly, subsequent testing of one of these sites (41PR44) by the University of Texas at San Antonio Center for Archaeological Research (UTSA–CAR) concluded that a series of stratified cultural features were in fact clusters of naturally–reddened colluvial sandstone that had become interbedded with stream alluvium (Greaves 2006).

Radiocarbon ages obtained from alluvium on Ft. Wolters by Brownlow et al. ranged from 9120 BP to 70 BP, with 71% dating younger than 1100 BP. The majority of these ages were obtained from the Qal(A/T) unit. However, two ages were obtained from buried soils within the terrace fill (Qt(T)). One of these ages, 530 BP, overlaps the ages from the subsequent unit and probably represents a mean residence age on soil organic matter. The other age, 9120 BP, seems a reasonable estimate for a fill with this landscape setting and soil characteristics. However, the investigators noted two zones of large (up to 3 cm diameter) carbonate nodules in the soil, and suggested that the 9120 BP age may also represent a mean residence age, and that the deposit could be up to 50,000 years old.

Segments of Rippy Branch, a tributary of Rock Creek on the north side of the Brazos, were re–examined as part of the current study at the gracious invitation of Michael Jordan of the Texas Army National Guard. Although the stream is incised, visibility of the alluvial sequence was limited because the banks are generally well mantled with spoil, slumped material, and veneer alluvium. However, one area, termed Fort Wolters Locality Number 1, consisted of a relatively well–exposed cutbank sequence. Based upon the map and locality description in Brownlow et al. (1999), this locality probably corresponds roughly to their Locality 8, where a buried paleosol approximately 1.6–1.8 m bgs in a terrace cutbank yielded the age of 9120 BP.

The Locality 1 exposure consists of a concave cutbank of Rippy Branch at the base of an upland colluvial slope, and exposes the fill of a terrace that lies 4–5 m above the stream and an inset floodplain 3–4 m above the stream (Figure 2–27). Localized meandering of the channel has resulted in the lateral erosion of a terrace of Rippy Branch and deposition of a low pointbar (T₀) 1–2 m above the channel on the convex bank. The cutbank exposed by the meandering stream is 4.5–5 m high, and supports a relatively clean vertical face only in the upper 2.5–3 m. One alluvial fill unit supporting a strong multistoried calcic soil is exposed in the cutbank. Although this unit is exposed at the surface away from the hillslope, it is buried by colluvium nearer to the upland. Because this colluvial unit affects the overall profile in a number of ways, two different vertical sections of the cutbank were recorded and sampled. Section 1 was situated on the T₁ scarp away from the valley wall, and is missing the colluvial sequence, while Section 2 is situated adjacent to the toeslope and includes alluvium and a covering wedge of colluvium (see Figure 2–27). The upper alluvial contact dips slightly from the intact section to the section overridden by colluvium, suggesting that the surface may have been scoured prior to the colluvial accumulation. At the downstream end, the terrace is laterally truncated by an inset floodplain fill with an A–C profile.

The soil developed in the alluvium of Section 1 exhibits an Ac–A–Btk1–2Btk–3Bk profile developed in a moderate to highly structured, mottled sandy loam. Clay cutans are readily apparent in both Btk horizons. The upper Btk horizon contains a moderate number of moderately–sized, irregular carbonate nodules and rhizoliths, while the 2Btk and 2Bk horizons contain common to abundant, large, irregular nodules and elongate rhizoliths. Color varies from 5YR3/2 to 5YR4/4, and faint reddish and brownish mottles are common in the 2Btk and 3Bk profiles. Although there are subtle differences in two soil descriptions, the unit is believed to equate to Brownlow et al.'s (1999) Locality 8 section. As described below, the radiocarbon ages obtained from the unit during this study are broadly consistent with, albeit somewhat

Figure 2-27: Cutbank on Rippy Branch, Ft. Wolters, exposing alluvial and colluvial deposits. Note stratigraphic relationships.

younger than, the age Brownlow et al. (1999) obtained from the buried paleosol at their Locality 8. The other profile, which is unlike anything described by Brownlow et al. (1999) consisted of a four meter thick section of alluvium overlain by two meters of sandy yellow-brown colluvium, and exhibited an A-Bk-2Btk-2Bk-2C profile. The character of the underlying alluvium was similar to that exposed in Profile 1: rubified, highly structured sandy loam exhibiting reddish mottling and coarse, hard carbonate rhizoliths and nodules. The overlying colluvium consisted of somewhat coarser, yellowish brown deposit exhibiting moderate soil structure and Stage I carbonate development.

Because no other datable materials were observed in the section, four bulk sediment radiocarbon samples were collected from the two profiles recorded at the locality. As an experiment, two chemical fractions of each of these samples was analyzed (see Appendix II). Chemical fractionation of bulk organic matter in soils and sediments is a common approach to investigations of organic matter dynamics within the soil system (Goh and Molloy 1978; Scharpenseel 1979; Bruun et al. 2005) and to maximizing the accuracy of stratigraphic and archeological dating with bulk samples (Scharpenseel 1971; Geyh et al. 1971;

Gilet-Blein et al. 1980; Matthews 1985; Haas et al. 1986; Kristiansen et al. 2003). Fractionation is a step-wise laboratory processes that subdivides organic matter in a sample into fractions based upon sequential treatment with a series of extractant chemicals. The first of these is termed fulvic acid, which consists of those organic compounds that are soluble in a strong acid such as HCl. The second compound is termed humic acid, and consists of those organic compounds that are soluble in a subsequent strong alkaline solution (e.g., NaOH) after the acid wash has been neutralized. The third fraction is termed humin, and consists of the residual organic compounds remaining after extraction of humic acid (in some cases, fulvic acid is differentiated from material extracted by the initial acid wash, which also removes carbon bound in carbonates. In this formulation, the alkaline extractant is dried and treated with another acid wash; material soluble in this second wash is designated the fulvic acid fraction, while the insoluble fraction is designated the humin fraction). It is important to keep in mind that fulvic acid, humic acid, and humin are not discrete chemical compounds, but rather complexes of heterogeneous molecules derived from decomposition of organic compounds (e.g., proteins, lipids, carbohydrates, lignins) that merely share a common solubility characteristic. Because the nature of these

compounds is dictated by the parent organics and the unique decomposition pathways in operation, the actual molecular composition of any of these fractions can vary widely, and the true character of like fractions from two different localities may or may not be similar.

When fractionated organics in soils and sediments are dated by radiocarbon methods, each fraction typically yields a different age (Scharpenseel 1979; Mathews 1985). Fulvic acid is the most mobile fraction, tends to date far younger than humic acid and humin, and is rarely dated in geological applications. Most laboratories date the humic acid fraction, the humin fraction, or a combination of the two. This latter fraction, often termed the total organic or bulk organic fraction, is probably most common when a single age is required, and is what the majority of sediment ages reported in this study represent. The terms “total organic” and “bulk organic” fraction are somewhat of a misnomer, as the samples have typically been picked to remove rootlets and other identifiable organic structures and submitted to an acid wash to remove inorganic carbonates (which also removes the bulk of the fulvic acid fraction). In the majority of cases, humic acid dates are younger than those on associated humin. However, humic acid dates are somewhat older than the associated insoluble fraction in some cases (Martin and Johnson 1995; Johnson and Martin 1998), and the best estimate of soil age is usually interpreted as the oldest fraction dated (Scharpenseel 1979; Martin and Johnson 1998).

Four samples were fractionated and dated from Locality 1 on Rippy Branch. In all four cases, the alkali-extractable fraction (humic acid) dated older than the residuum (humin). While in three cases the difference in ages was less than 20%, in the fourth case the humic acid fraction dated more than three times as old as the associated humin fraction (Figure 2–28; see also Figure 2–27). The two samples recovered from the alluvial section (Profile 1) are from the lower Btk horizon (80 cmbs) and the 3Bk horizon (250 cmbs). The shallower of these samples yielded ages of 3650 ± 40 (alk) and 3340 ± 40 (insol), while the deeper sample yielded ages of 8630 ± 50 (alk) and 7110 ± 40 (insol). In the other profile, the focus was on dating the unconformity between the alluvium and the overlying colluvium, and the samples were collected from locations above and below the contact, yielding ages of 1720 ± 60 (insol) 6150 ± 50 (alk) and 6950 ± 40 (insol) 8330 (alk), respectively.

Collectively, these ages and the geometry of the depositional units suggest two different possibilities. If the older humic acid ages are

more accurate, this suggests that the alluvial unit had accreted prior to approximately 8 ka and was overridden by colluvium sometime before 6 ka. Away from the overriding colluvial wedge, ongoing soil development resulted in a mean residence age of approximately 3 ka for the Bt horizon of the terrace soil. However, there are several problems with this interpretation. The relatively weak A–Bk profile developed in the colluvial unit is less developed than would be expected for a soil of early to middle Holocene age. There is also the problem of how allochthonous insoluble organic residue—humin—made its way into all parts of the profile, particularly the very divergent age from the colluvial unit.

A more likely scenario is posed by the humin ages, which suggest that the alluvial unit accreted episodically through the early–middle Holocene, forming a soil with a mean residence age of approximately 3.5 ka, and that colluvial burial was a Late Holocene phenomenon, occurring sometime after 2 ka. The relatively close correspondence of the two ages from the terrace Btk horizon suggest that the organic matter fraction is relatively homogeneous, while the wildly disparate ages from the colluvium suggest that the origins of its organic fraction is considerably more complex. It seems far more likely that this complexity was introduced by the addition of older soluble organics, which could be introduced through soil or groundwater flow, than by younger insoluble organics, which would require physical mixing to introduce.

Figure 2–28: comparison of ages from alkaline-extractable (humic acid) and insoluble (humin) fractions of sediments from the Rippy Branch locality, Fort Wolters.

Another aspect of the sequence is the very old (up to 50 ka) age proposed for what is probably the same fill by Brownlow et al. (1999). This interpretation appears to be based exclusively on the intense development of large calcic concretions in the alluvium. However, this interpretation makes several assumptions. First, it assumes that the carbonate nodules are pedogenic in origin. Second, it assumes that the nodules formed through the prevailing “top–down” or “per descensum” model of carbonate accretion, developed in the arid southwest (e.g., Gile et al. 1966; Goudie 1983; Machette 1985; see Section 2.2.1.4). Finally, it assumes that each stratum of nodular development represents a discrete stacked soil, each of which developed over very long timescales. These assumptions follow from the notion that carbonate accumulation in soils occurs through gradual dissolution, translocation, and reprecipitation of carbonate from the upper solum to the lower solum by infiltrating vadose water (see Section 2.2.1.4). Although this is by far the prevailing model, several researchers have raised questions about its universal applicability (e.g., Freytet and Plauziat 1978; Slate 1998; Abbott 2001b). Based on observations made on the Coastal Plain, it seems clear to this author that nodular carbonate development, and rhizolith development in particular, can and does arise readily in saturated (phreatic) conditions, and does not require prolonged time periods to develop. Rather than discrete soils separated by millennia, stacked zones of nodular development may represent fluctuations in average groundwater level over a relatively short time. It is also worth noting that groundwater charged with calcium ions is an alkaline solution, and would be expected to mobilize humic acid to some degree, thereby possibly explaining the anomalously old humic acid ages. Given the low elevation of the terrace, the character of the terrace fill, and the character of the carbonate precipitates, it seems far more likely that the dense nodular zones reflect this latter mechanism.

Other Localities

In addition to the areas described above, a number of other localities in the Brazos drainage were examined at a somewhat lower level of detail. During the course of the project, several days of landscape reconnaissance was conducted to identify other areas within and adjacent to the ROW where existing exposures might contribute data. In addition, over 50 planned project localities within the district were visited and evaluated not only for their cultural resource potential, but also for their potential to contribute data to the geoarcheological project. Most of these latter localities, which were primarily the location of planned off–system bridge replacements, were judged not suitable for additional work because of limited area and/or previous disturbance. Even where investigation was warranted, the project area was typically so small that only one or two trenches was needed. Consequently, the degree of stratigraphic

information that these areas provided was limited, and none are described in detail. However, they did provide one valuable insight, as evidence of substantial historic/modern aggradation was apparent in a wide variety of profiles.

While far from ubiquitous, many of the stream–proximal profiles documented during the project include thick accumulations of stratified alluvium with weak to negligible soil development. Typical examples in the Brazos drainage include localities investigated on Big Grindstone Creek (Abbott n.d.(a)), Rock Creek (Abbott n.d.(b)), and an unnamed tributary of Rock Creek (Abbott n.d.(c)) in Parker County. The Big Grindstone locality consists of a 5 m section of flood terrace with a buried paleosol at the Old Millsap Road crossing. It was recorded from the natural cutbank. The principal fill consisted of approximately 1 m of exposed, massive to trough–crossbedded sandy gravel that graded into approximately 3.5 m of sandy loam exhibiting an A–AB–Bw1–Bw2–Bw3 profile. This fill was capped by 50 cm of crossbedded to massive loamy fine sand supporting an A–C profile. Although no chronometric data was obtained, this sandy veneer exhibits no pedogenic alteration other than root activity and formation of a weak A horizon, and is probably of historic age. At Rock Creek and Grimes Road, three trenches were placed in a low flood terrace situated 4–6 m above the channel. Each of these trenches exposed apparent late Holocene alluvium capped by a sequence of stratified sands and loams between 60 and 100 cm thick. Although undated, the sequence of cross–bedded loamy sands enveloped and completely buried a treated, round–topped post of the type used for a highway barrier, indicating that the stratified material that buries it aggraded in the very recent past. On a nearby tributary of Rock Creek, a trench placed at the crossing of Bennett Road revealed a sequence of stratified sands and sandy loams approximately 80 cm thick. The historic age of these deposits is demonstrated by mold–made bottles and fragments of historic glass dispersed through the fill.

As described below, a number of similar distinctly stratified deposits were also documented in the Trinity drainage. Although it is tempting to ascribe all such deposits to disturbance resulting from historic ranching and agriculture, some of these stratified deposits appear to have more time depth. For instance, similar distinctly stratified sands and loams were present in trenches excavated into a point bar sequence at Erath CR 109 at Barton Creek. These deposits were at least 2 m thick and contained a number of organic drapes and weak soils that document a punctuated aggradational sequence. A radiocarbon age of 450 BP was obtained from dispersed charcoal contained in a mud couplet at a depth of approximately 150 cmbs, suggesting that the onset of rapid, flashy aggradation occurred well before Anglo settlement. Even here, however, rusted iron fragments were present at depth of up to 60 cmbs, indicating a considerable amount of aggradation during the historic/modern

period. The implications of these deposits are discussed further in Section 2.4.

2.3.2 The Trinity River Basin

The drainage basin of the Trinity system is illustrated in Figure 2–29. The Trinity River proper does not exist in the Fort Worth District. Rather, the northern part of the district is traversed by the West Fork of the Trinity River, the Clear Fork of the Trinity River, and their respective tributaries, including Big Sandy Creek, Big Cleveland Creek, Willow Creek, Bear Creek, Deer Creek, Walnut Creek, and Mountain Creek. The Trinity River proper arises at the confluence of the West Fork and the Elm Fork in Dallas County, downstream from the Fort Worth district boundary. Other regional streams in the Trinity system that drain parts of the Fort Worth District include Denton Creek, which drains northeastern Wise County and flows into the Elm Fork of the Trinity in Denton County, and North and South Chambers Creek, which flow east from eastern Johnson County to a confluence with Richland Creek in southeast Navarro County, and thus eventually to the Trinity River in northern Freestone County.

Figure 2–29: *Extent of the Trinity River drainage basin.*

2.3.2.1 Stratigraphy and Geomorphology of the Trinity River

As mentioned previously, fundamental stratigraphic research in the Trinity basin performed by Reid Ferring of the University of North Texas forms the basis of current understanding of the system. There were older studies in place when Ferring began his work (e.g., Patillo 1940; Taggart 1953; Hendricks

1957; Crook and Harris 1957; Slaughter et al. 1962), but most are not particularly helpful for providing a landscape context to archeological studies. For example, in addition to his discussion of the Brazos, Hendricks (1957) also addressed the Trinity basin in his monograph on the geology of Parker County. Unfortunately, the treatment was perfunctory and exclusively morphological, noting the presence of flat-lying valley fills with one distinct terrace surface separated from the floodplain by a distinct scarp. Similarly, Patillo (1940) and Taggart (1953) primarily focused on morphology, attempting terrace identification and correlation. The only previous attempt at a comprehensive stratigraphic framework was by Crook, developed in conjunction with the investigation of Lake Lewisville (Crook and Harris 1957). This framework was adopted and in some cases modified by subsequent researchers (e.g., Slaughter 1962). Unfortunately, as Ferring notes, the study exhibits a number of problems, including the identification of different facies and localized soils within a single fill as discrete stratigraphic units, poor temporal control, and the inclusion of a number of inaccurate radiocarbon results due to the presence of lignite in cultural features.

In a series of publications, Ferring (1990a; 1990b; 1991; 1994a; 1995; 2000; Ferring and Yates 1997) developed the overall alluvial stratigraphic framework for the Trinity system in detail, and formalized a number of stratigraphic units and marker soils in the sequence (Figure 2–30). Morphologically, he identifies three terraces in the upper Trinity basin. The highest of these is the Stewart Creek terrace, which consists of a series of dissected high surfaces that Ferring correlates with the Marsalis terrace of Taggart (1953) and the Buckner Home terrace, Hackberry Creek terrace, and Travis School terrace of Slaughter et al. (1962). Ferring (1994a:33) suggests that the Stewart Creek terrace may actually represent a complex of more than one terrace that has been rendered indistinct through dissection, and identifies 130–145 ft (40–44 m) as the typical height of the terrace above the modern channel. Alluvium underlying the Stewart Creek terrace(s) is defined as the Irving alloformation, which consists of up to 8–10 m of heterogeneous, gravelly to loamy alluvium supporting a very strong soil with an argillic horizon up to 3 m thick. No ages are available for the unit, although Ferring infers that the deposits are of pre-Wisconsinan age based on landscape position and soil development.

The next lowest terrace, termed the Hickory Creek terrace, consists of a broad, level surface that is extensive in the main stream and extends up most of the major tributaries. Ferring correlates it with the Love Field terrace of Shuler (1935) and Taggart (1953) and the Lewisville terrace of Crook and Harris (1957). Ferring (1994a) notes that the broad Hickory terrace is only lightly dissected, and often occurs as a paired terrace that is typically wider on the west or north side of the stream. Because the regional gradient of the terrace is lower than the

Figure 2–30: Generalized stratigraphic model of the upper Trinity system, after work by Ferring.

active Trinity channel, elevation above the stream is not constant, increasing from roughly 11 m above the floodplain (18+ m above the stream) above Lake Ray Roberts to 21 m above the floodplain (30+ m above the stream) at Dallas Love field. Alluvium underlying the Hickory Creek terrace is defined as the Coppel alloformation. It consists of a generally fining-upward sequence of alluvial gravels, sands, silt loams and clay loams that support Mollisols, Vertisols, and Alfisols. The Mollisols and some of the Alfisols are characterized by well-developed argillic and nodular Stage II calcic horizons with leached matrices, while Alfisols developed in sandier facies tend to be decalcified and exhibit thick argillic horizons and ferromanganese concretions. Thickness of the fill is variable, but typically exceeds 8 m, and the unit rests on a wide, buried bedrock bench that is 4–8 m above the bench supporting the next lower terrace (based on figures in Ferring 1994a). Using stratigraphic and soil development criteria, Ferring interprets the Coppel alloformation as a time-transgressive deposit spanning the middle Wisconsin, with the oldest deposits occurring at depth in the downstream reaches, and successively younger deposits occurring with elevation and with distance upstream. Ferring believes that aggradation lasted more than 10 ka, and was terminated by renewed downcutting around 30 ka.

The next terrace surface, or complex of surfaces, is termed the Denton Creek terrace by Ferring (1994a; 2000). Unlike the Hickory Creek terrace, it is narrow, poorly defined, and difficult to trace along the streams. It averages 3–6 m above the present floodplain (10–17 m above the extant channel). Paired terraces are rarely present, and erosion has made remnants of the surface difficult to distinguish from erosional bevels on the margins of the Hickory Creek terrace based on

morphology alone. However, the sediments making up the fill, termed collectively the Carrollton alloformation, are usually distinctively sandy in comparison to the Coppel sequence. The terrace rests on a bedrock bench that may be above or below the elevation of the extant floodplain. Often, the margins of the terrace were erosionally beveled and subsequently buried by aggradation of the floodplain. Soils developed in the Carrollton alluvium are typically Paleustalfs, and are characterized by a prominent, reddened Bt horizon and moderate to advanced decalcification of the solum. Stratigraphic constraints and radiocarbon ages suggest that aggradation of the Carrollton alloformation began around 30 ka and was terminated by renewed incision sometime before 15 ka, when the subsequent Aubrey unit began to aggrade. Based on the magnitude of that incision, uncorrected radiocarbon ages ranging from 22,130 BP to 20,660 BP obtained from the unit by Willimon (1972), and the suite of available ages from the subsequent Aubrey unit, Ferring believes that aggradation of the Carrollton Formation probably terminated with renewed downcutting around 22–20 ka.

This episode of channel entrenchment was the last major downcutting event in the sequence. The remainder of the Trinity sequence consists of a series of four units stacked in this excavated bedrock trench, demarcated by paleosols and/or significant lithologic changes, and underlying the extensive modern floodplain. The oldest and deepest of these units is the Aubrey Alloformation, which consists of 6 to 9 m of sand and gravel with minor interbeds of marl, muddy alluvium, and lacustrine/ palustrine deposits. Radiocarbon ages from the Aubrey Site indicate that the unit was actively aggrading by 14.2 ka and terminated around 11.5 ka. The upper boundary is marked by a lithologic discontinuity and a weakly to moderately developed, unnamed soil. This

formation is the unit that contains the Paleoindian levels at the Aubrey Site, a deeply buried sequence of occupations studied by Ferring (1989; 1990c; 2001). In general, the Aubrey Formation is rarely exposed, but is recognized from a number of boreholes in the Dallas area (Ferring 1994a). Because of its depth and the paucity of natural exposures, it is unclear whether and to what extent the Aubrey Formation is present in the tributaries, but it clearly exists at a number of localities on the trunk stream. Based on sedimentology and planiform scars inset into the higher surfaces and valley walls, Ferring interprets the Aubrey alloformation as the product of a stream with a substantially greater discharge than at present. In any case, the sedimentary characteristics of the Aubrey fill are very different than the subsequent units, implying a distinct change occurred around 11.5 ka in either the magnitude of stream discharge, the character of sediment supplied to the system, or both.

Overlying the Aubrey unit is the Sanger Alloformation, which consists of 3–4 m (typically) of heterogeneous alluvium dominated by calcareous silt loams, clay loams, and clays. Based on radiocarbon data from a variety of localities, the Sanger formation began to aggrade almost immediately after cessation of Aubrey Formation deposits at 11.5 ka, and continued to aggrade until 7.5 ka to 6.0 ka. As the unit stabilized in the middle Holocene, a paleosol began to develop at its surface, ultimately forming a relatively prominent soil with a thin, truncated A horizon and a thicker Btk horizon with Stage I to Stage II carbonate morphology. This soil, which represents a stratigraphic marker but is occasionally absent due to erosion, was termed the Arlington paleosol by Ferring (1990a). While the term is referenced in some subsequent studies (e.g., Caran 2000; Peter et al. 2001), it is worth noting that most descriptions of the sequence by Ferring (e.g., 1991; 1994a; 1995; 2000) do not use it. The Sanger unit was buried by renewed aggradation around 4.5 ka, terminating pedogenesis. It grades laterally into the valley walls, subsequent channels, or penecontemporaneous to slightly older colluvial/fan deposits (which are not included in the unit definition). Lenses and channel fills containing interbedded massive to laminated clays and marls are occasionally present.

The Pilot Point alloformation represents the last major episode of valley-wide aggradation in the upper Trinity sequence. This fill, which typically overlies the Sanger alluvium, normally varies in thickness from less than 2 m to more than 4 m. It is similar in texture to the Sanger alluvium, with silts and clays dominant except where influenced by sediments derived from local sandy bedrock. The unit is dominated by fine-grained flood basin deposits that have developed an overthickened cumulic soil termed the West Fork soil, which yields ages as recent as approximately 0.5 ka. In a number of places

adjacent to the stream, this soil is buried by alluvium that Ferring (1994a) calls “recent.” Although he doesn’t specify the age more precisely, it apparently dates to the last few hundred years, and in some cases may represent historic alluviation stimulated by Anglo land disturbance. Radiocarbon ages given by Ferring (1994a) for the Pilot Point fill range from 4480 BP through 510 BP, although most (>78%) date more recently than 2.5 ka. Because it is at most shallowly buried, considerably more architectural detail is available for the fill, which is dominated by overbank and flood basin deposits but includes channel fills penetrating into the underlying deposits. Significantly, extensive lateral accretion deposits that would indicate that the Trinity channel was actively migrating across the floodplain, cannibalizing older deposits, are relatively rare. Rather, Ferring’s studies suggest that the channel was either relatively stable or subject to cutoffs and avulsions, depending on the location in the valley. For example, Ferring and Yates (1997) identify two cross-cutting channel complexes that are associated with the Pilot Point fill (Figure 2–31) at the Gemma Site (41CO150) in Collin County. The older of these two channel fills consists of a sequence of cross-bedded to massive packets of silty loams to silty clay loams that accumulated in a dry channel. This unit contains an interstratified sequence of cultural occupations representing repeated occupation of the abandoned channel, which Ferring interprets as a chute cutoff event. As this channel filled, a new channel was cut and quickly abandoned, filling with a sequence of laminated silts and clays laid down in an oxbow lake. Both of these events represent limited forms of stream avulsion, where the channel “jumps” from one point to another without eroding intervening deposits. The extent to which this characterization is valid is quite important from the standpoint of site preservation.

As the aggradation of the Pilot Point unit slowed, the cumulic West Fork soil/paleosol began to form. This soil, which was defined by Ferring (1986), has been used commonly as a stratigraphic marker by archeologists working in the region (e.g., Caran 1990; Ferring 1994b; Cliff et al. 1999; Burson et al. 2000; Huhnke and Wurtz 2004; Lintz et al. 2008). It typically consists of an overthickened, very dark gray clay loam A horizon within what is typically a dark gray alluvial fill, and represents the highest (and often only visible) paleosol in the sequence. Soil development is not particularly pronounced, but weak structure, carbonate films and/or filaments, and weak iron–manganese stains and small masses is sometimes present. Often, however, the West Fork soil consists only of a thick (up to 1–1.5 m) accumulation of alluvium containing significantly more organic matter than underlying and overlying deposits. The West Fork soil is sometimes exposed at the surface on the distal floodplain, but is typically buried by up to 2 m of recent deposits in proximity to the stream.

Figure 2-31: Block diagram depicting the stratigraphy of the Gemma site, Collin County.

In his 1994 dissertation, Ferring does not refer to the floodplain paleosols by name, although he does discuss their characteristics at length. Notably, he observes that the soils vary in character considerably based on the depositional facies represented by the parent material. One reason for this is that very fine sands and silts are calcareous, while the clays are largely noncalcareous. Ferring notes that the textural variation in carbonate content, coupled with the typical fining-upward character of deposits, often mimics zones of pedogenic carbonate leaching and enrichment, but stresses that these initial differences are depositional, rather than pedogenic, in origin. He also notes that secondary reorganization of carbonate by pedogenic processes has occurred, and is usually more advanced in the relatively permeable coarse-grained fraction. Floodbasin soils are characterized by relatively high organic matter content, Stage I to weak Stage II secondary carbonate development, ferromanganese staining and small concretions, and intense bioturbation by insects and annelids. Channel facies soils, in contrast, are more carbonate-enriched, and often support well structured soils with Stage II carbonate morphology. Depositional facies exhibit strong control over the character of the profile, even after relatively protracted weathering (Ferring 1994a; 2000).

Caran (2000:A-8) has criticized Ferring's overall alluvial model as "imprecise," arguing that his characterizations of strata underlying the floodplain and the intercalated soils do not accurately represent the true variation apparent in depths, facies, and soil properties. Nevertheless, Caran acknowledges

that "Ferring's stratigraphic and geomorphic models are generally applicable in investigations through most of the upper Trinity River valley."

Similarly, in a series of studies of the Dallas Floodway Project in Dallas County, Autin, Shanabrook and their colleagues (Cliff et al. 1998; 1999) found that the basic stratigraphic framework established by Ferring was valid, but that the thickness and character of the units underlying the floodplain were more variable than Ferring's model implies. In particular, they note that while the extant floodplains of the Trinity and its larger tributaries are broad and level, the depth of the cut valley and the thickness of different fill units is quite variable, implying that the most recent fill covers an older alluvial landscape with considerably more relief and complexity. The valley cross-section prepared by Autin (Figure 2-32) is schematic in character, but illustrates a number of differences with Ferring's model. The most glaring difference is the stratigraphic position of the Carrollton alluvium, which Autin places at the base of the deepest channel trench with the subsequent Aubrey alluvium instead of resting on elevated straths, as Ferring's model does (cf. Figure 2-30).

Hall (Lintz et al. 2008) examined the West Fork Trinity sequence at site 41TR170 in southwestern Fort Worth. Hall's examination focused on cultural materials and stratigraphy in the upper two meters of the Clear Fork floodplain fill, including the West Fork paleosol. Although the depth of investigation was limited, Hall identifies three "pre-paleosol" alluvial units, the West Fork paleosol, and one "post-paleosol" unit at

adapted from Figure 4, Cliff et al. 1999.

Figure 2–32: *Stratigraphic model of the Trinity system in the Dallas area based on the work of Autin & Shanabrook.*

41TR170. All three units were exposed in trenches excavated less than 2 m into the floodplain. Based on the exposure in an adjacent artificial channel, Hall suggests that the entire sequence is on the order of four meters thick (see Lintz et al. 2008). The oldest unit consists of rounded limestone gravels weakly to moderately cemented by carbonate. Hall interprets this unit as a truncated Pleistocene fill, and tentatively correlates it with the Coppell Alluvium of Ferring's sequence. The other two units underlying the paleosol, in presumed age order, Hall terms the "yellow clay" and the "gray clay." The yellow clay consists of a massive, occasionally pebbly, yellowish brown (10YR5/6) silty to sandy clay. It was only observed resting on top of the cemented gravel unit, and contains poorly developed carbonate filaments in the lower part. One radiocarbon age of 2910 BP was obtained from bulk sediment collected near the base of the unit. The gray clay consists of massive, grayish brown (10YR5/2) silty to sandy clay, and grades upward into the West Fork paleosol. Two radiocarbon ages on detrital charcoal from this unit yielded ages of 2360 BP and 1640 BP. Hall uses this information to infer that an unconformity dating to approximately 2500 BP exists between the two clay units.

Although this interpretation may be correct, it is worth noting that the Hall's stratigraphic reconstruction is not consistent with the basic unit geometry of Ferring's model, nor is it the only interpretation possible. If we set aside the solitary humate age from the yellow clay for a moment and consider the broader stratigraphic setting, several alternate interpretations are possible. Hall's interpretation posits

several inset units of very different ages in the shallow subsurface, while Ferring's model suggests that while the Carrollton Alloformation may be above or below the extant floodplain surface, units deposited in the time period between the Carrollton and the Pilot Point Alloformations should be deeply buried beneath the floodplain. Instead of a distinct unit, it is possible that the yellow clay is a fine grained facies of the same fill represented by the cemented gravel. Although the clay and gravel are separated by an abrupt boundary, such boundaries are common in aggrading streams and do not necessarily represent appreciable temporal unconformities. Hall correlates the gravel unit with the Coppell alluvium, although given the typical elevation of the Hickory Creek terrace bedrock bench underlying the Coppell unit, the latest Pleistocene Carrollton alluvium seems a more likely candidate (see Figure 2–30). None of the trenches excavated during the project contained both the yellow clay and gray clay units in the same trench. In the two trenches that contained the yellow clay, the unit was separated from the overlying West Fork soil by a gravel-mantled erosional surface, while the gray clay clearly grades up into the paleosol.

Hall notes that the West Fork soil is a cumelic floodplain soil "largely devoid of pedogenic features, such as clay skins or clay accumulation, blocky or ped structure, or secondary carbonates" (Lintz et al. 2008:48). He suggests it formed through slow aggradation of the floodplain surface, and owes its massive character to bioturbation by burrowing insects, snails, and earthworms. Hall stresses that a soil should be considered a paleosol not because it is buried, but because

it reflects the product of a specific, former soil-forming environment. Hall also argues that while precipitated carbonate (primarily filaments along root traces) is present in the sequence, these features are “probably derived from dissolution of calcareous clasts in the fine sediment and transported by groundwater in the more permeable alluvium beneath the less permeable clayey paleosol” and therefore “not related to soil forming processes” (Lintz et al. 2008:49). In the author’s opinion, this latter argument is an example of a conceptual problem that arises from the almost exclusive acceptance of the “*per descensum*” model of soil carbonate accumulation as the only legitimate mechanism of carbonate accumulation in soils, coupled with an unrealistically sharp distinction drawn between “pedogenic” and “groundwater” carbonates that arises from this concept (e.g., Birkeland 1984; West et al. 1988; Nordt et al. 1994; cf. Abbott 2001b). The carbonates Hall describes are filaments associated with fine roots, their position and aspect in the profile is consistent with Bk horizons in the Southern Plains and Central Texas. There is little evidence of prolonged saturation in the underlying sediments, and it is therefore difficult to support Hall’s argument that groundwater (rather than vadose soil water) was responsible for the delivery of the precipitated carbonate. However, even if groundwater was the primary carbonate delivery conduit, because precipitation of the carbonate salts occurred in conjunction with water uptake by roots in the soil zone, it can be argued that the resulting precipitates are the result of pedogenic processes.

Only one locality was examined in any detail on the Trinity trunk streams during the current study. A series of four hollow-auger cores were recovered, described, and sampled from the West Fork Trinity River where it is crossed by US Highway 281, in northwestern Jack County (Figure 2–33). This locality is situated considerably upstream of Ferring’s main study area, in the northwestern corner of the Fort Worth District (see Figure 2–8), and therefore provides an opportunity to evaluate the consistency of the sequence through the district. At this locality, the Trinity River is situated at the southern margin of the Holocene valley fill, which is roughly 300 m wide. On the south side of the river, a low sandstone bench capped with an older alluvial fill is present. The sandstone bench is well-exposed in the cutbank, suggesting that the river is continuing to migrate slowly to the south, eroding the bedrock bank as it goes. Both the Holocene floodplain and the older surface dip gently toward the river, and grade gradually into moderately-sloping colluvial deposits upslope.

Although the limited number of cores from the US 281 locality does not provide a particularly robust sample, each core was able to penetrate through the valley fill into the underlying bedrock. One core was placed on the low, alluvially-mantled bench south of the river, while the other three cores were

placed in a transect across the Holocene alluvial surface north of the river. All four cores were excavated in the existing ROW of US 281. The bench fill, which correlates with Ferring’s Carrollton alluvium, consists of an erosionally-beveled Alfisol developed in approximately 2 m of rubified sandy sediment, and forming a sloping terrace surface approximately 7–12 m above the stream. Colors range from 7.5YR hues in the subsoil to 5YR and 2.5YR hues in the soil, which is characterized by an A–Bt–B2–Bg–C profile capped by a thin veneer of gray-brown sandy slopewash. Although no ages were obtained from the fill, its appearance, texture, and stratigraphic position are consistent with the Carrollton Alloformation (Ferring 1994a), and it is interpreted as a Late Pleistocene deposit with little potential to contain cultural material in primary context.

At the time that the Carrollton terrace was abandoned by renewed incision, the stream was apparently on the northern side of the valley. As it incised, it also migrated to the south, cutting progressively deeper into the substrate (ingrown meandering). Ultimately, the incising channel cut up to 16 m into the underlying bedrock before beginning to aggrade again. Because of this progressive incision, the depth that bedrock was encountered beneath the sloping floodplain varied from approximately 3 m bgs on the northern side of the valley to more than 14 m bgs in the more axial part of the valley. Consequently, the most complete sequence was recovered from the core closest to the stream.

As both Ferring and Hall have suggested, the entire Holocene sequence on the Trinity represents a gradually accreting series of stacked deposits where the distinction between sediments and intercalated cumelic soils can be relatively subtle. Organisms have affected the entire column to varying degrees, primarily by turbating the sediment and contributing organic matter. Texture and bulk carbonate values do vary, but owe as much or more of this variation to the characteristics of the primary deposits as they do to changes introduced by soil processes. Accordingly, while soils embedded in the sequence represent periods of relatively slower aggradation, it is a subtle difference indeed between these soils and the overbank sediments in which they are developed. Differences between depositional units are similarly subtle, because the preserved soil forming intervals that separate them appear to represent periods of reduced sediment influx rather than unconformities related to channel entrenchment. There is at least one apparent phase of surface erosion, which removed the soil developed at the top of the Sanger fill.

Age control at the US 281 locality is provided by a series of nine ages on sediment organics and finely-divided charcoal from Core 1 and Core 4. Basal ages were taken on sediment from dense clays resting on bedrock in both cores, and yielded

Figure 2–33: Stratigraphy of the West Fork of the Trinity at US 281, Jack County.

nearly identical ages (10.3 and 10.1 ka, respectively), despite the fact that they differed in elevation by nearly four meters. This suggests that the deposits were laid down as a dipping floodplain draping the cut bedrock surface. These two samples are broadly consistent with the stratigraphic context of Ferring's Aubrey alluvium, while the ages fall in the earliest phases of the subsequent Sanger unit. It is unclear which is represented, but there does not appear to be a thick, coarse-grained deposit representing the Aubrey unit preserved at the locality unless it is restricted to the southernmost part of the incised channel trench. However, the deepest part of Core 1 included a very dark grayish brown (10YR 3/2) clayey paleosol, which graded up into brown (7.5YR) hues, then the yellowish brown (10YR) hues typical of the overlying Sanger unit. This dark paleosol may well represent the final overbank phases of the Aubrey fill spreading out on the margins of an asymmetric channel trench.

The basal clays in Core 1 are capped by a 6 m sequence of sands, loamy sands, and sandy to silty clays that appears broadly equivalent to Ferring's Sanger alluvium. This unit is approximately 6 m thick in Core 1 and 4 m thick in Core 4. Colors are dominantly in the yellowish brown (10YR hue) range. Core 1 grades up from approximately 2.5 m of saturated fine sands into mottled clay loams cut with thin sandy beds. Core 4, in contrast, coarsens upward, grading from redox mottled clays to planar bedded medium and fine sands with interbedded stringers and lenses of gravel. This suggests that the channel complex migrated north during aggradation of the unit. As is often the case in saturated sands, recovery in the core barrel was limited, because the sands simply flow back out as the core was withdrawn. Almost none of the sands in core 1 were recovered, while only the upper half of the two meter channel sequence was recovered from Core 4. Ages from the Sanger fill range from 9670 BP on sediment from immediately above the channel sands (approximately 9 m bgs) to 5980 BP on sediment from the top (approximately 6 m bgs) of the presumed Sanger fill in Core 1. An intermediate age of 7440 BP, also on sediment, was obtained from the upper part of the channel sequence in Core 4.

No soil is present at the top of the Sanger sequence in either of the cores. This, coupled with the fact that the channel sequence in Core 4 sits a meter or more higher than the top of the sequence in Core 1, suggests that the stream shifted south and incised into its alluvium as the Sanger fill episode waned. This incision permitted erosion of the floodplain margin, beveling the terrace surface prior to aggradation of the subsequent Pilot Point unit. Available dates suggest that the Sanger unit aggraded from approximately 10 ka to sometime after 6 ka, which is slightly later than Ferring's ages for the unit.

By approximately 3.2 ka, the next fill had begun to aggrade on top of the Sanger unit. This fill, which is distinguishable primarily on the basis of color change to browner sediments (predominantly 7.5 YR hues), consists of a number of relatively thin, stacked packets of silty to sandy clay with interbedded packets of muddy sand. It is tentatively correlated with Ferring's Pilot Point alluvium. In Core 4, deposits of the Pilot Point fill appear to extend to the surface, where they are disturbed by highway construction. Although undated, the deposits of Core 3 upslope are similar and are believed to also represent the Pilot Point unit.

The muds and sands of the Pilot Point alluvium appear to have accreted relatively rapidly, based on ages of 3190 BP and 3010 BP obtained from depths of approximately 3.1 m and 1.4 m in Core 4, respectively. However, the deeper of these two ages was on dispersed charcoal, while the shallower age was on bulk sediment organics. As described below, very similar ages were obtained on another pair of charcoal and humate samples from Core 1, where they are separated by a moderately developed clayey paleosol. In Core 1, the shallower of the two dates is clearly too old, probably due to the incorporation of allogenic organic matter; it follows that the upper sample in Core 4 may also be too old.

The sequence in Core 1 consists of almost six meters of similar deposits which again consist of relatively thin, stacked packets of brown (7.5YR hues) silty and sandy clays with interbeds of loamy fine to medium sand. Overall, they are not readily distinguishable. However, the sequence includes a relatively prominent paleosol at approximately 3 m bgs that is not present upslope in BT4. This paleosol is tentatively interpreted as the local equivalent of the West Fork paleosol. If so, it marks the top of the Pilot Point in Core 1, and the upper three meters of Core 1 consists of a wedge of recent deposits. However, this soil yielded an age of 2840 BP on finely-divided charcoal, which is about a thousand years too early for Ferring's West Fork paleosol. The picture is further complicated by a stratigraphically reversed age of 2960 BP on sediment organics obtained from approximately a meter below the natural ground surface in the same core. Given the imprecision inherent in sediment ages (Abbott 1997b; Abbott and Frederick 2003; see Section 2.2.1.3), it is likely that this age reflects reworking of soil organic from upstream in the drainage. Still, given the similarity between the ages obtained from the upper four meters of Cores 1 and 4, the possibility exists that the entire sequence above approximately 6 m represents the Pilot Point fill, and the presumed West Fork paleosol actually represents localized ponding in a swale on the aggrading floodplain. If so, then there is no equivalent of Ferring's West Fork paleosol at the US 281 crossing.

Despite the remaining ambiguity in the latter part of the sequence, the cross-section at US 281 does demonstrate

several points. First, there are arguably deposits that are broadly equivalent to each of Ferring's post-Coppell units preserved at the extreme western side of the district, although the extent of both the Aubrey and post-Pilot Point deposits is less than clear based on the few cores taken. Second, the architecture of the West Fork is also relatively consistent across the district, with Holocene deposits stacked in a deeply incised, narrow channel trench. This suggests that alluvial sites older than Late Archaic should be deeply buried beneath the floodplain and rarely encountered in the Trinity trunk system. Low terraces overlooking the floodplain are Pleistocene in age, and therefore should have the potential to host sites from all cultural periods, albeit as near-surface palimpsests with little integrity potential except where they are stratified in colluvium.

2.3.2.2 Stratigraphy and Geomorphology of the Trinity System Tributaries

A number of Trinity River tributaries have been examined and documented to varying degrees by geoarcheologists and alluvial stratigraphers. In southeastern Tarrant County, Collins (1988) conducted geoarcheological reconnaissance in the valley of Walnut and Mountain Creeks in conjunction with the construction of Joe Poole Reservoir. This investigation, which was explicitly designed to locate buried sites and to characterize the alluvial stratigraphy, resulted in the identification and description of the alluvial valley fills, but identified few buried sites. In order to characterize the system as a whole, Collins elected to focus on a discrete number of localities, which were described and minimally dated. Both streams are north-flowing tributaries of the Trinity system, and occupy what Collins calls mature valleys with extensive alluvial surfaces. Despite this similarity, Collins found that the two systems had very distinctive fills, with Walnut Creek characterized by well-stratified, silty and sandy deposits, and Mountain Creek by poorly stratified, clayey deposits. This difference almost certainly reflects the lithology underlying the drainages, which consist of Woodbine Formation sandstones and Eagle Ford Formation clays and marls, respectively.

Collins identified two generalized alluvial surfaces in the study area: a series of high terraces along the valley margins at an elevation approximately 20 m above the stream, and a single Holocene surface averaging 5–7 m above the stream. The Dallas sheet of the Geologic Atlas of Texas (Barnes 1988) also maps two surfaces upstream and downstream of the reservoir, including a Holocene ("Recent") fill approximately a kilometer wide and a Pleistocene surface in excess of three kilometers wide that is equivalent to Ferring's (1994a) Hickory Creek terrace. Examination of the Britton, Texas USGS 7.5 minute topographic map, published prior to reservoir construction, indicates that the elevations of

these surfaces are consistent with Collin's description. While remnants of these high Pleistocene terraces are mapped upstream of Joe Poole Reservoir in the Walnut Creek drainage, none are mapped in the Mountain Creek drainage.

Working without benefit of Ferring's stratigraphic model for the Trinity system, Collins assumed that the system would have the type of inset fill geometry typical of streams in Central Texas, and designed his trenching program to prospect for such inset units. When he was unable to locate older units near the margins of the valleys, he concluded that deposits of Paleoindian through Middle Archaic age were either rare or deeply buried. Although limited, enough chronometric information was collected to lead Collins to conclude that the project area as a whole had experienced "massive" alluviation over the past three millennia. The principal exception to this was a spatially-limited deposit of dense black clay found in the Walnut Creek valley that was dated to between approximately 6 ka and 1 ka. Collins interprets this deposit as a local lake, possibly formed by a log-jam or other obstruction of the stream, which persisted for more than 5,000 years. However, given that this tentative conclusion is based on only three radiocarbon ages on humates, two of which dated to roughly 1 ka and one of which dated to approximately 6 ka, this conclusion must be considered tentative, as it seems equally likely that the one old age is erroneous. In any case, the persistence of an active log-jam for five millennia seems extremely unlikely, even with the periodic addition of reinforcing tree-falls.

Downstream in the Dallas District, Frederick examined the valley stratigraphy of Rowlett Creek, a tributary of the East Fork of the Trinity (Figure 2–34; see Tinsley and Dayton 2009). Interestingly, Rowlett Creek exhibits laterally-inset alluvial architecture, suggesting that the deep incision of the Trinity system may not have been transmitted upstream through the tributary systems. Although the overall dating of this sequence is limited, with all available chronometric ages recovered from a small archeological excavation block, the basic stratigraphic interpretation is reliable, and demonstrates that not all streams in the Trinity system exhibit stacked, "layer cake" stratigraphy.

Denton Creek

Denton Creek is a moderately incised, perennial tributary of the Trinity River. It originates in west-central Montague County near the town of Bowie, and flows southeast through Wise, Denton, Tarrant, and Dallas Counties to its eventual confluence with the Elm Fork of the Trinity River in the Dallas subdivision of Carrollton. Denton Creek was examined at the crossing of US 380, in east-central Wise County. The upper reaches of the system drain the

Figure 2–34: *Stratigraphy of Rowlett Creek, based on work by Frederick.*

Lower Cretaceous Antlers Sand, but approximately 7 km upstream of the crossing, Denton Creek flows up-section out of the Antlers formation and into the more confining Goodland Limestone and Walnut Clay (undivided). As a consequence of the transition to this relatively resistant lithology, the Holocene valley fill constricts considerably, narrowing from approximately 1.5 km to as little as 0.2 km immediately downstream of the crossing.

Figure 2–35 illustrates peak discharge vs. water elevation for a stream gage near Justin, TX, some 21 km downstream of the US 380 crossing. Approximately 15 relatively large overbank (>8,000 cfs) events were recorded at the Justin gaging station during the 48-year period of record, and a similar number of near bank-full events (approx. 5,000–8,000 cfs) are recorded during the same period. Given the marked constriction of the valley downstream of the study area, it is certain that many of these latter events also overtopped the banks in the vicinity of US 380. Accordingly, the potential for site burial on the floodplain is relatively high.

Trenching of the Denton Creek floodplain was conducted in the existing ROW of US 380 in October, 1999 (Abbott n.d.(d)), and compliments observations made outside the ROW by Ferring (1994a; 1995). This area is adjacent to the Dodd Pit Site, a prehistoric site stratified in eolian sands that was first recorded by Olin McCormick in the early 1970's. Stratigraphic research conducted at the Dodd Pit site by Ferring has appeared in a variety of venues, including his dissertation on

the upper Trinity system (Ferring 1994a) and a special geoarcheological volume published by the Geological Society of America (Ferring 1995) (Figure 2–36). The Dodd Pit Site sequence consists of a local accumulation of four meters or more of eolian sand resting on a Pleistocene terrace of Denton Creek. Ferring points out that the local bedrock consists of Cretaceous carbonates, and that the source of the sand is clearly the Denton Creek channel. Ferring maps two Pleistocene and one Holocene surface in the valley. Although he does not explicitly correlate these surfaces with his overall sequence, the alluvium underlying the older Pleistocene surface (Qa) is interpreted as a middle-late Pleistocene fill, presumably the Coppel

Figure 2–35: *Peak discharge of flood events on Denton Creek near Justin during the period of record.*

Figure 2-36: Stratigraphy of Denton Creek at the Dodd Pit site, after Ferring 1994.

alloformation, while the younger, inset Pleistocene terrace surface (Qb) is underlain by a late Pleistocene fill that is presumably the Carrollton alloformation. The sand accumulation is mapped on the lower of these surfaces, suggesting that it began to accumulate after the terrace was abandoned by incision around 18–15 ka. The floodplain is underlain by two discrete units, separated by a buried paleosol. Although not stated explicitly, Ferring implies that the older of the two units, which dates to the early–middle Holocene, is equivalent to his Sanger alluvium, while the younger dates to the late Holocene and is equivalent to his Pilot Point alluvium.

The current stratigraphic examination revealed a sequence that is broadly similar to Ferring’s overall stratigraphic model for the upper Trinity system (see Ferring 1994a), but differs somewhat in alluvial architecture and in the timing of periods of aggradation and stability. Figure 2-37 provides schematic profiles of representative trenches, and illustrates an idealized cross-section of the Holocene valley. The oldest stratigraphic unit observed in the trenches is represented by a prismatic-structured, sandy loam Bt horizon detected at the base of BT13, the westernmost trench. Although barely exposed at the base of the trench, this deposit is believed to represent late Pleistocene alluvium equivalent to Ferring’s (1994a) Carrollton alloformation. This fill is locally capped by the thick suite of structureless eolian sands that was exploited by the Dodd Pit sand quarry. These sands are up to 3 m thick in the ROW, even though an unknown thickness of sand appears to have been removed prior to construction. The upper 30–100 cm of each trench has been previously disturbed, but the underlying sediments appear to be reasonably intact and are crossed with relatively widely spaced, thin, brown

clay lamellae. The sands themselves are structureless, suggesting that syndepositional or post-depositional processes destroyed the internal bedding. The lamellae represent post-depositional pedogenic features, and could have developed considerably after the time of deposition. One of the striking things about the sands is a distinct tendency for them to be increasingly light colored at depth with distance from the stream, grading from pale brown (10YR 6/3) in BT11 to very pale brown (10YR 7/3 in BT12; 10YR 8/2 in BT13). It is unclear if this trend relates to the age of the sediments, their distance from the source, or some other

factor, but the concentration of fine clastics and oxides that give quartz sands color apparently varies across the deposit.

The age of the sands are poorly constrained; their maximum age is the post-Carrollton period, while Ferring’s age of 525 BP from cultural material stratified in the upper dunes demonstrates that the deposit was continuing to accrete well into the late Prehistoric period. Given the nature of eolian processes, it is unlikely that the sands accumulated continuously, as aggradation would depend on the fortuitous delivery of the right type of sediment, limited vegetation to facilitate transport, and conducive wind patterns (see Section 2.3.5). It is worth noting that while the texture of preserved deposits on the modern floodplain are somewhat diverse, clays are dominant and none of the deposits are a potential eolian sand source of any consequence. This suggests that active eolian movement would not be occurring if the area had not been disturbed by quarrying and agriculture. At the same time, it must also be noted that the sand sheet itself does not contain stacked soil horizons indicative of a punctuated pattern of deposition. In fact, Ferring identifies only one buried soil in the eolian sequence, and suggests that it is probably of Pleistocene age (1994a:89). It therefore seems that eolian deposition was either continuous enough to keep paleosols from forming, or the sand sheet experienced disturbances or deflation that destroyed them.

The next oldest alluvial unit is present only on the east side of Denton Creek in the US 380 corridor. It consists of a subtle buried clay paleosol with prominent slickensides, ferromanganese mottles, and common soft masses of carbonate. It appears to represent the top of the Sanger alloformation (the Arlington soil), and equates to the buried

Figure 2-37: Stratigraphy of Denton Creek at US 380.

soil noted downstream at Ferring's Denton Creek #1 locality. A radiocarbon age of 5420 BP was obtained on organic sediment from the soil, while Ferring had previously obtained ages of 6410 BP and 8510 BP from the underlying fill at the Denton Creek 1 locality. These ages are consistent with the previously defined age of the Sanger alloformation, which ranges from approximately 11.5 ka to 4.5 ka.

Overlying the Sanger alloformation are sediments representing Ferring's Pilot Point alloformation. The Pilot Point unit accumulated between approximately 4.5 ka and 1.8 ka, with slowed aggradation resulting in the formation of the cumelic West Fork soil thereafter (Ferring 1994a). In the study area, the Pilot Point fill subsumes a sequence of deposits and weak intercalated soils that probably reflect localized activity. On the eastern side of the stream, the unit is represented by clayey flood basin alluvium supporting a calcic soil with vertic properties. With the exception of eolian (and reworked eolian) sands, the deposits on the west side of the stream all represent deposits that fall within the temporal range of Ferring's Pilot Point alloformation. However, the deposits exhibit a complex stratigraphy with considerable architectural and facies heterogeneity, including several intercalated soils. This sequence is constrained by four radiocarbon ages (see Figure 2-37). Architectural features include a prominent swale fill and two discrete buried soils. Based on its dimensions (as judged based upon surface expression), depth, and the presence

of bedded gravels at depth, the swale probably represents a former main channel of Denton Creek. A radiocarbon age from immediately above the gravel in the base of the channel swale demonstrates that the former channel was abandoned and beginning to fill in with sandy clay by 1740 BP. This event isolated and subsequently buried a remnant of the aggrading floodplain between the former channel and the current one, sealing a remnant of the point bar surface with a paleosol dated to 2140 BP. After the avulsion, both the former channel and the current channel appear to have aggraded rapidly as the stream migrated eastward. Stratigraphically-reversed ages of 1600 BP and 1490 BP were obtained on sediments recovered from depths of 1.1 m and 3.3 m, respectively, in channel-proximal deposits. Because organic matter in soil storage is older than contemporary organic matter in the system, such reversals are often indicative of the onset of episodes of landscape instability that lead to rapid channel aggradation (Abbott 1997b).

On both sides of the stream, the floodplain is capped with a thin (typically < 1m) deposit of clayey alluvium that probably correlates with Ferring's "recent" deposits. These deposits overlie the West Fork paleosol or grade down into Pilot Point deposits, and grade laterally into a veneer of reworked eolian sands that have expanded from the margins of the sandsheet onto the terrace, filling the swale. The suite of natural deposits is capped in turn by disturbed and reworked construction spoil that varies considerably in thickness.

The Denton Creek cross-section is important for several reasons. First, it provides one of the best example of archeologically-relevant eolian environments known in the district, even though most of the intact deposits are located well outside the US 380 right-of-way. Second, it suggests that Ferring's alluvial sequence—and particularly the layer cake stratigraphy of his Aubrey through recent units—may be too simplistic a model in the tributary network. While the basic timing of major episodes of alluviation and stability does seem viable, these units exhibit geometries and contain local soils and erosion surfaces that make them far more complex than Ferring's model implies. Although this is a somewhat unfair characterization—Ferring's purpose was to discern major trends, and excessive focus on local variability distracts from that goal—it does have important implications for use of the stratigraphic model for effective geoarcheological planning, particularly at the level of an individual site.

Willow Creek

Willow Creek is a north-flowing tributary of the West Fork of the Trinity in southwestern Wise County. It drains terrain underlain by the lower Cretaceous Twin Mountains Formation, which provides sands, muds, and gravel to the system. Willow Creek was documented at the crossing of Wise County Road (CR) 3850, where deep, headward-cutting erosion had turned the roadside ditch into a gaping chasm that provided a striking, albeit partial, cross-section of the Holocene Willow Creek terrace. Because the locality was encountered in the late afternoon on the last day of that

particular reconnaissance session, the initial recording of the Willow Creek section was conducted relatively quickly, and consisted of drafting a quick stratigraphic cartoon of the exposure and sampling of exposed units for radiocarbon. A follow-up visit was planned to record detailed unit descriptions, but unfortunately construction of the bridge destroyed the section before this could be accomplished. Consequently, the few notes made on the first visit are all that are available.

This is unfortunate, because like the US 380 crossing of Denton Creek, the Willow Creek section also provides an indication of stratigraphic complexities not captured by Ferring's overall model. The exposure revealed a minimum of four stratigraphic units (Figure 2–38) dominated by sands and sandy loams. The oldest unit (Unit 1) was exposed approximately 5 m bgs at the back of the gully and at similar depth in the opposing cutbank, and was a minimum of 3 m thick. In the fresh cut at the back of the gully, it exhibited a dark red color (although no Munsell colors were recorded, the impression was of 5YR to 2.5YR hues) and a weak to moderate prismatic structure, while the weathered cutbank was similarly structured but was a much lighter pinkish gray color. Because of the color difference, the two units were initially interpreted as two discrete units in the field, with the dark red unit believed to be a Pleistocene fill. However, they yielded ages less than a thousand years apart (9130 BP and 8220 BP), with the darker red exposure the younger of the two. Given their stratigraphic context and the ages obtained, they are currently believed to represent the same fill.

Figure 2–38: Stratigraphy of Willow Creek at Wise County Road 3850.

The next unit (Unit 2) consists of a fining-upward sequence that grades up from trough cross-bedded fine sands and silts to structured loams. The crossbedded deposits are restricted to a relatively narrow channel trench incised into the underlying unit (while not measured, it probably does not exceed 25 m wide). These channel deposits grade up into structured loams that extend to the east, overlapping Unit 1. The unit is at least 6 m thick, with the channel facies making up at least 3 m of that thickness and a prominent dark paleosol with an A-Bw profile developed at the top. Two radiocarbon ages were obtained from Unit 2 (see Figure 2–38). A sample taken from the transition between the channel and overbank facies yielded an age of 6160 BP, while a sample from the capping paleosol yielded an age of 760 BP.

Unit 2 is capped by Unit 3 on the eastern side of the stream, while in the cutbank exposure on the western side, Unit 2 is absent, and Unit 3 rests directly on Unit 1. Where it caps Unit 2, Unit 3 is divided into two subunits (3A and 3B) separated by a weak (A–C profile) paleosol. Subunit 3A consists of a tabular package of yellowish brown sandy loams approximately 50–70 cm thick. This unit, and the upper part of Unit 2, is laterally truncated by Subunit 3B, a wedge of yellowish brown laminated silts and fine sands that supports a weak soil with an A–C profile. On the west side of Willow Creek, Unit 1 is overlain by approximately 5 m of similarly colored silts and fine sands, which are also tentatively interpreted as Unit 3B. Finally, Unit 4 consists of a low, discontinuous floodplain composed of laminated fine sands in the modern channel trench.

The architecture and timing of the Willow Creek sequence is difficult to reconcile with Ferring's model for the upper Trinity as a whole. The ages of 8220 BP and 9130 BP obtained from Unit 1 (see Figure 2–38) fall within the range of the Sanger alluvium, but because they are from near the top of the fill they either document erosional truncation of the unit or an earlier termination of the episode in the local area. The ages from Unit 2, which span the last few thousand years of the Sanger Unit and the entirety of Pilot Point Unit, suggest that the latter explanation is preferable. While it is possible that both ages obtained from Unit 2 at Willow Creek are erroneous—the older age may be too old due to the incorporation of allogenic organic matter, and the younger age probably reflects the mean residence time of soil organics in the paleosol—a simpler explanation is that some of the events driving the stratigraphy of the trunk stream were manifested differently, and possibly at different times, in much of the tributary network. Such situations are not unusual and reflect complex response of a stream system to changes (Bull 1991). Nevertheless, given the stratigraphic position, age, and character of the dark paleosol capping Unit 2, it is likely that this soil correlates with Ferring's West Fork paleosol.

Taken at face value, the Willow Creek sequence documents the accumulation of a rubified sandy to loamy fill (Unit 1) which was terminated sometime in the early to early-middle Holocene by channel incision and subsequent aggradation of cross-stratified sands and fine gravels. At the section, the deposits underwent a transition to overbank loam by approximately 6100 BP, which suggests that an avulsion event that shifted the locus of channel sedimentation must have occurred around that time. Unit 2 continued to aggrade throughout the middle to late Holocene, ultimately slowing sufficiently for a paleosol to develop on the floodplain. Over the last few hundred years, a short period of sedimentation was followed by brief pedogenesis, a cycle of significant downcutting and aggradation, and another period of incision that created the current channel.

Hunt Creek

Hunt Creek is also a north-flowing tributary of the West Fork of the Trinity, and drains into Lake Bridgeport west of Willow Creek (unusually, Hunt Creek is not named on any of the relevant USGS topographic maps, but is identified on TxDOT's county map of neighboring Jack County). Like Willow Creek, it primarily drains rocks of the clastic Twin Mountains Formation and mixed clastic and carbonate rocks of the Pennsylvanian Jasper Creek and Willow Point Formations. It was described and sampled for radiocarbon at the crossing of Castleberry Road (Wise County Road 3701). All work was conducted on existing cutbank exposures. Like Willow Creek, Hunt Creek was identified as a locality of interest because the character and architecture of units seemed at odds with Ferring's general model for the upper Trinity system.

Hunt Creek is a relatively short tributary that joins Boon's Creek before flowing into Lake Bridgeport. It is incised 4–5 m below the level of the principal terrace tread. Much of the incised channel is occupied by alternating gravelly bedforms (Unit 3), while the thalweg includes gravelly bedforms and exposed bedrock. During reconnaissance, it was noted that cutbanks on two sides of the creek exhibited very different profiles (Figure 2–39). On the south side of the stream, a cutbank exposing the convex bank of a meander reveals a stacked sequence of yellowish brown sandy loams and loams with two relatively weak, intercalated grayish brown paleosols. These deposits are designated Unit 2a, 2b, and 2c. In contrast, the opposite cutbank exhibits a much stronger soil developed in strong brown to reddish brown alluvium (Unit 1). Because this contrast indicates the presence of two laterally-opposed (i.e., inset) fill units of very different ages, radiocarbon samples were collected from both fills in an attempt to date the units. This attempt was not entirely successful. While the results of the radiocarbon analyses do

Figure 2–39: *Stratigraphy of Hunt Cree at Castleberry Road, Wise County.*

not support the interpretation, the age on the redder soil is rejected as an indicator of the time of deposition.

Radiocarbon samples on the deepest and thickest unit in the stacked sequence (Unit 2a) suggest that aggradation was ongoing by 4.5 ka, and continued until stabilizing briefly around 1.7 ka, when a moderate cumelic soil developed. This timespan dovetails nicely with Ferring's ages for the Pilot Point alluvium. Since that time, two additional pulses of sediment (Units 2b and 2c), each up to a meter thick, were dispersed across the floodplain, each burying the preceding soil. Both times, the surface stabilized long enough for a cumelic soil to develop. Because the majority of the fill was covered by an inset bar composed of imbricated gravel (Unit 3), only the upper 1.5 m of the reddish unit could be sampled. A bulk sample taken from the B horizon of this soil yielded an age of 1,070 BP. This age is interpreted as a mean residence

age on organics in the soil, and is rejected as an indication of the age of the deposit. At present, the age of Unit 1 deposition remains unclear, although the context and color of the deposit suggests that it is considerably older than 4.5 ka.

Big Sandy Creek and Watson's Branch

Big Sandy Creek consists of a north–south oriented tributary of the West Fork of the Trinity that drains the Antlers Sand terrain of northern Wise County. This area is characterized by sandy soils that are highly susceptible to erosion, particularly when the natural vegetation is disrupted (see Sections 2.3.4 and 2.3.5). Kibler (2003) provides a limited amount of stratigraphic information obtained during an archeological survey of FM 1810 at Big Sandy Creek in western Wise County. A total of 14 trenches were excavated across the broad (approx. 600 m) Big Sandy floodplain, and three additional

trenches were excavated across the mouth of a tributary named Watson's Branch. Trenching was limited to approximately the upper 2–2.5 m of the fill by a high water table. Two of the fourteen trenches exposed sandy sediments interpreted as channel facies, while the remaining twelve trenches exposed sandy loams with a prominent buried paleosol at depths between 126 and 200 cmbs. This soil consisted of a dark to very dark grayish brown clay or clay loam with a moderate blocky to prismatic structure, and varied from approximately 40 cm to more than 75 cm in thickness. A second, less prominent clay soil present in roughly half the trenches was separated from the underlying more prominent soil by 20–30 cm of brown sediment that ranged from clay to silty sand in texture. The surficial unit, a distinctly stratified sequence of sands, sandy loams and sandy clays, is between 80 and 200 cm thick. No chronometric data was obtained during the study, but the degree of soil development and the landscape position of the sequence is consistent with late Holocene age; Kibler argues that the stratified character of the surficial deposits suggests that they are quite young, possibly dating to the historic period.

Kibler does not draw explicit correlations between his Big Sandy sequence and other stratigraphic models developed for streams in the region, nor does his investigation include chronometric data that can be compared with earlier investigations. Nevertheless, the thick, dark paleosol he describes probably represents the local equivalent of the West Fork soil. The weaker soil overlying it is interesting, particularly in light of similar weak soils noted above the presumed West Fork paleosol elsewhere in the Trinity drainage (e.g., Hunt Creek; Willow Creek). This suggests that the soil may represent a short term regional perturbation near the end of the West Fork soil-forming interval, rather than simply a localized anomaly. It is also interesting that this thin soil overlying the West Fork paleosol is not always present in the trench profiles on Big Sandy Creek. While this may indicate localized scour of the floodplain surface, another possibility is that the soil itself is developed in wedges of loamy alluvium deposited non-uniformly across the floodplain, and that the upper part of the West Fork soil essentially bifurcates and rejoins depending on the thickness of the local overbank deposit and the speed of subsequent burial and ongoing pedogenesis. In other words, where overbank deposits were thin, soil development was able to penetrate all the way through the veneer, welding it to the underlying soil, while in areas of thicker deposition it was unable to alter the entire veneer before renewed deposition arrested pedogenesis. Both of these models represent speculation; only broad exposure of the sequence (e.g., in a gravel pit wall) can hope to resolve the question, and such exposures have not yet been located and examined.

Farther upstream, a limited investigation of the Big Sandy Creek floodplain was conducted by Jordan, Price, and Abbott (2001) at the crossing of Wise CR 1790. It also revealed the presence of

thick sandy deposits of very recent age and a dark, clayey paleosol at depth. The study area flanked the main channel of Big Sandy Creek, which at the crossing is on the west side of a broad (approx. 425 m) floodplain. BT1 was excavated on the eastern side of Big Sandy Creek, and revealed approximately 50 cm of massive to bioturbated loamy fine sand overlying more than a meter of soft, ripple bedded to trough crossbedded loamy fine sand (Figure 2–40(1)). A moderately developed A horizon 20–25 cm thick was developed at the surface, but no pedogenic alteration was apparent below it. A prominent small channel fill was present approximately 60–100 cmbs, and the trench was discontinued at approximately 1.5 m bgs. BT2 was excavated on the narrow western floodplain, and BT3 was excavated on the adjacent toeslope. BT2 exhibited a thick (1 m+) surface mantle of weakly bedded to massive loamy sands with subtle color stratification and interbedded stringers of fine gravel. At approximately 110 cmbs, the profile graded abruptly into a buried clay loam paleosol exhibiting an A–AB profile (Figure 2–40(2)). Charcoal recovered from the buried A horizon yielded an age of 140 BP, suggesting that all of the overlying unit is of historic age. Trench 3 was placed on the adjacent toeslope, and revealed a colluvial profile composed of approximately 80 cm of gravelly loam. Little soil development was apparent in the unit, suggesting that the colluvium probably represents the same cycle of historic landscape disturbance responsible for the thick sands in the valley system.

Similar recent deposits were exposed in the floodplain of Watson's Branch at the crossing of Wise County Road 2391 (Abbott n.d.(e)). Here, recent loamy deposits overlie a dark, clayey paleosol in one trench (Figure 2–40(3)), and extended to a depth of more than 2 m in another. Although undated, these thick sediments are also probably historic in age. As detailed in Section 2.3.4, the sandy soils of northern Wise County proved extremely fragile, and erosion from fields was so severe that entire communities were abandoned in the early 20th century (see discussion in Section 2.3.4). Although such erosion is problematic to farmers trying to work fields on the hillslopes, it is equally troubling to their friends and neighbors working fields in the bottomlands where all that eroded sediment ends up. This suggests that archeological materials are likely to be deeply buried in the stream systems of northern Wise County, and that shovel testing is probably not an effective way to locate buried archeological sites in the lowlands here.

Other Localities

As in the Brazos drainage, a number of other projects too small in scope to provide a comprehensive stratigraphic window into local deposits were examined in the Trinity drainage during the course of the project. As at Willow Creek, Hunt Creek, and Rowlett Creek, several of the other tributary streams exhibited alluvial architecture that differs from Ferring's model of the trunk system. One example is in extreme western Tarrant

Figure 2-40: Detail of recent alluvial profiles on Big Sandy Creek (a, b) and Watson's Branch (c). The thick, sandy deposits exposed in these profiles are probably related to agricultural disturbance and gully of fragile sandy soils.

County at the crossing of St. Mary's Creek by Diamond Bar Trail (Abbott n.d.(f)). Here, St. Mary's Creek exposes laterally-opposed depositional units of differing ages. The older of these units, exposed in the cutbank on the north side of the stream and in two trenches excavated in the bridge approach, consisted of approximately 2 m of very dark grayish brown to grayish brown, somewhat gravelly clay loam and silty loam over approximately 2 m of stratified gravels. The fill supports an A-AB-Bk1-Bk2 soil profile with moderate structural development, and grades from carbonate filaments in the Bk1 horizon to fine nodules and filaments in the Bk2 horizon. Based on analogy with other sequences studied in central and north-central Texas (e.g., Nordt 1992; Blum and Valastro 1989; 1992), this degree of soil development suggests that the unit is probably of early-middle Holocene age. The opposite side of the stream was not examined in any detail because the backhoe was too heavy to cross the bridge, but the alluvial surface was almost a meter lower than the north side and appeared to be composed primarily of gravel, suggesting that it represents a much younger inset.

Rapidly aggraded sediments of apparent recent origin were also encountered in other parts of the Trinity drainage, including eastern Jack County, Northern Parker County, and southeastern Johnson County. In Jack and Parker County, these deposits were situated next to small, upland drainages underlying low level or sloping terrace surfaces. The deposits typically consisted of relatively pale sands or loams with ripple bedding or trough crossbedding, although some beds did not exhibit internal bedforms. Reactivation surfaces and mud drapes were also common features,

separating packets of aggraded sediment. Gravels, wood fragments, and a variety of historic-era trash (e.g., glass bottles, metal fragments, car batteries, highway reflectors) were often incorporated in the upper part of the sequence, and provide the best evidence of historic age. Although most of these sequences were not dated, an age of 160 BP was obtained on charred wood recovered from a meter below surface at the crossing of Ash Creek and Newsome Mound Road in northeastern Parker County.

In southeastern Johnson County, a more complex sandy sequence was exposed that represents a somewhat larger fluvial system (Abbott n.d.(g)). Here, four trenches were excavated into a point bar of the South Fork of Chambers Creek. Although this locality is in the Blackland Prairie and the trenched area is mapped as dense Gower Series clay by the USDA (sandy Pulexas soils are also mapped along the creek), the exposed deposits were composed almost entirely of fine sand and muddy fine sand (the locality is situated downstream from an outcrop of the Cretaceous Woodbine Sandstone, and is a good example of the type of sandy riverine corridor described by Dan Prikryl in his review of the original mapping protocol—see Appendix 3). Figure 2-41 illustrates the trench profiles and their location on the point bar.

Two depositional units were identified in the sequence. Differentiation between them was made solely on the basis of color differences reflecting varying pedogenic histories. The sands were either much darker (very dark brown to

South Fork Chambers Creek at FM916

Figure 2-41: *Sandy late Holocene profiles exposed on the South Fork of Chambers Creek, Johnson County.*

black throughout in the case of Unit 2) or redder (brown to strong brown with very dark brown surface soils in the case of Unit 1) than would be expected of the relatively unmodified sands of the Pulexas series, which are typically light-colored, consisting of yellowish brown and brown sands with distinct preserved bedding. No cultural material was noted in any of the trenches. In fact, no clasts or inclusions of any type larger than a sand grain (other than roots) were noted in any of the trenches.

Unit 1 consists of a brown to strong brown (7.5 YR 4/4 to 4/6) deposit supporting a moderate organic soil (A–Bw profile), and represents an older fill unit (in relative terms) preserved in the core of the point bar. The age of Unit 1 is not clear; it has been in place long enough to oxidize to a rich brown color and develop a dark, organic paleosol, but other aspects of soil development (e.g., structural development, clay translocation, secondary carbonate) are limited, and the unit probably dates to no earlier than the Late Holocene.

Unit 2 abuts and drapes across the top of Unit 1, forming a thick fill in proximity to the channel and in a filled swale or paleochannel on the distal point bar. It consists of highly organic loamy fine sand ranging between very dark grayish brown (10YR 3/2), very dark brown (10YR 2/2), and black (10YR 2/1), with thick (20 cm+) bands of subtle color stratification common. This very dark color almost certainly represents considerable incorporated organic matter, and given its quasi-uniform distribution through the profile it is almost certainly inherited in large part from the parent material. Subtle dark lamellae were noted at depth in BT4 (see inset, Figure 2-41), implying that fine materials are infiltrating into the unit in the swale, but it was impossible to examine them in detail because the sediments were saturated and extremely unsafe. Like Unit 1, the age of Unit 2 is not established. However, given the dark color, it is likely that the unit is a consequence of drastically accelerated erosion of upland A horizons from

the Woodbine Fm upstream. The most likely stimulus for such erosion is historic disturbance of the watershed.

2.3.3 Upland and Hillslope Settings

Unlike alluvial systems, no systematic stratigraphic work has been done on upland and hillslope systems anywhere in the Fort Worth District. The terms ‘upland’ and ‘hillslope’ are not standardized in the earth sciences, and the following discussion draws a distinction between upland settings and hillslope settings that differs in some ways from other usages. In this volume, the term “upland” is reserved for high points on the landscape that are both relatively low-gradient and elevated above surrounding landforms, so that there is no ready source of potential colluvial or slopewash sediment. Uplands tend to be planar or convex in form. Hillslopes, in contrast, are gently to steeply inclined surfaces that lie above the stream valley network, and may be convex, concave, or straight in form and erosional, depositional, or stable in character—typically an individual hillslope will include different segments with all these characteristics (see Section 2.2.2.3). Hillslopes provide the transition from uplands to lowlands, and in most of the district, form the majority of the landscape. Note that the key distinction of this operational distinction relates to the surface gradient, and to the resulting opportunity for sedimentation by colluvial and slopewash processes, which are appropriate criteria given the goals of the study.

The term upland is defined somewhat more broadly elsewhere. For example, Bates and Jackson (1984:547) define upland as “a general term for an extensive region of high ground, esp. far from the coast or in the interior of a country” or “the high ground of a region, in contrast with its valleys and plains.” These definitions are both much more expansive than the one used here, and include both uplands and hillslopes as currently defined.

Although the term slope is often used as a synonym for hillslope (e.g., Sparks 1960; Ritter 1978; Derbyshire et al. 1979), Fairbridge (1968:1002–1020) notes that the term ‘slope’ is also used in several other senses in geomorphology, including a restricted sense that refers only to the “angle that any part of the earth’s surface makes with a horizontal datum,” and a general sense that refers to “any geometric element of the earth’s solid surface.” According to this latter usage, every solid surface on the earth, whether level or inclined, subaerial or subaqueous, and natural or anthropogenic, is properly considered a slope, and the study of geomorphology is effectively the study of natural slopes (Fairbridge 1968:1002). Chorley et al. (1984:255) make essentially the same argument: “...taking the word slope in its most general sense, one may consider the entire earth to be composed of

both subaerial and subaqueous slopes of greatly varying inclination, orientation, length and shape.” For this reason, both of these sources (and others; see for example Selby 1993) prefer the term “hillslope” to refer to slope landforms, and that convention has been followed here. However, as with the term *upland*, the meaning of the term *hillslope* varies among users. For example, Fairbridge (1968) defines hillslopes as “the dynamic connection between interfluvial crests (hilltops) and valley bottoms (channels),” while Chorley et al. (1984) define them as “the surface between a drainage divide and a valley floor.” Parsing these definitions, we can see that Fairbridge includes alluvial terraces and landforms outside the active channel in his definition of hillslope, and (arguably) excludes upland surfaces (in the sense used in this volume), while Chorley et al. exclude the valley floor (and therefore valley-floor alluvial landforms), but include everything up to the drainage divide (which includes those surfaces termed uplands here).

Uplands in the Fort Worth district, as elsewhere, generally have little potential to bury and preserve sites with reasonable context. With the exception of eolian environments and local depressions, which are limited in extent (see Section 2.3.5), there are few effective mechanisms of site burial in the uplands, where strongly developed and/or degraded soils are typical. Potential burial processes in operation include bio-sedimentation (e.g., incremental burial by insect/earthworm ejecta [see Section 2.2.2.6]) and localized wash, rainsplash, and gravitational processes (see Section 2.2.2.3). Although it is possible that archeological remains may be fortuitously preserved in the uplands in the Fort Worth District by such processes, the probability of preservation at any particular locality is low, and confident identification of areas worthy of investigation is difficult to impossible.

Colluvial and hillslope settings, in contrast, often do have reasonable potential to bury and preserve archeological sites. Moreover, like alluvial and eolian systems, slope systems often respond to changes in climate (Bull 1991; Selby 1993), and can therefore potentially preserve records of such changes (e.g., Hanson et al. 2004). As with alluvial and eolian landforms, hillslope responses can consist of changes in the rate of activity, the general character of activity (i.e., erosion versus deposition, or sheet erosion vs. gully erosion), or by effectively ceasing activity (turning “on” and “off”). As a consequence, preservation of sites in hillslope settings requires the confluence of cultural activity and active hillslope processes, and can therefore exhibit strong age biases.

A further complication is introduced by the spatial complexity of hillslopes. Unless the area in question is heavily gullied, precise identification of areas with higher or lower potential for burial and preservation of archeological sites is difficult.

The few geoarcheological studies in the vicinity of the Fort Worth District that have addressed colluvial deposits (e.g., Brownlow et al. 1999:30–32; Ferring 2000:15; 17–18) have done so in a relatively superficial manner, concluding that colluvial deposits are present but are so heterogeneous in form and age that generalizations are not possible. For example, the Fort Wolters study by Brownlow et al. (1999) states:

“Ten sections were excavated in the alluvial–colluvial slope landforms. The one unifying characteristic of these exposures is their variability. Sections as close as 60 m differed in terms of sediment color, presence or absence of buried soils, and degree of soil development. Some sections contained soil carbonate as nodules or filaments; some sections contained buried soil horizons; some sections preserved primary sedimentary structures; but most had neither. There was no consistent pattern to the stratigraphy or the soil development in this unit” (Brownlow et al. 1999:31).

While admittedly “broad-brush” and far from comprehensive, observations made during the current study support this

general conclusion. Although exposed slope catenas are relatively rare in the district, where they are visible, they often exhibit remarkable heterogeneity. In some cases, that heterogeneity is somewhat systematic, whereas elsewhere it is considerably less so. Unfortunately, determining where hillslope profiles exhibit systematic (and therefore predictable) variation is far from straightforward.

Figure 2–42 illustrates a slope catena exposed along FM 2210 in the southeastern corner of Jack County, and is an example of a relatively systematic exposure. This catena, which reflects increasing truncation of a moderately–developed Alfisol as one moves upslope, is formed in the relatively soft, fine sandstones of the Paluxy formation. As the figure illustrates, the upslope section exhibits thin profiles, with Ap–BC–Cr and Bw–BC–Cr profiles, while the downslope section preserves more complete A–Bt–Bw–BC–Cr profiles. The argillic horizon pinches out upslope, while it is overlain by a veneer of colluvium on the lower slope. This colluvium, which is almost certainly derived from sheet erosion of the soil upslope, has potential to bury and preserve sites situated on the former ground surface.

SLOPE CATENA, PALUXY FM

Figure 2–42: *Slope catena developed in the Paluxy Fm, Jack County.*

The character of this catena is strikingly similar to examples documented on the Paluxy Formation (and colluvium derived from the Paluxy Formation) in the Fort Hood area (e.g., Abbott 1994c; 1995b; Kibler 2000; Figure 2–43). On Fort Hood, the Paluxy Formation occurs as a thin, discontinuous outcrop around the margins of the valleys, and weathers into soils that are quite distinctive from the soils developed on surrounding limestones, marls and clays of the Glen Rose Formation and Walnut Clay Formation. Charles Frederick and the author first identified the distinctive setting, and noted an apparent affinity that prehistoric inhabitants had for the substrate, during re-evaluation of prehistoric archeological sites on Fort Hood (Abbott 1994c); subsequent studies (e.g., Abbott and Trierweiler 1995; Kleinbach et al. 1999; Mehalchick et al. 2003; Zeidler et al. 2004) have confirmed and further explored the setting and its relationship with the prehistoric record.

As at Fort Hood, the relationships between profiles exposed in the FM 2210 catena suggests that the slope is currently down-wearing. Erosional forces are attacking the upper slope with greater intensity, so that the solum is increasingly truncated as one moves upslope, and reworked soil material is being deposited as a colluvial

wedge on the lower slopes, burying and potentially preserving both the soil A horizon and any associated cultural material in that context. This provides support for the notion that deposition, and therefore site preservation, is more likely on lower slopes, even above the point where a concave profile has developed (the *footslope*). Of course, artifacts may also be a component of the material moving down from upslope, and care must be taken to distinguish between *in situ* and reworked material.

Elsewhere, colluvial deposits and soil are more heterogeneous. Figure 2–44 illustrates representative profiles from a second slope catena that was documented in southeastern Jack County, less than two miles from the FM 2210 locality. Here, there is considerable variability in the thickness and character of the soil along the slope, particularly in the argillic (Bt) horizon. Like the FM 2210 catena, preservation of the soil A horizon is limited to the downslope section, where it is mantled with a veneer of colluvium and slopewash. Unlike the FM 2210 profile, expectations about the character of the soil profile at any point on the slope are difficult to develop, because the thickness of the Bt horizon and the character and depth of the subsoil vary in an unpredictable manner. It should be noted that while there is a relatively uniform recent veneer

Figure 2–43: Idealized profile of the slope catena developed in deposits derived from the Paluxy Formation in the vicinity of Fort Hood, Bell and Coryell Counties, central Texas..

Figure 2-44: Complex catena developed in slope deposits adjacent to Gibtown Road, southeast Jack County.

that caps all of these profiles, it is unclear if it represents a natural deposit or spoil associated with the artificial cut forming the exposure.

Another example of slope variability is provided by a slope catena exposed in a low roadcut along CR 365 in western Erath county (Figure 2-45). Here, the soil catena is developed on the Cretaceous Twin Mountains Formation, which includes crossbedded sandstones, claystone, and thin beds of conglomerate representing terrestrial (fluvial) deposition (Barnes 1972; Rose 2007). As the figure illustrates, there is considerable variability in the soil profile along this slope exposure. The most striking aspect is the degraded sandy calcrete (K or Bkm horizon) that occurs in the upslope profiles (Profile 1–6). Such a mature calcic horizon represents a substantial period of soil formation, and would typically underlie a thick argillic (Bt) horizon in an intact profile. Instead, it is buried by a relatively weak, sandy A horizon (or A–Bk or A–C) that is clearly a later addition. This indicates that the slope formerly hosted a far more mature soil profile that was heavily truncated by erosion. (Interestingly, the USDA–NRCS web soil survey site [<http://websoilsurvey.nrcs.usda.gov/app/>] maps the slope with Bolar, Denton, and Purves series soils, which are relatively shallow soils characteristic of limestone and marl uplands. The epipedon of these soil series range from clay loam and silty clay to clay, while epipedon

of the profiles exposed in the roadcut is sandy. This suggests that NRCS mapping was based primarily on exposure of the shallow calcrete, which was mistaken for limestone).

Examination of the variability of the upslope exposures provides further support for this notion. The character of the calcrete varies from a hard, massive (albeit brecciated) type that is almost white, to a yellow–brown type that is less indurated and contains visible coalescing nodules. Such variability is generally common with depth in K horizons (Birkeland 1984). In most of the documented profiles, the indurated zone either grades into the nodular zone with depth (e.g., Profile 1, Profile 3, Profile 5) or has been removed completely, leaving only the nodular zone (e.g., Profile 2, Profile 4). However, in Profile 6, the hard calcrete grades abruptly into a mottled brown loamy sand with very low amounts of visible secondary carbonate. It is difficult to explain the abrupt transition to this brown sand, which appears to represent weathered bedrock based on its stratigraphic position, although one possibility is that the nodular zone was removed by dissolution associated with lateral groundwater movement.

The brecciation and dissolution of the K horizon in most of the Wise CR 365 profiles is consistent with its exhumation by sheet erosion of the former epipedon, which would hasten

Figure 2-45: Soil catena exposed along Erath County Road 365.

weathering and change the character of pedogenic processes affecting the horizon. The contact between the recent material and the underlying calcrete varies from clearly erosional (e.g., Profile 3) to a gradual transition resulting from advanced dissolution of the K horizon (e.g., Profile 4). In several cases, the indurated horizon appears to have been truncated to a relatively abrupt contact, which implies subaerial exposure (e.g., Profile 2, Profile 3, Profile 5, Profile 6). The character of the A horizon varies, too; in some profiles (e.g., Profile 1, Profile 5), the overlying sandy A horizon contains large fragments of the massive calcrete, while in others (e.g., Profile 2, Profile 4), such fragments are absent. In Profile 6, the massive carbonate is overlain by a zone of dense rubble derived from the K horizon, mixed with loamy sands from the overlying sands. It is unclear whether this material, and the larger chunks of calcrete in profiles higher in the other profiles, represents colluvial redeposition, fossorial rodent bioturbation, or some combination of the two. Finally, the contact between the A horizon varies from approximately 10 cm thick in Profile 4 to more than 30 cm in Profile 2.

These three catenas provide some indication of the complexity of hillslope deposits, and by implication hillslope processes, in the Fort Worth District. They demonstrate the inherent

uncertainty about the character of resulting soil profiles and location of small-scale depositional loci that are inherent in hillslopes of the Fort Worth District. Moreover, the character of the underlying bedrock and the degree of relief fundamentally affect the character of colluvial and slope deposits. Each of the above examples represents soils weathered from sandy bedrock. Because they are both slower to erode and move downslope (in general), and more susceptible to post-depositional disturbance by shrink-swell processes, the relatively gentle slopes and dark clayey soils of the Blackland Prairie and Grand Prairie are less likely to preserve archeological deposits than the sandier (and often steeper) slopes of the Cross Timbers and Low Rolling Plains. However, it should be noted that the dark, low chroma soils of the Blackland/Grand Prairie also tend to obscure visual evidence of colluvial processes that is far more obvious in the brighter, more variably-colored soils and substrates present in other parts of the district, and the complexity of deposits developed from the black, clay-rich prairie soils may be underappreciated.

One interesting question that remains to be explored is the possibility that mid-Holocene soil erosion affected the district. As discussed above, there is evidence that the

hillslope in Erath county (CR 365) was eroded to a resistant calcic horizon at some point in the past and subsequently reburied by colluvium and stopewash. A similar phenomenon has been documented in detail in central Texas, where a thick regional soil cover was stripped by erosion during the middle Holocene (e.g. Toomey 1993; Toomey et al. 1993; Mosgrove et al. 2001; Cooke et al. 2002; Cooke et al. 2003). The engine driving this erosion appears to have been a pronounced mid-latitude shift to more arid conditions. First identified in the Great Basin, where it was termed the Altithermal (Antevs 1948), decades of research have documented a period of warmer global temperatures between approximately 8 ka and 4 ka (the specifics and timing of this phase are still debated). This period is typically termed the Climatic Optimum (e.g., Davis et al. 2003; Kalis et al. 2003), although the more localized term 'Altithermal' is still commonly used on the Great Plains (see Section 1.6).

While the impact of Holocene climate change on Fort Worth district hillslopes remains to be explored, the impact of Anglo-American settlement is relatively unambiguous. As many local sources attest, the fragile sandy soils of northern Wise County, which are developed on the outcrop of the Antlers Sand, were severely disrupted by cotton farming in the early 20th century. This disastrous attempt at agriculture led to extensive erosion and gullying of the landscape and collapse of the local economy that presaged the onset of the dust bowl in the 1930's. Examples of sources include text of historical markers at the Rhodes Family Cemetery (*"The cotton growers who once plowed this land were forced to relocate in the 1920s and 30s when their fields' soil and fertility were depleted by years of cultivation."*), Rush Creek Community Cemetery (*"Rush Creek community declined in the 1930s when families left due to land erosion."*), and Olive Branch Cemetery (*"As declining soil conditions caused families to move from the area, the [church's] congregation became inactive."*). Similar historic gullies are apparent in other parts of the district, particularly Parker and Erath Counties, where outcrops of the texturally-similar Paluxy Formation are common. Figure 2-46 illustrates examples of gullying in Parker and Wise Counties, including an aerial photograph that shows active and "healing" gullies, and erosion-control terraces created in response to the problem.

Large, rapidly expanding gullies present a tremendous challenge to economic land use. Such features typically represent massive sediment loss in a relatively short period of time. In addition to dissecting fields and interfering with agriculture in the uplands, such rapid erosion also causes significant problems in the lowlands. The eroded sediment chokes existing drainages, impeding stream flow and increasing the frequency and magnitude of flooding, and it

lies thickly on the stream terraces, burying the more fertile soil under a thick blanket of what is typically acidic, nutrient-poor sands. From a geoarcheological perspective, gullying has implications for site preservation on the slopes, and site visibility in the lowlands. On hillslopes, the formation of large gullies in agricultural fields will destroy sites that intersect the gully network. It may also result in the destruction of surrounding sites as farmers respond with earthmoving operations (e.g., filling, erosion terrace construction) that penetrate more deeply under the surface than simple plowing. On alluvial lowlands, it buries the land surface, limiting site visibility and protecting prehistoric sites from plow damage and looting.

In summary, little work has been done on slope deposits in the Fort Worth district, and the extent and age of colluvium and stopewash is not well understood. However, it is clear that many hillslope settings in the Fort Worth District may bury and preserve archeological materials. Unfortunately, predicting the presence of deposits conducive to preservation is impossible without specific, targeted fieldwork that is much more closely focused than the current study allows. Therefore, the predictions of archeological potential that follow in Part III of this document are necessarily generalized in scope.

2.3.4 Eolian Settings

Only a limited number of eolian settings have been identified in the Fort Worth District, and most of these have been previously discussed in connection with the relevant alluvial record. In his dissertation, Ferring (1994a) identifies two archeological localities of eolian origin, but discusses them only briefly. These two localities, termed the Dodd Pit site and the George King site, are both in Wise County. The Dodd Pit site is situated on the north side of a meander bend of Denton Creek (see Section 2.3.2.2). It is approximately 1 km in area, and consists of up to 6 m of structureless very fine sands with an overthickened A horizon and abundant clay lamellae. Ferring (1994a) refers to the area as a dune field, and reports that others are present farther up and down Denton Creek. Although there is no reason to doubt this assertion, the term "dune field" is somewhat of a misnomer, as there are no visible dune forms preserved at the Dodd Pit locality or at other locations up and down Denton Creek. Instead, the deposit appears to represent a featureless to slightly mounded accumulation of sand that was blown out of the channel and accumulated on the adjacent meander. Rather than a dune field, it is better considered a sand sheet, albeit one that is thick and localized. Similar localized eolian environments are known elsewhere in Texas where topographic setting, prevailing wind direction, and suitable sediment supply conditions are met (e.g., Bailey et al. 1989; Abbott 1990b).

Figure 2-46: *Historic gullying.*

The George King Site has been described briefly by Ferring in a number of synthetic discussions (1990a; 1994a; 1995; 2000), but the author is unaware of any detailed work published about the locality. It is described as a large (10 ha) vegetated dune field on a divide in the upper Catlett Creek drainage, which would place it a few kilometers north or northeast of the city of Decatur. Ferring describes the site as an accumulation of 3 to 4 meters of eolian sand over a buried Bt horizon. Paleoindian artifacts attributable to the Dalton and Cody traditions are present on the buried surface of the Bt horizon at the base of the sand column. Although these deposits are apparently dated only with reference to the tool forms, a bison kill from the upper part of the sands was radiocarbon dated to approximately 500 BP (Ferring 1995). This suggests that the deposit started accumulating during the Holocene (probably the Early Holocene) and was continuing to accrete, at least episodically, until at least 500 years ago. However, Ferring believes that the majority of dune accumulation occurred during the middle Holocene, when protracted dry conditions devegetated the uplands and allowed to sands to mobilize.

The only significant eolian locality examined during this study is the poorly-defined sequence of sheet sands identified mantling Turner Bend, the meander bend of the Brazos River at US 67 in Somervell County described previously (see Section 2.1.1). This locality is situated downstream of an extensive outcrop of the Paluxy Sand, which provides an abundant source of fine sands to the alluvial system for subsequent eolian entrainment (see Figure 1–9). As described previously, the US 67 outcrop consists of a thick (6 m +) accumulation of loamy fine quartz sand with a substantial component of rubified fines. The sand sheet probably accreted gradually as deposits of fine to very fine sands and coarse silts were entrained by deflation of fresh stream alluvium and deposited on the vegetated meander bend surface. The presence of lamellae indicates that infiltration of the silt and clay is probably ongoing, but because there is no apparent modern source for it, it is likely that much of the silt was delivered at the same time as the sand. These deposits appear to be localized on the meander bend, suggesting that they are derived from deflation of adjacent alluvium. Similar thick, localized eolian deposits are known from stream-proximal environments other parts of the state, such as O. H. Ivie Reservoir on the Colorado River (e.g., Abbott 1989; Blum and Lintz 1993) and the Dodd Pit site (Ferring 1994a; 2000; see above), but neither of these localities comes close to the amount of dispersed red silt present in the Turner Bend sediments. No chronometric data is available directly from the Turner Bend sand sheet, but their appearance and the available bracketing ages from alluvium indicate that there are sands of at least two ages in the sand sheet, including a long-term accumulation that may date back as far as 20 ka, and another cycle that probably dates to no earlier than the middle Holocene (see Figure 2–16). No organic paleosol was noted separating these two presumed units, indicating that an

episode of deflation probably preceded renewed aggradation. Given the energy involved and the apparent age range of the deposits, the upper few meters of deposits have excellent potential to preserve cultural material in reasonable context.

In addition to these relatively extensive deposits, localized small dunes occur on the margins of active agricultural fields in various parts of the district, including Wise, Hood, Somervell, and Erath Counties (Figure 2–47), and thin cover surficial sheets of eolian or colluvial origin are common wherever sandy epipedons are present. However, no examples of the latter were noted that could be unambiguously identified as prehistoric deposits, and most appear to relate to erosion stimulated by the various forms of devegetation and surface disturbance that accompanied and followed Anglo settlement. Although older eolian sheet deposits are almost certainly present as a result of devegetation and disturbance in the past (e.g., wildfires, drought, slope failure), under humid climates such processes would only expose the ground to deflation for short periods before succession vegetation began to colonize it. Therefore, the likely result of such processes would be limited amounts of deflation, resulting in thin sheets of sand being deposited downwind. Pedogenic processes would rapidly weld such sheets to the underlying soil, making them difficult to identify.

Thicker sandy deposits, such as those present at the three localities described above, would require a more sustained sediment source. It is very likely that the Brazos River furnished such a source in places other than Turner Bend. Denton Creek is also probably the source of other sheets besides the Dodd Pit locality, as are other reasonably-sized streams draining sandy terrain (e.g., the Paluxy River, Sandy Creek) also probably provided point sources or short linear sources of deflatable sand. However, there is no evidence that deflation and sand sheet formation was ever pervasive (or even common) up and down the length of any of these streams. Rather, as on the Colorado River (Abbott 1989), accumulation of substantial eolian deposits from deflation of stream alluvium in the Fort Worth district probably required the convergence of conducive stream geometry, flow conditions, and prevailing winds, and occurred relatively rarely. In most parts of the district, stream-sourced eolian deposits probably did not escape the incised trenches occupied by the channel and floodplain, and were therefore rapidly reworked by flooding.

Thick accumulations away from obvious alluvial sources of sand, such as Ferring's George King Site, are not common—in fact, to the author's knowledge, George King is the only such locality documented in the district. However, this does not mean that it is necessarily unique, because recognition of

Figure 2–47: *Examples of deflation from agricultural fields and field margin dunes in the Fort Worth District.*

sand sheets can be a problem in sandy bedrock terrain. All of the eolian deposits in the district lack recognizable dune morphology, and may have accumulated under partially-vegetated conditions (Kocurek and Nielson 1986; Lancaster 1995). None of the eolian localities discussed above are recognizable as such in the relatively small-scale stereo photography used for geomorphic mapping during this study. Given the reported size and thickness of this deposit, it would be surprising if it was the only such area in the district.

However, in areas where relatively poorly cemented sands form the parent rock, such as the Paluxy Formation terrain, it would be easy to mistake eolian deposits for regolith, particularly if a strong soil had developed. The real question is how such an upland source could form and be maintained long enough for several meters of eolian sand to accumulate. The most obvious answer involves an extended period of aridity, but other explanations are possible (e.g., repeated fires, heavy grazing pressure).

Because fossil eolian depositional loci are not readily apparent, the best method to identify their likely location is to focus on the underlying geology and the character of extant soils. Because there is no indication that long-distance transport of eolian material (e.g., loess) was ever of any consequence in the district, appreciable accumulations of sand should track closely with primary geologic sources (i.e., sandy bedrock) and secondary geologic sources (e.g., alluvial systems draining catchments with sandy bedrock). However, extant geological mapping focuses on relatively coarse-scale characterization of lithostratigraphy (for example, the Paluxy Formation also includes mudstones and limestones). For this reason, soil mapping by the USDA Soil Conservation Service (now Natural Resource Conservation Service) provides the most detailed and

sensitive proxy of the distribution of erodible sediments available. Examination of the characteristics of mapped soils in the Fort Worth District reveals 51 series with surface horizons composed of sand or sandy loam, including 19 that have relatively thick, sandy surface horizons that would be highly subject to deflation if exposed (Table 2–4). Figure 2–48 illustrates the distribution of these soils in the district, in comparison to the three documented eolian localities. Several aspects of the distribution are readily apparent, such as the strong association with the eastern and western Cross Timbers, the lack of comparable areas in the Blackland and Grand Prairies (except where they are crossed by streams draining sandy terrain upstream), and the association with outcrops of specific geologic units like the Paluxy Sand.

Table 2–4: List of Sandy Soil Series Mapped in the Fort Worth District

SERIES	CHARACTERISTICS	SERIES	CHARACTERISTICS
Anocon	A horizon fine sandy loam to 16 inches	Jacksboro	A–E fine sandy loam and gravelly fine sandy loam to 11 inches
Apalo	Ap–A–Bw1–Bw2 very fine sandy loam to 52 inches	Keeter	A–E very fine sandy loam to 7 inches
Aquilla*	Ap–A–Bw–E&Bt1–E&Bt2 fine sand and loamy sand to 62 inches	Konsil	A–E fine sandy loam to 12 inches
Arenosa*	A–C fine sand to 80+ inches	May	Ap–A fine sandy loam to 16 inches
Aubrey	A horizon fine sandy loam to 6 inches	Mabank	Ap horizon fine sandy loam to 7 inches
Bastrop	A1–A2 fine sandy loam to 13 inches	Minwells	Ap horizon fine sandy loam to 6 inches
Bastsil*	A–E loamy fine sand to 16 inches	Nimrod*	A–E fine sand to 27 inches
Birome	A–E fine sandy loam to 9 inches	Paluxy	Ap–B21t–B22–C very fine sandy loam to 62 inches
Bonti	A–E very fine sandy loam to 8 inches	Patilo*	A–E fine sand to 50 inches
Bunyan	Ap fine sandy loam to 10 inches	Pedernales	Ap horizon fine sandy loam to 11 inches
Callisburg	Ap fine sandy loam to 6 inches	Pulexas/ Sandy Land/ Arents*	A–C1–C2–C3 fine sandy loam and loamy sand to 60 inches
Chaney*	A–E loamy sand to 14 inches	Rader	A–E1–E2 fine sandy loam to 25 inches
Cisco*	Ap loamy fine sand to 10 inches	Rayex	A horizon fine sandy loam to 8 inches
Cona	A–E sandy loam and gravelly sandy loam to 8 inches	Santo	A horizon fine sandy loam to 8 inches
Coving*	A1–A2 loamy fine sand to 28 inches	Selden*	Ap–E fine sand to 10 inches
Crosstell	A horizon fine sandy loam to 5 inches	Shatruce	A–E gravelly sandy loam to 14 inches
Darnell	A–Bw fine sandy loam to 15 inches	Silstid*	A–E fine sand to 37 inches
Decordova*	Ap horizon loamy fine sand 14 inches over B21t–B22t–B3t fine sandy loam to 80+ inches	Shavash*	A1–A2 stony loamy fine sand and loamy fine sand to 10 inches
Demon*	A–E loamy sand to 24 inches	Silawa	Ap–E fine sandy loam to 13 inches
Duffau	A–E fine sandy loam to 10 inches	Stephenville*	A–E loamy fine sand to 15 inches
Eufaula*	Ap–E1–E2&Bt loamy fine sand and fine sand to 80+ inches	Truce	A–E fine sandy loam to 8 inches
Exray	A–E fine sandy loam to 8 inches	Vashti*	A1–A2 loamy fine sand to 14 inches
Gaddy*	Ap–C1–C2 loamy fine sand and fine sand to 60+ inches	Windthorst	A–E fine sandy loam to 10 inches
Gasil	A–E fine sandy loam to 17 inches	Weatherford	A–E fine sandy loam to 10 inches
Heaton*	A–E fine sand to 30 inches	Yahola	Ap–C1 fine sandy loam to 40 inches
Hassee	Ap–A–E fine sandy loam to 11 inches		

* sand fraction is dominant textural fraction

Figure 2-48: Map of potential eolian sources based on soil mapping.

Part III:
Late Quaternary
Potential Archeological
Liability Mapping of the Fort
Worth District

PART III: Potential Archeological Liability Mapping of the Fort Worth District

3.1 Introduction

This section describes the purpose and the development of the Fort Worth Potential Archeological Liability Map (FTW-PALM). The FTW-PALM is an integrity-based predictive model designed to assist TxDOT in its compliance with state and federal cultural resource laws. Archeology is performed and sponsored by TxDOT as part of the overall environmental process. In cases where projects involve federal funds or federal oversight, this consideration is mandated by the National Historic Preservation Act of 1966 (as amended) (NHPA) and is afforded in accordance with a programmatic agreement (PA) among TxDOT, the Federal Highway Administration (FHWA), the Texas State Historic Preservation Officer (SHPO), and the Advisory Council on Historic Preservation (ACHP). In cases where federal funds or oversight are not involved, consideration is mandated by the Texas Antiquities Code, and administered under a memorandum of understanding (MOU) between TxDOT the Texas Historical Commission (THC). These agreements strongly encourage development programs to identify and mitigate significant cultural resources by means that are scientific, timely and cost-effective.

Eligibility for listing in the National Register of Historic Places (NRHP) is a formal status determined according to evaluation criteria specified in Title 36, Chapter I, Part 60 of the Code of Federal Regulations (36 CFR 60.4). The process for identifying and treating such sites (termed the Section 106 process after the section of the NHPA that mandated its creation) is specified in 36 CFR 800. In the Section 106 process, listed and eligible sites are termed *historic properties*, and there is no distinction drawn between sites that have been formally listed on the register and those that are simply eligible for listing. In order to be considered a historic property, a site must satisfy two distinct requirements. First, it must satisfy at least one of the following four criteria of significance: (a) be associated with events important to broad patterns of history; (b) be associated with an important person; (c) display distinctive characteristics of a type, period, method, or be the work of a master; or (d) have yielded, or be likely to yield, information important to prehistory or history. Second and equally important, the site must “possess integrity of location, design, setting, materials, workmanship, feeling, and association” (36 CFR 60.4), which is the focus of this discussion.

In an NPS bulletin that provides guidance on evaluating archeological properties, Little et al. (2000:35) point out

that all of these aspects of integrity are not uniformly important in every case, but rather that different property types have differing integrity requirements that follow from a consideration of *why*, *where*, and *when* the property is significant. For sites significant under criterion (d), the most important aspects of integrity are location, design, materials, and association (Little et al. 2000:36). Integrity of design refers to “the combination of elements that create the form, plan, space, structure, and style of a property”, while integrity of materials refers to “the physical elements that were combined or deposited during a particular period of time and in a particular pattern or configuration to form a historic property.” Thus, in the case of prehistoric sites eligible primarily under criterion (d), design integrity is the persistence of evidence for the distribution of features, structures, and workspaces that were created by the prehistoric inhabitants, while materials integrity is the character and distribution of artifactual material—primarily refuse—generated during the occupation. The importance of integrity of location (“The place where the historic property was constructed or the place where the historic event occurred”) to such sites is relatively obvious—archeological sites that represent a collection of artifacts moved wholesale across the landscape by natural or cultural processes rarely merit designation as a historic property. Finally, the use of the term “integrity of association” is somewhat counterintuitive. Little et al. define it as “[t]he direct link between an important historic event or person and a historic property. Under [criterion] D it is measured in the strength of association between data and important research questions” (2000:36). Thus, it is not physical association among artifacts and features that is referred to, but the abstract association between extant questions and a site’s potential to contribute answers to those questions.

In order to make integrity determination, the archeologist must first evaluate several other aspects of archeological integrity that are far less abstract than those listed in the NRHP criteria, including *spatial integrity*, *stratigraphic integrity*, and *preservation integrity*. Spatial integrity refers to the persistence of small-scale (intrasite) behavior patterning in a planiform artifact assemblage, while stratigraphic integrity refers to the persistence of discrete strata containing artifacts in a depositional setting. Preservation integrity refers to the degree to which perishable and durable archeological materials are preserved or transformed by post-abandonment physical (e.g. abrasion, crushing) and chemical/biological (chemical weathering, decay) processes. Together, these measures provide the basis for evaluating the three-dimensional context of prehistoric artifacts and associated

deposits, and therefore their potential for integrity of design, materials, location, and association (and, by extension, their eligibility) under the NHPA. The focus of this effort is on spatial and stratigraphic integrity, the persistence of which is a function of the cumulative effect of depositional, erosional, and disturbance process (of both natural and cultural origin) acting on the site. Because such processes are patterned on the landscape (see Part II), integrity-based modeling is possible. The focus of a model like the FTW-PALM is on integrity of design and materials (and to a lesser degree integrity of location and association), which have particular applicability to prehistoric archeological sites.

In the ideal application of the NRHP criteria of eligibility (36 CFR 60.4), an investigator will first determine a property's significance under criteria a–d, and then evaluate the integrity of the property relative to that significance (Little et al. 2000:36). In such a two-step process, it follows that it is likely that some sites will be found significant, but will fail the integrity test and be determined not eligible (it must be noted that in practice, the two steps are often conflated, and the terms *significant* and *eligible* are treated synonymously). The reason for staging the evaluation is that the character and rationale of the significance finding determines the eligibility “bar” that the site must satisfy to be eligible.

However, if the likely nature of significance is known beforehand, it is possible to use integrity criteria in advance of property identification for planning and scoping work to be performed. A geoarcheological model uses characteristics of the landscape to predict where such integrity requirements are and are not likely to be met. Prehistoric archeological sites, and particularly the hunter-gatherer sites typical of most parts of Texas, are typically eligible only under criterion (d). Although some probably disagree, it is this author's contention that some degree of spatial and stratigraphic integrity is necessary for a prehistoric site in the Fort Worth District to be NRHP eligible under criterion (d). Granted, it may be possible to address certain research questions (particularly technological questions) using diagnostic artifacts alone, and conceivable that questions can be formulated that require only the broadest of associations. Public archeology should be weighed against other aspects of the public good, which is the point of the NHPA in the first place. If all sites are significant, then none are.

The FTW-PALM is a geoarcheological model designed as a decision-support tool for use by TxDOT in the compliance process. The model represents a relatively simple, spatially-oriented classification of the landscape in the Fort Worth District developed using the concepts and data outlined in the previous part of this document. It allows relatively confident and consistent *a priori* assessment of the potential

for a transportation activity to impact previously unidentified archeological historic properties without requiring a field visit. Properly utilized, FTW-PALM can increase the efficiency of cultural resource management (CRM) operations by (1) identifying areas where the character or age of deposits is not consistent with preservation of archeological sites in good context, thus limiting the area where archeological survey and testing is recommended; and (2) identifying areas where depositional processes have been active during the Late Pleistocene/Holocene, requiring deep mechanical prospection to locate buried archeological sites.

The argument is sometimes made that archeologists should not pick and choose survey localities (e.g., Fish and Kowaleski 1990), but should instead survey the entire landscape using a uniform level of scrutiny. There are a number of reasons given for such arguments (e.g., eliminating biased or skewed samples, elucidating settlement systems, understanding the range of activities represented by a cultural system), and all are valid to some degree. However, it is also an argument that smacks of the ivory tower. Years ago, I was present when one of the State's preeminent archeologists opined that (here I am paraphrasing) “all archeological sites are significant, because they potentially all have something that they can contribute to our understanding of prehistory.” Although I agree with the second half of this statement at an abstract level, on balance I find it to be antithetical to the goals and tenets of the NHPA. The ultimate goal of the compliance process is explicit: to identify and treat *significant* archeological sites. Public archeology does not exist in a vacuum, and must be balanced against competing requirements of the public good (e.g., development, resource acquisition, funding). Many sites simply do not merit the time and money needed to recover their information, either because they simply don't contain much material in the first place, or because the context and integrity renders information derived from that material too ambiguous or generalized to be informative. Although it is true that every site could have something to contribute (if nothing else, its very existence—the fact that at some time, someone did something *here*), it is also true that the potential return of reliable, robust archeological data on the investment of effort and capital diminishes rapidly as integrity declines. Because archeological compliance is expensive and time-consuming, it follows that a mechanism for early identification of areas where significant sites are not likely to occur or are likely to be deeply buried can yield considerable savings in manpower and expenditures, and allow more time and resources to be devoted to areas . Although significance varies based on the extant suite of research questions that drive evaluation, few questions can be adequately addressed from sites lacking a modicum of contextual integrity. Thus, a landscape model such as FTW-PALM is a powerful and practical tool for maximizing information return and minimizing expenditures incurred locating and testing sites lacking legal significance.

The FTW-PALM is explicitly a tool to facilitate management of archeological resources in the district under a contextual paradigm (Butzer 1980), and was developed under consultation with the Texas SHPO and outside reviewers (see Section 3.2.1). Given that reasonable archeological integrity is requisite for a site to be judged significant under most current standards, the FTW-PALM provides an efficient mechanism to concentrate agency resources where they will be most beneficial.

Although CRM is often equated with “conservation archeology” (Schiffer and Gumerman 1977; Kerber 1994), there is an important distinction between the two. Conservation archeology is essentially a paradigm for study that recognizes that archeological excavation is an inherently destructive process that should be carried out only if “the destruction of the resource is beyond the archaeologist’s control, or if the information contained in that resource is believed to be potentially of great immediate research value” (McGimsey and Davis 1984:120). It advocates conservation of representative sites for future generations when improved techniques will allow extraction of more comprehensive or higher quality data (Fowler 1982; Kerber 1994). In contrast, CRM archeology is not a paradigm, but rather a process by which adverse impacts on cultural resources are addressed and minimized under existing federal and state laws. Because CRM is intended to compensate for impacts of governmentally-regulated actions on cultural resources (including, but not limited to, archeological sites), it deals with impacts that are generally beyond the archeologist’s control, and thus consistent with tenets of conservation archeology.

However, the Section 106 process does not allow significance determination on the basis of a presumed future research value. The Secretary of the Interior’s Standards and Guidelines for Evaluation state that “evaluation of the significance of historic properties uses established criteria” and “a statement of the minimum information necessary to evaluate properties against criteria should be provided to direct information gathering activities”. In other words, the significance of a historic property (i.e., an archeological site) under Criterion (d) is dependent upon the ability of the property to further *extant* research goals using *extant* methodology. Although the significance of a historic property may change as research questions evolve or methods improve (see CFR 800.4 (c)), the potential *future* research value of a historic property is not relevant to significance decisions made in connection with scheduled undertakings affecting a given site.

Although FW-PALM can be considered a predictive model, it differs from most other models in archeology in that the

emphasis here is predicated on the preservation potential of the environment, rather than on behavior. Behavioral models predict the location of sites based on reconstruction and interpretation of prehistoric actions—what the prehistoric population did or did not do—rather than the processes of site formation. Integrity models, in contrast, are based on the potential for site-bearing deposits to be preserved with reasonable integrity. Although in general they are far less common than behavior-based models, it is interesting to note that at least one previous integrity-focused model has been developed in the district (Parrish and Burson 2002). The FTW-PALM is quite similar to the Houston-PALM, an integrity-based model for the Houston area previously developed by the author (Abbott 2001a). However, different challenges are posed by the more diverse Fort Worth landscape, and somewhat different solutions were developed for this effort than were used for the Houston geoarcheological model. Development of the FTW-PALM is described below.

3.2 Map Design and Implementation

This section describes the design and development of the FTW-PALM. The project was conceived as a planning tool that would provide decision support for TxDOT planners and archeologists, regulatory agencies, TxDOT consultants, and the broader archeological community. In order to be an effective tool, it was determined that the model should be:

- * **Accurate**—The primary attribute of a successful model is reasonable accuracy and reliability, which is necessary to justify management decisions made on its basis.
- * **Explicit**—The criteria for mapping and methods used should be reasonable, scientifically grounded, and clearly stated.
- * **Readily Interpretable**—In order to be a useful tool for a broad range of users, the map units should be conceptually simple and straightforward.
- * **Appropriately Detailed**—The scale of mapping should be adjusted to provide a sufficient level of resolution for the proposed use without a surfeit of distracting detail.
- * **Accessible**—The finished map should be delivered in a form readily accessible to the primary users.
- * **Updateable**—The finished map should be developed in a manner that permits periodic updating, particularly regarding changes resulting from development and urbanization.

- * ***Developed in a Timely Manner***—The map should be delivered in a reasonable amount of time under a reasonable budget.

The methodology for developing the FTW-PALM was designed to provide appropriate accuracy and detail for the types of long, linear impacts created by transportation projects. While this level of detail is also applicable to other linear impacts (e.g., pipelines, transmission line routes), it is arguably less appropriate for impacts affecting contiguous areas (e.g., subdivisions, landfills, reservoirs) which, due to their coverage, are more likely to contain significant internal variability. Therefore, while the mapped units should provide a good indication of overall preservation potential in a given tract, survey decisions should balance the FTW-PALM information against the extent and intensity of impact. In many of these cases, prudent consideration of the archeological record may require more conservative survey decisions (i.e., more work) than implied for the locality by the FTW-PALM. Alternatively, because the proposed model is relatively coarse-grained and does not incorporate behavioral data or consideration for the scope of the project, there will be instances where the FTW-PALM recommendations are too conservative for a given undertaking, and the level of effort implied by the model may not be warranted. In short, the FTW-PALM is designed to be a resource for archeologists making decisions, not an automated expert system.

3.2.1 Protocol Development and Review

Development of the FTW-PALM protocol was a multi-stage process. Based on requirements identified for the finished product and discussions with colleagues and supervisors, the author developed a draft mapping protocol proposing a methodology and rationale for generating the FTW-PALM. Development of this protocol occurred episodically through 2002 and early 2003. Simultaneously, a number of potential reviewers were identified based on their knowledge of the region's prehistory and Quaternary history, as well as general geoarcheological expertise. Each potential reviewer was contacted and asked to examine and comment on a preliminary document containing the draft protocol and, at a later point, the draft of the finished report. Six individuals were contacted, and four agreed to participate as reviewers; however, one reviewer was subsequently forced to withdraw from participation due to overcommitment. The final reviewers were Dan Prikryl of the Texas Water Development Board, who has extensive archeological experience in the Fort Worth region, and consulting geoarcheologists Dr. Charles Frederick and the late Dr. David Kuehn, who both had extensive experience with Texas landscapes. Collectively, these reviewers provided a number of comments about strengths

and weaknesses of the proposed mapping protocol and ways to improve it (Appendix III). Many of these improvements were subsequently incorporated, while others—for one reason or another—were not. The following discussion incorporates these changes, and addresses suggestions that were not adopted. The reviewer comments on the mapping protocol were addressed, and a revised protocol that included the comments and TxDOT responses was submitted to THC in November 2003, before mapping was initiated.

The FTW-PALM was conceived as a synthetic construct created by weighting and combining landscape characteristics within a computerized GIS system to yield a probability map. While the proposed implementing methodology was very different, the underlying decision process was conceptually similar to that used in the previous Houston-area model. As with the Houston-PALM, the FTW-PALM was to be based on consideration of several discrete types of information, including geomorphic setting, soils, underlying geology, and development/urbanization. In the case of the Houston-PALM, these factors were weighed and incorporated by the analyst during the primary mapping process, which was performed with reference to recent aerial stereopair photography, soils maps, and geological maps. While the resulting map is a valuable tool, its use-life is somewhat limited because it will become increasingly obsolete as urbanization continues. For the FTW-PALM project, the decision was made to map the contributing factors separately, and use the GIS system to combine them using an explicit algorithm to produce the final map. With this approach, the map could be updated periodically (e.g., as next generation DOQQ's are released) by revising the distribution of any or all of the contributing factors and repeating the process.

Three primary data types were chosen as sources for the probability map: (1) landscape setting; (2) soil type; and (3) historic/recent land disturbance. The three primary datasets are discussed in more detail below.

3.2.1.1 Landscape Setting

Landscape setting, or geomorphic context, is a very powerful predictor of the potential for archeological preservation. However, mapping the landscape is a complex task that may be approached in a number of different ways. By far the most common method of mapping terrain is simple contour mapping, which presents a straightforward, symbolic approximation of the land surface (or indeed any three-dimensional surface). While a number of different mathematical approaches can be employed to produce contours, the process is conceptually very simple (Davis 1986). Because topography is a form of spatially continuous data, its value at any location in space is predictable. In other

words, if one knows the horizontal and vertical position of a population of points, and if that population has sufficient density and placement to effectively sample the variability of the associated surface, then one can use the known points to interpolate (predict) the values of intervening points in the area and construct isolines (contours) connecting points of equal elevation.

While a contour map of a given area provides a valuable tool for interpreting the landscape context of that area, higher-order interpretation of the landforms represented is entirely left to the user. Individual landforms (e.g., a floodplain, a cuesta) are not identified during the contour mapping process, but rather must be identified by interpreting the completed map. At the other end of the spectrum is detailed symbolic landform mapping (e.g., Demek 1972; Demek and Embleton 1978; Gardiner and Dackombe 1983). This type of mapping can be performed at a variety of scales and levels of detail. It typically uses point and linear-based symbology, and can be either exclusively morphologic or incorporate moderate to very high degrees of genetic interpretation. In the latter cases, high-order landform interpretation is produced almost entirely by the analyst.

Detailed symbolic geomorphic mapping can be readily incorporated and displayed in a GIS system. However, it is difficult to effectively analyze such data in combination with other data layers because the symbology utilizes points and lines (i.e., centroids and boundaries) rather than continuous polygons. While such symbols are readily interpreted by humans, computers are not capable of abstract thought, and must be taught complex rules to do what humans can do effortlessly and intuitively. However, if contiguous, non-overlapping polygons are employed to classify the landscape by area, the data can be readily combined with a wide variety of other data to yield synthetic spatial analyses.

Due to the extent (>6,900 mi²) and relatively small nominal scale (1:24,000) of this effort, the amount of spatial detail that could be captured was relatively limited, and the suite of mapping units was similarly restricted. There was little to be gained from an attempt to differentiate and map different slope segments, for example, at the scale that the map was prepared. Table 3-1 presents a generalized classification of landforms in the Fort Worth District, including a characterization of the geoarcheological potential of each class, which is a function of the types and magnitudes of sedimentation and soil development processes affecting each. The classification in Table 3-1 is not the only classification possible; in fact, a different classification was used for mapping (see below). While this hierarchical division into upland, hillslope, and valley bottom landforms provides a good conceptual basis for presenting the range of landscape settings in the district, it is not adequate to

effectively classify the Fort Worth district landscape into units of quasi-uniform geoarcheological potential.

One complication is presented by the fact that the individual named landforms presented in Table 3-1 will vary considerably in character depending upon their context. For example, although both settings are termed a floodplain, the geoarcheological potential of thick floodplain deposits associated with a major stream like the Brazos and Trinity is far different than the potential of a floodplain associated with a first-order stream in the Blackland Prairie. Similarly, the potential for colluvial burial is very different on gentle hillslopes with clay soils developed on Cretaceous marls and chinks than on steep, sandy hillslopes developed on sandstones. A second complication is presented by pronounced differences in the archeological potential of the various settings at differing depths. Landscapes mantled with upland veneer deposits may have extremely high potential at shallow depths, while associated deeper deposits may have no potential at all. In contrast, depending on their context, the geoarcheological potential of lowland landscapes may be maintained or even enhanced with depth. For these reasons, a wide variety of classes is needed to capture the variability inherent in the Fort Worth landscape. While the creation of a single series of discrete landform classes was considered to encompass this variability, it was rejected as unnecessarily complex (or voluminous). Instead, a three-part landform classification was proposed. This classification is presented in Table 3-2.

The landform classification system worked as follows: There were initially fifteen discrete landform classes, designated with 2-3 letter abbreviations that correspond to the named classes of landform. Mapping was conducted with reference to aerial stereopair photographs viewed through a stereoscope and mapped on a USGS topographic base. The photography used was black and white imagery captured as part of the National Aerial Photography Program (NAPP) during January and February, 1995. The images used were large format (9 x 9 inch) contact prints at a scale of approximately 1:37,500. During the mapping process, each landform was identified, the boundary was drawn, and its potential to contain shallow and deep cultural remains was evaluated according to the analyst's judgment and the range of possible values in Table 3-2. The resulting polygon was then labeled with a three-part symbol made up of the letter representing the landform and the numbers representing the evaluated potential for shallowly buried and deeply buried remains. For example, the distal part of a small-scale, shallow alluvial fan judged to have relatively high shallow potential and relatively low deep potential would be designated "AFD31", while a level, stable upland with low potential

Table 3–1: Generalized Classification of Landforms in the Fort Worth District

Category	Landform Class	Description and List of Common Landforms Included In Class	Generalized Geoarcheological Potential	Comments
Upland Landforms	Flat Upland	plateau; cuesta; ancient alluvial terrace	low	Surface may be level or gently inclined (e.g., a cuesta surface); may be hummocky (e.g., pimple mounds)
	Convex Upland	ridge, upland margin	low	
	Concave Upland	upland depression; low-order drainage; broad saddle	low to moderate	
	Depositional Upland	sand sheet; dune field, springs and seeps	moderate to high	May be difficult to recognize in some cases
	High Fluvial Terrace	Depositional and Strath terraces; in general, >12m above stream channel	low	Typically >15 ka
Slope Landforms	Steep Erosional Slope	cliff, scree slope, talus slope	low	In general, includes all slopes greater than 20–25 degrees.
	overhang	rockshelter	high	low visibility; shelters created by spring sapping may be inferred during mapping based on plan morphology
	convex/ straight slope	midslope	low	In general, includes slopes between approximately 5 and 20 degrees.
	concave slope	footslope; toeslope; midslope bench	moderate	In general, includes slopes less than approximately 5 degrees. Midslope benches may be level; however, midslope bench surfaces significantly broader in plan than the flanking slopes, such as ancient terraces, will be mapped as level uplands.
	alluvial fan	proximal fan medial fan, distal fan, fan channel	high	relatively rare; geoarcheological potential varies with fan scale and location relative to fan-head
Valley Bottom Landforms	low terrace	terraces and flood-terraces, in general < 12m above modern stream	high	includes features classified as floodplains by Ferring (1993; 2000)
	floodplain	vegetated floodplains and insets; usually < 4 m above modern stream, but may be up to ~ 8 m above the stream on large systems	moderate	typically narrow and poorly developed
	water	artificial ponds and lakes; springs & seeps; swamps and bogs	negligible to high	most bodies of standing water are artificial; they may inundate areas of relatively high potential

Table 3–2: Landform Classification Used for Mapping the Fort Worth District

MAP SYMBOL	LANDFORM	SHALLOW POTENTIAL	DEEP POTENTIAL
CH	Stream Channel/Unvegetated Bar	negligible (0)	negligible (0)
FP	Floodplain	very low–moderate (1–3)	very low–high (1–4)
LT	Low Terrace/ Flood Terrace	moderate–very high (3–5)	moderate–very high (3–5)
HT	High Terrace	very low–moderate (1–3)	negligible–low (0–2)
ES	Sand Sheet/Dune Field	low–high (2–4)	low–high (2–4)
AFP	Proximal Alluvial Fan	very low–low (1–2)	very low (1)
AFD	Medial/Distal Alluvial Fan	low–high (2–4)	very low–moderate (1–3)
AW	Pond/Reservoir/Stock Tank	negligible (0)	negligible–low (0–2)
NW	Spring/Paludal/Lacustrine Deposit	moderate–very high (3–5)	moderate–very high (3–5)
CTS	Toeslope/Colluvial Apron	low–moderate (2–3)	low–moderate (2–3)
B	Midslope Bench	low–moderate (2–3)	low–moderate (2–3)
SL	Midslope/Shoulder–Slope	negligible–low (0–2)	negligible–very low (0–1)
UP	Level/Gently Inclined/Convex Upland	negligible–very low (0–1)	negligible (0)
UD	Upland Depression/ Sink	very low–moderate (1–3)	negligible–low (0–2)

for intact surface deposits and negligible potential for buried deposits would be labeled “UP10”. The use of symbols was necessary because the mapping process was accomplished manually (through the tracing of map units onto mylar overlying the USGS quads). These symbols were then used to populate the database with explicit evaluations during the digitizing process. This system accommodated the complexity of the landform assemblage while providing a concise labeling system for mapping. The sixteen general landform classes originally proposed for mapping are described below:

A. Stream channel/unvegetated bar (map unit CH): This map unit encompassed the channels and associated unvegetated bar surfaces of discernable stream channels in the district. The geoarcheological potential of this unit was considered negligible (0), as associated prehistoric remains are almost certainly reworked. In most cases, however, the channels were too small to be mapped productively, and were included in the mapped extent of floodplain or flood terrace/low terrace units.

B. Floodplain (map unit FP): The term floodplain, in this context, refers to those areas where a low vegetated surface is present adjacent to the channel. In most cases, floodplain surfaces are inset into the principal valley floor, although in small tributary valleys they may be inset into the valley wall. Most examples in the district are narrow and discontinuous, and are typically inundated on a yearly basis. The geoarcheological potential of these features was considered very low (1) to moderate (3) depending on their scale, context, and apparent degree of preservation.

C. Flood terrace/low terrace (map unit LT): The term flood terrace/low terrace typically refers to the principal alluvial surface flanking the streams. It can vary from as little as 1–2 m above the channel on some small systems to 8–10 m above the channel on some larger systems. The surface can be smooth or subtly scrolled, level or gently ramped toward the channel. It is not typically inundated by floodwaters on an annual basis, but may be overtopped on occasion by large floods. In the Trinity basin, such surfaces generally conform to Ferring’s (1994a; 2000) designated floodplain surface. Archeological potential varied from moderate (3) to very high (5).

D. High terrace (map unit HT): This category encompassed all strath and fill surfaces that lie higher than the flood terrace/low terrace. In the Trinity basin, Ferring (1994a; 2000) has identified a flight of extensive high terraces that may date back as far as the Middle Pleistocene, and occupy extensive areas

of upland adjacent to the larger streams in the Trinity system. The geoarcheological potential of these features varied from moderate (3) to very low (1) at the surface and very low (1) to negligible (0) at depth. In some cases, older alluvial straths and terraces were probably mapped as upland.

E. Sand sheet/dune field (UNUSED): While eolian sands are not recognized as a major component of the Fort Worth district landscape, some areas of significant localized eolian deposition are known in association with streams, such as the Dodd Pit site on Denton Creek (Ferring 1994a). Several of the bedrock units in the region, and particularly the weakly cemented Antlers and Paluxy sandstones, weather into a fine sand idea for eolian reworking. However, these areas proved impossible to recognize in the small-scale black and white photographs (even when their existence was known, such as the deposits at the Dodd Pit site), and none were mapped.

F. Proximal alluvial fan (map unit AFP): The proximal fan class represents zones of entrenched channels at the head of relatively steep alluvial fans, and are characterized by dominated by sediment bypass. This class was not common, as the alluvial fans in the district are typically either relatively small or gently inclined. The geoarcheological potential of this category was considered moderate to very low (3 to 1), depending on the scale and character of the landform.

G. Medial/distal alluvial fan (map units AFD and AF): This category encompassed all parts of alluvial fans that do not conform to the characteristics of proximal fans as described above. They were more common in the district than the entrenched proximal fans (Category F), but were still relatively uncommon. In general, the map unit AFD was used in conjunction with unit AFP, while AF was used where AFP was not separately mapped. Depending on their scale and apparent age, the geoarcheological potential of this category varied from low to high (2–4) in the near-surface and very low to moderate (1–3) at depth. Many fans were too small to identify (particularly under vegetative cover) or to merit separate mapping, and were included in the toeslope/colluvial apron class.

H. Pond/reservoir/stock tank (map unit AW): This category encompassed artificial bodies of standing water. In the case of artificial features, the mapped unit also encompassed associated earthworks. Although we recognize that sites could be preserved adjacent to and beneath such water bodies and earthworks, routine prospection for them is neither practical nor advisable. Geoarcheological potential of these features was therefore considered negligible (0).

I. Spring deposit/Paludal deposit/Lacustrine deposit (NOT USED): This category encompassed deposits associated with springs, natural lakes, and swamps and bogs. They were added to the original classification at the suggestion of David Kuehn. However, none were recognized during the mapping process, so the category was not used. It is likely that most paludal and lacustrine deposits in the district were captured in the mapping of floodplains and low terraces.

J. Toeslope/colluvial apron (map unit CTS): These settings represent areas subject to burial through colluviation and sheetwash. They vary considerably in potential depending upon the height and inclination of the backing slope, the lithology of the underlying bedrock, and the configuration of the stream system in the valley. In mapping practice, this category consisted of the lower, concave part of the slope system, including footslopes as well as true depositional toeslopes. Toeslopes of sufficient size to justify separate mapping are considered to have moderate to low (3 to 2) geoarcheological potential at the surface and at depth; small toeslopes were usually not mapped separately.

K. Midslope bench (map unit B): These settings represent colluvial/slopewash depocenters in midslope settings. They typically result from lithological influences, but may reflect long-term cycles of landscape evolution. In many cases, midslope benches proved difficult to distinguish from high fluvial terraces during mapping, and many were too small to merit separate mapping. Geoarcheological potential ranged from low to moderate (2 to 3). It was not used often.

L. Shoulder slope/midslope/cliff (map unit SL): These settings encompassed convex and straight hillslopes, and were typically too steep to have much potential. The dividing line between landforms considered upland and those considered hillslope was a judgment call during the mapping process. Geoarcheological potential was considered low to negligible (2 to 0) in the near-surface and low to negligible (0 to 1) at depth.

M. Level/gently inclined/convex upland (map unit UP): This category included all upland areas without evidence of appreciable Late Pleistocene/Holocene deposition, and thus low potential to contain archeological materials in reasonable context. It included areas with ancient or residual soils and bedrock exposures. While the soil may be thin and eroded, this category also includes areas of deep soil, particularly in the Blackland and Grand Prairies. Geoarcheological potential is considered negligible to very low (0 to 1) at the surface and negligible (0) at depth.

N. Upland depression/sink (map unit UD): This category encompassed all settings where local relief contributes to an upland basin that could contain appreciable accumulations of alluvial, slopewash, and/or colluvial sediments. Although upland depressions may occur at a variety of scales, the mapped depressions tended to be relatively prominent features. Relevant landforms include solution features, structural features, erosional depressions, and occasionally saddles and water-gathering landscapes associated with low-order drainages. Geoarcheological potential was considered very low to moderate (1–3) in the near surface and negligible to low (0–2) at depth. Like benches, the map unit was not used very often.

O. Rock shelter/overhang (NOT USED): This category includes rock shelters, overhangs, and cave entrances. Although it was recognized that these features were unlikely to be identified, the category was included for completeness. Any features identified would have been mapped with high (4) geoarcheological potential, but none were noted.

P. Made Land (map unit ML): This category describes prominent manufactured landforms created or extensively modified by people (it is likely that most landforms of this type date to the 20th–21st century). It includes landfills, shopping center pads, quarries, mines, spoil piles, and other similar features. In his review of the protocol, Frederick pointed out that such landforms may only cover the natural landscape, and that intact deposits may be preserved at depth. While we acknowledge that this is sometimes true, we continue to believe that such preservation would be rare, the level of effort necessary to conduct survey beneath made land of this type would be unjustifiably high, and routine survey of such areas in the absence of promising site-specific information is unwarranted. However, it is also important to note that “made land” is not equivalent to “urbanized” and that features mapped as made land were limited to substantial landscape modifications only. Accordingly, these features were mapped as having negligible (0) potential at the surface and at depth.

3.2.1.2 Soils Data

Soils mapping by the USDA–Natural Resource Conservation Service (formerly Soil Conservation Service) is another valuable data source for predicting preservation potential. Table 1–1 (see Section 1) lists the mapped soil series occurring in the district. All soil surveys in the Fort Worth District have been produced in digital form under the NRCS’ detailed soil mapping (SSURGO) initiative. While

most of these are electronic transcriptions of previously published surveys, no paper survey was ever prepared for Jack County, and the electronic version represents the first generation of data release.

One hundred twenty four distinct soil series are mapped in the Fort Worth District. Fifty-one (41%) of these are Alfisols, 31 (25%) are Mollisols, 18 (14%) are Vertisols, 12 (10%) are Inceptisols, 11 (9%) are Entisols, and one (0.8%) is classified as an Ultisol. The typical profile, landscape setting, parent material, and taxonomic classification of each series were presented previously in Table 1–1. These characteristics are distilled from descriptions on the USDA’s Official Soil Series Description website (<http://soils.usda.gov/technical/classification/osd/index.html>). Because the USDA Soil Taxonomy is constantly evolving and becoming more tightly integrated, individual series descriptions and classifications often differ from the older characterizations presented in the paper surveys. Some series have been taxonomically reclassified (e.g., Aledo soils are classified as Lithic Haplustolls in the paper Parker County soil survey [Greenwade et al. 1977] and as Lithic Calciustolls under the current system), while others have been reassessed (e.g., soils mapped as the Yomont series in the paper Parker County survey [Greenwade et al. 1977] are currently mapped as the Coarsewood series, apparently due to reconsideration of soil moisture characteristics during the growing season).

On the basis of an examination of the character and classification of the soils, an assessment of the shallow and deep geoarcheological potential, or likelihood that the soil could contain buried cultural material in reasonable context, was developed for each soil series. This classification was based on a number of factors that are obtained or inferred from the published description, including landscape setting (particularly upland vs. lowland setting), age of parent sediments, sediment texture, degree of horizon development, potential for culturally-relevant eolian and/or colluvial materials to be represented, presence of buried paleosols, and presence of shrink-swell clays and vertic pedofeatures. The decision matrix for determining shallow potential is illustrated in Figure 3–1. Deep potential was determined by evaluating the thickness of the soil and the character and thickness of the substrate, as described for the typical profile, to judge the likelihood for deeply buried (>1 m) deposits. In all cases, the deep potential of each series was either equal to or less than its surface potential. While we recognize that deep potential may often exceed shallow potential where disturbance or filling has affected the surface, such cases are not practical to identify and map (see the discussion below in the section on disturbance). The shallow and deep potential of each series was also previously presented in Table 1–1.

Eight series are judged to have very high potential in the near-surface and at depth. All eight (Balsora, Bosque, Coarsewood, Frio, Pulexas, Pursley, Weswood, and Yahola) are relatively recent alluvial soils where buried paleosols are either included in the typical profile description or noted in the range of profile characteristics discussion. Four of the very high potential series are Entisols, three are Mollisols, and one is an Inceptisol. The combination of significant late Quaternary deposition and paleosol preservation, which indicates punctuated deposition, contribute to the likelihood that any archeological remains encapsulated by these soils are very likely to be preserved in good context.

Seventeen soil series, including 6 Mollisols, 4 Alfisols, 2 Inceptisols, and 5 Entisols are judged to have high geoarcheological potential in the near surface and at depth. These high-potential series are developed in thick, stratified deposits of Late Pleistocene/ Holocene alluvium or alluvium capped with eolian sediments. Although they lack paleosols of the “very high potential” soils, these soils are still of an age and character to merit survey in almost every case.

Three series are judged to have moderate to high potential, and 19 others are judged to have moderate potential, in the shallow subsurface. These soils are predominantly characteristic of uplands, upland footslopes, and higher alluvial terraces, although the group also includes floodplain soils with high shrink-swell properties. All of these soils exhibit characteristics and/or locations consistent with a potential for appreciable deposition, and all have a moderate to high likelihood of disturbance. The moderate-high potential group includes 3 Mollisols and 2 Alfisols, while the moderate potential soils include 10 Alfisols, 4 Vertisols, 3 Mollisols, and 1 Inceptisol. At depth, the potential of some of these soils diminishes. The moderate-high potential group includes 2 Mollisols and 1 Alfisols, while the moderate potential soils include 4 Alfisols, 3 Vertisols, 2 Mollisols, and 1 Inceptisol.

Thirty-two soils are judged to have low-moderate potential in the near surface, while only ten soils are judged to have low-moderate potential at depth. The 32 soils with low-moderate potential in the shallow subsurface typically have relatively thin sandy or weakly developed upland profiles. These soils generally have characteristics that indicate Late Pleistocene age, but may conceivably include a thin eolian or colluvial veneer based on the published description. They are dominated by Alfisols (22), with Mollisols (5) and Inceptisols (5) also common. The soils with low-moderate potential at depth are generally deeper soils of uplands and high alluvial terraces, where deep burial is not particularly likely but cannot be ruled out. This group includes 5 Alfisols (all Paleustalfs), 3 Mollisols, and 2 Inceptisols.

Figure 3–1: Flow chart documenting decision tree for determining the nominal shallow potential of a given soil series based on its typical characteristics.

The 44 soil series judged to have low potential in the shallow subsurface consist of strongly developed upland soils with minimal potential for a significant veneer based on the published description. They include 13 Alfisols, 14 Vertisols, 11 Mollisols, 3 Inceptisols, 2 Entisols, and 1 Ultisol. At depth, 76 soils are judged to have low potential, including 37 Alfisols, 15 Mollisols, 15 Vertisols, 6 Inceptisols, 2 Entisols, and 1 Ultisol.

Although the areal coverage of these soils is not equal, it is telling that 76 of the 124 soil series in the Fort Worth District (61%) are judged to have low–moderate or poorer archeological potential in the shallow subsurface, while 86 (69%) are judged to have low–moderate or worse potential at depth. Most of these

low–potential soils are the product of prolonged pedogenesis, and the sediments are simply too old to contain archeological materials in good context. However, in some cases there is a possibility of burial through slopewash, eolian sedimentation, or biogenic sedimentation (e.g., deposition by earthworms and insects) in the soils judged to have low potential, while in other cases materials may be worked into such soils through shrink–swell cracking or bioturbation. In contrast, the soils judged to have moderate–high potential or better represent pedogenic alteration of relatively recent alluvial, colluvial, and eolian sediments. While these soils are also subject to turbation disturbance and the emplacement of more recent sediment veneers, they have higher geoarcheological potential because the sediment bodies in which the soils formed accreted during the period of demonstrable human occupation in the region.

In addition to the soils, the soil maps incorporate other polygons that represent culturally modified portions of the landscape such as quarries, dams, and water bodies. As discussed in the previous section under the category of “made land” intact archeological remains may be serendipitously preserved in some of these settings (i.e., in alluvium inundated by a lake or buried by dam fill). However, the potential for such remains to be discovered during survey is very poor, while the cost of and effort involved in such surveys would be very high. Therefore, these areas judged to have negligible potential for planning purposes.

Potential limitations of the geoarcheological soils characterization include errors and imprecision in the soil maps and in the judgment of geoarcheological potential made for each soil. As anyone who has used soil surveys in the field knows, detailed soil maps are imperfect characterizations of the complex soil landscape. This complexity is fully recognized and incorporated into soil mapping by the USDA. In the case of general soil maps, the mapped units are termed *soil associations* or *general soil map units*, and are typically named for groups of geographically-associated soils (e.g., the *Palopinto–Hensley–Lindy association*). At the detailed level, contiguous spatial units differentiated and mapped by the USDA–SCS and USDA–NRCS are termed *detailed soil map units*. Terminology used to describe these detailed units typically incorporates one or more dominant soil series, a range of slope characteristics, and other pertinent characteristics. An example of a detailed soil mapping unit from Wise County is the *Silawa fine sandy loam, 3 to 8 percent slopes, eroded*.

Importantly, soil mapping units frequently include more than one soil type, and any diverse soils occurring within a mapping unit cannot be differentiated based on the mapped information. In cases where a single soil is dominant, only one series name is typically used, even though the mapped area may include a number of subsidiary soils. For example, the Wise County mapping unit *Purves clay, 1–3 percent slopes* may include up to 25% Aledo and Somervell soils. In other cases, two or more dominant series may be so intimately intermingled on the landscape that differentiating them is not considered warranted, and they are mapped as a complex or association (e.g., the *Bonti–Exray complex, stony, 1–8 percent slopes*). These map units may also incorporate subordinate series. Another consideration in any multiple county project is that the definition of detailed mapping units is unique to each survey, even though the same soil series are identified. For example, the *Aledo–Bolar complex, 3 to 8 percent slopes* map unit in Johnson County includes approximately 60% Aledo soils, 20% Bolar soils, and 20% miscellaneous soils, including Brackett, Hensley, Lewisville, Purves, Seawillow, Sunev, and rock outcrop. In contrast,

the *Aledo–Bolar complex, 5 to 20 percent slopes* map unit in Tarrant County includes approximately 65% Aledo soils, 25% Bolar soils, and 10% miscellaneous soils, including the Frio, Medlin, Sanger, and Brackett series.

After the geoarcheological potential of each soil series was established (see Table 1–1), the shallow and deep potential of each detailed map unit was determined for each county. This determination was made on the basis of the highest potential soil series in the map unit name. Thus, map units with only one named series (e.g., *Bontil fine sandy loam, 2 to 5 percent slopes*) were assigned the probability determined for the series (ignoring secondary soils), while map units with more than one named series (e.g., *Aledo–Bolar complex, 5 to 20 percent slopes*) were assigned the most conservative (i.e., highest) probability among the named series. While this approach ignores the potential for unnamed subordinate soils that may have higher potential to occur, the alternative would skew the result so strongly that the utility of the map would be compromised.

Figure 3–2 illustrates the geoarcheological potential of soil mapping units in the Fort Worth district. Figure 3–3 presents a comparison between the relative number of soil series included in each geoarcheological potential class and the percentage of area occupied by each class. Examination of each figure quickly demonstrates that higher potential areas are relatively restricted, while low potential areas are widespread. Although they make up 24% of the mapped series, areas with higher than moderate potential only occupy 14% of the total area. Low–moderate and low potential soil series, in contrast, make up 60% of the mapped series and occupy 75% of the total area. This difference largely reflects the concentration of relatively high potential soils in depositional lowlands. Another trend that is readily apparent is that very high and high potential soils tend to retain their potential at depth, while soils with moderate and low–moderate potential in the near surface zone tend to be low potential at depth; as a result, more than 77% of the district has very poor potential for preserved archeological materials below shovel test depth.

3.2.1.3 Historic/Recent Disturbance

The distribution of historic disturbance in the district was mapped by heads–up digitizing of disturbance zones using ArcGIS. Heads–up digitizing is a term used to describe a process where a map is created on a computer screen by using a mouse, trackball, or other device to manually trace over one or more reference data sets with computer drawing tools. The base data used to gauge and locate disturbance in the Fort Worth district was a set of digital ortho quarter quadrangles (DOQQ’s) containing imagery dating to the mid–1990’s.

Figure 3-2: Map of the geoarcheological potential of Fort Worth area soil series as evaluated according to the methods described in the text.

Both 1 m and 2.5 m resolution quadrangles were used during the digitizing process. Figure 3-4 illustrates the disturbance dataset produced by heads-up digitization.

While an effort was made to maintain consistency, the subjective nature of the heads-up digitizing process is not particularly conducive to replicability. Each mapping decision required the analyst to make judgments about the extent and degree of disturbance and fix a boundary relatively quickly. While intensely developed areas are relatively straight-forward to map, the decision becomes more difficult as urbanization gives way to a less intensely developed landscape. For example, densely-packed suburban neighborhoods were mapped as disturbed because of the high degree of landscape modification typical in their development, while low-density, semi-rural developments are typically less modified and were less likely to be considered disturbed during mapping. Thus, mapping involved a threshold decision: *at what point does the density of development in an area merit excluding the area from survey?* While every effort was made to make such decisions as consistently as possible, the threshold conditions were evaluated subjectively, and some inconsistency is almost certainly inherent in the dataset. Figure 3-5 illustrates

DOQQ images of typical urban and rural settings in the district overlain with the extent of mapped disturbance.

The suite of “disturbed” areas in urban landscapes includes a wide variety of residential, commercial, industrial, and transportation-related features. The mapping of disturbance in rural landscapes was a more straightforward process, and the types of features mapped as disturbed were more limited. In a very few cases, particularly prominent erosion control terraces were mapped as disturbed, but for the most part features related to cultivation were not considered disturbed for this purpose. Unless pervasive disturbance was indicated, individual rural farmsteads were also not considered disturbance zones. However, large feedlots and dairies were an exception to this generalization.

By far the most common mapped type of disturbance features in the rural areas were stock tanks and ponds. These features are constructed by a variety of methods, and vary considerably in scale. Smaller tanks are typically constructed by bulldozing up small dams across ephemeral drainages or swales, or simply by excavating depressions and surrounding them with embankments constructed from the spoil. Where practical (typically on larger tanks and dams, such as those

Figure 3-3: Graph illustrating the relationship between the number of soil series in each soil potential class (excluding negligible potential features) and the area occupied by each.

constructed by the Soil Conservation Service), mapping of these features isolated the dam and associated disturbance, and did not map the resulting ponded area within the disturbed zone. However, most of the thousands of small depression tanks captured during the head-up digitizing process were mapped with an encompassing polygon (typically a circle) that captured both the water and an assumed area of disturbance surrounding it (see Figure 3-5).

Near the end of the overall mapping effort the author became aware of a useful layer available as part of the USGS's National Hydrography Dataset (NHD). This layer, NHDWaterbody, includes a very detailed and comprehensive set of lakes and ponds. Comparison with the disturbance layer revealed that while there was a good deal of overlap, the NHD dataset also included a number of relatively small features—primarily stock tanks—that had not been captured in the head-up digitizing process. Accordingly, these pond and lake features were merged with the existing data to create the final Disturbance layer (see Figure 3-4).

3.2.2 Methodology

The preceding sections describe the data sets that were compiled to create the FTW-PALM. This section describes the mechanism by which these data were compiled into their final form, yielding a recommendation for the appropriateness of survey. The discussion begins with a quasi-tabular presentation of process steps conducted during GIS processing. This is followed by more detailed discussions of specific issues and decisions involved in the process, and differences with the preceding Houston-PALM model. To clarify some of the terminology for those unfamiliar with ArcGIS, Figure 3-6 presents a schematic overview of the different geoprocessing operations used during construction of the model. The algorithm used to obtain the overall probability determination drew on the supporting datasets to arrive at a nominal statement of the geoarcheological potential of any given portion of the Fort Worth landscape (Figure 3-7). Two determinations were made for each location, one describing the geoarcheological potential of near-surface deposits (up to approximately 1 m, roughly equivalent to shovel-test depth), and the other describing the potential for deeper (greater than approximately 1 m) deposits.

The following basic process-steps were followed:

3.2.2.1 Landform Potential Mapping

1. Base mapping of landforms was conducted on mylar sheets, with paper USGS 7.5 minute quadrangles serving as the base layer and 1995 NAPP 1:37,500 scale aerial stereopair photographs used to identify and map landforms according to the method described in Section 3.2.2.1.
2. The mylar maps were digitized, converted to a continuous GIS layer, and the associated database was populated by the Ferguson Unit GIS Facility of the Texas Department of Criminal Justice using a supervised, semiautomated process. Topological errors were repaired where possible and flagged for later repair where the author's input was required. The projection used for the output was UTM, Zone 14, NAD 83.
3. Upon receipt by TxDOT, the resulting data set was loaded into a ArcGIS personal geodatabase and cleaned of remaining topological errors. Additional fields for landform class (upland/lowland) and final landform scoring were created and populated by calculation from existing fields.

Figure 3–4: Plot of disturbance dataset, showing the character of the two sources and the final combined dataset.

3.2.2.2 Soil Potential Mapping

1. SSURGO datasets for each of the nine counties were obtained from TxDOT’s internal TARHE server. These datasets are the same as are available from the USDA–NRCS, but have been previously joined to their associated data tables. Working copies were saved to local storage and fields irrelevant to the current effort were eliminated.

These files were in unprojected (geographic) decimal–degree coordinates.

2. Text–based tables relating soil mapping unit to the previously determined potential of the constituent soil series (see Table 1–1) were prepared and joined to each file on a county–by–county basis. The county files were merged with the ArcGIS “union” command to form

Figure 3–5: Detailed views of the disturbance dataset overlaid on the source aerial imagery in urban and rural settings.

Figure 3–6: Illustration of GIS geoprocessing concepts and terms useful in understanding the creation of the FTW-PALM model. Each figure consists of a paired polygon group (showing how the data appears in the GIS display) and a schematic, color-coded view of the associated data Table.

Figure 3–7: Schematic illustration of the inputs and processing steps used in the creation of the FTW-PALM.

a single district-wide file, and re-projected to UTM, Zone 14, NAD 83.

3.2.2.3 Outer Boundary Rectification and County Boundary Creation

1. In order to correct differences in the defined district boundaries among data sets (see discussion in Section 3.2.3 below), the Soil_Potential dataset was trimmed to the boundary of the Landform_Potential data and the Landform_Potential dataset was trimmed to the boundary of the Soil_Potential data using the ArcGIS “clip” tool.

2. To create an “operational district boundary” that was coincident with the clipped Landform and Soils datasets, the polygons in the clipped Landform data were merged to form a single polygon using the ArcGIS “dissolve” tool.

3. To create an “operational county boundary” dataset, the district boundary created in step (2) was subdivided using the “split” geoprocessing tool as the base layer and the TxDOT county boundary file as the split features. This dataset was then examined and minor cleanup performed to finalize the operational county polygons (minor editing in the form of polygon splits and merges were necessary at specific corners, such as the northeastern corner of Johnson County, to eliminate tiny “panhandles” caused by slight differences in outer boundary locations).

4. Each county boundary was saved as a separate file to facilitate additional processing.

3.2.2.4 Disturbance Mapping

1. Base mapping of disturbance was conducted by heads-up digitizing on a base of digital ortho quarter quadrangles (DOQQ's) at 1.0 to 2.5 m resolution. These images dated to the mid 1990's. Heads up digitizing was performed at a variable scale that ranged between approximately 1:1,000 and 1:10,000. Mapping was conducted with reference to imagery projected in UTM, Zone 14, NAD 83. A value field was created and populated with zeros.

2. Additional disturbance was documented by incorporating the layer “NHDWaterbody” from the National Hydrographic Dataset. This data is in native unprojected (geographic) decimal-degree coordinates. It was projected to UTM Zone 14, NAD 83, and clipped to the “operational” district boundary. Irrelevant data fields were deleted, and a value field was created and populated with zeros.

3. Because initial attempts to merge these two datasets failed repeatedly (available computer memory was insufficient),

the district-wide files were each clipped to create separate heads-up and NHD disturbance layers for each of the nine counties. These layers were then joined with a “union” geoprocessing command. Because this operation resulted in many stacked polygons (where NHD waterbody data overlay water bodies and buffer zones mapped during the heads-up phase), internal boundaries were removed with a “dissolve” command to create a disturbed areas map for each county.

4. To obtain a map of undisturbed areas, ArcGIS’ “symmetrical difference” routine was run for each county using the operational county boundary as the input feature and the relevant disturbed areas map as the update feature. A value field was then created in the resulting file and populated with ones.

5. The final disturbance file was created by performing a union of the disturbed and undisturbed files, and copying the respective zeros and ones into a single value field. Table 3–3 lists the extent of areas mapped as disturbed in each county.

3.2.2.5 Compilation

To create the final county Potential Archeological Liability Maps (PALMS), the following steps were completed for each county:

1. The Soil_Potential and Landform_Potential datasets were merged with the ArcGIS “union” command, and the resulting file was then merged with the county’s disturbance file using the “union” command.

2. The merged file was then placed into editing mode and all polygons were selected. The ArcGIS “explode” tool was then used to eliminate multi-part polygons (in most cases this actually required several iterations with different parts of the dataset selected to avoid memory errors).

3. An acreage field was then created and ArcGIS was used to calculate the area of each polygon. The data set was then sorted according to size, and all polygons smaller than 0.05 acres (roughly 200 m²) were selected.

4. The ArcGIS “eliminate” tool was used to merge these very small polygons into their larger neighbors as a single batch operation.

5. Shared boundaries between each county and other counties in the district were then systematically inspected, and sliver polygons created by minor differences in the location of the various county boundaries were merged into adjacent polygons.

Table 3-3: Area of Mapped Disturbance by County

Name	Total Area (sq. mi.)	Disturbance Captured by Heads-Up Digitizing (sq. mi.)	Final Mapped Disturbance Area (sq. mi.)	Percentage of Total Area
ERATH	1080	26.07	38.13	3.5%
HOOD	425	20.67	39.76	9.4%
JACK	920	14.16	26.00	2.8%
JOHNSON	731	28.29	46.77	6.4%
PALO PINTO	949	23.37	55.44	5.8%
PARKER	902	30.83	50.42	5.6%
SOMERVELL	188	4.60	10.27	5.5%
TARRANT	868	324.23	487.65	56.2%

6. New fields for final numeric scoring and text potential were created and populated using the ArcGIS field calculator, according to the algorithm presented in Figure 3-7. Interim calculation fields were then deleted, but the original values for the landform, soil, and disturbance datasets were retained in each file, so that the constituent data is still readily available. Table 3-4 presents the characteristics and size of each file, and Table 3-5 describes the field structure of the final county PALM files. Appendix 4 illustrates small scale versions of each of the nine county PALMs.

7. The individual files were combined into a single district-wide file using the ArcGIS “append” command. Because this file was so large (almost half a million polygons, requiring approximately 650 mb of disk space), the individual county files were also retained for more localized planning and compliance needs.

3.2.3 Discussion

This discussion addresses several aspects of the mapping process in greater detail than is supplied above in the process description. It first contrasts the procedures used in the current effort with those used in the previous PALM mapping of the Houston District. It then includes discussion of several issues that arose during the process and how they were addressed.

3.2.3.1 Comparison with Previous PALM Mapping Procedures

In the Houston-PALM model (Abbott 2001a), the decision was made to structure the mapping process so that all information was synthesized during primary drafting, which occurred with reference to a variety of simultaneous sources (aerial stereopairs, topographic maps, and soil mapping). While functional, this solution has the disadvantage that any update would require a wholesale replication of the mapping

process. With Fort Worth, the decision was made to leverage existing GIS data (i.e., SSURGO soils) and create parent datasets that could be used for eventual updates if needed.

Another aspect changed from the previous model is the character of recommendations, which are intentionally phrased in a less explicit manner this time. In the Houston-PALM, a given project might occupy an area where the model concludes, for example, that “surface survey is always recommended, and deep prospection is recommended if deep impacts are anticipated.” As the detailed presentation accompanying the Houston-PALM made clear (Abbott 2001a), the model was never intended to be a decision maker, but rather a support tool to be used in concert with other data. Thus, it was expected that the Houston-PALM would sometimes conflict with the staff archeologist’s recommendation. While this approach to labeling areas in the Houston-PALM provided a straightforward solution, it also presented a situation where the ultimate recommendation made by the staff archeologist could contradict the model, thus raising questions in the mind of third parties about the accuracy of the model, competence of the archeologist user, or both. More troubling were indications that the model was sometimes being used as a final arbiter of survey decisions, a function that it was not suited for (for one thing, the model has no relevance whatsoever for historic-age resources). For these reasons, the decision was made to present the final recommendation for any given location in the Fort Worth District as a probability statement rather than a recommendation, thereby (1) avoiding this source of potential confusion and (2) more accurately reflecting the true intent of the presentation.

3.2.3.2 Boundary Discrepancies

This problem was not anticipated ahead of time, although in retrospect it probably should have been. As soon as the digitized landform data was received from the TDCJ, it was loaded into the GIS system and displayed on top of the previously completed soils data to provide a “sneak-preview”

Table 3–4: List of the GIS Datasets Used to Compile the FTW–PALM

Dataset	Native Projection	Native Scale of Source	Number of Polygons in Dataset	Comments
INITIAL DATASETS				
Landform Dataset (TxDOT/TDCJ)	UTM Zone 14, NAD83	1:24,000	23,883	Converted from mylars digitized on a hard copy USGS 1:24,000 topographic map base (NAD 27; projection identified variously as "polyconic" and Albers Equal Area
Soil Datasets (USDA–NRCS)				
Erath County	Geographic (Decimal Degree), NAD 83	1:20,000	13,183	
Hood/Somervell County	Geographic (Decimal Degree), NAD 83	1:20,000	9,262	
Jack County	Geographic (Decimal Degree), NAD 83	1:24,000	8,327	
Johnson County	Geographic (Decimal Degree), NAD 83	1:20,000	10,537	
Palo Pinto County	Geographic (Decimal Degree), NAD 83	1:24,000	5,441	
Parker County	Geographic (Decimal Degree), NAD 83	1:20,000	12,081	
Tarrant County	Geographic (Decimal Degree), NAD 83	1:20,000	9,956	
Wise County	Geographic (Decimal Degree), NAD 83	1:24,000	16,482	
		total	85,269	
County Boundaries (TxDOT)	Geographic (Decimal Degree), NAD 83	n/a	9	
District Boundary (TxDOT)	Geographic (Decimal Degree), NAD 83	n/a	1	
Heads–Up Disturbance	UTM Zone 14, NAD83	varies	33,156	Digitized on FSA aerial imagery by TxDOT ENV; scale of base view during mapping varied.
NHD Waterbody	Geographic (Decimal Degree), NAD 83	1:12,000 to 1:24,000	61,745	Count of polygons is clipped to district boundary
COMBINED DATASETS				
Final Disturbance (FTW District)	UTM Zone 14, NAD83	varies	96517; dissolved to 60,824	Combination of Heads–Up Disturbance and NHD Waterbody (after projection to UTM Zone 14)
Erath County	UTM Zone 14, NAD83	varies	9560	
Hood County	UTM Zone 14, NAD83	varies	3417	
Jack County	UTM Zone 14, NAD83	varies	14043	
Johnson County	UTM Zone 14, NAD83	varies	7327	
Palo Pinto County	UTM Zone 14, NAD83	varies	7637	
Parker County	UTM Zone 14, NAD83	varies	8938	
Somervell County	UTM Zone 14, NAD83	varies	1302	
Tarrant County	UTM Zone 14, NAD83	varies	4529	
Wise County	UTM Zone 14, NAD83	varies	10077	
		total	66,830	
Landform–Soil Union (FTW District)	UTM Zone 14, NAD83	n/a	229,591	
Erath County	UTM Zone 14, NAD83	n/a	35,250	
Hood County	UTM Zone 14, NAD83	n/a	16,643	
Jack County	UTM Zone 14, NAD83	n/a	24,859	
Johnson County	UTM Zone 14, NAD83	n/a	26,779	
Palo Pinto County	UTM Zone 14, NAD83	n/a	17,512	
Parker County	UTM Zone 14, NAD83	n/a	35,294	
Somervell County	UTM Zone 14, NAD83	n/a	8,447	
Tarrant County	UTM Zone 14, NAD83	n/a	26,339	
Wise County	UTM Zone 14, NAD83	n/a	40,884	
		total	232,007	
FINAL PALM MAP				
Erath County	UTM Zone 14, NAD83	n/a	68,520	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres
Hood County	UTM Zone 14, NAD83	n/a	31,625	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres
Jack County	UTM Zone 14, NAD83	n/a	52,609	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres
Johnson County	UTM Zone 14, NAD83	n/a	51,711	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres
Palo Pinto County	UTM Zone 14, NAD83	n/a	46,097	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres
Parker County	UTM Zone 14, NAD83	n/a	65,654	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres
Somervell County	UTM Zone 14, NAD83	n/a	14,688	after exploding all multi–part polygons, merging edge–effect polygons, and eliminating all polygons <0.05 acres

Table 3–5: Data Structure of the Final FTW–PALM GIS Database

FIELD NAME	DATA TYPE	PARENT SOURCE	COMMENTS
FID	ObjectID	ArcGIS	Key field assigned automatically by ArcGIS
Shape	Geometry	ArcGIS	Link field between geometry (graphic elements) and database, assigned automatically by ArcGIS
Landform	String (10)	Landform Model	This field lists the mapped landform associated with each polygon. It was created during primary landform–based mapping on topographic base maps. See Section 3.2.1.1 for key to mapping symbols.
LandFmGroup	String (8)	calculated field	Superclass of landforms. Landforms are classified as either "upland", "lowland", or "other." "Other" class consists of mapped artificial landforms that can occur in either context (e.g., artificial water, made land).
MUNAME	String (175)	county SSURGO files	Classification of soil mapping polygon inherited from original SSURGO GIS file, which in turn reflects paper soil mapping by the USDA Soil Conservation Service (now NRCS).
LF_S_POT	Short Integer	Landform Model	Landform–based, shallow geoarcheological potential. The original score (not retained) was assigned primary landform–based mapping on topographic base maps. This final score was calculated by multiplying original score by two for lowland landforms and by 1 for upland landforms. Range 0–10.
LF_D_POT	Short Integer	Landform Model	Landform–based, deep geoarcheological potential. The original score (not retained) was assigned primary landform–based mapping on topographic base maps. This final score was calculated by multiplying original score by two for lowland landforms and by 1 for upland landforms. Range 0–10.
SOIL_S_POT	Short Integer	soil model	Soil–based, deep geoarcheological potential. Score assigned according to ranking of soil series according to method described in Section 3.2.1.2, calculated from MUNAME. Range 0–6.
SOIL_D_POT	Short Integer	soil model	Soil–based, deep geoarcheological potential. Score assigned according to ranking of soil series according to method described in Section 3.2.1.2, calculated from MUNAME. Range 0–6.
DistScore	Short Integer	heads–up mapping from 1995–era DOQQ and NHD	Binary score for disturbance mapped on digital ortho quarter quads (DOQQs) within ArcGIS, merged with ponds mapped as part of the National Hydrographic Database (NHD). Score either disturbed (0) or undisturbed (1).
SHAL_POT	Short Integer	calculated field	Shallow geoarcheological potential. Calculated numerical potential derived from combination of LF_S_POT, SOIL_S_POT, and DistScore according to the algorithm described in Section 3.2.2.5. Range 0–16.
DEEP_POT	Short Integer	calculated field	Deep geoarcheological potential. Calculated numerical potential derived from combination of LF_D_POT, SOIL_D_POT, and DistScore according to the algorithm described in Section 3.2.2.5. Range 0–16.
Shallow	String (20)	calculated field	Simplified, text statement of shallow geoarcheological potential derived from reclassification of SHAL_POT field. Ranges from High Probability to Negligible Probability.

of the final dataset. Alarming, a number of areas were noted where differences existed between the outside county boundaries in these two sources. In most cases the difference was relatively trivial (20 meters or less, a distance that would fit comfortably under a pencil line at a scale of 1:24,000) but in a few case the difference was considerably greater (up to half a kilometer in a few cases; see Figure 3–8) These boundaries were then compared with the TxDOT official county boundaries file, which proved different than either of the other two. However, it was noted that the differences between the “official” TxDOT boundaries and the USGS topo–derived boundaries used for landform mapping were comparatively minor, while the soils data sets included far more obvious differences.

When this difference was first observed, there was a fear that the different datasets were actually mis–registered somehow (i.e., that given points inside the body of the respective maps did not represent the same position on the ground, due to map projection problems or other forms of error). This would clearly have been a serious problem, but the fear was quickly allayed. First, the errors were not systematic in the way that GIS–based registration error (e.g., error resulting from the use of different map datums or projections) would produce. Second, obvious features (e.g., stock tanks) on both maps matched with each other and with equivalent features on the aerials. It quickly became apparent that the differences in boundary locations was a legacy phenomenon: the USDA soils data

used the county boundaries shown on paper soils maps, the landform data used the boundaries on the USGS topo maps, and neither matched each other or the “official” TxDOT boundaries.

Clearly, it was necessary to choose a boundary set to use for the data. Although this decision should ideally have been made before starting the process, the problem wasn’t recognized until much too late to prevent it, as primary mapping, scanning, and digitization was complete. After examining the respective extents and weighing options, the decision was made to avoid additional mapping by cropping the data set to the shared extent of soil and landform mapping. This decision resulted in an “operational” or assumed district boundary that conforms closely but not precisely with the TxDOT standard boundary (it is roughly 15.7 km² (0.08%) smaller and 200 m (0.03%) shorter). Further comparison reveals that unmapped areas within the TxDOT–defined district boundary total 17.7 km², while mapped areas outside the TxDOT–defined boundary total 2.06 km². Finally, more than 12.8 km² (72%) of the 17.7 km² discrepancy between the TxDOT boundary and the final, “operational” PALM boundary is attributable to one area: the border between Tarrant and Denton Counties, which differs by up to 560 m along the 34 km border (although it was contained in specific editing suggestions and is therefore not published in the appendix, Duane Peter of Geo–Marine Inc. noted that Tarrant and Denton Counties continue to dispute the boundary). This difference is

Figure 3-8: Detail of the western district boundary between Erath County and Comanche and Eastland Counties in the neighboring Brownwood District, showing an example of a relatively pronounced county line discrepancy in the soil dataset, and “pencil-line” discrepancies caused by magnification beyond the mapping scale in the landform dataset.

inherited, in that it mirrors a drastic difference between the TxDOT county boundary and the boundary depicted on the USGS topo series.

At this point, the STRATMAP boundary file (the closest thing Texas has to an “official” GIS boundary) was downloaded from the Texas Natural Resource Information System (TNRIS) website and compared to the existing boundary (up to this point, analysis had labored under the false impression that the TxDOT boundary was the STRATMAP boundary. This series of boundaries matched up very closely with the existing TxDOT boundaries, with the notable exception of the Tarrant–Denton County line, where it matched the USGS topo boundary. When this boundary was compared with the “operational” boundary used for the PALM, the difference was much more limited. Areas within the district boundary (per STRATMAP) but excluded from the PALM totaled 5.06 km² (approximately 0.02% of the total area), while areas inside the PALM but outside the STRATMAP boundary were limited to 0.015

km². Examination of the boundary differences suggest that differences between the boundaries are the result of the resolution of mapping (pencil thickness error, as described above), coupled with a few slivers where the area was reduced by clipping to the soil maps.

3.2.3.3 Compilation Algorithm Considerations

Several versions of the combination algorithm were tried before the final version was determined. At the outset of mapping, the plan was to weight the landforms (mapped in-house) twice as heavily as the soils data across the board, per the revised protocol for mapping. However, upon initial review of the data, it was observed that this had the unplanned consequence of inflating the score of many upland landforms more than was considered warranted. Reassessment of the scoring system used during mapping led to the conclusion that while the scores were assigned judgmentally, the decisions were made relative to internal criteria (e.g., within each given class of landforms) and the scores assigned different landforms were not particularly comparable. For example, a score of 2 assigned to an alluvial fan landform reflected a judgment of relatively poor potential among fan landforms (the possible range of scores assigned to medial/distal fans varies from 2 to 4; see Table 3-2), but was not really equivalent to a score of 2 assigned to a slope landform. Accordingly, the decision was made to only double the score of the lowland landforms (e.g., low terrace, fan, colluvial toeslope, floodplain, channel). This resulted in scoring that was considered more realistically balanced between different landform categories.

The GIS files were merged and numeric scores ranging between 0 and 16 were calculated for each polygon by merging the Landform Potential score, Soil Potential score, and Disturbance score according to the algorithm in the upper part of Figure 3-7. The near-surface and deep potential of each mapping polygon was then reduced to a simple, four-part recommendation (negligible, low, moderate, or high) according to the classification presented in the lower part of Figure 3-7. Both classifications were maintained in the final model to provide the user with a degree of flexibility in balancing available detail vs. straightforward presentation. Figure 3-9 illustrates the relative area occupied by the different mapping units in the shallow and deep models. Unsurprisingly, the relative proportion of low-potential areas increases markedly with depth. As comparison of the two graphs illustrates, however, this increase is derived primarily from the moderate and negligible categories.

Figure 3-9: Plot of the area (in km²) and relative percentage of the entire district covered by the different mapping units for the shallow model and the deep model.

One issue that arose during map compilation was the generation of small, distracting mapping tracts that resulted from lack of congruence between the datasets. Unlike the boundary issue, this problem had been anticipated prior to processing the final files. This phenomenon can be termed “edge uncertainty”, and arises primarily because the process of drawing boundaries separating natural phenomena is an imprecise art. For example, while the boundary between two mapped soils may show a great deal of similarity to the boundary between the landforms these soils occupy, it is very unlikely that the boundaries themselves will be coincident. Consequently, generation of a composite coverage results in the creation of a number of small polygons along the map boundary (Figure 3-10). In general, most of these small polygons are retained in the final model because merging them would introduce distortions into the parent data (which is also retained in the final model). However, there were a number of very small

polygons with negligible discrete information content in each combined county file. These data were examined, and the decision was made to merge any polygon smaller than 1/20th of an acre into adjacent polygons using the ArcGIS “eliminate” geoprocessing command. This simple procedure eliminated between approximately 5% and 20% of the polygons in each merged county, saving considerable storage space with no meaningful loss of data.

3.2.3.4 Scale and Usage Considerations

The preceding methodology represents an explicit approach to mapping geoarcheological potential in the Fort Worth District. However, proper application of the resulting map requires that an appropriate scale be applied. The resolution of the FTW-PALM is appropriate to the scale of landform mapping (1:24,000). The design of map units and the level of detail shown in the resulting soil map are dependent on that map scale. Enlargement of maps beyond the scale of mapping, which is readily accomplished in a GIS system, can cause misunderstanding of the detail of mapping, the accuracy of line placement, and the character of small areas that could have been shown at a more detailed scale.

As previously described (Section 3.2.2.5; Table 3-5), the FTW-PALM model includes a number of different data fields reflecting its origin as a compilation of different data sets.

This allows the end user to display the final FTW-PALM in either relatively high resolution format (a numerical score that ranges from 0 to 16, with higher numbers equating to higher potential) or in a simplified “low-moderate-high potential” format. Each of these options occurs twice in the dataset: once for the area’s calculated shallow (< 1 m bgs) potential, and once for its deep (> 1 m bgs) potential. Unlike the previous Houston-PALM, this information has not been combined into a single display option, so it will be necessary for the user to review at least two maps to determine the FTW-PALM recommendation. Users may also examine the constituent data (soils, landforms, and disturbance) by plotting the appropriate fields (see Table 3-5). Finally, as a result of the very large number of constituent polygons, it is suggested that users modify the display so that polygons border thickness is set to zero, particularly for use of the model at scales smaller than approximately 1:50,000.

Figure 3-10: Schematic illustration of the origin of "sliver" polygons during the union of datasets in a GIS system.

3.3 Model Evaluation

Integrity-based modeling is not intended to predict where sites are likely to occur on the landscape. The location of archeological sites is a function of human behavior, not of natural processes. This makes evaluation of integrity models somewhat more difficult than it is for behavioral models. In a behavioral model, evaluation is simply a matter of comparing the predictions of the model against the universe of identified sites. If the existing inventory is robust and varied enough to be a valid sample, then the strength of the model is simply a measure of how well it predicts the occurrence of the known sites. With an integrity model, in contrast, the question is not "is a site there?" but rather "are landscape conditions conducive to preservation of a site if it happens to be there?" The sample to test against, therefore, is not the universe of known sites, but rather sites that have been previously found to have reasonable spatial and stratigraphic integrity, which usually (but not always) is a prerequisite for a finding of NRHP eligibility. Examining all known sites can actually be misleading, because high integrity sites are typically buried and therefore have relatively low visibility on the landscape (and therefore less likelihood of recordation), while surface sites are less likely to retain reasonable integrity but have higher visibility and more likely to be included in the existing inventory.

The problem is compounded in Texas because there is no extant list of sites that have been found NRHP eligible. The State of Texas site records are maintained at the Texas Archeological

Research Laboratory (TARL) at the University of Texas J. J. Pickle Research Campus in Austin. These physical files consist primarily of site forms and supporting documentation collected during one or more evaluation visits. In the late 1990's, these files were transcribed and made web-accessible as the Texas Historic Sites Atlas in a cooperative project between TARL and THC, funded by FHWA as a transportation improvement under ISTEA (the Intermodal Surface Transportation Efficiency Act of 1991). The Atlas provides an efficient mechanism of conducting remote file searches, but the problem remains that the information in the Atlas is generally the first blush impressions that make it onto a site form, not determinations made after eligibility testing. Although most of the many different survey forms compiled in the Atlas include some variation on a "recommendations" field, the qualifications of the person making the recommendation, the site characteristics that they value, and the unique history of disturbance make this recommendations difficult to use. For example, relatively early site forms and some non-professional site forms are more likely to weight material quantities more strongly than context in making recommendations,

while it is frequently unclear whether a recommendation of "no further work" stems from a dearth of material, a landscape setting that has poor potential to preserve sites, or a location where recent disturbance has destroyed what may have previously been a site with good integrity. Finally, although most forms include some variation of an observation of "site type" or "temporal period", the Atlas does not even include a mechanism to readily distinguish between prehistoric and historic sites.

Although the Atlas data is far from an ideal test, it is an interesting data set to compare with the PALM predictions. An ArcGIS shapefile of site centroids for the nine FTW District counties was graciously supplied in May, 2009 by Jonathan Jarvis at TARL. This shapefile contained 1151 site centroids, varying from 32 recorded sites in Jack County to 330 in Palo Pinto County. Density varies from a low of 0.013 sites per km² (or 1 site per 74 km²) in Jack County to a high of 0.32/km² (1 site per 3 km²) in tiny Somervell County. The distribution of sites (Figure 3-11) is strongly skewed, with obvious clustering and linearity indicating the locations of roads, pipelines, transmission lines, reservoirs—in short, where people have been motivated to look and record sites by federal and state laws. The clustering of sites in intensely surveyed areas raises the question of whether, after a hundred years of archeological work, the extant site inventory is a statistically meaningful sample of the prehistoric record in the overall district.

Figure 3–11: Plot of known prehistoric sites in the Fort Worth district, classified by their final shallow geoarcheological potential.

Nevertheless, these data do provide a mechanism to look at the relationship between the predictions of the FTW–PALM and sites in the Fort Worth District. To explore this relationship, the Atlas site files were reviewed to extract two basic types of information about the 1151 sites: (1) whether they are prehistoric, historic, or both, and (2) whether additional work was recommended by the recorder. This review revealed that 682 (59%) of the recorded sites are prehistoric, 288 (25%) are historic,

25 (2%) are both, and 156 (14%) are not described in enough detail to tell (although it is likely that the majority of these generally older site records also represent prehistoric sites). When compared to the shallow potential probability map, 192 (17%) fall in high potential areas, 364 (32%) are in moderate potential areas, 448 (39%) are in low potential areas, and 147 (13%) are in areas mapped as having negligible potential (including water bodies). Prehistoric sites are more likely to occur in high

potential areas than historic sites are—approximately 21% of recorded prehistoric sites occur in areas with high potential for shallow remains, compared to only 8% of historic sites. Of course, this means that roughly 79% of the known prehistoric sites occur in areas with moderate, low or unknown potential, but it is still telling that 21% of sites occur in what are typically low-visibility settings that make up only 11% of the district by area.

Trends in recommendations for additional work were not particularly informative. Overall, 58% of recorded sites were recommended for further work (or, more accurately, not explicitly recommended for no further work). Broken down by map area, 66% of high potential, 55% of moderate potential, 54% of low potential sites, and 72% of negligible potential sites were not dismissed at the survey level. When only prehistoric sites are considered, 68% of high potential, 61% of moderate potential, 59% of low potential sites, and 76% of negligible potential sites were recommended for additional work. This suggests that surveyors are not particularly prone to explicitly recommending no further work on the basis of initial impressions, which is not really surprising given the nature of the archeology industry and the natural tendency to give sites the benefit of the doubt. What is somewhat surprising is the high number of sites in high potential areas that *are* recommended for no additional work. Review of the Atlas database indicates that the justification for this recommendation typically relates to low frequencies of material and/or severe disturbance or erosion.

Examining the suite of listed National Register properties and State Archeological Landmarks is also not particularly informative. According to the Archeological Sites Atlas, there are only ten SAL listed archeological properties in the district (41PR2, 41PR3, 41PR4, 41SV57, 41SV58, 41SV59, 41TR62, 41TR113, and 41TR118), and only one of these (41TR62, the Marrow Bone Spring site) is also listed on the NRHP. More than half of these SAL's (the Parker and Somervell County sites) represent sites in State Parks (Mineral Wells State Park and Dinosaur Valley State Park, respectively) that were designated in the first part of 1983, which suggests they are part of a brief initiative to list sites by Texas Parks & Wildlife (TPWD). While the Dinosaur Valley Park sites clearly have potential based on their description, the three Parker County sites are described in such dismal terms that their inclusion represents an atypical application of the Texas Antiquities code (although all archeological sites on property of the State or one of its political subdivisions are technically State Archeological Landmarks (SALs), formal designation is usually reserved for sites with recognized research potential).

3.4 Advantages and Disadvantages of the Approach

There are several advantages as well as potential disadvantages in the application of a landscape model like FTW-PALM to cultural resource management. This section outlines many of these strengths and weaknesses, and argues that the former far outweigh the latter. Each recognized disadvantage is listed and explained, and a rebuttal argument is made that illustrates why the disadvantage is outweighed. In several cases, it is pointed out that design and implementation of complementary planning tools would compensate for deficiencies in the approach. This discussion is followed by a list of the advantages of the approach for efficient and effective compliance with cultural resource laws, and for the advancement of scientific knowledge about the prehistory of north-central Texas.

3.4.1 Disadvantages of the FTW-PALM

Disadvantage: FTW-PALM may fail to correctly map areas with good contextual potential.

Amplification and Rebuttal: No landscape model is perfect. As mentioned earlier, landscapes have a fractal quality in many respects, in that significant variability is typically observable at all scales. It is unrealistic to assume that examination of geoarcheological potential in a regional framework can produce a map that is sufficiently detailed that *all* areas of high potential are captured and *all* areas of low potential are excluded. Moreover, from a practical standpoint, it is undesirable to produce a map that is so detailed that it will not be used for the intended purpose. Thus, it is virtually assured that some sites with reasonable integrity will be missed (i.e., mapped as low potential), but this is a function of the scale and character of the model.

Disadvantage: FTW-PALM may fail to correctly map areas with poor contextual potential.

Amplification and Rebuttal: For the same reasons outlined above, some low-potential areas were almost certainly included in high potential mapping areas.

Disadvantage: FTW-PALM has no mechanism for identifying sites in low potential parts of the landscape.

Amplification and Rebuttal: As stated above, the geoarcheological model adopted here is directed

towards identifying where sites are likely to be *preserved in reasonable context*, rather than where they are likely to *exist*. This distinction is crucial. The distribution of sites obtained through application of this model will exhibit bias against activities that may have been regularly conducted in stable or erosional parts of the landscape. Thus, viewed in isolation, the data set produced is not well suited to broad-scale issues such as settlement patterning and certain aspects of resource procurement. While TxDOT recognizes this failure, extant cultural resource laws are not concerned with every archeological site, but rather with sites that contain enough meaningful data to qualify as historic properties. In almost all cases, reasonable spatial and stratigraphic integrity is required for a site to satisfy these criteria. Moreover, the extant site inventory contains many sites that *do* relate to settings with poor potential for integrity because they tend to be more highly visible, while deeply buried and stratified sites are almost certainly underrepresented because appropriate steps to identify and locate them are not always taken. By directing future research toward areas where such sites are likely to occur, the potential for advancing the state of knowledge about Texas archeology is enhanced.

Disadvantage: FTW-PALM is unsuited to identify intentionally buried prehistoric resources.

Amplification and Rebuttal: Because the FTW-PALM is focused on identifying areas where natural processes have the potential to bury and preserve archeological sites, it is poorly suited to address sites characterized by intentional prehistoric excavation (e.g., burials) or artificial sediment accumulation (e.g., burned rock middens) in parts of the landscape that otherwise have low potential. The potential clearly exists for such sites to occur in stable, upland settings judged to have poor geoarcheological potential using the criteria in the current model. One possible solution is the development of a behaviorally-based model of topographic setting for these sites, to be used in conjunction with the FTW-PALM to identify the need for archeological assessment.

Disadvantage: FTW-PALM is unsuited to identify historic archeological resources.

Amplification and Rebuttal: The model employed in this study is predicated on prehistoric remains; the assumption is that sites formed on stable upland surfaces have been exposed for so long that disturbance

and cultural overprinting will typically render any contextual data recovered suspect. However, the same is not true of historic sites, where the diversity of time-diagnostic materials and limited time depth render spatial/stratigraphic disturbance and cultural overprinting much less problematic than it is for prehistoric sites. Thus, the map units in the FTW-PALM do not apply to historic resources. On the other hand, location of historic resources can use a broader set of data sources (e.g., historic maps, land records, aerial photographs) than are useful in locating prehistoric resources, and it would be relatively easy to establish a distinct protocol for evaluating the need to determine whether areas exempted from prehistoric survey on contextual grounds might require survey focused on historic remains.

3.4.2 Advantages of the FTW-PALM

In TxDOT's opinion, the advantages of FTW-PALM far outweigh the disadvantages. These advantages include:

1. FTW-PALM allows for more rapid and consistent evaluation of archeological potential for proposed projects, and more rapid coordination with regulatory agencies.

Amplification: All CRM archeologists, including those working for TxDOT as employees and contractors, must make frequent decisions about whether a survey is necessary to satisfy legal antiquities protection requirements for planned undertakings falling under federal and/or state jurisdiction. Such decisions are based on a variety of information, including the landscape setting, soils, distribution of previously identified sites on the surrounding landscape, and the character and extent of planned impacts. Such decisions are also filtered through the conscious or subconscious preferences and experience of the person making the decision. Needless to say, because each archeologist has unique experiences and perspectives, the recommendation that different archeologists would make on any given project may differ. FTW-PALM provides a straightforward evaluative framework that is reasonable, consistent, and scientifically-grounded.

Moreover, because the decisions currently made by archeologists about whether to survey and test are by nature individualistic, the process of review by archeologists in regulatory positions (THC) requires considerable thought and effort, which is itself time consuming. FTW-PALM provides a mechanism for TxDOT and THC to reach broad consensus on the

patterning of areas possessing or lacking archeological potential on a regional basis, thus eliminating much of the effort, and the time, involved in this aspect of compliance review.

2. FTW-PALM eliminates the need for archeological survey in existing and proposed right of way in a considerable portion of the Fort Worth Highway District.

Amplification: Archeological survey is an expensive and time-consuming process. TxDOT's legal and ethical responsibility to account for archeological resources in the process of fulfilling its mandate is balanced by its fiduciary responsibility to the taxpaying public. It follows that it is incumbent on TxDOT to develop mechanisms to accomplish compliance with existing antiquity laws in ways that are as scientifically effective and as fiscally efficient as possible. As Part 2 of this volume demonstrates, there are many factors that contribute to the preservation or degradation of an archeological site, and the distribution of environments conducive to preservation is patterned and predictable on the landscape. Because reasonable archeological integrity is a necessary attribute of a significant site within the current operational framework, it is possible to predict where preservation is unlikely, and where the need for survey can therefore be eliminated.

It is important to stress that archeological integrity is not a binary concept, but a relative measure that spans the continuum between perfect behavioral integrity and utter entropy. Few sites occupy either end of the continuum; most reflect the combined influence of behavior and the filters imposed by subsequent physical and biological processes. The phrase "reasonable integrity" refers to a position on that continuum where it is still reasonable to expect that aspects of the behavioral context can be teased out with a degree of confidence. Because people tend to reoccupy certain places on the landscape, and because the majority of materials recovered from prehistoric archeological sites in Texas are not themselves time-diagnostic, an important component of reasonable integrity is the potential for the occurrence of stratigraphically-isolable components or component elements. For this reason, FTW-PALM emphasizes loci where depositional processes have been active in the culturally-relevant period.

3. FTW-PALM allows District Transportation Planners to better anticipate compliance needs in evaluating routing alternatives.

Amplification: Transportation planners must make many decisions in planning and evaluating the evolution of transportation networks. This process involves evaluation of need, and development of alternatives to meet that need. Such decisions are made on the basis of a wide variety of information, including the physical and engineering characteristics of alternative sites, the location of existing buildings and infrastructure, forecasts of future demands on the system, cost-benefit analyses of proposed improvements, and costs associated with environmental compliance. At present, the impact of archeological compliance on a given project is a pure black box to the transportation planner; in almost every case, they have no idea how or whether archeology will impact any given project. FTW-PALM provides a tool that supplies the transportation planner with another line of information to use in designing a system that maximizes efficiency and minimizes cost to the taxpayer.

4. FTW-PALM limits tax dollars spent identifying and testing sites that ultimately will be judged ineligible due to lack of archeological integrity.

Amplification: As discussed above (point 2), the process of archeological survey is expensive and time consuming. However, this statement is even more true for the process of significance testing, which usually involves the excavation of a number of formal test pits, frequently supplemented by the excavation of backhoe trenches, surface collections, and additional shovel tests. The costs for field labor are compounded by the extensive time and expense of analysis, report preparation, and curation. For this reason, site testing investigations in Texas often take weeks and cost tens, or sometimes hundreds, of thousands of dollars. Under standard archeological practice (i.e., the traditional application of the Section 106 process), determinations of ineligibility on the basis of insufficient integrity are typically only made after significance testing has been performed (although there are exceptions; see Trierweiler 1994). While evaluation of data content can usually only be made following significance testing, it is possible to predict the likelihood that many sites will not satisfy required integrity criteria on the basis of the site's setting. FTW-PALM is such a predictive model. Because the existing cultural resource laws are concerned not with sites *per se*, but with potential historic properties, FTW-PALM provides a mechanism to save tax dollars that would have otherwise been spent locating and testing non-significant sites.

5. FTW-PALM focuses survey investigations on areas with moderate to strong potential to contain sites with stratigraphic integrity, and thus contribute to our understanding of the prehistoric record.

Amplification: FTW-PALM provides an important benefit to the scientific discipline of archeology, in that it directs the focus of investigations to settings that are likely to yield high-quality, focused data. Because the processes that promote site preservation also tend to limit site visibility, there is a relatively consistent inverse relationship between the quality of data integrity at a site and the odds that it will be found with traditional pedestrian survey techniques. For this reason, and because of the long-term emphasis on phase-building and material culture characterization, traditional Texas archeology has tended to focus on sites that are relatively visible and contain relatively large quantities of cultural material. Unfortunately, these are exactly the wrong kind of sites to capture discrete behavioral episodes, and therefore to characterize adaptive behaviors in anything but a broadly generalized way (Collins 1995; Ferring 1986). At the same time, those sites that do contain such assemblages have been largely ignored because they have poor visibility and

low material density, and were thus rarely looked for, and often dismissed when they were found because of low artifact frequency. FTW-PALM is predicated on the tenet that buried, isolated components representing discrete behavioral episodes represent the highest quality data source to address cultural questions, and is designed to focus resources on environments likely to yield these types of data.

In summary, the FTW-PALM model provides a reasoned, consistent approach to evaluating project locations for the likelihood of eligible, prehistoric archeological properties in the nine county Fort Worth Highway District. It focuses on spatial and stratigraphic integrity as a means to focus archeological efforts, and to provide a mechanism for transportation planners to take archeological concerns into account during the planning process. The model does not do a particularly good job of predicting where archeological sites are located in the district, but that is not its function. Although it would be instructive to compare the model to an extensive inventory of thoroughly evaluated sites, such an inventory simply does not exist at present for the district as a whole. The FTW-PALM model is submitted in the hopes that it will prove a valuable tool for archeologists and planners working in the Fort Worth District.

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Appendix I

Glossary of Terms

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A Horizon: The surface horizon of a natural soil. An A horizon is a mineral soil horizon characterized by an accumulation of partially decomposed to decomposed organic matter and eluvial loss of constituents such as clays and carbonates, which tend to accumulate in the B horizon. It represents the upper solum of a soil. Common subordinate descriptors include lowercase p (Ap horizon), which designates an anthropically modified or disturbed A such as a plow zone; lowercase b (Ab) which indicates burial; and lowercase ss (Ass), which indicates the presence of slickensides.

Absorption: The uptake of one substance into the structure of another.

Adsorption: The adhesion of a thin layer of molecules of a liquid or gas to the surface of a substance.

Albic Horizon: A light colored soil horizon characterized by a significant loss of clay and free-iron oxides, a lack of organic accumulation, and a concentration of residual silica. Synonymous with E horizon.

Allogenic: Refers to a material formed elsewhere and transported to its current location. cf: authigenic.

Allostratigraphy: Method of subdividing and correlating rocks (including unconsolidated sediments) into units on the basis of bounding unconformities. Allounits may be lithologically diverse (i.e., heterogeneous related facies, such as channel, floodplain, and slope assemblages), and may or may not be formally defined. cf. Biostratigraphy, Chronostratigraphy, Lithostratigraphy, Pedostratigraphy.

Alluvium: Clastic (detrital) material deposited by a channelized, flowing stream, including material deposited outside of the channel during overbank flooding. Occasionally used to denote any sediment transported and deposited by flowing water.

Angular Unconformity: An unconformity where younger sediments were laid down on a surface eroded into deformed or tilted older rocks, so that bedding planes in the two units are discordant. Relatively rare in Late Quaternary rocks.

Architecture: In a stratigraphic sense, refers to the three-dimensional arrangement of, and relationships between, sedimentary units within any given landscape setting.

Argillic Horizon: A soil horizon (Bt horizon) that exhibits significant enrichment in illuvial clay minerals or clay-size particles. Such clays typically form grain coats, grain bridges, and ped-face coats of oriented clay that are visible in thin section, and usually can be identified with a hand lens. Such minerals may have either formed by silicate weathering higher in the profile or been deposited as clay minerals in the first place, but must exhibit significant illuvial accumulation of clays translocated from overlying horizons to qualify as argillic; clay-rich primary deposits do not qualify.

Argilliturbation: Mixing of soil or sediment, and materials contained therein, due to the expansion and contraction of clay minerals with wetting and drying.

Authigenic: Formed in place. cf: Allogenic.

Autocompaction: Compaction of a sediment, particularly in a deltaic setting, under its own weight. Deltaic autocompaction is largely a function of gradual dewatering.

Avulsion: Process where a river abandons its channel and establishes a new channel. Avulsion is most common in a rapidly aggrading system where the natural levees aggrade and the water surface builds up to an elevation at or above the surrounding floodplain.

B Horizon: The lower solum of a natural soil. A B horizon is a mineral soil horizon characterized by an accumulation of constituents such as clays, carbonates or salts, or organic complexes that have been translocated from the A horizon. Common subordinate descriptors include lowercase t (Bt), which indicates accumulation of illuvial clays; lowercase k (Bk), which indicates accumulation of carbonate; lowercase g (Bg) which indicates pronounced gleying; lowercase s (Bs), which indicates illuvial accumulation of sesquioxides (Fe and Al), and lowercase w (Bw), which indicates structural or color changes with no significant accumulations of alluvial material. Incipient soils frequently lack a B horizon.

Bed Load: Clastic sediment moved by rolling or sliding along the bed of a stream or at the air/ground interface.

Biostratigraphy: Method of subdividing and correlating rocks (including unconsolidated sediments) into units on the basis of incorporated fossils. Rarely used in Quaternary studies. cf. Allostratigraphy, Chronostratigraphy, Lithostratigraphy, Pedostratigraphy.

Bioturbation: Mixing of soil or sediment by the action of plants or animals. Subsumes both faunalurbation and floralurbation.

Brecciation: The process of breaking rock or indurated soil horizons into angular fragments. When rock is brecciated and then re-cemented it forms a sedimentary rock called *breccia*.

C Horizon: Weathered, but relatively little altered parent material at the base of a soil profile. Roughly synonymous with subsoil, although the latter term is often used to encompass the lower B horizons.

Calcic Horizon: In general usage, a soil horizon characterized by the accumulation of pedogenic carbonate. In the USDA Soil Taxonomy system, a calcic horizon must meet specific criteria (thickness, CaCO₃ content). Depending on the degree of development, a calcic horizon can either be designated as a Bk horizon or as a K (or Bm) horizon.

Calcification: A soil-forming pathway typical of semi-arid to arid climates and characterized by incomplete leaching of carbonate, resulting in the development of a calcic horizon. Organic matter content is primarily controlled by the rate of organic production, which typically exceeds the rate of microbial destruction of organic matter.

Calcrete: See K horizon.

Cambic Horizon: A B horizon exhibiting color change and/or structural development relative to the parent material, but lacking clear evidence of illuvial accumulation of material. Synonymous with Bw horizon in general usage. In the strict usage of Soil Taxonomy, a cambic horizon must satisfy a number of specific criteria.

Capacity: A measure of the total clastic load carried by a stream under a given set of conditions, including the traction load and suspended load. While competence relates to the largest clast that can be moved, and is a function primarily of velocity, capacity relates to the total volume of sediment moved and is dependent primarily on discharge.

Capillary Fringe: Zone immediately above the water table where water is drawn upward and held in pore spaces by surface tension.

Catena: A suite of spatially-related soils whose differences primarily reflect the influence of their position on a hillslope, and the nature of the processes that have resulted. A catena represents a type of toposequence.

Chronosequence: A spatially related assemblage of soils whose differences primarily reflect the influence of time as a soil forming factor, or systematic spatial variation in soil properties or soil development attributable to the influence of the duration of pedogenesis.

Chronostratigraphy: Method of subdividing and correlating rocks (including unconsolidated sediments) into units on the basis of age. cf. Allostratigraphy, Biostratigraphy, Lithostratigraphy, Pedostratigraphy.

Clast: Any detrital particle (sediment) created by the weathering and disintegration of a larger rock mass and transported by, or subject to physical transport by, water, wind, or ice. Also includes discrete particulates created and deposited by volcanic action (pyroclastics).

Clastic: Describes a system dominated by the physical transport of sediment clasts, or a body of rock derived from such a system.

Clay: Used in two senses. In a mineralogical sense, refers to one of a class of very fine, siliceous minerals formed by layering of silicon, aluminum, oxygen, iron, and other atoms. Some clay minerals can take on water and expand in volume, while some do not, but all are platy and exhibit an electrostatic (colloidal) charge that causes them to attract ions. Texturally, the term refers to clay minerals and other similarly sized particles (<0.002 mm), such as sesquioxides and amorphous minerals in association with humus, that share these colloid properties.

Climate: The average condition of the atmosphere at any individual location over the long term, encompassing both the norms and the extremes of variables such as temperature, precipitation, cloudiness, winds, and atmospheric pressure. Not directly observable, and known to change gradually through time. Cf. *weather*.

Colluvium: Term for slope deposits formed primarily under the influence of mass wasting (gravity-driven) processes; in practice, typically includes both gravity- and wash-derived material. Cf. *slopewash*.

Competence: A measure of the ability for a stream to transport a sediment clast of a particular size or mass in the traction load or short-term suspension (cf. capacity). Competence is largely a function of the velocity of the stream.

Complex Response: Term used to characterize a progression of changes in a fluvial system in response to an external stimulus (e.g., a climatic shift or wildfire); such changes often may be spatially disparate and/or temporally disjunct.

Concordant bedding: said of two rock/sediment bodies that exhibit parallelism in internal bedding. cf. *discordant bedding*.

Concretion: A product of localized mineral precipitation, commonly in the soil zone or in marine sediments. Concretions exhibit a concentric laminar structure due to the addition of successive layers from the exterior or interior, and may be subspherical or elongate. Many concretions contain cracks and/or internal voids, and are more properly termed pedodes or septaria.

Cuesta: An asymmetric ridge landform representing the erosion of inclined beds in the sedimentary parent rock. The more gentle face typically represents the inclined top of the unit, while the steeper face represents its eroding margin.

Cumulic Soil: A soil formed in a setting experiencing relatively slow deposition, so that freshly introduced sediment is incorporated into the A horizon, leading to overthickening of the surface horizon. Cumulic soils are common in alluvial overbank and colluvial settings.

Deflation: Removal of fine-grained surface material by eolian processes, often resulting in a lag of coarse clasts. The use of this term to denote downwearing of the surface of a site by any process (e.g., sheet erosion, rainsplash) is common in the archeological literature, but is imprecise and should be discouraged.

Deformation: Plastic reorganization of sediment due to any one of a number of factors including pressure, consolidated mass movement, loss of support, dewatering, subsidence, etc. Can result in characteristic sedimentary structures such as contorted bedding or microfaulting.

Deltaic: Related to deposits formed where a stream enters a standing body of water, such as a sea or a lake, and loses its ability to transport sediment. A delta is a landform composed of deltaic sediments.

Depocenter: The area of maximum deposition in a depositional basin.

Diapir: A dome/mushroom shaped geologic structure formed by the extrusion of relatively plastic material in a stratum through a rupture in overlying strata. Salt domes on the Gulf Coast are diapirs formed by the extrusion of salts from deep evaporite beds through overlying strata.

Dip: The angle between the sloping surface of an inclined, tabular body of rock or sediment and a level plane, as measured at right angles to the strike.

Discharge: The amount of water moving through a given cross-section of a stream in a given amount of time (e.g., cubic feet/sec or cubic meters/sec). Discharge (Q) is equal to the cross-sectional area (A) times the mean velocity (V).

Disconformity: Unconformity that separates two sediment or rock units that exhibit a similar strike and dip of internal bedding (concordant bedding). Such a boundary may be either roughly parallel to the internal bedding or inclined at a different angle. Much more typical of recent rocks and sediments than an angular unconformity.

Discordant bedding: Said of two adjacent rock bodies that do not show parallelism of internal bedding.

E Horizon: A light colored soil horizon characterized by a significant loss of clay and free-iron oxides, a lack of organic accumulation, and a concentration of residual silica. When present, situated between the A and B horizons in a soil profile. Synonymous with albic horizon.

Éboulis: French term for coarse clasts contained in rockshelter and cave fill, usually as a result of spalling of the walls and roof.

Edaphic: A term referring to the soil environment, particularly in reference to its influence on organisms.

Eluviation: Removal of material (e.g., organic matter, clay, calcium carbonate) from a soil horizon by percolating water. This material is moved (translocated) through the profile (typically downward) where it may either be deposited or precipitated (illuviated) in another horizon or removed (leached) in groundwater.

Entrainment: Refers to the initiation of movement of a clastic particle by a fluid transport medium (i.e., water, wind, or ice).

Entrenched Meander: Phenomenon where a meandering stream has cut down into bedrock, fossilizing a meandering pattern established in unconsolidated sediment. While entrenched streams may show a meandering pattern, they are encased in bedrock and meandering is strongly inhibited. Also sometimes spelled as *intrenched*. *cf: ingrown meander, incised*.

Eolian: Refers to sedimentary processes and deposits resulting from the action of wind. Also spelled *aeolian*.

Erosional Unconformity: Unconformity indicative of erosion of the older unit prior to renewed deposition.

Exhumed Soil: Typically, a formerly buried soil that has been exposed by erosion of overlying sediments.

Facies: A definable (and frequently mappable) subdivision of a formal or informal stratigraphic unit based on the aspect, appearance, and/or characteristics of the rock or sediment making it up. The term facies is used in many different contexts, including lithofacies (characterized by a particular lithology), biofacies (characterized by biotic inclusions or fossils), stratigraphic facies (defined primarily on the basis of boundaries, geometry, and mutual relationships rather than internal uniformity), and sedimentary facies (defined primarily on the basis of intrinsic characteristics like grain size and color). One particularly useful application is the correlation of facies designations to rocks or sediments representing distinct depositional environments; thus a unit representing a meandering stream deposit may be subdivided into channel, point bar, levee, crevasse splay, flood basin, and abandoned channel fill facies.

Faunalturbation: Disturbance or mixing of soil or sediment by the action of animals, and particularly burrowing animals.

Floralturbation: Disturbance or mixing of soil or sediment by the action of plants.

Fining-upward: Sequence of deposits that becomes progressively finer-grained moving upward through the column. Typical of a channel-point bar-overbank sequence laid down by a meandering river system.

Floodplain: Portion of a river valley away from the active channel that is subject to inundation on a relatively regular basis during storm events.

Flood Terrace: A level to low relief alluvial surface elevated above the normal flood level but subject to inundation during large floods. Transitional between floodplains and true terraces, flood terraces are common in Texas due to the incidence of occasional very large flood events.

Fluvial, Fluvatile: Of, or pertaining to, rivers or streams. A rough synonym of alluvial, although the latter term is often used to describe any deposits laid down by running water, whether or not they are confined to stream channels. The term fluvial is often reserved for processes, while resultant deposits are denoted as fluvatile.

Fluviodeltaic: Refers to the complex processes and deposits of a river delta. Typically, fluviodeltaic deposits represent a mix of material deposited due to energy dissipation as the stream flows into the standing body of water and higher energy alluvial deposits laid down as the delta progrades seaward.

Footslope: Lower portion of a slope, which exhibits a concave profile in cross-section and represents the part of the slope where colluvium and slopewash derived from upslope begin to accumulate.

Geoarcheology: A subdiscipline of archeology that uses concepts and methods of the geosciences to address archeological issues.

Gley: Alteration of a soil horizon or sediment by prolonged saturation in an anoxic environment; characterized by greenish gray to bluish gray colors with low chroma produced by reduction of iron compounds.

Gravel: In a textural sense, refers to particles > 2.0 mm in size. Commonly divided into boulders, cobbles, and pebbles. The term stones is also sometimes used as a textural synonym. In general usage, the term gravel generally denotes material rounded by transport, as in a stream.

Hardpan: A hard, impervious soil horizon formed by the accumulation and cementation of minerals such as iron, silica, or calcite.

Holocene: Geological period spanning roughly the last 10,000 years. Roughly equivalent to the Post–Glacial period, and often referred to as the “Recent” period in geology. Many geologists consider the Holocene to be an *interstadial* in the ongoing Pleistocene epoch.

Horizon: A discrete, relatively uniform layer in a soil profile that is typically subparallel with the surface and formed as the result of pedogenic processes.

Illuviation: Accumulation of material (e.g., organic matter, clay, calcium carbonate) introduced into a soil horizon (typically a B horizon), usually by percolating water. This material may be introduced as either finely divided solids or through precipitation from solution.

Induration: Hardening, as by advanced cementation or lithification.

Ingrown Meander: Type of entrenched meander characterized by an asymmetric transverse profile exhibiting a relatively gentle slip–off slope and a steep cutbank slope. Characteristic of a system where downcutting was accompanied by lateral planation.

Inset: In terms of alluvial stratigraphic architecture, refers to two laterally opposed units separated by a sloping to vertical disconformity. An inset is formed by a cycle of incision, which creates the boundary through erosion, and subsequent aggradation of the second unit as the inset body.

Interdigitate: Lateral contact between two different bodies of sediment characterized by vertically alternating “fingers” overlapping in the contact zone, much as is formed by the interlaced fingers of two hands. Typical of the contact between sedimentary facies (e.g., levee sands and floodbasin muds) where the boundary between the two environments oscillates over time.

Interfluve: Area of high ground separating two rivers. In some definitions, the term is restricted to rivers flowing the same direction or which both lie in the same drainage basin, to differentiate it from a *drainage divide*. *cf.* upland.

Interstadial: A warmer subphase of a glacial period, marked by temporary retreat of continental ice.

Isotope: One of two or more species of a chemical element, differentiated by the number of neutrons contained in the nucleus. See radioisotope and stable isotope.

K horizon: A mineral soil horizon where accumulation of pedogenic carbonate has advanced to the stage that it is plugged and/or indurated by secondary calcite (Stage III or above). Approximate synonyms include calcrete (although this term is sometimes reserved for a K horizon developed in gravelly parent material) caliche (although this term is also often applied to Stage I or II Bk horizons), and petrocalcic horizon (the USDA Soil Taxonomy term, which must meet specific criteria). The K horizon designation is not used by the USDA–NRCS (equivalent horizons are termed Bkm).

Karst: topography formed on limestone, gypsum, or other soluble rock, and characterized by the formation of caves and sinkholes.

Krotovina: A discrete, anomalous area visible in plan or profile in a soil resulting from the infilling of a void (e.g., a burrow or root trace) with dissimilar sediment. Some investigators prefer to limit the term to animal burrows, preferring the term “root trace” for infillings related to decayed roots. Some krotovina are obvious, while others are tiny or exceedingly subtle and may only be identified in thin section or by weathering of an exposure.

Lag: A deposit of relatively coarse material—possibly including artifacts—resulting from the erosion of what was formerly a fine-grained encasing matrix. Note that if more than one cultural stratum was present in the former matrix, the lag will represent a mixed or palimpsest assemblage. Lag deposits may be buried by subsequent deposition.

Leaching: Removal of soluble components from a soil due to percolating water. Such components enter the saturated zone and are transported elsewhere by groundwater movement.

Lithification: The process where sediment is converted into solid rock, typically by compaction, cementation, and crystallization.

Lithosequence: A spatially related assemblage of soils whose differences primarily reflect the influence of parent material as a soil forming factor, or systematic spatial variation in soil properties or soil development attributable to the influence of different parent materials.

Lithostratigraphy: Method of subdividing and correlating rocks (including unconsolidated sediments) into units on the basis lithologic characteristics (see Lithostratigraphic Unit). cf. Allostratigraphy, Biostratigraphy, Chronostratigraphy, Pedostratigraphy.

Lithostratigraphic Unit: A stratigraphic subdivision based on lithologic characteristics of a body of rock, including textural and/or mineralogical attributes, and its stratigraphic position. Definition does not require homogeneity, only the presence of specific unifying lithologic characteristics. Lithostratigraphic units are typically tabular and conform to the law of superposition. Lithodemic units are defined similarly, but describe irregular rock bodies composed of intrusive, highly deformed, or highly metamorphosed rock that do not conform to the law of superposition.

Lowland: Low part of a given landscape, particularly a stream valley. Together with slopes and uplands, comprises the terrestrial landscape.

Matrix: In geoarcheological usage, refers to the sediments in which the artifacts at an archeological site are encased.

Midslope: Portion of a slope between the dominantly erosional *shoulder slope* and the dominantly depositional *footslope*, and characterized by the movement of material downslope. Also termed the *translational slope*.

Misfit Stream: A stream that appears out of scale with the valley it occupies. Most commonly, a stream will appear underfit (too small to have carved the valley it occupies). Occasionally a stream may appear overfit (too large for its valley), such situations are rare and almost always associated with recent stream piracy (some geomorphologists discount the existence of overfit streams entirely).

Morphostratigraphic Unit: A stratigraphic subdivision based on morphologic characteristics of outcrops, including topographic expression and soil development. Not recognized by the 1983 North American Commission on Stratigraphic Nomenclature.

Mottling: Irregular color variation in a soil profile or sediment body. Mottling is typically due to either the action of redox processes, carbonate segregation, or patterns of krotovina and root traces. Many prefer to limit the term to redox features (i.e., iron/manganese concentrations, depletions, and phase changes).

Mud: In geological usage, a fine-grained sediment dominated by silt and clay, often containing considerable water.

Nodule: A product of localized mineral precipitation, commonly in the soil zone or in marine sediments. True nodules have no particular internal fabric, although the term is often used in general terms to include features better classified as concretions. Common nodules formed in the soil zone include materials made of carbonate compounds, ferric compounds, manganese compounds, and (in locations where weathering is intense) siliceous compounds. All may capture and engulf other soil constituents. Nodules may be either elementary or complex, where the latter represent fusion of smaller nodules.

O horizon: A dominantly organic horizon composed of undecomposed and/or partially decomposed organics, and possibly some mineral components, at the surface.

Offlap: An arrangement of related, conformable sediment bodies in which the updip margin of each successive unit lies farther basinward, leaving the inland part of the preceding unit exposed. They are characteristic of regressive marine deposits (cf. onlap). In a more colloquial sense, the term is sometimes used to refer to beds that exhibit a similar pattern, such as lateral accretion deposits making up a point bar.

Onlap: In specific usage, refers to an arrangement of related conformable rock or sediment bodies in a transgressive marine sequence, where the updip margin of each successive unit lies farther shoreward, burying the preceding unit (cf. offlap). In a more colloquial sense, the term is sometimes used to refer to any two inset units where the successive depositional unit has aggraded sufficiently to overlap and bury a portion of the older unit.

Overfit Stream: *see* misfit stream.

Paleosol: Although the term has been used in a number of different contexts, paleosol typically equates to “buried soil” in geoarcheological usage. Others prefer a broader usage, basing the definition on a relationship between morphology and previous environments, and encompass relict and exhumed soils within the term. Still others dislike the term intensely and avoid it altogether, except to chastise colleagues for using it.

Palimpsest: Archeologically, refers to a mixed assemblage of cultural material of different ages. Palimpsest deposits are commonly found resting on surfaces that were relatively stable for a long period, allowing for repeated occupation by a succession of groups, or in loci where materials of different ages are conflated due to erosion (lag palimpsest). Note that not all palimpsest assemblages are currently exposed, as they may be buried by additional sediments after their formation.

Pedode: A type of soil nodule or concretion containing one or more internal voids. Void forms include brecciated voids, characterized by fracturing of the interior, and delamination voids, characterized by often curvate voids formed by separation along laminar lines in a concretion.

Pedostratigraphy: Method of subdividing and correlating rocks (including unconsolidated sediments) into units on the basis of soils. Perhaps the most controversial subdivision of the North American Stratigraphic Code, largely due to the problems inherent in reconciling depositional and soils processes. Basic unit of pedostratigraphy is termed a *Geosol*. cf. Allostratigraphy, Biostratigraphy, Chronostratigraphy, Lithostratigraphy.

Pedoturbation: General term for processes resulting in the mixing of soil.

Penecontemporaneous: Formed or occurring at approximately the same time. Generally used to describe deposits that accumulated during the same general period, but which cannot be related more precisely because stratigraphic relationships either do not exist (e.g., sequences in two different valleys) or are obscured (e.g., sequences exposed in unconnected exposures in the same valley).

Perched Ground Water: Zone of saturated, unconfined ground water separated from the main body of ground water by an unsaturated (and relatively impermeable) zone.

Phreatic Water: Water that occurs in the saturated zone of a soil, sediment or rock; synonymous with ground water.

Piping: Form of hillslope erosion resulting in the formation of open networks of sloping channels or tubes in the subsurface.

Pleistocene: The first epoch of the Quaternary Period, spanning the time between approximately 2.0 to 1.65 million years ago and 10,000 years ago. Characterized by repeated continental glaciations, the Pleistocene witnessed the evolution of modern humans.

Polygenetic Soil: A soil that exhibits characteristics that suggest formation under a succession of different climatic regimes. A classic example is a soil that contains both iron concretions (presumably formed during wet phases) and carbonate concretions (presumably formed during dry phases), although this conclusion is considered questionable.

Polypedon: A spatially discrete area mapped as a single soil mapping unit., such as are used in USDA–SCS soil surveys.

Profile: A sequence of horizons making up a soil; a description or depiction of the same.

Quaternary: The second period of the Cenozoic Era, encompassing the Pleistocene and Holocene epochs; roughly the last 1.65 million years.

R Horizon: Soil science term for hard bedrock, which may or may not form the parent material for the overlying soil.

Radioisotope: An isotope subject to radioactive decay, such as ^{14}C or ^{238}U . The decay of such isotopes is the basis of radiometric dating. Cf. stable isotope.

Redox reaction: Term encompassing the suite of biochemical reactions where oxygen is lost (reduction) or gained (oxidation) from a molecule, such as the common conversion between ferric iron (Fe_2O_3) and ferrous iron (FeO) when sediments are saturated or drained. Reduction is caused by anaerobic respiration of soil microbes, and its severity is measured by the redox potential of the soil.

Relict Soil: In general, an extant soil that has not been buried and reflects the influence of former environmental conditions in its morphology. Like the term paleosol, usage has varied, and the threshold at which a soil merits relict status is poorly defined (see Section 2.3.1).

Rhizoconcretion: A concretion formed in the soil zone, usually elongate and subvertically oriented, that represents laminar precipitation of mineral matter as an irregular tubule surrounding a root. Rhizoconcretions commonly form from the precipitation of carbonates or ferric minerals, although occasionally siliceous or gypsic precipitation may contribute.

Rill: Small channel cut by water flowing off a hillslope. Rills typically occur in networks, and may be parallel, dendritic or anabranching and persistent or ephemeral depending on the character of the sediment and the slope. There is no established size threshold that separates rills from gullies, but rills are typically only a few cm deep.

Rip-up clast: Informal term for gravel-sized clasts of mud or clay that have been eroded from a fine-grained bed by flood scour and deposited as clasts in coarser flood or channel deposits. They appear as rounded or angular pockets of mud contained within sands. Original bedding laminations may be preserved in the interior of such features; when present, they tend to be randomly oriented. Also sometimes termed mud balls or clay balls, but should not be confused with the low-fired archeological artifacts referred to by the same terms that were used as a thermal substitute for rock in areas with little bedrock available.

Saltation: Mode of sediment transport by a low-viscosity fluid (air or water) where clasts are lifted off the bed in a near vertical trajectory and settle quickly back in a parabolic trajectory, striking the bed and imparting energy that can stimulate other particles to saltate. Saltating particles essentially bounce along within a short distance of the bed.

Sand: In a textural sense, refers to particles in the size range from 2.0 mm to 0.06 mm.

Sapping: Localized erosion around a spring or at the base of a cliff, often resulting in undercutting of deposits and contributing to mass movements.

Sediment Load: Measure of the amount of sediment carried by a stream.

Sedimentary Structure: A structure resulting from bedding features, surface features, and physical or organic modifications preserved in sediments and sedimentary rocks. Sedimentary structures may be either primary or secondary, although usage of these terms varies. In sedimentary geology, the term “primary” is typically used for all structures formed prior to lithification. When addressing unconsolidated late Quaternary rocks, it is more useful to limit the scope of “primary” structures to those features (typically bedding structures) formed at the time of deposition, and use the term “secondary structure” to features formed after deposition (e.g., bioturbation structures, deformation structures, etc.). However, because it deviates from standard geological usage, this distinction needs to be explicitly stated to avoid confusion on the part of the reader.

Septode: A type of soil nodule characterized by radial cracks and fissures, often exhibiting a polygonal pattern on the nodular surface.

Sheetwash: Unconfined flow of water across a surface; erosion or deposition of sheet sediments by such flow; or deposits formed by such a process. In general usage, typically subsumes true unconfined flow and channelized flow in small rills.

Shoulderslope: Upper portion of a slope, which exhibits a convex profile in cross-section and represents a zone of net erosion.

Silt: In a textural sense, refers to particles in the size range from 0.06 mm to 0.002 mm.

Slickensides: Grooved, polished faces between peds in an expansive clay soil formed by friction as the peds swell and press together during wetting cycles.

Slope: This term is used in several senses in this document. In terms of the process discussion, a slope is defined as an inclined geomorphic surface of any scale, which may experience any of a suite of slope processes. Elsewhere, used to describe the portion of the landscape that separates the *upland* and the *lowland*.

Slope Break: A sudden change in the gradient of a slope.

Slopewash: Term for the suite of processes (such as rainsplash and overland flow) that erode thin sheets of sediment and move them downslope, or for deposits formed by such processes. In practice, difficult to separate from *colluvium*. Syn: *sheetwash*.

Smectitic clays: A family of clay minerals, including smectite and montmorillonite, that exhibit strong shrink-swell properties on wetting and drying.

Sorting: A measure of the range of clast sizes in a deposit; sediments made up of clasts of approximately the same size (e.g., a sand dune composed of medium sand) are said to be well sorted, while sediments composed of a wide range of textural size grades (e.g., a landslide deposit composed of bouldery clay) are said to be poorly sorted.

Stable isotope: An isotope not subject to radioactive decay, such as ^{13}C or ^{18}O . Compare with radioisotope.

Strath: A relatively flat-lying cut alluvial surface that has been abandoned by renewed channel incision, forming a terrace-like landform. The distinction between a strath (also called a strath terrace) and an alluvial terrace is that the former is a predominantly degradational (cut) landform caused by lateral planation of the stream, while the latter is primarily an aggradational (depositional) feature. Strath surfaces may be cut into bedrock, or less commonly, into older alluvium (a fill strath or alluvial strath).

Stream Piracy: Diversion of a stream into a new valley system at any given location along its length, usually by intersection of a headward-cutting valley, but sometimes as a result of an intersection resulting from lateral migration of either channel. Also termed stream capture.

Strike: Direction defined by a horizontal line on the surface of any inclined, tabular body of rock or sediment. Occurs at right angles to the dip.

Suspended Load: Clastic particles transported by suspension in a turbulent fluid (air, water).

Taphonomy: The study of the post-mortem fate of organic remains (and, in the case of archeological materials, associated inorganic remains) and the transformations that they undergo before, during and after incorporation into geological deposits.

Terrace: In fluvial systems, a level to low relief alluvial surface elevated above the normal flood level, created when the stream incised into its valley, abandoning a former floodplain.

Thalweg: A line connecting the lowest points of each cross-section moving up or down a channel. Plotted against elevation, the thalweg defines the longitudinal profile of a stream.

Throughflow: Lateral downslope flow of infiltrated water through soil during and following a storm event. Appreciable surface runoff usually does not occur until infiltration is restricted by saturation of the soil.

Toeslope: Lowest part of the slope, composed almost entirely of sediment shed from upslope and deposited by the valley-bottom stream. Lower part of the footslope.

Toposequence: A spatially related assemblage of soils whose differences primarily reflect the influence of relief as a soil forming factor, or systematic spatial variation in soil properties or soil development attributable to the influence of landscape position. A catena is a toposequence occurring along a single slope.

Traction Load: Component of sediment transported as bedload and saltating load.

Translational Slope: *see* midslope.

Travertine: A finely crystalline, massive to laminated deposit of calcium carbonate precipitated from groundwater around springs and seeps (*cf.* *tufa*). Both travertine and tufa can encase and preserve archeological and biotic remains.

Tree Throw: A bioturbation phenomenon resulting from the uprooting of a tree. Earth trapped in the root system is displaced vertically and laterally as the roots rotate up and out, and is then gradually released as the root system dries out and decomposes. In large trees, tree throw can result in the redistribution of a considerable volume of sediment.

Tufa: A spongy, vesicular deposit of calcium carbonate deposited from discharging groundwater around springs and seeps, often in association with algal mats (*cf.* travertine). Both travertine and tufa can encase and preserve archeological and biotic remains.

Unconformity: Stratigraphic term for a boundary created by a significant depositional hiatus, usually accompanied by surface erosion or soil formation in the older unit. *cf.* angular unconformity, disconformity.

Underfit Stream: Term for a stream that occupies a valley with geometric characteristics that suggest it was formed by a much larger stream.

Upland: As used in this document, a general term for higher portions of the landscape between lowlands (stream valleys), which together with lowlands and slopes comprises the terrestrial environment. Although uplands may contain loci of sediment accumulation (depressions, saddles, sheet sands or dunes), they are typically stable to erosional in character. Uplands may be level or sloping, including the upper convex portion of slopes as strictly defined. For this reason, the line of demarcation between upland and slope is often not obvious. *cf.* interfluvium.

Vadose Water: Water in the aerated portion of a sediment, soil, or rock, that is capable of moving freely downward under the influence of gravity; *cf.* phreatic water.

Water Table: Surface defined by the top of the saturated zone.

Weather: The instantaneous state of the earth's atmosphere at any individual location, reflecting the influence of temperature, moisture, and atmospheric pressure in the air column at (and above) that location and in surrounding locations. *Cf.* climate.

Appendix II

Results of Radiocarbon Dating

Appendix II: Results of Radiocarbon Dating

A4.1 Introduction

This appendix presents the results of radiocarbon analyses conducted during the course of this project. The context and implications of the results are discussed as appropriate in the text. All analyses were conducted by either the Center for Applied Isotope Studies, University of Georgia, or Beta Analytic of Miami Florida.

Fort Worth Geoarcheology Project Samples									
Sample	Material	Lab Number	Conventional Age			$\delta^{13}\text{C}$	Calibrated Age	Method	
Locality 1, Section1, Btk horiz, 80cm (FortWolters#1alk)	sediment	UGA 13462	3650	±	40	-17.3	2140 to 1890 BC	AMS	
Locality 1, Section1, Btk horiz, 80cm (FortWolters#1insol)	sediment	UGA 13463	3340	±	40	-18.28	1740 to 1710 BC and 1700 to 1520 BC	AMS	
Locality 1, Section1, Btk horiz, 250cm (FortWolters#2alk)	sediment	UGA 13464	8630	±	50	-19.2	7800 to 7570 BC	AMS	
Locality 1, Section1, Btk horiz, 250cm (FortWolters#2insol)	sediment	UGA 13465	7110	±	40	-19.48	6070 to 6040 BC and 6030 to 5880 BC and 5860 to 5840 BC	AMS	
Locality 1, Section2, Bk horiz, 170–180cm (FortWolters#3alk)	sediment	UGA 13466	6150	±	40	-20.37	5260 to 4940 BC	AMS	
Locality 1, Section2, Bk horiz, 170–180cm (FortWolters#3insol)	sediment	UGA 13467	1840	±	60	-17.34	AD20 to 40 and AD50 to 350	AMS	
Locality 1, Section2, Ab horiz, 240–260cm (FortWolters#4alk)	sediment	UGA 13468	8330	±	50	-19.59	7540 to 7300 BC and 7270 to 7240 BC and 7230 to 7180 BC	AMS	
Locality 1, Section2, Ab horiz, 240–260cm (FortWolters#4insol)	sediment	UGA 13469	7030	±	40	-20.25	6000 to 5800 BC	AMS	
SH16@Brazos, GT 7, 160 cmbs	charcoal in matrix	UGA 14024	1340	±	40	-16.41	AD 640 to 780	AMS	
Wise CR 790 @ Big Sandy Ck, GT2, 110 cmbs	charcoal in matrix	UGA 14200	140	±	40	-25.57	AD 1660 to 1960	AMS	
SH16@Brazos, GT 2, 203 cmbs	sediment	UGA 14201	1990	±	40	-18.42	100 to 70 BC and 60BC to 90 AD and AD 100 to 130	AMS	
SH16@Brazos, GT 5, 180 cmbs	sediment	UGA 14203	3980	±	50	-17.28	2630 to 2300 BC	AMS	
SH16@Brazos, GT 10, 160–170 cmbs	sediment	UGA 14205	9390	±	50	-17.26	9100 to 9000 BC and 8800 to 8450 BC	AMS	
Wise CR 3701 @ Hunt Ck, Prof 1, PS2, 170 cmbs	sediment	UGA 14206	1750	±	40	-15.84	AD 130 to 160 and AD170 to 200 and AD 210 to 410	AMS	
Wise CR 3701 @ Hunt Ck, Prof 1, 290 cmbs	sediment	UGA 14207	4550	±	40	-18.36	3490 to 3470 BC and BC 3370 to 3090	AMS	
Wise CR 3701 @ Hunt Ck, Profile 2, 80 cmbs	sediment	UGA 14208	1070	±	40	-20.04	AD 890 to 1030	AMS	
SH16@Brazos, GT 4, 320–330 cmbs	sediment	UGA 41202	6360	±	50	-19.85	5480 to 5230 BC	AMS	
Denton Creek, BT1, 1.05–1.15 m (DC1)	sediment	Beta- 142308	1600	±	60	-19.4	AD 340 to 600	radiometric	
Denton Creek, BT1, ~3.3 m (DC2)	sediment	Beta- 142309	1490	±	50	-17.3	AD 440 to 655	radiometric	
Denton Creek, BT2, ~1.8 m (DC3)	sediment	Beta- 142310	2140	±	50	-15.5	365 to 45 BC	radiometric	
Denton Creek, BT5, ~3.6–3.85 m (DC4)	sediment	Beta- 142311	1740	±	50	-18	AD 155 to 45	AMS	
Denton Creek, BT9, ~2.9 cm (DC5)	sediment	Beta- 142312	5350	±	70	-17.8	4340 to 3990 BC	AMS	
1 Thompson Rd–1 60–70cm	sediment	Beta- 164779	2100	±	60	-17.2	360 to 290 BC and 230 BC to AD30	radiometric	
2 Thompson Rd–1 140–150cm	sediment	Beta- 164780	4110	±	80	-18.2	2890 to 2470 BC	radiometric	
3 Thompson Rd–3 140–150cm	sediment	Beta- 164781	4110	±	80	-16.9	2890 to 2470 BC	radiometric	

Fort Worth Geoarcheology Project Samples (continued)								
Sample	Material	Lab Number	Conventional Age			δ ¹³ C	Calibrated Age	Method
6 Thompson Rd–5 110–120 cm	sediment	Beta– 164784	4680	±	70	–16.1	3640 to 3340 BC	radiometric
7 Thompson Rd–7 120–130cm	sediment	Beta– 164785	2150	±	100	–15.7	400 BC to AD 60	radiometric
8 Thompson Rd–8 130–140cm	sediment	Beta– 164786	2590	±	60	–15	830 to 750 BC and 700 to 540 BC	radiometric
9 Thompson Rd–9 125–135cm	sediment	Beta– 164787	2440	±	70	–13.1	790 to 390 BC	radiometric
10 Thompson Rd–10 65–70cm	sediment	Beta– 164788	1430	±	60	–13.3	AD 530 to 690	radiometric
11 Willow Unit 2 4.3 m	sediment	Beta– 164789	6160	±	40	–17.8	5240 to 4960 BC	AMS
12 Willow Unit 1 4.4 m	sediment	Beta– 164790	8220	±	50	–19.1	7450 to 7400 BC and 7360 to 7080 BC	AMS
13 Willow Unit 2 1.1–1.2 m	sediment	Beta– 164791	760	±	50	–15.9	AD 1190 to 1300	radiometric
14 Willow soil on west side 5.5 m	sediment	Beta– 164792	9130	±	40	–20.2	8430 to 8360 BC and 8340 to 8260 BC	AMS
15 Newsome Mound 95cm	charred wood	Beta– 164793	160	±	60	–26.2	AD 1640 to 1950	radiometric
Brazos @ US67, Core 1, 1.4m (JTA101)	bulk humate	Beta– 175113	370	±	40	–24.4	AD1440–1640	AMS
Brazos@ US67, Core 1, 5.2m (JTA102)	charcoal in matrix	Beta– 175114	210	±	40	–25.1	AD1640 to 1690 and AD1730 to 1810 and AD1920 to 1950	AMS
Brazos@ US67, Core 2, 2.8m (JTA103)	bulk humate	Beta– 175115	1190	±	40	–19.7	AD1640 to 1690 and AD1730 to 1810 and AD1920 to 1950	AMS
Brazos@ US67, Core 2, 5.7m (JTA104)	bulk humate	Beta– 175116	1380	±	40	–18.9	AD620 to 690	AMS
Brazos@US67, Core 3, 5.2m (JTA105)	bulk humate	Beta– 175117	13010	±	60	–20.9	14060 to 13100 BC	AMS
Brazos @ US67, Core 3, 2m (JTA106)	bulk humate	Beta– 175118	5710	±	40	–17.4	4680 to 4460 BC	AMS
Brazos@US67, Core 4, 7.6m (JTA107)	bulk humate	Beta– 175119	19770	±	110	–22.3	not calibrated	AMS
Brazos@US67, Core 5, 7.4m (JTA108)	bulk humate	Beta– 175120	5260	±	50	–24.4	4230 to 3790 BC	AMS
West Fork Trinity River, Core 1, 1.4m (JTA109)	bulk humate	Beta– 175121	2960	±	40	–19.8	1300 to 1030 BC	AMS
West Fork Trinity River, Core 4, 3.6m (JTA110)	charcoal in matrix	Beta– 175122	3190	±	50	–21.8	1530 to 1390 BC	AMS
West Fork Trinity River, Core 1, 6.1m (JTA111)	bulk humate	Beta– 175123	5980	±	40	–20.2	4940 to 4760 BC	AMS
West Fork Trinity River, Core 1, 8.3m (JTA112)	bulk humate	Beta– 175124	9670	±	60	–20.1	9240 to 9100 BC and 9020 to 8810 BC	AMS
West Fork Trinity River, Core 1, 13.7m (JTA113)	bulk humate	Beta– 175125	10360	±	110	–18.1	10900 to 9760 BC	Radiometric
West Fork Trinity River, Core 4, 9.1m (JTA114)	bulk humate	Beta– 175126	10010	±	60	–19.1	9990 to 9290 BC	AMS
West Fork Trinity River, Core 4, 4.8m (JTA115)	bulk humate	Beta– 175127	7440	±	50	–19.3	6410 to 6220 BC	AMS
West Fork Trinity River, Core 4, 1.2m (JTA116)	bulk humate	Beta– 175128	3010	±	70	–17.9	1420 to 1020 BC	Radiometric
West Fork Trinity River, Core 1, 3.1m (JTA117)	charcoal in matrix	Beta– 175129	2840	±	50	–27.1	1130 to 880 BC	AMS

Appendix III

Peer Reviewer Comments and TxDOT Responses

Appendix III: Peer Reviewer Comments and TxDOT Responses

COMMENTS ON PROTOCOL

These initial comments were solicited during the preparation of project protocol, and were included along with their responses in the revised mapping protocol.

Review Comments on “**Proposed Protocol for Geoarcheological Mapping of the Fort Worth District**” by James T. Abbott, Environmental Affairs Division, Texas Department of Transportation, Austin, Texas.

Reviewed by David D. Kuehn, David Kuehn Consulting, El Paso, Texas.

October, 2003

On July 21, 2003, the author was invited to review a planning document entitled “Proposed Protocol for Geoarcheological Mapping of the Fort Worth District”, by James T. Abbott, Texas Department of Transportation (TxDOT). The manuscript outlines the procedures proposed for the development of a Potential Archeological Liability Map, or PALM, for the Fort Worth District. The overall goals of the Fort Worth PALM are: (1) “to identify areas where the character or age of deposits is not consistent with the preservation of archeological sites with good context”, and (2) to “identify areas where depositional processes have been active during the Holocene and late Pleistocene therefore requiring deep mechanical prospecting to locate buried sites”.

Building on the success of the Houston–PALM (Abbott 2001), the protocols proposed for the Fort Worth District map will utilize an integrity–based model to define, evaluate, and identify areas with low, moderate, and high archeological site potential. Like the Houston PALM, source data for the GIS–based map will include landscape setting, soils, and recent disturbance characteristics. Unlike the Houston model, predictions regarding geoarcheological potential in the Fort Worth PALM will be expressed as probability statements rather than final recommendations; a change designed to reduce potential ambiguity in TxDOT management recommendations. Thusly formulated, the Fort Worth PALM is expected to aid the often burdensome task of managing potentially significant cultural resources in the large and diverse Fort Worth District.

After a thorough description of region–wide geology, soils, and biotic resources, the three principal sources of data for the PALM are identified. The first of these is landscape setting, or geomorphic context. A key consideration for the landform characterization process is logistical – collecting the necessary information on specific landforms in the Fort Worth District is certain to be complex and time–consuming, in large part because of the problem of scale. Using contour maps in the model would be a comparatively easy way to facilitate the landform mapping, but contour maps, especially those with large scales, are generally incompatible with the fine level of detail required in geoarchaeological modeling. Simple contour mapping would also likely preclude the identification of many individual landforms and make it difficult, if not impossible, to identify associations between landforms and specific sedimentary depositional environments (Krumbein and Sloss 1963, Selley 1978). Without reliable data on depositional environment, landforms would contribute little to the discrimination of process–response relationships between sedimentary environments and sedimentary facies (Middleton 1978; Walker 1979). The loss of these kinds of data would weaken the strength of the model by making it more difficult to measure a number of important variables such as rates of local landform deposition and erosion, and processes of natural site formation (cf. Waters and Kuehn 1996). Fortunately, these potential complications are effectively avoided in the Fort Worth PALM by the decision to use a form of detailed symbolic landform mapping rather than contour mapping. Detailed symbolic landform mapping allows for the use of multiple scales and multiple levels of detail. The author also points out that detailed symbolic landform mapping is easily incorporated with GIS. On the other hand, because it uses points and lines, it does not easily facilitate the addition of extra layers of data. That limitation, however, can be avoided by classifying landform area with non–overlapping polygons. Doing so will allow for the addition of various other forms of data in the future, such as information on sedimentary environments.

Landforms are organized into three main categories – upland landforms, slope landforms, and lowland landforms. These are in turn subdivided into 15 general landform classes. The major landform classes are: A. Stream channel/unvegetated bar, B. Floodplain, C. Flood terrace/low terrace, D. High Terrace, E. Sand sheet/dune field, F. Proximal alluvial fan, G. Medial/distal alluvial fan, H. Pond/reservoir/stock tank, I. Toeslope/colluvial apron, J. Midslope bench, K. Shoulder slope/midslope/cliff, L. Level/gently inclined/convex upland, M. Upland depression/sink, N. Rock shelter/overhang, and O. Made Land.

The landform classification proposed for the Fort Worth PALM is, for the most part, appropriate, workable, and logical. That said, there are a couple of suggestions that could possibly help strengthen the landform discussion.

First, there was a bit of confusion with regard to the numbering of tables in this section. In the draft document, there are two tables labeled “Table 2”. The first, on page 21, had the three landform categories (upland, slope, lowlands). It also had a column of landform class types and a column on geoarchaeological potential. The next table, on page 22, was also labeled Table 2 however it should be labeled Table 3 as suggested by the discussion in the text.

Secondly, the 15 major landform classes presented in Table 3 are representative of most categories of upland, slope, and lowland landforms, however, sedimentary depositional environments associated with springs and seeps are not included. In addition, the geoarchaeological potential of lacustrine/pond environments tends to be unduly limited as currently defined.

Springs, especially artesian springs and associated spring pond settings, are high probability depositional environments associated with a number of significant archaeological sites in the Southern High Plains and adjacent areas (cf. Meltzer 1991; Meltzer and Collins 1988; Haynes and Agogino 1966). The omission of spring-related deposits in the Fort Worth PALM could reduce the predictive power of the model in certain types of lowland and slope-related settings. Data on some of the larger spring environments should be currently available USGS 1:24,000 topographic maps, which often include the location of prominent springs and seeps.

The definition of lacustrine landforms is restricted in that the only lake-related landscapes identified are bodies of extant standing water (pond/reservoir/stock tank). This landform category is evaluated as having negligible potential for both shallow and deeply buried archaeological materials, and does not account for the possibility of former pond sediments currently not associated with standing water. In other words, in terms of lacustrine/pond depositional environments, the model does not address Walther’s Law – particularly the possibility of lake-related sedimentary facies existing in lateral and/or vertical association with modern lakes and ponds (cf. Boggs 1987:532–533; Waters 1992:40). If the model provided some measure of spatial facies relationships, landforms like ponds would not necessarily have negligible geoarchaeological potential. This same argument could apply to a variety of other landform categories such as sand dunes, however these are not classified as having low-levels of potential.

The soils and landscape disturbance data sets are well described and logically organized. Both contribute greatly to the workability of the model. Soil classification follows soil series and soil mapping units identified in the Fort Worth District area by the USDA Natural Resource Conservation Service (NRCS). All of the soil maps from the NRCS in the Fort Worth District are available in digital format. The profile description, topographic setting, and geoarchaeological potential of NRCS soil series in the District are presented in an extensive summary table.

Twenty seven of the 127 soil series identified in the Fort Worth District are evaluated as having high ($n = 23$) or very high ($n = 4$) geoarchaeological potential. All but two of these soils occur in “relatively recent” or “Late Pleistocene/Holocene” floodplain/alluvial landforms, although the basis for these age estimates is not identified. The two remaining soils are associated with eolian depositional environments. Thirty nine soil series have moderate or moderate to high geoarchaeological potential. These are primarily located in upland, upland footslope, or higher alluvial terrace landform settings. These particular settings, like the soils identified as having high or very high potential, are mantled with moderate to thick accumulations of unconsolidated Late Quaternary sediments. The soils evaluated as having low geoarchaeological potential are predominately associated with upland landforms that have few if any significant accumulations of Late Quaternary sediments.

The use of soils as a major variable in the Fort Worth PALM is strengthened considerably by the strong landform-based character of the NRCS soil series. Soils associated with landforms that are strongly aggradational in character, such as alluvial terraces, will be evaluated as having high geoarchaeological potential, as will the landform itself. Likewise, soils associated with erosional landforms will tend to be evaluated as having low potential and so will the erosional landform. In the Fort Worth PALM, soil and landform potential are mutually reinforced.

While landform associations are one of the principle strengths of the soil component, a potential drawback is the paucity of available NRCS data on the diachronic/temporal distribution of soils, particularly data on the age of paleosols, or buried soils that are not necessarily associated genetically with modern surface soils. This is a largely unavoidable limitation found in most NRCS-based mapping efforts and reflects limited funding and agency-wide resource management priorities. While unavoidable, the lack of NRCS-based data on the diachronic characteristic of soils does limit the predictive power of the Fort Worth PALM primarily to the geoarchaeological potential of extant surface or near surface soils. The potential usefulness of the liability map to archaeological and geoarchaeological research efforts in the Fort Worth District would be enhanced considerably if data on the age, distribution, and morphology of paleosols were incorporated into future updates of the planning document. Likewise, as geoarchaeologists become increasingly cognizant of the association between large-scale landscape change and the preservation and systemic context of the archaeological record, the incorporation of data on the age of specific landforms such as stream terrace networks into the model would also help to ensure the lasting research value of the Fort Worth PALM.

In conclusion, the proposed protocols for development of the Fort Worth Potential Archaeological Liability Map are both theoretically and methodologically sound. With the exception of springs and lacustrine depositional environments in the landform component, the protocols promise to facilitate the development of a truly useful planning document for TxDOT's management of cultural resources in the Fort Worth District. Other land managing agencies in Texas could certainly benefit from the development of similar planning documents.

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RESPONSE:

Kuehn's review pointed out several gaps in the landform classification scheme that were remedied in the revised version. Lacustrine (natural lake) environments were previously considered but were not scheduled for work on the initial iteration because they are not expected to occur with any frequency and extant lakes are difficult to address archeologically. As Kuehn points out, this does not necessarily mean that they have little archeological potential. Spring deposits and paludal (marsh) deposits had not been considered previously; although the protocol was revised to incorporate the suggestion, no spring/marsh environments were mapped.

Review of the proposed geoarchaeological mapping protocol of the Fort Worth District

by Charles D. Frederick, Department of Archaeology and Prehistory, University of Sheffield, England

Overall, I think that this is a good plan. It is thoughtful and appropriately weights the analyst's opinion over the somewhat questionable data sets like the soil survey. This is obviously a much more challenging landscape than that covered by the Houston PALM given the geologic variability and the general level of understanding of the Quaternary geology of the region.

I like the approach in this plan to use the GIS to develop the final map from the constituent maps via an algorithm. Although I have an objection to one of the formulas used in this calculation (see below), I think this approach will lead to a more objective result. My main theoretical reservation is the scale and reliability of the constituent data sets, but there is no economical way around this problem for a mapping project of this scale. As long as the mapping of areas of questionable or unknown potential are coded as potentially high or moderate rather than low or negligible *and* that this leads TxDOT to field check them, then I think that this will work well. Let me be explicit here so there is no misunderstanding, I am referring to field checking areas only when a proposed project crosses one of these areas, not wide spread regional field checks at this stage of model development. But as I commented on the Houston PALM, there *must* be some way of reintegrating such new geologic information on a regular basis so the model/map remains current, and is refined through time.

Beyond this, I have three significant comments on the proposed plan that concern the:

1. exclusion of the bedrock or solid geology,
2. number of geoarchaeological potential categories, and
3. use of urban land as a nullifying or no-go designation in the mapping algorithm.

I offer these as comments for consideration, and of the three I am most concerned by the last one. I discuss each of these three points briefly below. Following them are a series of that I wrote as I read the text. Most of these are fairly insignificant.

Exclusion of the bedrock or solid geology

On p.18, last paragraph, you exclude the inclusion of the geologic atlas of Texas from the data set because as it is not digitized and its coarse scale. I am not sure I agree with this reasoning. Yes, the scale is crude, but it is, at least in my experience, as often right and perhaps more often so (except with respect to Quaternary units) than the soil maps created by the USDA. Second, the amount of time necessary for a person to digitize those maps for inclusion in this program is surely fairly inconsequential. Obviously, I am speaking from a more theoretical position here, but given my recent experience with digitizing contour maps for a project in Greece, digitization of the Geologic Atlas of Texas is a fairly small project. I would rather see it these data included, rather than excluded despite its scale limitations. However, its inclusion, and notoriously poor Quaternary coverage might complicate the algorithm compilation of the final map. On the other hand, it is also very clear that the modern soil maps are heavily reliant upon the BGS mapping, so this information is already included in some form in the USDA soil survey maps.

Number of geoarchaeological potential categories

As to the geoarchaeological potential categories, I think I would almost prefer three: negligible, low and high, which more accurately reflect the quality of the data in hand for such a vast area. If the plan is to be accurate but conservative (that is, it errs on the side of the resource, rather than on the side of the developer, in this case TxDOT) then I think fewer geoarchaeological potential categories make more sense. In this case, if the analyst is uncertain about the age or geoarchaeological potential of a landform, it should be coded as having high potential, so that it gets field checked when it comes up on a new project. Another approach to this would be to add a new category that specifically flags landforms of ambiguous character/geoarchaeological potential so that they are easily identified on the map and get field checked when they come up on new projects.

Use of urban land in the mapping algorithm

I don't like the *deep score calculation* being nullified by the disturbance score. Surely, if the landform has moderate or high deep rating in terms of geoarchaeological potential, the disturbance score should not reduce it to zero. Perhaps you should consider having shallow and deep disturbance categories. Obviously, this will be a somewhat spurious judgment call, but it is fairly easy to predict which forms of development have been deep and those that are not. Most urban areas are not deeply impacted, but rather only shallowly, and deep sites (over ~0.5 m) are usually unscathed. My basis for this was following a backhoe around the downtown Austin convention center site, which was and is situated in part on Holocene alluvium. Much of the urban areas illustrated on Figure 8 (Figure 3-5 in this volume-ed.) are shallow impacts, and you could easily make a list of deep impacts (dams, landfills, etc.) and distinguish them from general urbanization, which is usually not deep.

Other comments (some already discussed above)

1) p.20 last paragraph which discusses the landform classification system, I would suggest that when landforms are identified and their potential for buried cultural material is evaluated, that the judgment be conservative, that is to say, assumes a high deep burial potential if there is no good basis for assessing or estimating the age of the deposit.

2) p.22, the floodplain mapping unit I would consider to have a higher potential than is indicated here. I am thinking of some of the sites I have seen in such settings, like the Rush site (Concho River) which was fully within the floodplain and had exquisite preservation and integrity, despite the presence of very obvious modern bars and topography I would have otherwise thought not very conducive to good preservation. Although it is possible that this surface might have been mapped as a flood terrace/low terrace, I am not completely convinced of this. Again, I think it would be wise to err on the conservative side and consider these generally moderate or high geoarchaeological potential despite their apparently young age.

3) p.23, high terrace category, it is not immediately obvious to me how you are assessing geoarchaeological integrity of these features in surface contexts. I would have thought they would all have low surface and subsurface potential. Are you thinking of concave surfaces like paleochannels perhaps? A bit more explicit comment on the rationale for the moderate ranking would have assisted here.

4) p.23, sand sheet/dune field, if you suspect the surface is eolian, wouldn't it be best to assume it has high potential and check it out on the ground in the field rather than run the risk of missing something good? I would just label them all high potential.

5) p.25, made land category, I also think this needs to have a shallow and deep potential, because a lot of made land just buries older landscapes. Is it worth sacrificing the material at depth just because it has cement on top of it? Surely you can make some kind of combination category (one of the preceding categories in combination with made land) that will allow you to judge this in a more sophisticated manner. Made land on a convex upland should be treated differently from made land on a Holocene terrace. I think you see my point. I fully understand why you have categorized it this way, but a more sophisticated coding is more consistent with the goals of this program.

6) p.28 just looking at figure 5 I am a bit curious (and concerned) that there is not more "very high" potential areas along the major river corridors. This category seems to be disproportionately located in low order stream valleys (2nd to 3rd?). Why is this? Shouldn't this be adjusted somehow? Should you revisit how some of the soils along the large river valleys are ranked for potential?

7) p.33, I am curious to learn if the top right corner of the color part of figure 9 (negligible to very low landform potential and high to very high soil potential) actually exist. I guess you need to include them theoretically but I would hope these do not actually exist.

RESPONSE:

Frederick makes three main points. First, he comments that it would be relatively inexpensive to capture the geologic data. While we agree that cost is not prohibitive, we considered this suggestion and elected not to incorporate it. As Frederick points out, geology strongly influences soils, and soils therefore provide a proxy representation of the underlying geology. More importantly, we considered mechanisms for factoring in geology directly and were not able to develop a suitable model for its inclusion due to the very small scale (1:250,000) of available mapping.

Frederick's second main comment is well-taken, and is reinforced in several of his subsequent comments. We agreed that it was important that the final classifications (near-surface potential and deep potential) be presented in a relatively simple, unambiguous manner. However, we retained the "moderate probability" class because we believed that it was appropriate given the range of factors feeding into the classification. If we had abandoned the "moderate" category in favor of a three-part classification ("negligible", "low", and "high"), we believed that the overall effect would be to decrease critical appraisal by the user, because the "moderate" category does the most to force the user to weigh potential against the scale and scope of the project. While Frederick's argument that all areas that are not considered to have low to negligible potential should be treated as high potential areas is understandable, we believe that such an approach would dilute the urgency imposed by the label and therefore would do a disservice to areas that are truly high potential.

Upon reflection, we concurred with Frederick's third main point, and modified the original calculation formula to lessen, rather than nullify, the calculated probability for intact subsurface deposits in disturbed settings. We considered revisiting the disturbance dataset entirely to differentiate between zones of shallow and deep disturbance, but were not convinced that any such assessment could be done accurately from the DOQQ data. Therefore, the formula was modified to decrease the subsurface score when the surface is disturbed, rather than zeroing out the score as was previously the case. Again, the net result is to force the end user to more critically evaluate the potential for disturbing a subsurface site against the size and scope of the project.

July 15, 2003

Mr. James T. Abbott
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Environmental Affairs Division
Dewitt C. Greer State Highway Bldg.
125 East 11th St.
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Re: Comments on Draft Document Entitled *Proposed Protocol for Geoarcheological Mapping of the Fort Worth District*

Dear Sir:

I have reviewed your draft document for the proposed geoarcheological mapping of the Texas Department of Transportation's Fort Worth District. I believe that model that is presented for evaluating the apparent geoarcheological potential using various soil type characteristics in combination with landform characteristics is very detailed and logical.

In my experience in conducting archeological investigations in the Fort Worth area, I found that many large multicomponent prehistoric campsites are found along geographic ecotones, especially along the boundary of the Eastern Cross Timbers and the Blackland Prairie. Along this ecotone, pockets of sandy topsoils are sometimes found east of the Eastern Cross Timbers in areas that are technically mapped as Blackland Prairie. The Cobb-Pool Site, which is now within the U. S. Army Corps of Engineers Lake Joe Pool project area, serves as an example. I also recall that in some cases such isolated pockets of sandy topsoil may not be identified on the county soil surveys. Based on my experiences, I feel that special consideration should be given to this geographic ecotone in selection of areas requiring cultural resources surveys. Areas along the boundary of the Western Cross Timbers and Grand Prairie may warrant the same special consideration. However, there are less available data for that ecotone.

I look forward to reviewing the full draft of your work. If you have any questions about my comments, feel free to contact me at work at (512) 397-6714.

Sincerely,

Daniel J. Prikryl

RESPONSE:

There is no specific response required for this comment. We intend to pay particular attention to such settings during geomorphic mapping.

COMMENTS ON REVIEW DRAFT

The following comments were made on the review draft of this final report in 2010. Several of these generalized reviews were accompanied by lists of page-specific editing suggestions, which are not included in this appendix. Although some of the suggestions were incorporated and others were not (often because of the additional time that would be required), no point-by-point responses were prepared to these comments.

Review of Geoarchaeology in North-Central Texas: A framework for archeological investigation, interpretation and cultural resource management in the Fort Worth Highway District, by James T. Abbott.

By Charles D. Frederick, Consulting Geoarcheologist

Geoarchaeology of North-Central Texas is the second publication of this type by the author, following publication of the landmark Houston Area Geoarchaeology in 2001. The document (and associated Geographic Information System (GIS) data set) aims to predict where on the greater landscape archeological sites may lie buried and is intended as a planning tool to assist archeologists making decisions on future legally mandated archeological (Cultural Resource Management or CRM) work in the nine county area that comprises the Texas Department of Transportation's Fort Worth Highway District. The book is divided into three, but arguably four parts.

The first part introduces the reader to the basic physical geography of north Texas, and describes the climate, geology, soils, vegetation, and fauna in addition to providing an overview of the existing knowledge of late Quaternary environments of the region. The second part, titled "Late Quaternary Stratigraphy and Geoarchaeology of the Fort Worth District", is actually two rather different things: 1) a thoughtful discussion of processes that affect distribution and integrity archeological sites in this region, and 2) a comprehensive overview of the Quaternary geology of the region. The first bears a strong resemblance to the background information of this type in the Houston Area Geoarchaeology volume, but its inclusion here makes this book a one stop shop for those new to the area. Rather than refer the reader to a multitude of different works most are unlikely to consult, this overview touches on the major formation process factors that influence the development of landforms, soils, and deposit integrity in North Central Texas. The second half of this part best fits the section title, and is a summary of the existing studies of the Late Quaternary geology of this region. It is the first (to my knowledge) summary of this type to integrate academic as well as CRM derived studies into a regional overview since C. R. Ferring was completing his doctoral work on the Trinity River in the early 1990s.

The third part of this book describes the construction and intended use of the Potential Archeological Liability Maps (or PALM) that categorizes the archaeological potential of the landscape by integrating information on the potential of landforms and soils to harbor buried archeological sites together with evidence of disturbance. Although similar to the Houston Area Geoarchaeology-PALM, the Fort Worth PALM presents a more challenging landscape and some aspects of this work are truly impressive. The most notable of which is the geomorphic classification and mapping of the entire 6,965 square mile Fort Worth district from 1:37,000 scale aerial photographs (landform potential mapping). Unlike other studies of a similar type that rely nearly completely upon existing GIS data sets such as soils and floodplain maps (e.g. Monaghan and Lovis 2005), Abbott painstakingly generated a new data set for the entire region, an action which undoubtedly enhances the utility of the PALM. The second data set involved in the PALM is soil data derived from the Natural Resources Conservation Service (NRCS) – National Cartography and Geospatial Center (NCGC) Soil Survey Geographic (SSURGO) Database. Each soil series in the SSURGO data set was evaluated and classified for its shallow and deep geoarchaeological potential. Finally, information on historic/recent disturbance was compiled from the aerial photos and integrated into the GIS data set.

These three classes of data are used to compile maps that predict where archeological sites may lie shallowly (<1m) or deeply (>1m) buried, which is useful information in deciding what methods should be employed in surveying these landscapes and for entities like the Texas Department of Transportation to predict where they are most likely to encounter significant archeological sites when building and maintaining roads. The methodological approach employed in constructing the maps is explicit, and the resulting maps are easy to consult in their primary and derivative forms. The approach of having the mapping protocol reviewed and those reviews available to readers renders the process that led to the development of the PALM completely transparent and justified.

In order to assess the validity of the map output for myself, I asked the author to print enlarged versions of the PALM maps for an area in Palo Pinto County where I recently completed fieldwork and have a detailed knowledge of the subsurface deposits. Four maps were provided: two presenting the simplified output (shallow and deep), and two presenting a more “nuanced” output (shallow and deep). Somewhat paradoxically, the simplified maps provided the best prediction of subsurface potential, and the shallow map proves to be a somewhat conservative prediction. The only place I would take exception with the classification is on the colluvial toe slopes, which are classified as moderate probability and I would consider them to have a high probability. The total area involved here is, however, quite small. Interestingly, the nuanced maps in general and the deep geoarchaeological potential map in particular, appears to be less accurate than the simplified map, which I suspect is a function of the inherent inaccuracies of soil surveys in complex soil landscapes such as alluvial valleys.

The main criticisms/liabilities with this document are generally going to be of two types: practical and theoretical. Practical problems with the model involve a) the scale of the mapping, b) quality of the primary data and c) the types of significant sites it cannot predict. Given the sheer scale of this ambitious work, the scale of the mapping precluded delineation of small-scale geomorphic features that are often significant on a site scale. Features such as local alluvial fans or colluvial aprons/toe slopes are perhaps the most significant problem area, and Abbott noted this liability (p.169). There is no easy fix for this problem and in this regard the application of this model relies upon informed conscientious users to think for themselves when applying the PALM. As Abbott commented, the maps are output as probability statements, and are but one line of information the users need to consider when making their decisions.

Perhaps more significant is that the validity of the resulting maps follows directly from the quality of the data sets used in compiling the PALM, and my principal reservation concerns the accuracy of the SSURGO data. The soil maps made by the NRCS are intended for use at a scale of 1:24,000 or greater, and below this scale and in dynamic Quaternary depositional environments, they are often wrong. The reasons for the errors are numerous, but major factors include the fact that soil surveys in depositional settings like streams pay NO attention to the geologic factors that control soil variation (primarily the alluvial stratigraphy), and because they lack sufficient control/observation points. As a result, the soil maps in many alluvial valleys are wrong the much of the time. The nature of the alluvial architecture plays a strong role in the accuracy of the resulting soil maps, and vertically aggrading systems like the Trinity are clearly less problematic than streams that cut and fill like the Brazos. The integration of landform information partially compensates for the problems inherent in the soils data sets, but it does not remove the problem.

Finally, just as these maps do not apply to Historic sites (cf. discussion in Section 3.4.1) the other place they will not apply is to prehistoric sites that contain a built environment that may be subterranean. The PALM is designed to identify where natural processes have or may impair archeological site visibility primarily by means of burial, and this model contributes nothing towards identifying where sites with significant subsurface deposits of a cultural origin (e.g. cemeteries, pit houses or storage pits) may lie buried. These kinds of sites are likely to hold significant buried deposits in almost any landscape setting except exposed hard bedrock. Although sites with these kinds of features are admittedly uncommon, the western part of the PALM is included in the range of the Henrietta Focus, and the sites associated with this Plains tradition are more likely to have such features. If the PALM is used to decide against pedestrian survey for some areas, then this will present problems if sites of this type are likely to be present. Establishing a protocol that will permit employing the PALM to best advantage without compromising the discovery of sites of this nature should be addressed.

On the more theoretical side, many people in the archeological community will object to the fundamental assumption that context is the most significant factor in identifying where significant archeological sites may be found. This was one of the objections to the Houston PALM and remains a point of discussion within the archeological community. Abbott directly addresses these issues (Section 3.1) but ultimately, this issue, like finding sites with known subsurface features, is not an issue of the effectiveness of the model, but rather its implementation as a CRM tool.

In summary, Abbott has compiled a comprehensive document that will stand as a reference for some time to come. The geological review and the extensive references together are a most useful addition to the literature. The GIS based PALM is a well-conceived, and explicitly compiled protocol that appears to effectively perform the task for which it was established. Although the FTW-PALM is intended to be used as an internal TxDOT planning tool, these maps could also be effectively

employed by many CRM contractors when compiling bids for archeological surveys in the Fort Worth District (and not only for TxDOT jobs) as the simplified map output provides a powerful predictive tool that can be used to tailor field methods to the diverse geologic conditions that prevail in this region. How the FTW-PALM will be used by TxDOT deserves more discussion than is presented here, as this is where the nitty-gritty objections in the archeological community lie. But as it stands, this is an impressive piece of work.

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Review and Commentary on:

Geoarchaeology in North–Central Texas: A framework for archaeological investigation, interpretation and cultural resource management in the Fort Worth Highway District. by James T. Abbott

By C. Reid Ferring, Department of Geography, University of North Texas, Denton

I found this report to be an excellent basis for meeting its goals concerning the identification of differential potential for preservation (and possible adverse impacts) to significant cultural resources in the Fort Worth District. It is very well written, and virtually free of errors. One concern is that many of the maps have no physical or political references beyond county boundaries. In many (probably most) cases, at least putting major streams on maps will help make them useful.

Part I: Late Quaternary Environmental Context of the Fort Worth District

This section provides an excellent background to the study. A question raised, however, is why no background to the archaeology of the district was prepared?

Part II: Late Quaternary Stratigraphy and Geoarchaeology of the Fort Worth District

Overall, this is a very important part of the report, including both synthetic discussions as well as new data from a number of localities, especially those studied by the author. While a fair number of comparisons were made to the “Ferring model”, it should be stressed that that “model” was based on data from the Middle–lower Elm Fork, its major tributaries and the West Fork between Ft Worth and Dallas. As such, it is mainly a trunk stream synthesis, with considerable emphasis on distal flood plain settings that provide a good long–term record of alluvial sedimentation rates. While some of my detractors have also worked in the same area, I remain stubbornly supportive of my main points, and find that they did not consider all of the borehole data I used in 1986 and in my dissertation. So be it. And, I am not surprised that localities farther west, in both large and small rank drainages, need local study, and do not necessarily conform to my “model”.

Indeed, my consideration of alluvial records on a large scale lead me to conclude that within the Holocene, long–range correlations between and among drainages are difficult if not possible, especially when buried soils are considered. Those records are just too noisy, probably because of a) regional differences in climate history and b) because climate change overall has not been able to override local controls on stream behavior (sediment supply, different resistive frameworks and very diverse vegetative communities, many of which are edaphically controlled (especially in this “marginal” region between the Gulf Coastal Plain and the Rolling Plains).

One of the major foci of my dissertation research was integration of sedimentary environments and soil forming situations. I relied heavily on the pedofacies concepts of Birkeland, Brown and others. The strong facies control on soils development led me to slow down if not stop using names for buried soils in the Trinity drainage. The “West Fork Soil” for example, turns out to be present in meander belt facies, mainly when there is a shift from rapid to slow deposition, following a shift in channel position. In distal flood basin settings, the entire Holocene record of soil formation is registered by a thick cumelic soil, often with vertic features. A soil formed during the Middle Holocene in the Elm Fork flood plain, and its tributaries including Denton Creek and Hickory Creek, but I have not seen the same farther up the West Fork (it may be discerned in Mandel’s section at South Bend and perhaps other settings as well). And, as shown by this report, Middle Holocene erosion is evident in some settings west of my study area. Also, in “my” study area there is no evidence for incision ca. 1.5 Ka, as mentioned in this report– and indeed, except for the low inset benches mentioned below, there are no Holocene terraces at all along the middle–lower Elm Fork or its tributaries.

Similar conclusions may be found when headwaters reaches and smaller tributaries are concerned; I have spent little time on those settings. The sedimentary–soils records on the entrenched reaches of the Brazos illustrate these considerations quite well. (Incidentally, I’m under the impression that the Brazos became entrenched over the long period of epeirogenic uplift

of the Edwards Plateau, beginning in the Miocene.) With respect to studying alluvial soils in general, it seems that control for sedimentary facies shifts, and all the factors involved, need to be addressed before naming and correlation of buried soils becomes dependable.

These cases illustrate the difficulties in establishing detailed stream comparisons, and stress the importance of local studies and local conclusions for site preservation, exposure, etc. This is a welcome and evident perspective in this report. Overall, the author exhibits excellent control of these perspectives, and I found his studies and discussions to be most sound.

The first section of Part II is a brief but comprehensive review of some basic geology, which cannot supplant education and training, but is certainly valuable for non-specialists and for those wanting to further their geoarchaeological studies. This merit will only be realized if this report becomes widely accessible, which I hope will ensue its final preparation. An Internet venue would be most useful for those working in the region.

Part III: The Fort Worth Potential Archaeological Liability Map (FTW-PALM)

This section is pretty much the conclusion of the document, as it comprises the means by which real decisions will be made in order to plan and implement cultural resources surveys in the Fort Worth District. This also is the section that previous reviewers addressed, with subsequent replies and some modifications by the author.

In the main, the author clearly understands the difficulties involved in predicting where significant sites may be found on a large, diverse landscape. The synthesis and data presentation in Section II are especially relevant here, with comments above.

The proposed scheme is essentially based on landform classifications coupled with soil series. Both of these are considered below. The decision to not use the Geologic Atlas mapping units is debatable, and I agree with Frederick that those maps are usually excellent means to identify landforms and sediments associated with terraces and floodplains, although they usually cannot be used to distinguish among lower terraces. I will comment on both of those settings (terraces and floodplains [or flood terraces]) later.

The geologic maps are essentially maps of soil parent materials. I teach students that on a large scale, the two most relevant factors for predicting soil characteristics are parent material and climate. On a regional scale (same climate), the two factors are parent material and slope. [This can be done quite readily with GIS, using bedrock and DEM layers, as they do in making Universal Soil Loss maps.] Despite its elegance in most dimensions, the most obvious shortcoming of the Soil Taxonomy for Quaternary geomorphology is its broad exclusion of parent materials, except in the extreme cases (Andisols, Psamments, Fluvents, for example). With respect to predicting site contexts in this region, it is very important to note whether a Mollisol formed in Cretaceous clays or Pleistocene alluvium or Holocene alluvium. This is largely, but not completely addressed by the landform classifications used, but the geology maps get right to the point with respect to parent materials. Rather than laboriously adding a geologic layer to the present map base, the geologic maps can and probably should be used on an ad hoc basis for any given highway project.

With the geologic maps questions aside, I find the landform classification used here to be largely suitable. I thought I knew what a flood plain was, but the author pointed out my error in pretty much disregarding the generally low ephemeral benches along major streams that are technically “the floodplain”. Along the Elm Fork and West Fork, these are inset in the channel itself (as noted), and what I consider to be the flood plain is the higher, broad surface that receives sediment only during overbank floods. Those floods were much more common, it seems, prior to reservoir construction, and I tended to regard lower surfaces differently. My difference here is therefore just a terminological one. However, I do wonder as to the criteria used to rank some flood terraces’ archaeological potential “moderate” and some “very high” (averaged I guess to “high” in Table 3–1). Is this based on distance from the channel, or the stream rank, or other factors? On the Elm Fork, distal flood plain settings have proven to be places where middle Holocene alluvium is buried, interdigitated with flood plain alluvium.

The ranking of high terraces as having low potential for deep deposits is reasonable in most cases, although I disagree that the search for “pre-Clovis” archaeology should be essentially disregarded. I believe that we should indeed stress surveys of sediments dating back to 25–30 Ka. If we do not look we’ll never find, and the pre-Clovis barrier has definitely been broken. Probably of more immediate concern is that many sites in this region are found on the edges of terraces (as well as bedrock benches) overlooking flood plains. In my view, this should elevate the potential of those settings. This points out a probable deficiency in the approach used to generate the FTW-PALM, which is simply distance from drainages, regardless of landform. This factor probably explains most of the prehistoric site locations in this region and probably most regions of North America. Again, this factor can be incorporated into the final assessment of any proposed project. When combined with the comment on bedrock maps, this suggestion indicates my view that the FTW-PALM should be applied on a case-by-case basis; I understand this may be standard protocol.

The use of soils in the decision matrix in Figure 3–1 is about as reasonable as it could be. However, in the end, I think that landforms will probably trump soils in terms of identifying significant sites. This is especially true for flood plain settings, as indicated in this report. The soils surveys provide notably scant treatment of deeper deposits— that was not their mission. This means of course that the kind of work summarized in Section II of this report are most important, and should be incorporated explicitly in any survey planning protocols.

I found the Model Evaluation section to be quite important. With all of the limitations of the TARL database in mind, and with a focus only on prehistoric sites, the results of the test were striking. 53% of the sites in the database fell into low and negligible probability areas defined by the FTW-PALM. How would this translate into a survey planning design? More importantly, this study can provide a basis for a possibly significant evaluation of the FTW-PALM, namely by evaluating the specific contexts of all the sites in the TARL data base, and seriously asking why so many of them fall into low-negligible areas. Another approach to assessing the FTW-PALM is to put all of the sites in this region that have indeed been tested and mitigated to the “test”. Because few large land-use projects have been conducted in the FTW district, this may mean using nearly projects, such as Ray Roberts, Lewisville, Joe Poole, Richland Chambers, etc. the exercise would still seem worthy. Also, what about results of what I presume to have been many TXDOT surveys in this region (or perhaps these are already included in the TARL data?). The point is that the best way to evaluate a predictive model is to conduct ground truthing. The model evaluation here started that, but did not complete it. I suggest a more detailed analysis is warranted.

In sum, I find this document to be an exceptionally well-written and solid basis for achieving its goals. It will serve TXDOT (and hopefully other agencies) with a basis for assessing the potential impacts of proposed construction projects, and as a basis for evaluating individual prehistoric sites that may be encountered by survey. The synthesis and presentation of unpublished (or gray published) data on the Late quaternary Geology of the region is especially valuable, and I hope it becomes available to other researchers in this region. While I have noted ways in which the model and mapped results may be improved, I applaud the diligent effort made, and its overall positive results.

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Environmental Affairs Division
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SUBJECT: Review of *Geoarcheology in North-Central Texas: A Framework for Archeological Investigation, Interpretation, and Cultural Resource Management*

Dear Jim:

It is obvious that much thought and careful research went into the production of this volume. The document is well written and extremely thorough. The attention to detail is reflected by the effort related to boundary rectification. Many researchers would not have bothered.

I feel that you emphasize two critical points in presenting the Fort Worth PALM – the concept of integrity and that the PALM is a support tool. The emphasis on the potential integrity of a site context is greatly appreciated, for it is frustrating how many archeologists today still ignore contextual integrity when evaluating a site for eligibility for inclusion in the National Register of Historic Places or for designation as a State Archeological Landmark. As you noted, many archeologists are prone to giving a site the benefit of the doubt. Unfortunately, the end result is that much time and effort are spent on sites of questionable research value. Your other emphasis that the PALM is a support tool and not a final determination of the potential archeological liability is extremely important also, for it is a model and it cannot account for all geological and soil variability within the Fort Worth District. As large scale projects are implemented within the Fort Worth District, the accuracy and usefulness of the model may be tested. Unfortunately, there will be those who will use it as a final determination of potential archeological liability and will ignore the real variability present.

Given my prior experience in several of the counties in question (Tarrant, Erath, Palo Pinto, and Wise), I feel that the potential archeological liability projections accurately reflect on-the-ground conditions. In Palo Pinto County, for example, there are numerous surficial sites (<1 m in depth) located across the various landforms; however, most do not demonstrate the contextual integrity necessary to address meaningful research issues. It should be noted, however, that the occasional single component archeological site exists in a surficial context; consequently, it may possess high research value.

Parts I and II of the document are extremely thorough. Anyone new to the region would be well advised to make these sections required reading. In fact, Parts I and II could be the nucleus for a text book for those seeking to become an archeologist or geoarcheologist. All that is needed is the addition of specific examples of the processes or interpretations being discussed. These comments, however, raise the following question: “Who is the target audience for this volume?” Within the introduction, the purpose of the volume is defined as follows: “The current study is intended to familiarize archeologists, planners, and transportation professionals working in the region with relevant geoarcheological issues, thus serving as a resource for those involved in prospection, assessment, and interpretation of prehistoric archeological sites.” It is my impression that there are many archeologists who would find Parts I and II a very weighty discussion; consequently, they would go straight to Part III. If I am correct in this assessment, there is no reasonable chance that planners and transportation professionals would carefully read Parts I and II. It is my recommendation that additional consideration regarding the target audience be conducted. Depending on the primary target audience, reorganization of the document

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may be necessary, or perhaps, a second overview document aimed at informing planners and transportation professionals may be warranted.

You were very even-handed in your evaluation of alternative views of geological and archeological concepts and processes. In fact, I would argue that you are too even-handed. I would have liked to have seen you take a position on several of the issues discussed in Parts I and II. You avoided any discussion of the proposed search strategy in relation to each potential archeological liability area. Given the lengthy and often heated debate of the Council of Texas Archeologists regarding appropriate survey methodologies, this may have been a wise move on your part; however, such a discussion seems like the logical next step in the process. Your model provides a very rational basis for defining survey methodologies.

In summary, this volume is a valuable resource for aspiring and practicing archeologists and geoarcheologists. It is very well written and well researched. It definitely provides a quality benchmark for future prospection, assessment and interpretation of prehistoric archeological sites within the Fort Worth District. This integrity-based model provides a tool which allows researchers and planners to focus their limited budgets and associated efforts on those areas and resources which will provide the greatest information.

Sincerely,

Duane E. Peter
Vice President, Cultural Resources Division

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Appendix IV

FTW-PALM MAPS

Appendix IV: FTW-PALM MAPS

Erath County shallow (<1 m bgs) geoarcheological potential

Erath County deep (>1 m bgs) geoarcheological potential

Hood County shallow (<1 m bgs) geoarcheological potential

Hood County deep (>1 m bgs) geoarcheological potential

Jack County shallow(<1 m bgs) geoarcheological potential

Jack County deep (>1 m bgs) geoarcheological potential

Johnson County shallow(<1 m bgs) geoarcheological potential

Johnson County deep (>1 m bgs) geoarcheological potential

Palo Pinto County shallow (<1 m bgs) geoarcheological potential

Palo Pinto County deep (>1 m bgs) geoarcheological potential

Parker County shallow (<1 m bgs) geoarcheological potential

Parker County deep (>1 m bgs) geoarcheological potential

Somervell County shallow (<1 m bgs) geoarcheological potential

Somervell County deep (>1 m bgs) geoarcheological potential

Tarrant County shallow (<1 m bgs) geoarcheological potential

Tarrant County deep (>1 m bgs) geoarcheological potential

Wise County shallow (<1 m bgs) geoarcheological potential

Wise County deep (>1 m bgs) geoarcheological potential