LATE-QUATERNARY EVOLUTION OF SMALL BASIN IN THE KANSAS RIVER SYSTEM:
WOLF CREEK

by

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B.A., University of Kansas, 1982

Submitted to the Department of Geography
and the Faculty of the Graduate School
of the University of Kansas in partial
fulfillment of the requirements for
the degree of Master of Arts.

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Date Thesis accepted

ABSTRACT

Geomorphic research in the Wolf Creek basin, a small (163 km2) drainage in the Kansas River system, indicates that four late-Quaternary alluvial fills and terraces can be recognized. The uppermost terrace (T-4) is located in the uplands where it is underlain by pre-Wisconsin-age gravels (Fill I). The T-3 surface, created as late-Pleistocene entrenchment elevated the T-4 terrace, is a strath terrace cut on Dakota Sandstone along the valley margin. The dominant surface in the basin, the T-2 terrace, is underlain by silty early-Holocene and late-Holocene alluvium (Fills II and III, resp.) in the upper reaches of small tributaries and in late-Holocene fill in the larger streams. Ongoing stream entrenchment is producing the T-1 terrace complex, a series of ill-defined surfaces underlain by Fills III and IV that occupy the inside of meander bends. The floodplain (T-0) is poorly developed in the basin, consisting of a thin deposit of post-settlement alluvium that caps coarse gravel.

Events in the Wolf Creek basin generally correlate with other localities in the Kansas River system, indicating that widespread changes in climate during the late Quaternary governed fluvial behavior. As valleys in the Wolf Creek basin filled during the early Holocene, an interval of soil formation occurred at about 6,700 yrs B.P. Early-Holocene fill is exposed only in portions of the basins upper reaches, as extensive erosion during the middle Holocene removed most early-Holocene fill from Wolf Creek valley and its larger tributaries. As valleys filled between 5,000 and 1,000 yrs B.P., soil formation occurred about 1,800, 1,500, and 1,200 yrs

B.P. In the last 1,000 yrs as much as 6 m of entrenchment has occurred in some reaches of the basin.

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CHAPTER I
INTRODUCTION AND PROBLEM DEFINITION

Introduction

A high-resolution reconstruction of late-Quaternary landscape evolution in a small basin in the Kansas River system has yet to be reported. The lower Kansas River basin, as well as portions of its major tributaries, the Smoky Hill and Republican River basins, have been the focus of extensive geomorphic research. Consequently, the temporal and spatial patterns of aggradation, degradation, and stability are better understood for these watersheds. In contrast, a small basin has not thoroughly been studied thus far because investigations in these basins have been generally archeologically oriented, restricted to a single stratigraphic section, or confined to a short reach of a stream. As a result, the detailed landscape evolution of an entire small basin in the Kansas River system and the relationship between the upper and lower watershed is unknown.

Origin of the Research Problem

Although the number of late-Quaternary alluvial chronologies in the central United States has increased tremendously in the last ten years, the spatial and temporal relationships of fluvial behavior in small tributaries and large streams remains an enigma. Schumm (1977) suggested that the idealized fluvial system consists of three zones, wherein each serves a separate function within the system. Zone 1 is the uppermost part of the system, consisting of the sediment source area. The middle part of the basin is the location of Zone 2, or sediment transfer zone, where sediment input can equal output. Zone

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3 is the downstream area of deposition. Although erosion and storage of sediment naturally occur in all portions of the basin, Schumm (1977) argued that different portions of the drainage basin behave differently at the same time.

Evidence from the central United States supports the conclusions implied in Schumm's (1977) study that small tributaries responded differently to contemporaneous changes in climate or other variables than larger streams during the late Quaternary. In western Iowa, for example, Bettis (1990) reported that the Gunder Member of the Deforest Formation began to accumulate in valleys larger than 4th-order nearly 11,500 yrs B.P., and extended into 2nd- and 3rd-order valleys by 10,500 yrs B.P. Between 7,000 and 4,000 yrs B.P., however, sediment was flushed from 2nd and 3rd-order tributarties and accumulated in larger valleys downstream and as alluvial fans at tributary confluences. Radiocarbon ages in the fans range from about 8,700 to 3,000 yrs B.P., and corresponding deposits are lacking in the smaller tributaries. This major erosional episode in 2nd- and 3rd-order tributaries has been termed the "Deforest Gap" (Bettis and Thompson 1981).

During an extensive study of Holocene terraces and alluvial fills in the Pawnee River basin, a tributary to the Arkansas River in southwestern Kansas, Mandel (1990) demonstrated that different processes operated in small tributaries and large streams during the late Quaternary. While both early- and late-Holocene alluvial fills were recognized in the trunk valley of the Pawnee River, much of the early-Holocene fill was flushed from the tributary streams and deposited at the confluences of small tributaries and the main valley

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sometime during the middle Holocene.

Evidence also indicates that small basins in the Kansas River system responded differently to contemporaneous changes in climate or other variables than did the larger streams. A review by Johnson and Martin (1987) of research in the central Great Plains, including the Kansas River system, strongly suggested that large basins and small tributaries responded differently to contemporaneous variables during the late Quaternary. According to them, eight episodes of soil formation (i.e., floodplain stability) have been recognized in the Great Plains: 10,600-10,200, 8,900-8,300,, 7,250, 5,100-5,000, 4,300-4,000, 2,600-2,400, 2,100-1,600, and 1,200 yrs B.P. All of these periods of stability have been recognized in the large basins of the system.

In contrast, only periods of stability occurring at 10,600-10,200, 4,300-4,000, and 2,100-1,600 have been recognized in the smaller basins thus far. This discrepancy in fluvial behavior between the large basins and the small basins in the Kansas River system may be real, i.e., small basins flush their sediment more readily than do large basins. Conversely, other periods of floodplain stability might be unrecognized in small basins of the Kansas River system since they have not been the focus of high-resolution research.

Goals of the Research

In order to compare late-Quaternary landscape evolution in small and large basins of the Kansas River system, a small basin must be studied that contains alluvial deposits ranging in age from

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late Pleistocene through Holocene. Extensive research indicates that Wolf Creek, a small (163 km2) tributary within the central portion of the Kansas River system (Fig. 1:1), contains such deposits. This thesis presents a detailed reconstruction (i.e., age, relationship, number and distribution of terraces and alluvial fills) of late-Quaternary landscape evolution in this system. A secondary goal is to correlate the results from this study with other research, specifically, from the large streams in the Kansas River system. In addition, speculation will focus upon the causes of late-Quaternary landscape evolution in the Wolf Creek basin.
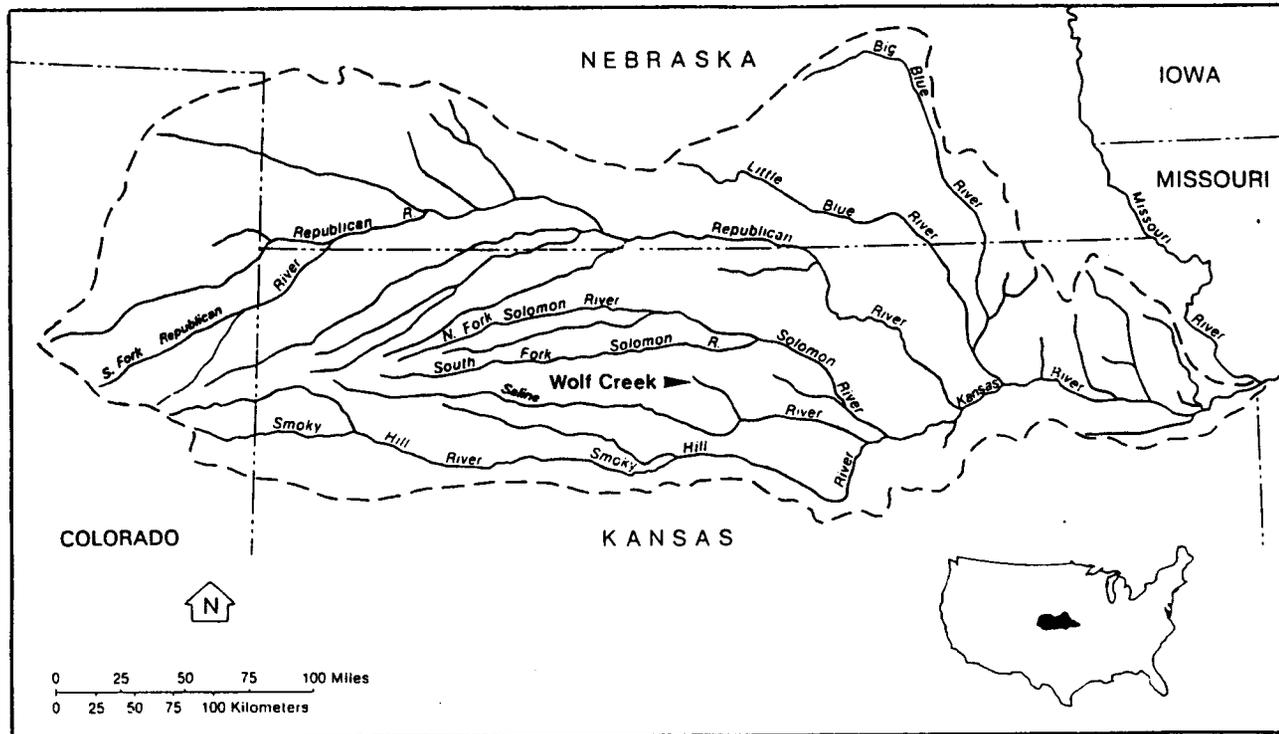
Figure 1:1   Location of the Wolf Creek basin within the Saline
             River drainage in the southcentral portion of the
             Kansas River system (modified from Johnson and Logan
             1990).

CHAPTER II
RELEVANT RESEARCH

Fluvial System Form and Process

Many streams have experienced cycles of alluviation and erosion during the late Quaternary, often resulting in the preservation of a variety of alluvial fills and landforms (e.g., Womack and Schumm 1977). The pervasive landforms produced by cutting and filling are floodplains and terraces. According to Dunne and Leopold (1978), the floodplain is "the flat area adjoining a river channel constructed in the present climate and overflowed at times of high discharge." The precise definition of the term "floodplain" has been the subject of some debate. Although the United States Geological Survey once maintained that an active floodplain was inundated by bankfull discharge every 2.33 years (Benson 1962), it is now generally accepted that an actively aggrading floodplain will be inundated by bankfull discharge every 1.5 years (e.g., Wolman and Leopold 1957; Leopold et al. 1964; Dury 1973; Richards 1982; Morisawa 1985; Ritter 1986). Terraces, in contrast, are "abandoned floodplains" produced following stream entrenchment, i.e., they are not flooded as frequently (Schumm 1977; Richards 1982; Morisawa 1985; Ritter 1986). Schumm (1977) argued that stream system adjustments are implied by differences in elevation and alluvial fill composition among terraces, and between terraces and the floodplain.

Floodplains are thought to be produced by one or more of three distinct processes: lateral accretion of unconsolidated point bar deposits, vertical accretion of fine sediments, and colluviation, mass-wasting, and/or alluvial fan development at the mouth of

tributary valleys. Ritter (1986) also noted that other major components of floodplains include channel lag and splay deposits.

It is widely accepted that the dominant process in floodplain construction is a combination of lateral accretion in the channel bed during lateral channel migration and vertical accretion through overbank deposition (e.g., Mackin 1937; Wolman and Leopold 1957; Leopold et al. 1964; Morisawa 1985; Ritter 1986). Wolman and Leopold (1957) observed that possibly 80 percent of floodplains are constructed in this fashion. Commonly, lateral accretion deposits are composed of point bars that accumulate within the inside of meander bends downstream from the point of greatest meander bend curvature (Morisawa 1986). Point bar deposits are generally coarse in texture, but often contain a mixture of grain sizes. Mackin (1937) argued that the maximum possible thickness of a point bar deposit does not exceed the "maximum depth of effective flood scour."

Once a point bar becomes established in the channel bed, it is often inundated by floodwaters that carry silt and clay-sized particles in suspension. In this fashion, fine materials are vertically deposited over the point bar (Selby 1985). Mackin (1937), in his illustration of the Shoshone Valley floodplain in Wyoming, described "coarse detritus" that was overlain by "silt" that was a result of overbank deposition. Wolman and Leopold (1957) suggested that, on average, only 10 percent of floodplain deposits consist of such fine, overbank sediments. Moreover, they proposed that the thickness of overbank deposits depends on three factors: the rate of erosion in the system, the concentration of suspended sediment at peak discharge, and the velocity of the water over the floodplain.

According to Ritter (1986), the amount of overbank deposition is controlled by the rate of lateral channel migration, i.e., increased lateral channel migration reduces the amount overbank deposition.

Studies along river valleys in Kansas (Schumm and Lichty 1963), in Canada (Stene 1980), and in southeastern Australia (Nanson 1986), indicate that vertical accretion can be the dominant process in floodplain formation. Stene (1980) reported that Holocene floodplains in southwestern Alberta consisted of a thin bed of basal gravel overlain by a thick deposit of fine overbank sediments. Nanson (1986) described floodplains that formed episodically by vertical accretion along high-energy, laterally stable channels.

Schumm and Lichty (1963) reported that the floodplain of the Cimarron River in Kansas was destroyed by a series of large floods which dramatically widened the river during the 1930s. This study revealed that, following a major flood in 1942, the floodplain began to reform as the river channel narrowed. They discovered that the floodplain was reconstructed in two ways: initially, by island formation and subsequent attachment of the island with the bank following channel abandonment, and secondly, by deposition and build up of areas not occupied by the low water channel.

Because of close proximity to the river, floodplains are typically the location of extensive alluviation or erosion (Leopold et al. 1964); consequently, a variety of geomorphic features can be observed. Lewin (1978) proposed that three scales of floodplain form could be identified: macroforms, mesoforms, and microforms. Features such as the floodplain and channel pattern, for example, are included within the category of macroforms. Microforms, in contrast,

consist of features such as plane beds, ripples, and dunes. Microforms are of considerable interest because they reflect the fluvial mechanics of various depositional environments (Ritter 1986).

The greatest topographic relief on the floodplain surface is in the area near the river where point bars are molded into alternating ridges and swales called "meander scrolls" (Leopold et al. 1964). These mesoforms, as proposed by Lewin (1978), are produced as the river migrates across the valley, leaving successive point bars and intervening swales on the inside of meander bends (Kolb and Van Lopik 1958; Leopold et al. 1964). Other depositional mesoforms include natural levees, which form as coarse silt and sand builds up near the river, and splay deposits, which are composed of alluvium spread onto the flooodplain surface through breaks in natural levees. In contrast, a chute, which consists of a low water channel scoured out of the floodplain surface, is an erosional mesoform.

A terrace is produced when, during the process of stream entrenchment, the surface of the floodplain is "abandoned", i.e., it is not flooded as frequently (Wolman and Leopold 1957; Leopold et al. 1964; Schumm 1977; Womack and Schumm 1977; Richards 1982; Morisawa 1985; Ritter 1986). Before 1890, the development of terraces was attributed to movements in the Earth's crust (e.g., Dana 1863; Foster and Topley 1865; Lyell 1871; Hull 1878). Later, terraces were considered to be products of climatic variations (e.g., Gilbert 1900; Davis 1902).

Today, terrace formation is thought to fundamentally reflect one or both of two controls: baselevel changes and variations in the discharge:sediment yield ratio within the basin (Richards 1982).

Baselevel change is usually attributed to tectonic, isostatic, or eustatic adjustments (e.g., Wolman and Leopold 1957; Sissons 1979) while changes in the discharge:sediment yield ratio are usually a function of climatic variability (e.g., Langbein and Schumm 1957; Wendland 1982; Knox 1983).

A number of attempts have been made to catagorize alluvial terraces. Bucher (1935) proposed that three types of terraces could be identified; strath, fill, and rock terraces. Further effort was made to catagorize terraces by Cotton (1948), who suggested that rock and strath terraces were synonomous, but that former floodplain surfaces should be called "valley-plain terraces."

Eventually, Howard and others (1968) suggested that two major groups, erosional and depositional terraces, should be recognized. Depositional terraces are those where the surface represents uneroded valley fill; consequently, such terraces are called "fill" terraces. The development of a depositional terrace always requires a period of valley filling followed by subsequent entrenchment (Ritter 1986). Erosional terraces, in contrast, are those that have been formed by lateral erosion. If bedrock is truncated, then the term "strath terrace" is commonly used. "Fill-cut" or "fill-strath" terraces are created when lateral erosion removed alluvial sediments from the surface (Leopold et al. 1964; Ritter 1986).

Another way to classify terraces is to compare the topographic relationship between terrace levels throughout the valley (Morisawa 1985; Ritter 1986). Leopold and others (1964) suggested that surface continuity along the valley and consistent height above the present stream should be the primary criterion for terrace correlation;

hence, the terms "paired" and "unpaired" terraces have become accepted by many (e.g., Schumm 1977; Richards 1982; Morisawa 1985; Ritter 1986). Paired terraces maintain the same height along the valley, and are typically underlain by fill of uniform age (Morisawa 1985; Ritter 1986). They are usually formed when rapid incision takes place in the basin. In contrast, unpaired terraces are formed by lateral erosion in conjunction with slow entrenchment, resulting in surfaces of different age that are staggered across the valley (Schumm 1977; Womack and Schumm 1977; Richards 1982; Morisawa 1985; Ritter 1986).

Causes of Stream Adjustments

A source of continuing debate is the cause of the late-Quaternary fluvial adjustments that produced different terraces and alluvial fills in stream systems (e.g., Schumm 1973; Womack and Schumm 1977; Wendland 1982; Knox 1983). Studies show that the fluvial system is inherently complex, and the problem of identifying specific causal factors of erosion, deposition, and landscape stability is difficult (Schumm 1973; Knox 1983). In general, changes in extrinsic (e.g., climate or vegetation) and/or intrinsic (e.g., valley gradient, hillslope stability) variables during the late Quaternary forced streams to adjust their gradients, sediment yield, cross-sectional morphology, and discharge. In many circumstances, extended periods of net erosion or deposition were initiated.

Several studies favor climate as the primary cause of erosion, stability, and deposition in river systems (e.g., Knox 1972, 1976, 1983; Baker and Penteado-Orellana 1977; Brackenridge 1980; Wendland

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1982). According to Knox (1983), the evolution of late-Quaternary river systems can be evaluated in relation to both the direct effects of extrinsic climatic events (e.g., seasonality, storms and floods) and the indirect effects of vegetation as it controls runoff and erosion. Specifically, variations in climate initiated changes in the magnitude, frequency, seasonal occurrence and duration of storms, and runoff, which, in turn, often caused major changes in vegetative cover, sediment yields, and potential destabilization of the system (Knox 1983).

The direct effects of climate (e.g., seasonality, storms and floods) are considered by many to be the cause of late-Quaternary fluvial adjustments (e.g., Burkham 1972; Leopold 1976; Brackenridge 1984; Hereford 1984; Knox 1985; Johnson and Martin 1987). According to Knox (1976), the ability of streams to maintain an equilibrium state depends upon the recurrence interval of floods, especially large ones. He argued that morphologic properties of most channel systems show strong correlations with the discharge characteristics of relatively frequent moderate magnitude floods, rather than less frequent large floods. Knox (1985) reported that Holocene floods in the upper Mississippi valley ranged from 10-15 percent larger to 20-30 percent smaller than contemporary floods of the same recurrence frequency. Thus, episodes of large and small floods were closely associated with long-term episodic mobility and storage of sediment.

Research in the southwestern United States supports the theory that flood frequency and magnitude profoundly influenced fluvial behavior during the late Quaternary. Along the Gila River in Arizona

major widening of the stream took place between 1905-1917 due to large floods, which carried small sediment loads. The period of floodplain construction, in contrast, was characaterized by floods having relatively low peak discharge and large sediment concentrations (Burkham 1972).

The recent history of the Little Colorado River in Arizona suggests that floodplain development was also initiated by climatically induced hydrologic fluctuations (Hereford 1984). He reported that frequent large floods and high annual discharge during the early twentieth century created a wide, sandy channel free of vegetation. In the 1940s and 1950s, mean annual discharge reduced to 57 percent of the preceding forty years, causing the channel to reduce its width.

While the direct effects of climate appear to dominate fluvial variability in many places, the indirect effect of climate, as it controls vegetation and runoff, cannot be underestimated. Langbein and Schumm (1958) defined effective precipitation as "the amount of precipitation required to produce a known amount of runoff." Using Fournier's (1949) parabolic curve, they found that the mean annual sediment yield in the United States is highest in semi-arid climates, where annual precipitation is about 30 cm. Results indicate either an increase or decrease in precipitation will decrease sediment yields. An increase in vegetation, which reduces runoff, will accompany a shift toward more mesic conditions. Similarly, a shift toward more xeric conditions will result in less runoff, thereby reducing sediment yields.

Research by Knox (1972) and Baker and Penteado-Orellana (1977)

support the conslusions derived from Langbein and Schumm's (1958) study. Knox (1972) demonstrated that Holocene valley alluviation cycles in southwestern Wisconsin occurred when climate and vegetation were not synchronous. During the mid-Holocene drought, for example, reduced forest cover likely increased the fifty-year flood by about 2,200 cubic meters per second above the present norm for a 16 km2 drainage basin. Between 6,000 and 5,700 yrs B.P., while the forest cover remained sparse, an increase in frequency and severity of floods increased runoff and the bedload component of the stream systems. Once the forest returned after 5,700 yrs B.P., the magnitude and frequency of peak flows was greatly reduced, decreasing sediment yields. According to Wendland and Bryson (1974), this pattern should be expected since vegetation change typically lags behind climate change by about 100 years.

Baker and Penteado-Orellana (1977) suggested that terrace morphology, paleochannel patterns, and channel sediments in the Colorado River of central Texas are consistent with alternating arid-humid climatic conditions there during the late Quaternary. These variations caused complex climatic-vegetation changes in the basin. Coarse-grained, low sinuosity river phases are closely correlated with periods of xeric vegetation and/or rare high magnitude floods in an arid climate. More mesic conditions and uniform streamflow characteristics of humid climates caused fine-grained, high-sinuosity phases to be initiated.

While the impact of climate variability is favored by a number of studies, Patton and Schumm (1981) cautioned there need not be a one-to-one correspondance between widespread climate change and

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alluvial-fill chronologies; rather, research in the southwestern United States (e.g., Schumm and Parker 1973; Schumm 1977; Womack and Schumm 1977) has demonstrated that terraces have formed independent of climatic controls. Moreover, Patton and Schumm (1981) have argued that channel cutting and filling need not be in phase everywhere, and may be occurring in different reaches of the same stream at the same time. Laboratory experiments conducted by Lewis (1944), Schumm and Parker (1973), and summarized by Schumm and others (1987) support the theory that alluvial chronologies need not be dependent upon external forces such as climate. In each study, precipitation applied to the experimental drainages was held constant, in effect, eliminating sediment yield variability as a cause for fluvial adjustments. Instead, the results are best explained by the concept of thresholds.

According to Schumm (1973), the importance of thresholds have long been recognized in many fields. In river systems, a typical threshold is the response of sediment size to an increase in velocity and the depth of water over it, i.e., if velocity increases past a threshold value at some point the particle will move. Schumm (1973; 1977) argues that two types of thresholds exist regarding fluvial behavior: extrinsic and intrinsic thresholds. Extrinsic thresholds, such as climatic variability, are those imposed by factors outside the drainage network. That is, the threshold exists within the system, but is not crossed without changes in precipitation, or magnitude of flooding (e.g., Langbein and Schumm 1958; Knox 1972; Baker and Penteado-Orellana 1977; Hereford 1984).

Intrinsic thresholds, in contrast, are thresholds that are

inherent to the system, i.e., they can be exceeded when input is relatively constant (Schumm 1973). Long-term progressive weathering of slope materials, for example, can result in mass movement following an intensive storm event. A special type of intrinsic threshold is a "geomorphic threshold," i.e., one that is inherent in the manner of landform change. If sediment storage in a valley progressively increases slope, for example, the gradient threshold may be surpassed, inducing channel entrenchment (Schumm 1977).

Lewis (1944) reported that rejuvenation of a very small drainage system initiated rapid erosion in the headwaters in conjunction with deposition at the mouth of the basin. As erosion decreased upstream gradients, sediment supply downstream decreased dramatically and the system stabilized. Lewis (1944) argued the significance of the study was the creation of terraces without any adjustments in baselevel or discharge.

Schumm and Parker (1973), Schumm (1977), and Schumm and others (1987) have experimentally demonstrated that one episode of cutting in a basin can result in multiple terrace levels; they reported that a drop in baselevel, for example, can result in progressive incision upstream, creating a terrace. As sediment is removed from smaller order tributaries, however, deposition is likely downstream. As the tributaries adjust to the new baselevels and upstream sediment loads decrease, renewed incision downstream begins with the formation of yet another terrace.

The results of these studies indicate that a variety of events (e.g., tectonic activity, climatic change, vegetation change, baselevel lowering, slope failure) can cause an erosional response in

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a drainage basin, creating high sediment yields, which in turn cause deposition and an increase in gradient elsewhere in the basin. Typically, a period of aggradation is followed by incision and the development of terraces. Schumm (1977) suggested that such a sequence of events, regardless of the cause, should be called a "complex response" of the fluvial system.

Previous Studies of Late-Quaternary Alluvial Terraces and Fills in the Kansas River Basin

The following discussion reviews previous studies of late-Quaternaary alluvial terraces and fills in the Kansas River basin in Kansas and southern Nebraska. Although similar research is extensive in other areas of the central United States (e.g., Brice 1964; May 1986a; Mandel 1990; Hall 1990), these studies are not immediately germaine to this study, which is to compare the Holocene alluvial chronology of Wolf Creek with results from the Kansas River basin. The review is organized by drainage basins within the Kansas River system, including (1) the Kansas River valley and its tributaries in northeastern Kansas, (2) the Smoky Hill River basin in central and western Kansas, and (3) the Republican River basin in southern Nebraska and northcentral Kansas.

Kansas River and its Tributaries in Northeastern Kansas

Significantly more is known about terraces and fills of the Kansas River valley proper than those of its tributaries (Johnson and Logan 1990). Although Newell (1935), Hoover (1936), and Jewett (1949) recognized the presence of terraces in the Kansas River valley, it was not until Davis and Carlson (1952) that the names

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"Menoken, Buck Creek, and Newwman" were applied to particular surfaces. Shortly thereafter, McCrae (1954) recognized still another surface, which he named the Holliday Terrace. Subsequently, Elks (1979) proposed that this surface should be called the Holliday Terrace Complex.

Traditionally, the Menoken, Buck Creek, Newman and Holliday terraces have been assigned ages of Kansas, Illinoian, Wisconsin, and Holocene, respectively (Johnson 1985). Many questions remain unanswered, however, about the origin and ages of the Menoken and Buck Creek terraces and underlying deposits (Dort 1987; Sorenson et al. 1987). In contrast, recent studies have provided a great deal of information about the ages of fills beneath the Newman and Holliday terraces. As a result, it is evident that the Holliday and Newman, and probably the Buck Creek terraces are much younger than previously thought (Johnson 1985).

The Menoken Terrace is up to 33 m above the present floodplain and is underlain by coarse outwash sediments fining upward to reddish sandy silt (Davis and Carlson 1952) deposited as the Kansas ice sheet retreated (Dort 1987). Other interpretations have suggested that the fill is composed of glaciolacustrine, till (Beck 1959; Jewett and others 1965), or ice-contact deposits (Sorenson et al. 1987). Dort (1987) suggested that the surface may be erosional in nature, truncating several sedimentary units, including the Meade Formation. Regardless, the areal boundaries of this terrace are not well known, but are not thought to be extensive (Johnson and Logan 1990).

Post-Kansas entrenchment, including erosion of the bedrock valley floor and subsequent filling, resulted in the 12-m-high Buck

Creek Terrace (Johnson and Logan 1990). Scattered remnants of this terrace have been recognized in the middle and upper reaches of the Kansas River valley, especially at the confluence of tributary valleys (Holien 1982). According to Beck (1959), the terrace is underlain by sand and gravel at the base, fining upward to silt and clay. In places, the terrace may be capped by Loveland and Peoria Loess (Davis and Carlson 1952; Beck 1959). A layer of possible fluvially redeposited Lava Creek B volcanic ash, found in a remnant of Buck Creek terrace, was fission-track dated at 600 ka. (Geil 1987), suggesting either an Illinoian or Yarmouthian age for the terrace fill (Richmond et al. 1986; Johnson and Logan 1990).

The dominant terrace in the Kansas River valley is the Newman Terrace, which occupies 10 percent to nearly half of the valley floor (O'Conner 1960). The underlying fill of the Newman Terrace consists of basal cobble/boulder gravel (Beck 1959) fining upward into dark, silty clay (O'Conner 1971). Although 3 m above the modern floodplain, the Newman Terrace was probably inundated by floodwaters in 1844 and 1903, and certainly in 1951, indicating the surface is still periodically aggrading (Davis and Carlson 1952).

Radiocarbon ages from soils buried within the Newman alluvium indicate that the fill accumulated largely during the early to mid-Holocene, as ages of 10,430±130, and 8,940±90 yrs B.P have been obtained near Bonner Springs (Holien 1982). Near Wamego, Bowman (1985) reported a radiocarbon age of 7,250±110 yrs B.P. on humates from a buried paleosol in Newman fill in a study relating channel-bank erodibility and rate of channel migration; an overlying paleosol at the same site yielded a younger age of 4,950±120 yrs B.P. (Johnson

and Martin 1987). From an adjacent exposure of Newman fill, Johnson and Martin (1987) reported a radiocarbon age of 8,310+120 yrs B.P. from another buried paleosol.

At some time during the late Holocene, another major period of cutting and filling occurred, resulting in the Holliday Terrace Complex, which rises only 1 to 2 m above the floodplain (McCrae 1954). The Holliday Terrace is composed of sand, silt, and clay, and can be found, as well as the Newman Terrace, throughout the Kansas River valley and the valleys of most major tributaries (Johnson and Logan 1990). Radiocarbon ages obtained from within Holliday fill near Bonner Springs range in age from 4,290+310 to 1,210+50 yrs. B.P. (Holien 1982). At a sand and gravel quarry near Topeka, a radiocarbon age of 2,620+70 yrs B.P. was obtained from a wood fragment exposed in Holliday fill (Johnson 1985).

Recent research has focused on alluvial terraces and fills in tributaries of the Kansas River in northeastern Kansas. The most extensive work has been related to archeological research in the Big Blue River basin, a large tributary of the Kansas River that extends into southern Nebraska. Most information comes from the Coffey Site (Schmits 1987, 1980) and from the vicinity of Tuttle Creek Reservoir (Schmits et al. 1987) north of Manhattan.

At the Coffey Site, Schmits (1987, 1980) recognized two alluvial landforms composed of five separate fills: a high terrace, designated T-1, and the floodplain, designated T-0, with fills designated as Units I through V. According to Schmits (1978, 1980), the T-1 terrace is underlain by only one fill, Unit I. Although absolute time control was not obtained from the fill, the presence of Folsom,

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Late Paleo-Indian, and Early Archaic artifacts at or near the surface suggested to Schmits (1980) that the terrace was stable throughout the Holocene.

Units II through IV comprise the fill that underlays the T-0 surface at the Coffey Site (Scmits 1987, 1980). Except for the Unit V fill, which overlaps the other units, the fills are inset fills of abandoned paleochannels that truncated older alluvium. A total of 18 radiocarbon ages were obtained from cultural remains and buried soils in these fills; these ages indicated that Units II through IV accumulated between about 6,300 and 2,000 yrs B.P. According to Schmits (1978, 1980), Unit V buried the other fills between 2,000 and 1,000 yrs B.P.

Additional information regarding the terraces and fills of the Big Blue River valley was obtained during archeological investigations at Tuttle Creek Reservoir (Schmits et al. 1987). The T-3 terrace, which is the oldest surface in the valley, stands about 19 m above the modern floodplain and may be capped by a thin deposit of Loveland Loess. An intermediate terrace, T-2, stands about 10 m above the floodplain and is extensive along much of the lower Big Blue. According to Schmits and others (1987), this surface correlates with the T-1 at the Coffey Site, suggesting a late-Wisconsin age for its underlying fill.

The most extensive terrace in the lower Big Blue River valley is the T-1, situated 3 to 4 m above the floodplain. Schmits and others (1987) obtained a radiocarbon age of about 6,300 yrs B.P. from near the base of T-1 fill. This age, and associated stratigrahpic evidence, enabled them to correlate the Unit II - IV fills from the

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Coffey Site with the T-1 fill at Tuttle Creek, suggesting that the fill also accumulated between approximately 6,300 and 2,000 yrs B.P. at Tuttle Creek. Like the Coffey Site, T-0 fill at Tuttle Creek likely accumulated after 1,000 yrs B.P. (Schmits et al. 1987).

During investigations at Tuttle Creek Reservoir, a number of tributaries in the vicinity were also examined. According to Schmits and others (1987), two terraces (T-1 and T-0) can be recognized in the small tributaries in the area. Although little absolute time control was obtained from these features, charcoal from a hearth about 20-30 cm below the surface of T-1 fill did yield a radiocarbon age of 1,090±80 yrs B.P.

Additional research in the Big Blue River basin has been conducted along the Black Vermillion River, a major tributary of the Big Blue River. Archeological investigations at the Deshazer Site have yielded information regarding T-1 deposits in the area. According to Schmits (1981), evidence suggests the T-1 fill at this site filled the valley bottom between approximately 5,000 and 2,000 yrs B.P. A radiocarbon age of 2,350±250 yrs B.P. was obtained from charcoal between a depth of 50 to 80 cm by Johnson (1973). In addition, radiocarbon ages of 5,320±790 and 4,215±180 yrs B.P. were obtained from charcoal associated with a cultural horizon 1.5 to 1.7 m below the surface (Schmits 1981).

Other research in tributaries of the Kansas River has focused on alluvial terraces and fills in the Wakarusa River basin in eastern Kansas. Early work in this basin was conducted by O'Conner (1960) and Johnson and Adkinson (1967), who recognized two terraces: a high one which they called the Buck Creek, and lower one, which they

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designated the Newman. Although topographic position suggested these surfaces are temporally equivalent with the type terraces in the Kansas River valley, radiocarbon ages were not obtained to verify these hypotheses.

A study by Mandel (1987) expanded the results of earlier research in the Wakarusa River basin. According to Mandel (1987), two terrace levels and two floodplain levels can be found in the valley. The highest terrace, designated T-2, is 4 to 6 m above the lowest floodplain, designated T-0b. Within the fill of the T-2 landform, a radiocarbon age of 15,350±390 yrs B.P. was obtained from an organic-rich deposit between 1.37 and 1.42 m below the surface, suggesting to Mandel (1987) that the terrace corresponds to the Buck Creek Terrace recognized by O'Conner (1960) and Johnson and Adkinson (1967). A lower terrace, designated T-1, stands 2 to 3 m above the T-0b floodplain and occupies 90 percent or more of the valley. Although radiocarbon control from the terrace fill was not obtained, Mandel (1987) argued that it corresponds to the Newman Terrace.

Stranger Creek, a tributary of the Kansas River in eastern Kansas, was the focus of a study by Logan (1985) that examined the differential effects of fluvial processes in preserving or eroding late-Quaternary terrace fills. In this basin, it appears that the Holliday Terrace Complex is the valley floor along the lower reach of Stranger Creek, since most Newman fill has been removed by lateral erosion (Logan and Johnson 1986). Remnants of the Newman Terrace can be found, however, scattered in the lower reaches of small tributaries to Stranger Creek. One radiocarbon age of 4,260±55 yrs B.P. was obtained from near the base of Holliday Terrace Complex

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fill.

An archeological study conducted by Logan and others (1989) around Perry Lake, an impoundment of the Delaware River and its major tributaries in northeastern Kansas, revealed information regarding the geomorphic history of the Delaware River valley. Three alluvial surfaces, designated T-2 terrace, T-1 terrace, and the floodplain were recognized. Radiocarbon ages of 8,220±350, 5,710±100, 2,620±110, and 1,200±60 yrs B.P. were obtained from charcoal samples buried in T-1 fill. Two paleosols were identified in T-1 fill and yielded ages of 2,450±70 and 1,000±70 yrs B.P., respectively.

Isolated studies involving opal phytolith research have yielded some information about alluvial fills in small tributaries to the Kansas River south of Manhattan. Kurmann (1985), in a study of opal phytolith and palynomorph assemblages contained within paleosols on Elbo Creek, obtained a radiocarbon age of 1,580±70 yrs B.P. on soil humates. On McDowell Creek, a radiocarbon age of 3,960±135 yrs B.P. was obtained from a buried paleosol in terrace fill (Twiss, reported in Johnson and Martin 1987).

Smoky Hill River Basin of central and western Kansas

The Smoky Hill River basin is the largest tributary of the Kansas River in west-central Kansas. The earliest work in the basin was conducted by Rogers (1984), who studied terraces along the Smoky Hill River near Hays, Kansas. He recognized five terraces, which are designated from lowest to highest, Terrace One through Terrace Five; they can be found 5.5, 7.5 12, 16.5, and 19 m, respectively, above the stream level. Although no radiocarbon ages were obtained, faunal

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evidence suggested to Rogers (1984) that the four lowest terraces are Holocene in age while Terrace Five is Wisconsin.

A relatively detailed study of terraces and valley fills in the Smoky Hill River valley was conducted by Mandel (1988). This study, associated with archeological investigations near Kanopolis Lake, recognized three landforms in that reach of Smoky Hill River valley and the valleys of major tributaries: two filltop terraces and the modern floodplain. The highest terrace, designated T-2, stands between 4 and 9 m above the modern floodplain; faunal evidence suggests that it aggraded during the late Pleistocene. The T-1 terrace, which is the lowest terrace in the valley, occupies the majoritiy of the valley bottom, standing 3 to 4 m above the modern floodplain. Most of the research in this study focused on the composition and age of T-1 fill, which is composed of four major fills that were designated Units I through IV. Radiocarbon ages from these units indicate that in the major valleys this fill accumulated between 4,500 and 2,600 yrs B.P., when stream incision created the T-0 terrace. In the small valleys of the basin, however, aggradation of T-1 fill occurred between 4,300 and 1,500 yrs B.P., punctuated by episodes of soil formation at $4,170\pm60$ and $2,620\pm70$ yrs B.P. According to Mandel (1988), radiocarbon ages of $2,090\pm60$ and $1,510\pm50$ yrs B.P. were obtained from a buried soil near the top of T-1 fill.

Another component of the study by Mandel (1988), focused on the origin and age of high-angle alluvial fans recognized at the confluence of 1st- and 2nd-order tributaries and larger valleys. Radiocarbon ages from buried paleosols contained within these fans indicated to Mandel (1988) that these landforms were built between

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3,200 and 600 yrs B.P.

Research by May (1986b) examined terraces and alluvial fills in the Saline River valley, a tributary of the Smoky Hill River, near Wilson Lake. In this study, three terraces were recognized in the main valley of the Saline. The highest terrace, T-3, stands about 16 m above the river bed and is underlain by a thick fill of unknown age. The intermediate surface, T-2, is a filltop terrace that stands 13 m above the river bed; it is composed of 3 separate fills. The oldest fill consists of crossbedded sand and gravel of unknown age. Inset against this fill is a finer-textured fill that contained a paleosol yielding a radiocarbon age of 1,940±70 yrs B.P. According to May, the youngest fill overlaps both the two older fills. The lowest terrace in the study area, T-1, is a fillstrath terrace. Interestingly, a radiocarbon age of 5,090±60 yrs B.P. was obtained from a paleosol less than 2 m below the surface, suggesting that much younger fill buried early-Holocene fill and was subsequently removed.

Additional information about alluvial fills in the Smoky Hill River basin has been obtained from other studies in the area. The westernmost site of radiocarbon-controlled alluvial information in the basin is the Koehn-Schneider Site on White Women Creek in Greeley County, where Mammoth bones found in basal fill produced a radiocarbon age of 11,050±180 yrs B.P. Three overlying paleosols yielded radiocarbon ages of 11,170±170, 9,800±120, and 7,460±130, respectively (Johnson et al. 1990). At the 12 Mile Creek Site in Logan County, radiocarbon ages of 10,435±260 and 10,245±335 yrs B.P. (apatite and gelatin fractions, resp.) were obtained from a Bison

Antiquus limb bone found in gully fill (Rogers and Martin 1984). On Deer Creek, a tributary of the North Fork Solomon River, two buried paleosols located within a short reach were dated at around 4,100 and 1,900 yrs B.P. (Johnson 1981).

Republican River Basin in southern Nebraska and northcentral Kansas

Terraces and alluvial fills have been the focus of extensive study in the Republican River basin. A brief description of terraces in the basin was conducted by Condra (1907) who recognized three terraces: a "low bench, intermediate terrace and high terrace" with surfaces 2-4, 7.5-12, and 18-24 m above the "first bottom," respectively.

The earliest, extensive research in the Republican River basin was conducted by Schultz and others (1948) and Schultz and Frankfourter (1948) in Lime Creek, a tributary of Medicine Creek. In these early studyies, which lacked absolute time control, five terraces were recognized in the valley; they were designated, from lowest to highest, RT-0 to RT-4.

More detailed research in the Lime Creek basin was conducted by Schultz (1951). In this study, which eliminated the letter "R" from the terrace nomenclature, an alluvial chronology was proposed that was based, to a large degree, on radiocarbon ages from the upper part of T-2 fill in the Lime Creek and Medicine Creek valleys (Davis and Schultz 1952). Radiocarbon ages of $10,493\pm1,500$, $9,880\pm670$, and $9,167\pm600$ yrs B.P. were obtained from charcoal in the upper part of T-2 fill. In nearby Louisa Creek, a tributary of the Republican River, radiocarbon ages were obtained on two paleosols; a paleosol

buried in T-2 fill yielded ages of 7,809±400 and 7,426±600 yrs B.P. and a paleosol in T-1 alluvium 4,150±350 yrs B.P. (Libby 1955)

On the basis of absolute ages obtained from the upper part of T-2 fill, relative ages were assigned to the other terraces in the basin. Schultz and others (1951) argued that T-4 fill, which is composed of a "complex" of deposits, ranges from late Kansas to early Illinoian in age. Similarly, they suggested that T-3 fill began to accumulate during Iowan (Wisconsin-I) time, but was mostly Tazweillian (Wisconsin-II) in age. T-2 fill is composed of two units: one a sandy and gravelly deposit at the base designated T-2B, and another, which is finer grained at the top designated T-2A. According to Schultz and others (1951), T-2B fill accumulated during very late Tazwellian time through the period of the Cary glaciation (Wisconsin-III). The radiocarbon ages obtained from T-2A fill mentioned above were correlated with Mankato (Wisconsin-IV) time. The fill beneath the T-1 terrace was assigned an age of Cochrane (Wisconsin-V) time.

A reinvestigation of alluvial terraces and fills in the Medicine Creek basin was conducted by Brice (1966). In this study, three terraces were recognized and assigned formal names: Wellfleet, Stockville, and Mousel; Brice (1966) argued they can be correlated to the surfaces proposed by Schultz and others (1951) in the Lime Creek valley. The highest terrace in the Medicine Creek basin, the Wellfleet Terrace, stands 38 m above the floodplain or "valley flat" and correlates with the T-3 terrace in the Lime Creek valley; it is underlain by Peoria Loess and older Pleistocene deposits (Brice 1966). The Stockville Terrace, which is the intermediate terrace in

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the basin, correlates to the T-2 terrace of Schultz and others (1951) and is found 4.5-6 m above the valley flat. A radiocarbon age of 2,202±200 yrs B.P was obtained from charcoal near the base of Mousel fill. According to Brice (1966), the floodplain/valley flat consists of 4 separate fills that are inset against each other. He reported that charcoal recovered from a depth of 2.3 m below the surface yielded a radiocarbon age of 420±160 yrs B.P.

Based on the combined results from earlier work in the Lime Creek basin and his research, Brice (1966) reconstructed a Holocene history of landscape evolution for the Medicine Creek basin. He proposed that the Wellfleet Terrace formed following incision due to climatic warming about 11,000 yrs B.P. Between 11,000 and 5,000 yrs B.P., aggradation of the Stockville fill occurred, which was incised around 5,000 yrs B.P. during the Altithermal. Accumulation of the Mousel Terrace fill began about 4,000 yrs B.P. and continued to 1,000 yrs B.P., when incision began anew, forming the Mousel Terrace. Deposits that have formed the floodplain have accumulated since 1,000 yrs B.P.

Further work in the Lime Creek basin has been conducted recently by May (personal communication) in association with archeological investigations at Harry Strunk Reservoir. At the Lime Creek Site (25FT41), radiocarbon ages on total humates of 7,980±1,000, 9,120±510, 10,040±270, and 10,090±450 yrs B.P. were obtained from a core at depths of about 14.5, 15.0, 15.5, and 16.5 m, respectively, beneath the Stockville Terrace. A second site, informally named "Cutbank #1", yielded ages on humin fractions of 7,600±270 (A horizon), 10,500±260 (A horizon), and 10,850±670 yrs B.P.

Recent research along the Republican River near Harlan County Reservoir has yielded additional information about the Holocene alluvial chronology in southern Nebraska. According to Martin (1990), alluviation in the main valley occurred under progressively drier conditions between 10,200 and 4,500 yrs B.P., when aggradation was punctuated by an episode of soil formation, as the climate became more mesic. Between approximately 4,500 and 3,700 yrs B.P., the Republican River entrenched about 10 m, due largely to a change in flood magnitude and frequency.

During the late Holocene, a general pattern of alluviation, punctuated by episodes of soil formation (i.e., floodplain stability) is evident between 3,700 and 1,200 yrs B.P. Martin (1990) recognized three periods of soil formation in late-Holocene fill that terminated at about 3,050, 2,800, and 2,000 yrs B.P. He suggested that the pattern of soil formation following rapid alluviation was likely due to changing flood magnitude and frequency. After 1,200 yrs B.P., the Republican River entrenched about 7 m, followed by gradual floodplain accretion to the present.

Summary

Evidence in the form of terraces, floodplains, and alluvial fills indicates that streams in the central United States and the Kansas River system experienced several cycles of alluviation and erosion, punctuated by episodes of floodplain stability, during the late Quaternary. Ongoing debate focuses on the cause of the adjustments in fluvial behavior that created these landforms. Several studies favor climate variability, specifically the frequency

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of large floods, as the primary cause of erosion, stability, and deposition in river systems (e.g., Knox 1972, 1976, 1983, 1985; Burkham 1972; Leopold 1976; Brackenridge 1980; Wendland 1982; Hereford 1984; Johnson and Martin 1987). In addition, some studies suggest that the indirect effects of climate, as it controls vegetation and runoff, can be the dominant variable (e.g., Langbein and Schumm 1958; Knox 1972; Baker and Penteado-Orellana 1977).

Other research suggests that alluvial chronologies need not be dependent upon external forces such as climate. Laboratory experiments indicate that given constant precipitation, changes in the basin can still occur (e.g., Lewis 1944; Schumm and Parker 1973; Schumm et al. 1987). Specifically, long-term activity can cause a critical threshold to be surpassed. A gradual increase in gradient, for example, can ultimately result in oversteepening of the valley floor and entrenchment. Schumm and Parker (1973), Schumm (1977), and Schumm and others (1987) have demonstrated that multiple terrace levels, in fact, can result from a single change in baselevel. Schumm (1977) argued that the complexity of fluvial behavior, regardless of the cause, indicates a "complex response" to ever changing variables.

A number of studies have examined late-Quaternary terraces and alluvial fills in the Kansas River basin. Results indicate that cycles of erosion, deposition, and stability are apparent in the basin during the late Quaternary. In the Kansas River valley in eastern Kansas, for example, a total of four terraces have been recognized (e.g., McCrae 1954; Elks 1979; Johnson 1985; Johnson and Martin 1987; Johnson and Logan 1990). Some synchrony in fluvial

behavior throughout the basin is evident, but is equally clear that all parts of the system did not behave the same during contemporanous periods of time. Specifically, it appears that small tributaries and large streams behaved differently during the late Quaternary. Episodes of floodplain stability, for example, have been recognized in large basins that do not exist in the smaller tributaries (Johnson and Martin 1987). Such variability may have resulted from external forces (e.g., climatic fluctuations) or internal adjustments (e.g., changes in valley gradient).

CHAPTER III
STUDY AREA

Because the Wolf Creek basin is a relatively small basin that contains a full range of late-Quaternary alluvial deposits and occupies a position in the central Kansas River system, (Fig. 1:1) it is an ideal place to compare late-Quaternary fluvial behavior in a trunk stream and its small tributaries. The basin is situated in central Kansas within the Smoky Hills physiographic province (Jantz and others 1982), and drains portions of Russell, Osborne, and Lincoln Counties. The trunk stream of Wolf Creek flows by Luray and through Lucas to its confluence with the Saline River about 3 km above Sylvan Grove and 2 km below Wilson Dam. The major tributaries in the system are the West Fork Wolf Creek, Coon Creek, and the East Fork Wolf Creek (Fig. 3:1).

Bedrock Geology

Upper Cretaceous rocks dominate the geology of the study area (Bass and Rubey 1925; Hattin 1978), although some unconsolidated Pleistocene loess (Fleming 1972; Jantz et al. 1982) and upland gravel deposits (Bass and Rubey 1925; Jantz et al. 1982) have been recognized in the basin (Fig. 3:2). The rocks dip north-northeastward at approximately 3.5m/km. The Wolf Creek valley is assymetrical in cross section, with the southern valley wall much steeper than the northern one (Bass and Rubey 1925). Hence, tributaries in the southern portion of the basin are more numerous, have steeper gradients, and are much shorter than in the northern part of the basin.

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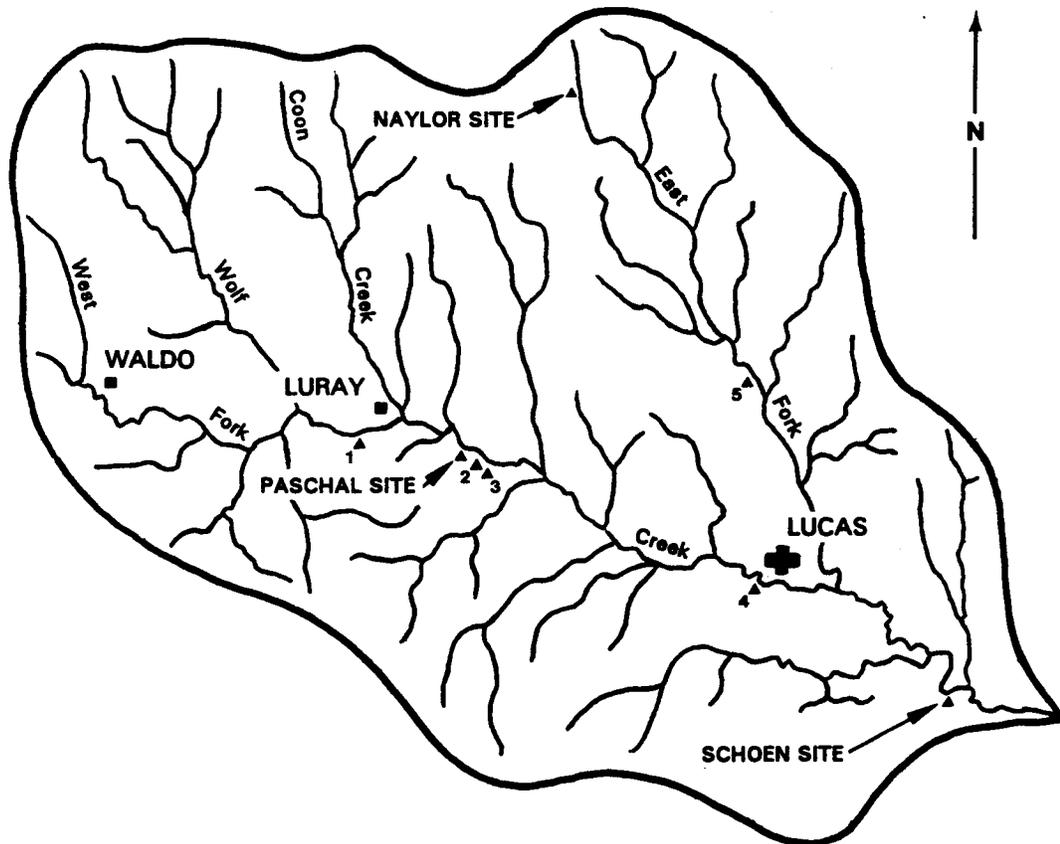
Figure 3:1 Map of the Wolf Creek basin showing towns, tributaries, and study sites. Of the eight sites studied, the Paschal, Schoen, and Naylor Sites were selected for detailed analyses.
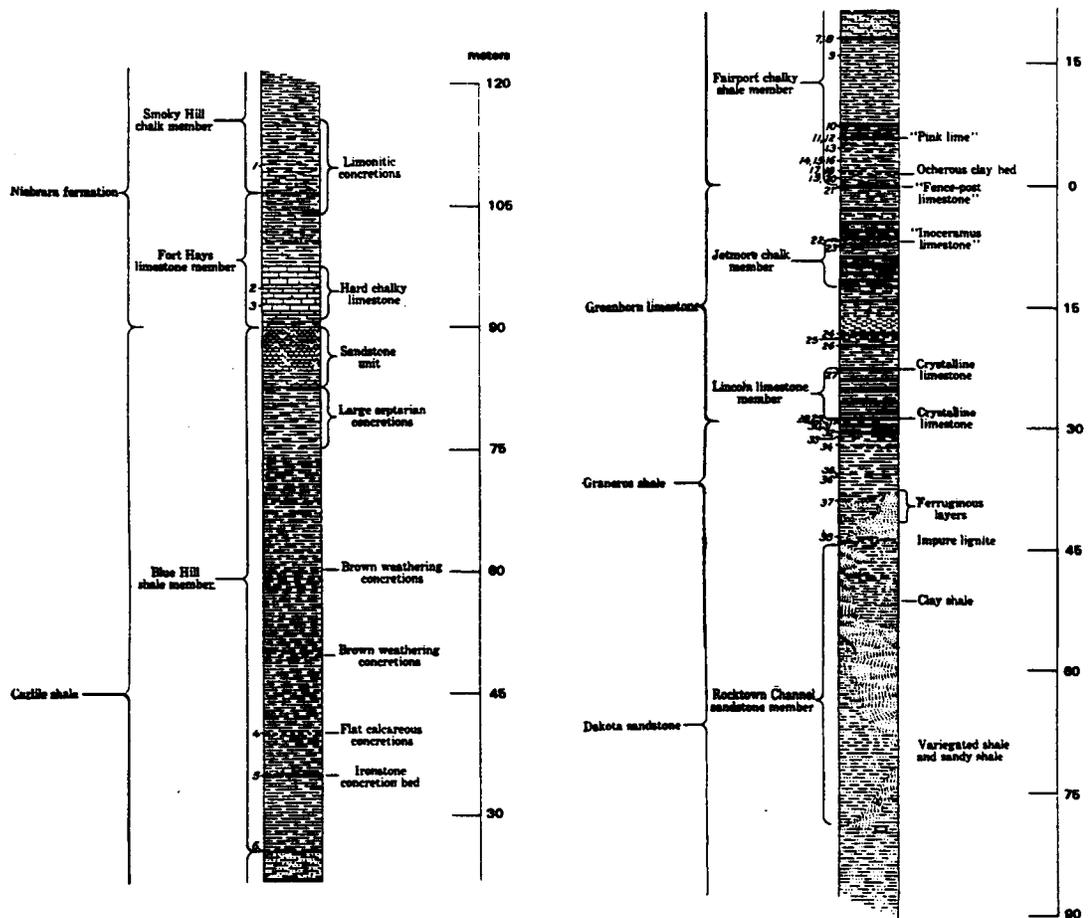
Figure 3:2 Geologic column of the Wolf Creek basin. Bedrock geology consists largely of Cretaceous-age marine sediments, although uncosolidated deposits of Pleistocene loess and gravel can be found in the upland divides of the drainage (from Bass and Rubey 1925).

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The oldest bedrock unit in the basin is the Dakota Formation, which crops out below Luray. The Dakota Formation, of which about 48 m is exposed in the study area, consists largely of non-marine, variegated mudstones and light yellowish-brown to dark brown channel sandstones that accumulated in an environmentally diverse, deltaic setting. Six major facies have been recognized in the Dakota Formation, with the upper 9.2-12.2 m representing a transition from non-marine to shallow marine deposits at the beginning of the Graneros transgression during the Greenhorn cyclothem (Hattin 1978).

Stratigraphically above the Dakota Formation is the Graneros Shale, which is about 12 m thick and crops out as a continuous narrow band in the study area (Bass and Rubey 1925). According to Hattin (1978), the Dakota-Graneros contact reflects intertonguing of adjacent parts of the two units, suggesting replacement of non-marine and marginal marine environments by broadly uniform, open-marine conditions.

An unconformity separates the Graneros Shale from the overlying Greenhorn Limestone Formation (Hattin 1978), which is the most conspicuous formation in the Wolf Creek basin, forming prominent benches along the valley walls (Bass and Rubey 1925). The Greenhorn Limestone consists of about 30 m of interbedded hard chalk and chalky marl deposits (Bass and Rubey 1925) that appear identical on casual observation (Muilenburg and Swineford 1975). In general, most exposures show thin, rather grayish-orange to yellowish-gray, laminated beds of alternating, soft shaly chalk and slightly more resistant chalk and chalky limestone (Muilenburg and Swineford 1975). The Greenhorn Limestone has been subdivided into four members, from

bottom to top, the Lincoln Limestone, Hartland Shale, Jetmore Chalk, and Pfeifer Shale (Muilenburg and Swineford 1975; Hattin 1978).

The uppermost bed of the Pfeifer Shale in the Greenhorn Limestone is the well-known "Fencepost Limestone," a .2-.25-m-thick bed of resistant chalk that was quarried extensively during European settlement. The lack of joints in this bed, along with its relative softness upon exposure, made it a favorite source for fenceposts and construction stone. The Fencepost Limestone marks the boundary between the Greenhorn Limestone Formation and the overlying Carlile Shale Formation.

The Carlile Shale Formation is an approximately 100-m-thick bed of argilliceous and chalky shale, expressed as benched slopes and isolated hills in the study area. Two members, the Fairport Chalky Shale, and Blue Hill Shale, have been recognized in the Carlile Shale Formation. The Fairport Chalky Shale is about 26 m thick in the study area, consisting of olive-gray to dark olive-gray chalky marl and thin beds of chalk (Bass and Rubey 1925). The Blue Hill Shale overlies the Fairport Chalky Shale along the northern divide of the basin and consists of noncalcareous dark gray silty shale that contains septarians concretions.

The youngest Cretaceous rock in the study area is the Fort Hays Limestone member of the Niobrara Chalk Formation, which crops out along the northern divide of the study area. An unconformity separates the Fort Hays from the underlying Carlile Shale Formation, suggesting to Hattin (1978) that near-shore erosional conditions prevailed prior to deepening seas and Fort Hays deposition. The Fort

Hays consists of thick to very thick beds of resistant chalky limestone that is light gray to medium gray where fresh and yellowish-gray, pale grayish-orange, or nearly white when weathered (Bass and Rubey 1925).

Rock units younger than Cretaceous in the Wolf Creek basin include unconsolidated deposits of Pleistocene loess (Fleming 1972; Jantz et al. 1982) and upland gravel beds (Bass and Rubey 1925; Jantz et al. 1982). Bass and Rubey (1925) recognized an upper and lower gravel deposit in northern Russell County. The lower gravel bed lies about 15 m above stream level, consisting of a 1 m thck deposit that contains steeply cross-bedded pink orthoclasts and chalk fragments well-cemented with lime. The upper gravel bed is lithologically similar to the lower one, but contains a few lenticular beds of sandy clay about .3 m thick; it lies about 20 m above stream level.

Pleistocene loess deposits are generally confined to the broad uplands in the northern portion of the basin (Fleming 1972; Jantz et al. 1982). Although the thickness and absolute age of these deposits is unknown, they may include the Loveland Loess, Gilman Canyon Formatin, Peoria Loess, and Bignell Loess recognized elsewhere in the region (e.g., Johnson 1990, Martin 1990).

Soils

Soils within the Wolf Creek basin are classified as mollisols, entisols, or inceptisols, and have been divided into upland, footslope, and floodplain soils. The following divisions have been made according to soil position in the landscape and association. Upland and footslope soils have formed in loess, chalky shale, shale,

chalky limestone, soft limestone, sandstone, and old alluvium. Soils formed in loess include the Crete-Harney-Nuckolls soil association, which are loamy in texture, well-drained, and are found in nearly level to moderately sloping and strongly sloping topography.

Moderately sloping to strongly sloping soils that have formed in shale residuum are soils of the Bogue-Corinth-Edalgo association. These soils, which have silty-clay subsoils, are generally moderately well-drained. Loamy, excessively drained soils that have formed in chalky limestone, soft limestone, shale, or chalky shale are included in the Armo-Nibson-Wakeen soil association, which occupies moderately sloping to steeply sloping positions on the landscape.

Excessively to moderately well-drained soils formed in sandstone and sandy shale residuum on moderately sloping to steep slopes are included in the Hedville-Lancaster soil associaton. Loamy soils underlain by sandy and gravelly sediments are contained in the excessively drained Dorrance-Wells soil association.

Floodplain soils formed in alluvial deposits of floodplains and stream terraces. The Detroit-Humbarger-Roxbury soil association, which is found on terraces anbd floodplains along Wolf Creek, is moderately permeable, calcareous, deep, and well-drained. Humbarger soils have more sand in their subsoils than do Detroit and Roxbury soils. Soils found on floodplains and terraces in the tributaries of Wolf Creek are components of the Eltree-Inavele-Roxbury soil association. Eltree soils are moderately permeable soils that have formed in silty colluvial or alluvial sediments. Inavale soils formed in sandy alluvium (Fleming 1972; Jantz et al. 1982).

Climate

The climate of the study area is strongly continental, characterized by large daily and annual variations in temperature. Two stations close to the Wolf Creek basin (Russell and Lincoln, Ks.) have maintained temperature and precipitation records since the late 1800s. Winter usually lasts from December to February with an average temperature of 0° C. The summer growing season is from April to September, during which time the average high temperature is 25.4° C. Annual precipitation reflects that the study area is generally west of the flow of moisture-laden air from the Gulf of Mexico and east of the strong rainshadow effects of the Rocky Mountains. Total annual precipitation is 67.31 cm. Of this 51.44 cm, or 76 percent falls during the growing season. Most precipitation comes from infrequent, but severe convective storms in the late-spring and early summer (Jantz et al. 1982; Barker and Hamilton 1985). Table 3:1 summarizes monthly temperature and precipitation values for the Lincoln station, just east of the study area.

Table 3:1 Temperature and Precipitation at Lincoln, Ks.

| | Temperature (C°) | | Precipitation |
	Mean Daily Max.	Mean Daily Min.	(mm)
J	11.5	-8.8	13.5
F	13.0	-6.0	21.1
M	15.3	-1.8	35.8
A	19.0	11.4	59.2
M	21.5	14.3	96.3
J	24.3	17.0	109.2
J	25.6	18.4	88.4
A	25.5	18.1	76.5
S	23.2	15.4	88.9
O	20.2	12.2	50.8
N	15.6	-1.3	20.1
D	12.3	-5.6	19.8

Source: Barker and Hamilton 1985:68.

Vegetation

Vegetation in the Wolf Creek basin can be separated into that which is natural to the area and that which has been imported by European settlers (Kuchler 1974). Land-use data for Russell County serve as an estimate of this division between natural and cultivated vegetation. In 1982, 120,810 hectares, or 52 percent of the total land area in Russell County, was under cultivation. 50,740 hectares, or 42 percent of the total land area in Russell County, was in pasture; the remaining 6 percent of the land was regarded as unuseable for agricultural purposes (Jantz et al. 1982). Pasture in the Wolf Creek basin is generally located on the moderately to strongly sloping uplands, while cultivated land is found along the valley of Wolf Creek, and the level uplands.

Grassland, in the form of tall and mixed-grass prairie, is the dominant natural vegetation of the study area, although wooded areas are found along Wolf Creek and the upland drainageways. Common prairie grasses include big bluestem (Andropogon gerardi), little bluestem (A. scoparius), sideoats gramma (Bouteloua curtipendula), indiangrass (Sorghastrum nutans), switchgrass (Pancacum virgatum), western wheatgrass (Agropyron smithii), blue gramma (A. hallii), prairie sandreed (Calamovilfa longifolia), and Canada wild-rye (Elymus canadensis).

The trees along Wolf Creek and smaller drainageways commonly are eastern cottonwood (Populus deltoides), green ash (Fraxinus pennsylvanica), common hackberry (Celtis occidentalis), black willow (Salix nigra), boxelder (Picea negundo), slippery elm (Ulmus rubra), American elm (U. americana), black locust (Robinia pseudo-acacia),

and American plum (Prunus americana) (Jantz et al. 1982).

Cultural History

Prior to European settlement, the study area was intermittantly inhabited by nomadic bands of Native American Sioux, Pawnee, Cheyenne, Arapahoe, Comanche and Kiowa. By the late 1860s, homesteaders from the eastern United States and Germany, Czechoslovakia, and the Scandinavian countries began to settle the area during the large westward migration. Generally, they were lured by the Homestead Act of 1862 and promotions that gave glowing accounts of the area's natural resources and assests. Competition with cattlemen from Texas for land was keen during the early days of settlement, as ranchers coveted the grassland as free range.

The development of the Kansas Union Pacific Railroad, which runs through the Wolf Creek valley, was especially influential in the early European history of the study area; it was unique in that the railroad preceded much of settlement. Once established, the railroad encouraged agriculturalists, industrialists, and town builders to buy tracts along the line through low land costs and freight rates. In addition, both federal and state governments offered generous land-grants and low-cost loans to potential settlers. Intensive promotion in the eastern United States and the European countries continued to attract settlers during this time. The realities of life on the Great Plains, however, were not what many people had envisioned, consequently many returned home (Muilenburg and Swineford 1975).

By the end of the 1880s the area was essentially settled.

Russell County was organized in 1872 (Jantz et al. 1982). Post-offices for Luray and Lucas, the principal towns in the study area, were established in 1872 and 1888, respectively (Baughman 1961). According to the 1980 census (World Book Encyclopedia 1988), the population of Lucas is 524 and Luray 295. Waldo, the smallest town in the basin, has a population of 75 and is decreasing. In keeping with the tradition of the area, the economy of the basin is based on farming, ranching, and related enterprises.

CHAPTER IV
METHODOLOGY

As a result of the large number of alluvial geomorphic studies in the central United States the past ten years, a generally accepted methodology has evolved that includes a variety of field and laboratory procedures. The following discussion is a summary of the procedures that were used in this study.

Field Procedures

Early in the project, a number of sources were acquired that yielded baseline information about the study area: U.S. Geological Survey 7.5- minute topographic maps, soils maps, aerial photography, and other relevant published and unpublished material. During this early stage, topographic maps, in conjunction with aerial photography, were analyzed in an effort to identify potential study sites and the spatial limits of significant geomorphic features (e.g., terraces. floodplains).

Once the topographic maps and aerial photography were analyzed, an extensive field survey was conducted to assemble an inventory of study sites, including terraces, cut-bank exposures, and gravel quarries. General stratigraphic descriptions were compiled for all cut-bank sites, which permitted stratigraphic markers (e.g., sedimentary units, paleosols) to be established in the valley. Stratigraphic units recognized in this study are similar to allostratigraphic units of the North American Stratigraphic Code, which delineates stratified bodies of sedimentary rock or sediment by boundaries that are laterally traceable disconformities (North

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American Commission on Stratigraphic Nomenclature 1983). A bipartite stratigraphic nomenclature was used in this study. Boundaries of stratigraphic units were marked by the upper boundary of surface soils or buried soils that had morphologically well-expressed horizons. Roman numerals designate the stratigraphic units, beginning with I at the top of the section.

Soils exposed in the stratigraphic profile were described using standard U.S.D.A. terminology and procedures (Soil Survey Staff 1987). Each soil horizon was described in terms of its texture, Munsell matrix color and mottling, structure, and boundaries. When present, root channels, krotovina, clay films, and matrix carbonate were also described.

Study sites that clearly illustrated the valley fills in the basin were selected for detailed description and sampling. Cut-bank exposures were cleaned and sampled by hand, but, in places, cores were retrieved with the Giddings Hydraulic Probe.

The fill at each detailed study site was sampled at close intervals for chemical and sedimentological analyses. Strata within the alluvial units were systematically sampled at 10 cm intervals (Krumbein and Graybill 1965). Significant sedimentary features (e.g, silt drapes, laminae) were sampled independently or were otherwise documented to help reconstruct depositional histories. In order to determine the onset and termination of pedogenesis in paleosols, bulk samples (approximately 2,000 gm) were collected from the lower and upper 5 cm of buried A horizons for radiocarbon age determinations.

Laboratory Procedures

A variety of laboratory procedures exists for determination of the chemical and physical nature of alluvial sediments. Chemical testing of close-interval samples collected included pH, organic carbon, and calcium carbonate analysis. Soil pH was determined with the glass electrode using a 1:1 soil-water suspension and percent organic carbon by the "loss-on-ignition" method (Dean 1974). Percent calcium carbonate was calculated by the "Chittick" method and stages of carbonate morphology (Table 4:1) were defined according to the classification scheme of Birkeland (1984).

The pipette method (Day 1965) was used for sedimentological analysis of close-interval samples; the distribution of particle sizes was determined to corroborate and refine field observations of texture. A 25-gm subsample was weighed to the nearest 0.01 gm. All samples were treated with 1 N HCL to remove calcium carbonate, and were then thoroughly rinsed by centrifuging. The samples were then treated with 5-15 ml of hydrogen peroxide to digest organic matter. All samples were dispersed with 125 ml of sodium hexametaphosphate and placed on a shaker overnight. The sand fraction (> than 62.5 microns) was then removed from the silt and clay fractions by wet sieving, and oven dried. Silt and clay (<62.5 microns) that passed through all sieves was returned to the suspension in the 1000 ml cylinder. Pipette readings were then taken at prescribed times, depending upon room temperature, to determine the proportion of fine, medium, and coarse clay and silt. The sand fraction was dry sieved in a sonic sifter at 0.25 phi intervals, and the weight of each interval was recorded.

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Table 4:1. Stages of carbonate morphology for nongravelly sediment.

Stage	Properties
I	Few filaments or coatings on sand grains; <10% calcium carbonate
I+	Filaments are common
II	Few to common nodules; matrix between nodules is slightly whitened by carbonate (15-50% by area), and the latter occurs as veinlets and as filaments; some matrix can be noncalcareous; about 10-15% calcium carbonate in whole sample, 15-75% in nodules.
II+	Common nodules; 50-90% of matrix is whitened; about 15% calcium carbonate in whole sample.
III	Many nodules, and carbonate coats so many grains that over 90% of horizon is white; carbonate-rich layers are more common in upper part; about 20% calcium carbonate.
III+	Most grains coated with carbonate; most pores plugged; >40% calcium carbonate.
IV	Upper part of K horizon is nearly pure cemented calcium carbonate (75-90% calcium carbonate) and has a weak platy structure due to the weakly expressed laminar depositional layers of carbonate; the rest of the horizon is plugged with carbonate (50-75% calcium carbonate).
V	Laminar layer and platy structure are strongly expressed; incipient brecciation and pisolith (thin, multiple layers of carbonate surrounding particles) formation.
VI	Brecciation and recementation, as well as pisoliths, are common.

Source: From Birkeland (1984: Table A-4).

All particle size results were converted to the logarithmic phi scale using software developed by Prante (1990). This program constructs a cumulative frequency curve for the particle distribution, and then reads the desired phi value from it. Using this technique, a range of percentile phi values was calculated for each sample; the fifth, fiftieth, and ninety-fifth percintile phi values were used in this study. The fifth percentile represents the coarse fraction of the sample, the fiftieth percentile the median value of the sample, and the ninety-fifth percentile the fine fraction of the sample. The degree of dispersion of sediment sizes (i.e., sorting) around the mean phi values was also calculated using parameters devised by Folk and Ward (1957).

Ten bulk soil samples were submitted to the University of Texas Radiocarbon Laboratory for radiocarbon age determinations. Prior to submission, all samples were dried, pulverized, sieved, and cleaned. At the radiocarbon laboratory, the samples were subjected to a variety of procedures that ultimately produced ages that were corrected for carbon 13 content.

CHAPTER V
RESULTS AND DISCUSSION

Introduction

This chapter summarizes the late-Quaternary alluvial stratigraphy and chronology in the Wolf Creek basin, and provides interpretations of that record. First, geomorphic and stratigraphic data from the Wolf Creek basin are described. Second, stratigraphic evidence and radiocarbon ages are used to construct a late-Quaternary alluvial chronology for the Wolf Creek basin. Third, the late-Quaternary alluvial chronology of the Wolf Creek basin is compared with alluvial chronologies from other streams in the Kansas River system. Finally, the possible causes of late-Quaternary alluviation, erosion, and landscape stability in the Wolf Creek basin are considered.

Terraces and Valley Fills

At least four terraces and four valley fills are present in the Wolf Creek basin. The T-4 terrace is underlain by Fill I and has been modified considerably by erosion and the T-3 terrace is a strath terrace. The T-2 and T-1 complex terraces appear to be largely filltop terraces (the uppermost terrace in the T-1 complex is a fill-strath terrace and the other T-1 complex terraces may have been eroded periodically). The T-2 terrace is underlain by Fills II and III and the T-1 complex is underlain by Fill IV. The floodplain (T-0) is poorly developed, consisting of narrow, thin deposits of post-settlement alluvium that cap coarse gravel adjacent to the stream. Figure 5:1 illustrates the generalized stratigraphic relationship
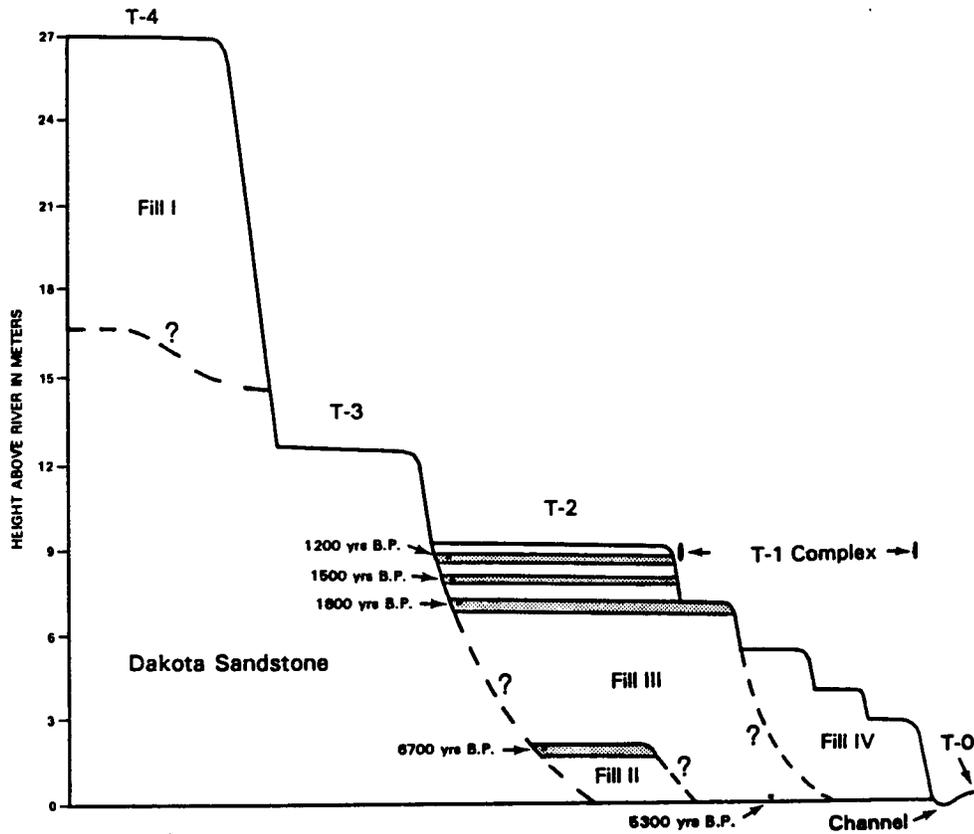
Figure 5:1 Cross-section of the Wolf Creek valley that shows
the relationship of the T-4, T-3, T-2, and T-1
complex and floodplain with the alluvial fills in
the basin. The T-4 terrace is underlain by Fill I;
the T-3 is a strath terrace on Dakota Sandstone; the
T-2 terrace is underlain by both Fills II and III
and the T-1 terrace complex and floodplain is
underlain by Fill IV.

between these terraces and alluvial fills in a valley cross-section.

T-4 Terrace

The T-4 terrace is unpaired and varies in height between about 27 and 18 m above the floodplain and is underlain by gravelly fill (Fill I) that was described by Bass and Rubey (1925) and Berry (1952). The best exposure of T-4 fill occurs in a gravel pit located in SW1/4, NE1/4, Section 7, T12S, R10W (Figure 5:2). Within this exposure, gravels and cobbles can be found in a variety of bedforms in conjunction with up to 1 m thick lenses of coarse silt. Although materials suitable for radiocarbon age determination were not recovered, the position of the terrace in the landscape suggests that the gravel is probably pre-Wisconsin in age. Berry (1952) concluded that similar gravel deposits in Lincoln County belonged to the Meade Formation and therefore, according to the classic chronology, were late Kansan or Yarmouthian in age.

T-3 Terrace

Along the valley margins of Wolf Creek is the T-3 terrace, a strath terrace on Dakota Sandstone (Rocktown Channel Sandstone Member?) that is about 5 to 6 m above the modern floodplain (Fig. 5:3). Where the T-3 terrace is most extensive (SE1/4, SE1/4, Sect. 25, T11S, R12W), the surface is capped by up to 7 m of loess. Although the absolute age of this surface is unknown, it was probably created when Wolf Creek entrenched following the deposition of T-4 fill.

Figure 5:2 View of the T-4 terrace, underlain by Fill I, at the
            Schoen Gravel Pit. Fill I consists of gravels, found
            in a variety of bedforms, that are probably pre-
            Wisconsin in age.

- T-3 Terrace
- Dakota Sandstone
- T-2 Terrace
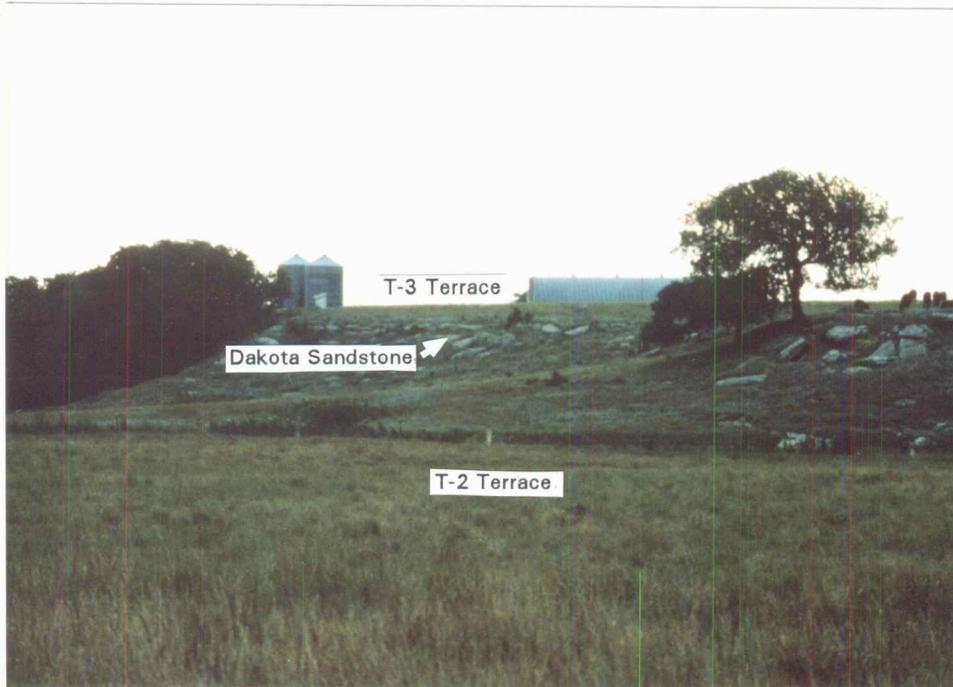
Figure 5:3 View of the T-3 terrace. The terrace is a strath
terrace on Dakota Sandstone along the valley margins
that was created as Wolf Creek entrenched following
deposition of Fill I. At this locality, the T-3
terrace is capped by approximately 6 m of loess.

T-2 Terrace

The dominant alluvial surface in the Wolf Creek basin is the T-2 terrace, a paired filltop terrace that stands between 3 and 5 m above the modern floodplain. In most portions of the basin, the T-2 terrace occupies about 95 percent of the valley floor. In a 3 km reach just below the town of Luray, however, up to 25 percent of the terrace and its underlying fill has been removed due to lateral erosion, leaving isolated fragments of the surface in the valley bottom (Figure 5:4).

The T-2 terrace is underlain by Fills II and III. Extensive foot survey indicates that the only fill exposed beneath the T-2 terrace in the main valley of Wolf Creek and the lower reaches of its major tributaries is Fill III, a generally silty late-Holocene alluvium with gravel at the base. Radiocarbon assays indicate that the bulk of fill III alluvium in this portion of the basin accumulated between about 5,300 and 1,000 yrs B.P. The stratigraphic record preserved in T-2 fill indicates that during the Holocene, periods of alluviation in the basin were punctuated by episodes of floodplain stability (i.e., soil formation). Seven sections where Fill III is clearly exposed were described in the main valley of Wolf Creek and the lower reaches of its tributaries. Figure 5:5 illustrates that significant features (e.g., sedimentary units, paleosols), can be morpho-stratigraphically traced throughout the lower reaches of the basin.

In the upper reaches of the basin, both Fills II and III are exposed in cutbanks beneath the T-2 terrace. In these exposures Fill II, which consists of 1.5 m of silty early to mid-Holocene
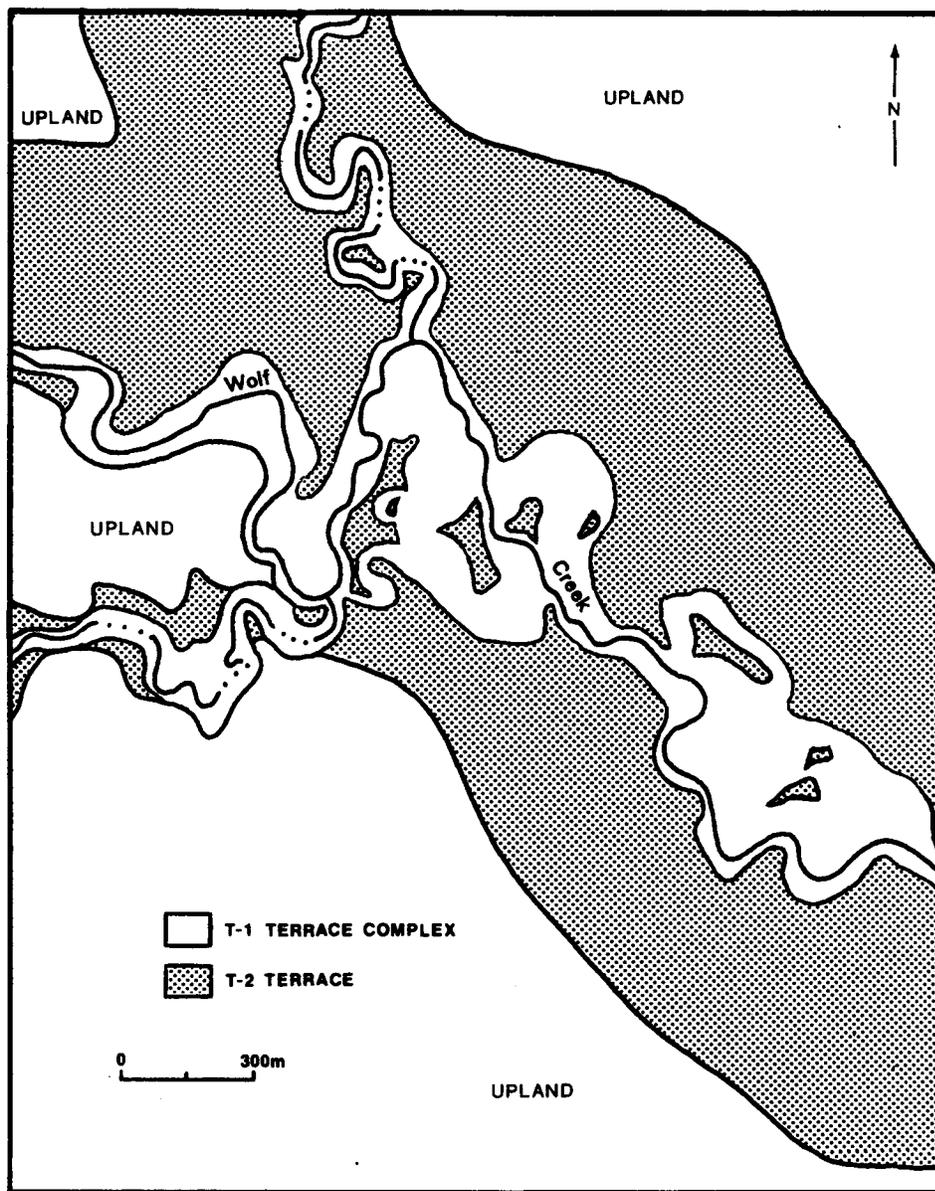
Figure 5:4 Extent of the T-2 terrace and T-1 terrace complex
1 to 2 km east of Luray. In this reach of the
stream, approximately 25 percent of T-2 fill has
been removed by lateral erosion in conjunction with
stream entrenchment, leaving isolated fragments of
the T-2 terrace.
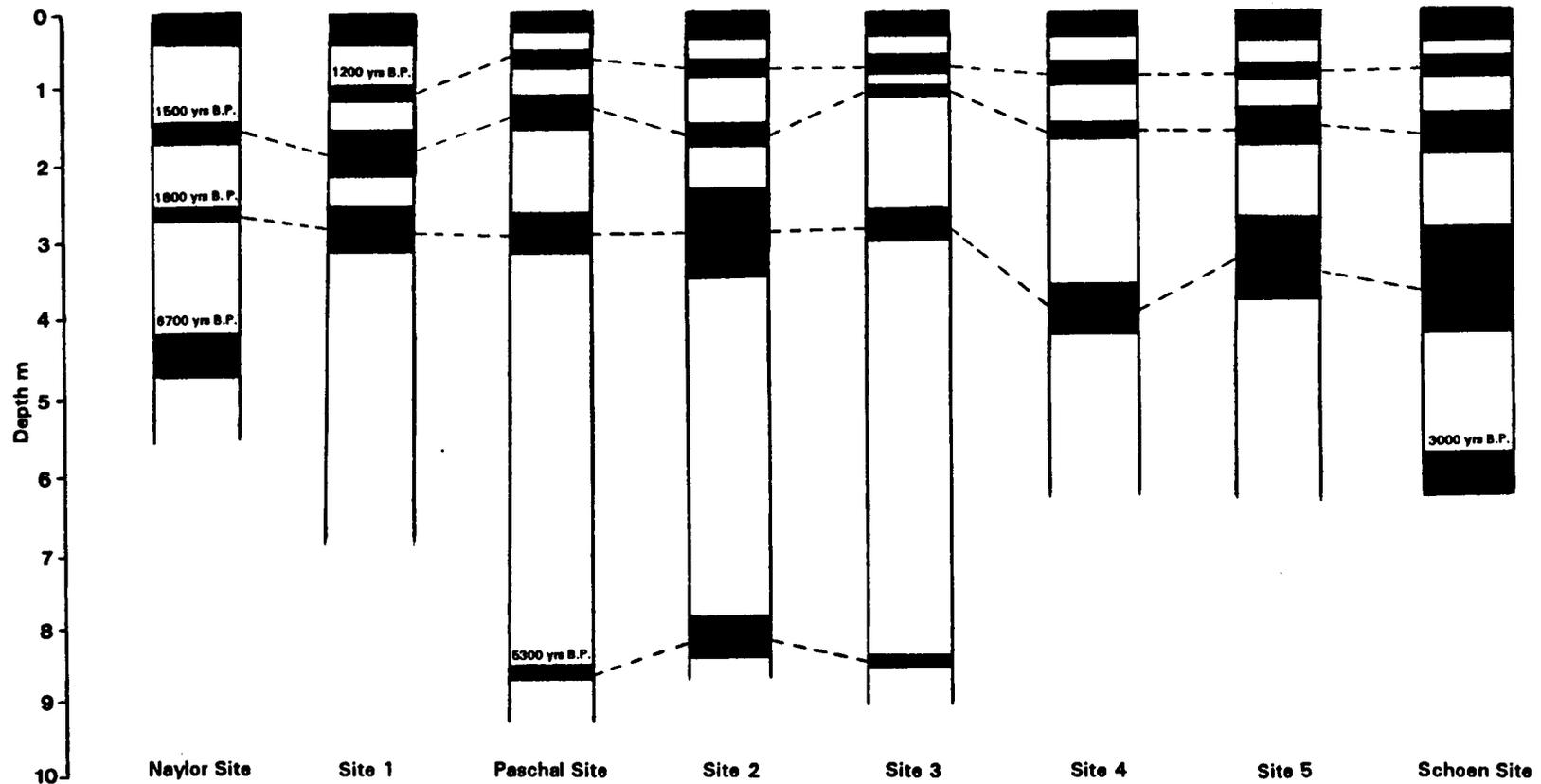
Figure 5:5   Location and ages of significant stratigraphic
markers (i.e., paleosols and organic-rich deposits)
beneath the T-2 terrace at sites illustrated in
Figure 3:1.   Results indicate that these markers can
be morpho-stratigraphically traced in cutbanks
throughout the basin. The numbered sites are
locations that were systematically described, while
the Naylor, Paschal, and Schoen Sites were described
and analyzed at close-intervals.

alluvium, is buried by about 4 m of late-Holocene (Fill III) alluvium. Figure 5:5 illustrates that in the upper reaches of the basin, one section, the Naylor Site, was described.

Of the eight cutbank sections that were described in this study, three were selected for detailed chemical, and sedimentological analyses at close intervals. Because the Paschal and Schoen Sites best represent Fill III in the upper and lower reaches of the trunk valley, respectively, they were selected for close-interval analyses. Similarly, the Naylor Site was described and sampled at close-intervals since this locality best expresses the relationship between Fills II and III in the upper reaches of the basin (Figs. 3:1; 5:5). The following is a discussion of the results obtained from these analyses.

Paschal Site. The Paschal Site, named after landowner William Paschal, is an east-facing cutbank exposure of late-Holocene alluvium (Fill III) located about 2 km east of Luray (Figs. 3:1 and 5:6). Approximately 9.5 m high, the section consists of deposits that are largely silt and silt loam in texture, and are generally poorly to very poorly sorted. Three sedimentary units and three paleosols are contained within Fill III at this locality (Fig. 5:7).

Unit III is the lowermost and thickest sedimentary unit in Fill III at the Paschal Site, extending from 9.51 to 2.66 m (Fig. 5:8). The fill in Unit III fines upward, as a 5.27-m-deposit of relatively fine-textured alluvium overlies thick gravel beds that are found between 9.51 and 7.93 m at the base of the exposure. Each gravel bed is separated by a layer of silt, indicating that floodplain formation
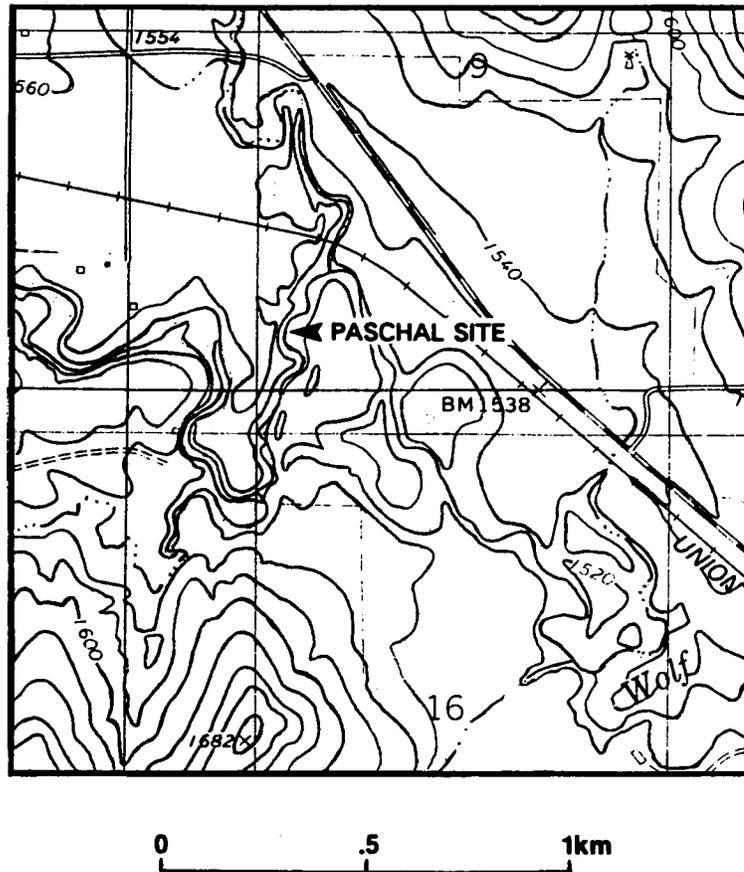
Figure 5:6   Topographic Map of the Paschal Site.   The Paschal
Site is an east-facing cutbank exposure in the SE
1/4, SW 1/4, Sect. 9, T11S, R12W, 6P.M., Luray
Quadrangle (1978).
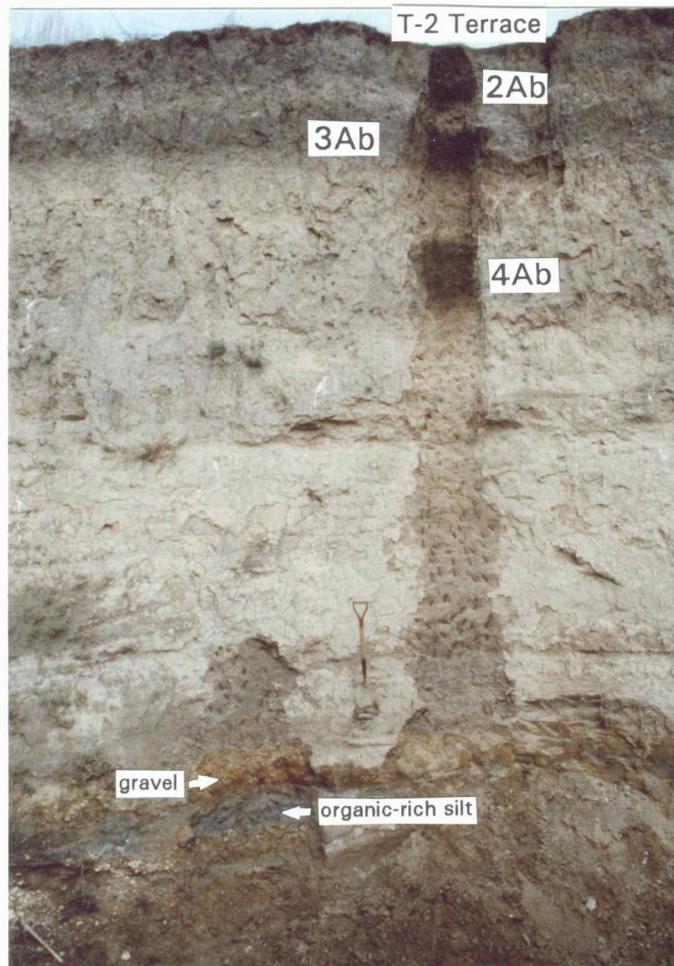
Figure 5:7   View of the Paschal Site that shows the T-2 terrace,
and about 9.5 m of late-Holocene (Fill III) fill.
The fill of the Paschal Site consists of three
sedimentary units, largely silt and silt loam in
texture, that are poorly sorted and well laminated.
At the base of the exposure are alternating layers
of coarse gravel and silt. Radiocarbon-age
determination on an organic-rich silt layer 8.6 m
below the surface yielded an age of 5,360+110 (Tx-
7078).   Radiocarbon-age determination on the
upper .05 m of the 4Ab, 3Ab, and 2Ab, yielded ages
of 1,830+70 (Tx-7077), 1,510+80 (Tx-7076), and
1,290+70 (Tx-7075)., respectively.

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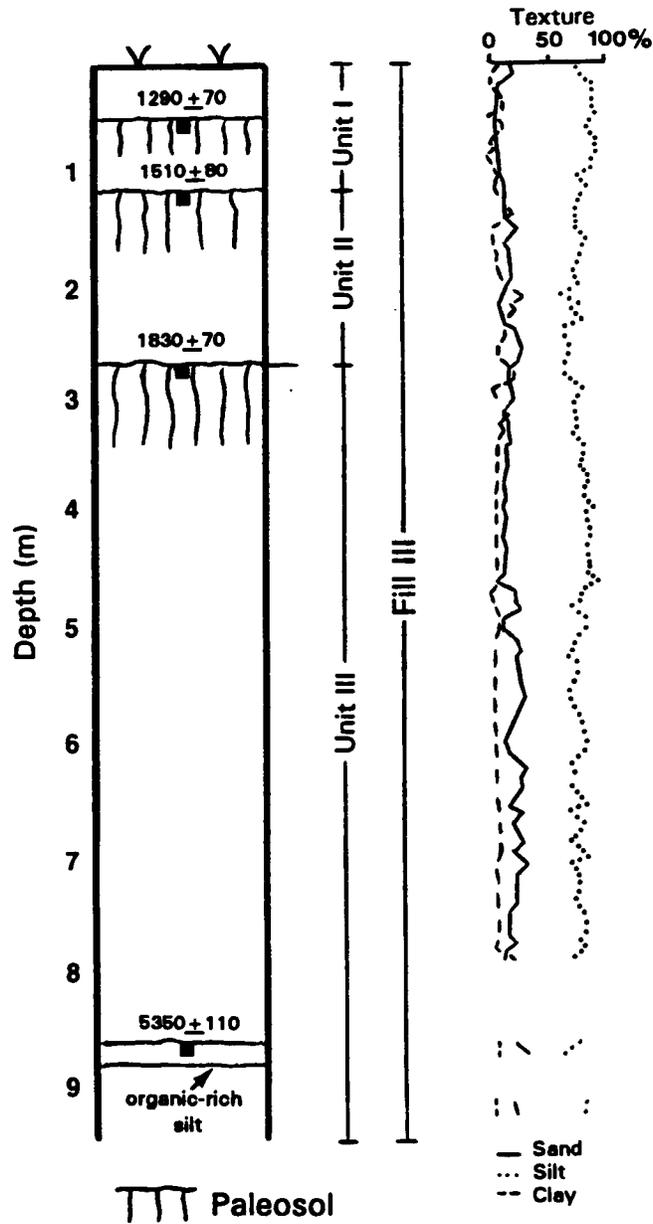
Figure 5:8   Stratigraphy and sediment texture of the Paschal
              Site. Three silty sedimentary units (Units III, II,
              and I) are recognized in Fill III. At the base of
              the exposure are alternating layers of coarse gravel
              and silt, indicating that floodplains 5,300 yrs B.P.
              were constructed by lateral accretion of point bar
              deposits and subsequent deposition of fine overbank
              sediments.

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during the late Holocene in Wolf Creek consisted of a combination of lateral accretion of coarse textured gravel followed by overbank deposition of fine sediments.

A representative sequence of deposits that combine the two processes mentioned above lies between 9.1 and 8.58 m. Between 9.1 and 8.76 m is a deposit of coarse fragments of limestone and sandstone that are up to .08 m in diameter. An 0.18-m-thick layer of silt loam overlies the coarse stratum. Figure 5:8 illustrates that the silty layer itself fines upward, as the lower portion of the stratum contains much more sand than the upper portion. This stratum is heavily gleyed (10YR4/1) and is relatively high in organic matter (2.3%); consequently, the upper .05 m (8.58-8.63 m) was sampled for radiocarbon age determination, and yielded an age of 5,350±110 yrs B.P. (Tx-7078).

Between 8.58 and 2.66, m the fill in Unit III consists of alternating deposits of poorly-sorted silt and silt loam textural classes that are generally well laminated, suggesting that accumulation of these deposits was rapid. Figure 5:8 illustrates that from 8.58 to 4.60 m the patterns in the fill are remarkably consistent. Other than a sharp increase at the top of the uppermost gravel lens and a sharp decrease at 4.70 m, the amount of clay in this portion of the fill is generally about 7 to 8 percent.

The variability in this portion of Unit III lies in the sand and silt content, suggesting that accumulation of this portion of late-Holocene fill consisted of a series of fining upward sequences during intense overbank floods. Figure 5:8 illustrates that increases or decreases in sand content are in conjunction with decreases or

increases, respectively, in silt. Between 6.40 and 6.20 m, for example, sand content is relatively high at 25 percent.

In contrast, the amount of silt in the fill is about 70 percent. Overlying this sandier deposit is a .45-m-thick layer that contains between 75 and 80 percent silt and only 10 to 15 percent sand. Similar patterns are seen elsewhere in this portion of Unit III. Figure 5:9 illustrates that sand and silt fractions are fine and coarse, respectively. The content of calcium carbonate is generally Stage II+ as well-defined stringers and nodules of carbonate exist throughout the fill. The soil pH curve generally mirrors the calcium carbonate curve and is consistently between 7.5 and 8.5 (Fig. 5:10).

At a depth of 4.6 m a sharp contact can be seen in Unit III, one that initiates a 1.2-m-thick deposit of poorly-sorted coarse silt (Figs. 5:8 and 5:9). In contrast to the relatively variable deposit below, this layer of silt is remarkably consistent in texture, suggesting that overbank floods during this time were of moderate intensity. The sand and clay fractions are consistently fine textured while the silt fraction is generally coarse (Fig. 5:9). Calcium carbonate content is consistently Stage II as well defined stringers are present throughout, and, correspondingly, soil pH is generally approximately 7.5 (Fig. 5:10).

Another sharp contact was observed at 3.4 m, one that initiates a series of well-laminated deposits that cap Unit III. Figure 5:8 illustrates that in this portion of Unit III, a series of fining upward sequences can be seen, suggesting that overbank floods again became more intense and variable during this time. In contrast to the lower deposits in Unit III that fined upward, the clay content in
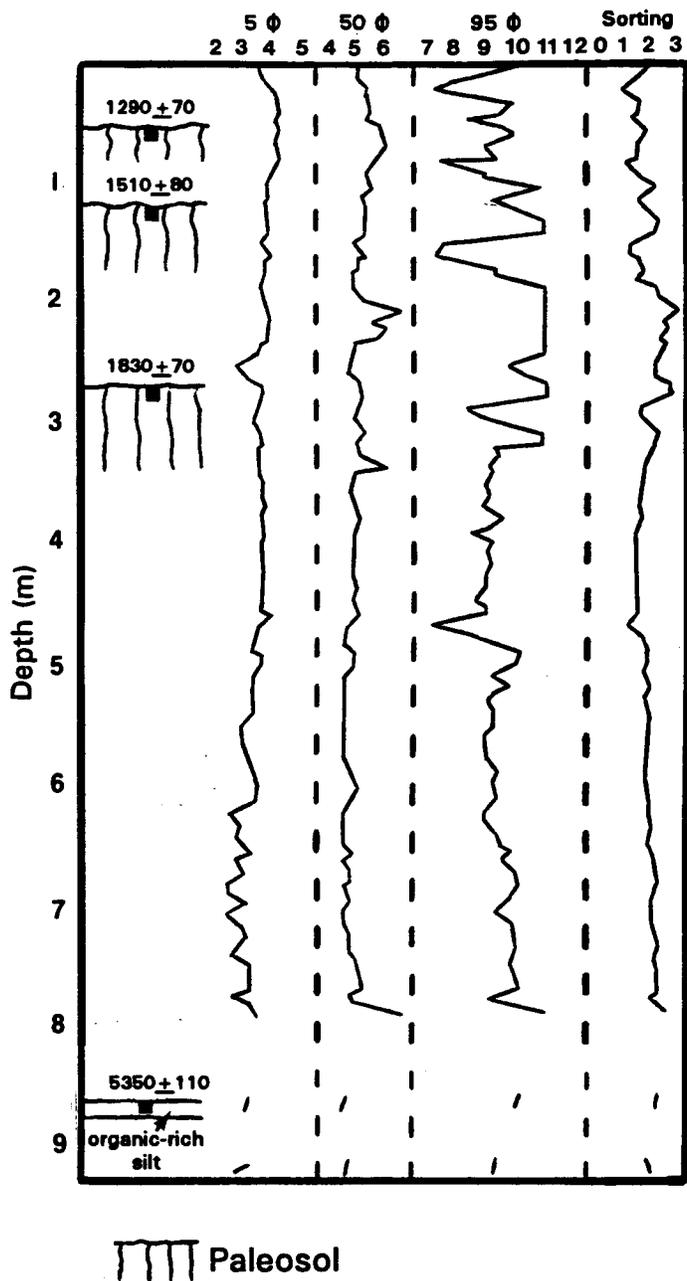
Figure 5:9 Graphical statistics of the sediments at the Paschal
Site. Results indicate that most of the fill is
poorly sorted and coarse silt in texture.
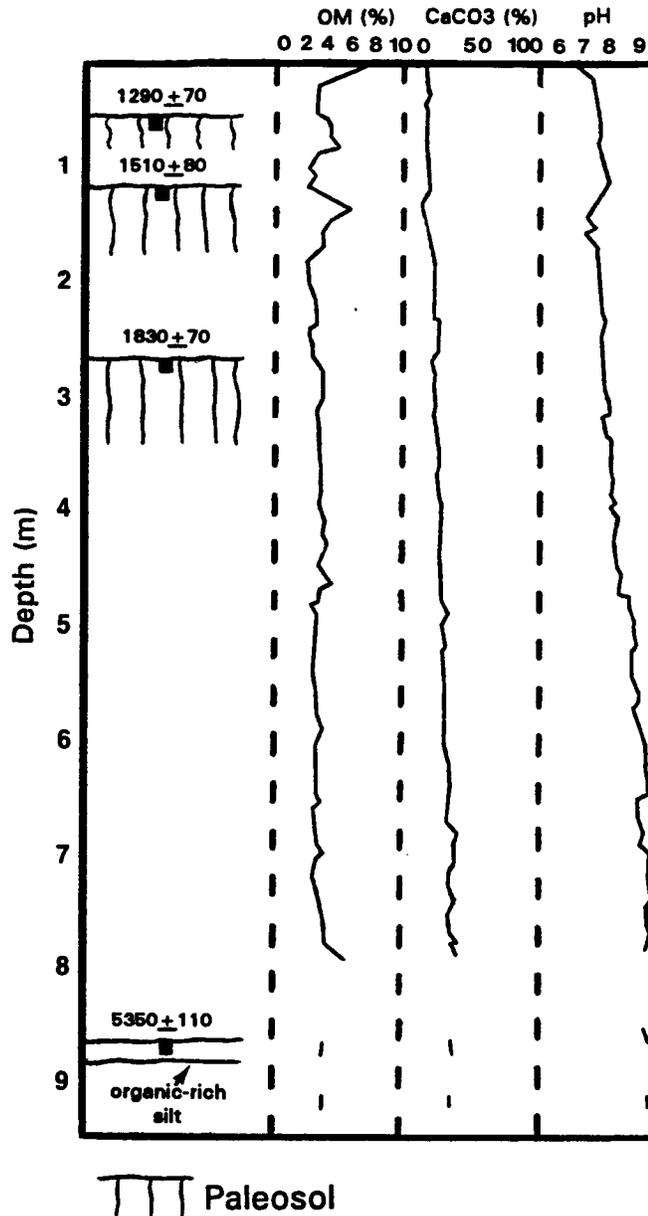
Figure 5:10   Chemical analyses of the sediments at the Paschal
Site. Results indicate that organic carbon content
defines paleosol boundaries well, calcium carbonate
generally increases from Stage I at the top of the
section to Stage II+ at the bottom, and pH ranges,
from top to bottom, from about 6.5 to 9.0.

the upper portion of Unit III is much more variable in conjunction with decreases or increases, respectively, of both sand and silt. Calcium carbonate content is generally Stage II and pH is about 7.5 throughout this portion of Unit III (Fig. 5:10).

Capping the top of Unit III is a moderately-developed paleosol that formed in the well-laminated deposits at the top of the unit. This paleosol consists of about a .54 m thick gray (10YR3/1) 4Ab horizon that is relatively high in organic content (3.2%). Radiocarbon age determination on humates from the upper .05 m (2.66-2.71 m) of the 4Ab horizon yielded a C-13 corrected radiocarbon age of 1,830±70 yrs B.P. (Tx-7077). Small fragments of bone, charcoal, and burned earth are scattered in the lower .60 m of the 4Ab horizon, but do not appear to represent an in situ cultural component.

The 4Ab horizon grades into the 4Cb horizon by way of a 0.22 m thick 4ACb horizon (Appendix A). Figure 5:10 illustrates that some illuviation of carbonate may have taken place in the paleosol since an increase from Stage I to Stage II occurs from the lower portion of the 4Ab horizon to the 4ACb horizon.

Following the episode of floodplain stability approximately 1,800 yrs B.P., Unit II began to accumulate at the Paschal Site. This sedimentary unit, which consists of alternating layers of sediment in the silt loam and silt textural classes that are generally poorly sorted, extends from 2.66 to 1.14 m. The lowermost .70 m of Unit II consists of a thick, fining upward sequence in response to variable flood magnitudes (Fig. 5:8). Between 2.66 and about 2.35 m the sand content is up to 25 percent, while silt and clay content are about 65 and 5 percent, respectively.

The fifth percentile phi values indicate that the sands are medium in texture (Fig. 5:9). A peak in the calcium carbonate curve (Stage II) between 2.66 and about 2.31 m suggests the underlying 4Ab may have impeded the downward movement of illuviated carbonate (Fig. 5:10).

Figures 5:8 and 5:9 illustrate that a sharp contact can be seen at 2.35 m, one that initiates a .35-m-thick-very-poorly-sorted layer that is represented by a sharp increase in silt and clay content in conjunction with a significant drop in sand content to nearly 5 percent. The highest percentage of clay is found at 2.10 m (ca. 30%), where the sediment is texturally classified as silty clay loam. Figure 5:9 indicates that each fraction of sediment in this portion of Unit II is relatively fine textured. Stage II carbonates are present throughout this sequence of deposits, but there is less in the overlying clay-rich layer. Soil pH ranges from about 7.5 to 7.75 throughout the sequence (Fig. 5:10).

At 1.96 m in Unit II the percentage of clay in the fill again becomes less than the sand content. Between this contact, and about 1.5 m the amount of clay in Unit II gradually decreases to nearly 2 percent. In conjunction with this drop in clay, sand content ranges between 20 and 25 percent, while the percentage of silt peaks to nearly 85 percent at 1.6 m (Fig. 5:8). Calcium carbonate content is highest (Stage II) just above the contact with the underlying silty clay loam layer mentioned above, but decreases to Stage I at about 1.5 m. Soil pH mirrors the decrease in carbonate content as it drops from approximately 7.5 at 1.96 m to 7.0 at 1.57 m (Fig. 5:10).

Between 1.5 m and the top of Unit II at 1.14 m, the amount of clay in the fill again increases in conjunction with a decrease in

sand and silt (Fig. 5:8). Figure 5:9 indicates that the clay fraction is fine textured, while the sand and silt fractions are fine and coarse textured respectively. Stage I carbonate is present in this portion of Unit II, and pH is about 7.0 (Fig. 5:10).

Contained within Unit II is a moderately-developed paleosol that formed in the deposits, texturally classified silt loam, within the upper portion of the unit. This paleosol consists of about a .48-m-thick, dark gray (10YR3/1) 3Ab horizon that is rich in organic content (6.0%); the organic matter curve in Figure 5:10 clearly illustrates the boundaries of the 3Ab horizon. Radiocarbon age determination on humates in the upper .05 m (1.14-1.19 m) of the paleosol yielded a C-13 corrected age of 1,510±80 yrs B.P. (Tx-7076).

The 3Ab horizon grades into the 3Cb horizon by way of a .13-m-thick 3ACb horizon (Appendix A). Precipitation of calcium carbonate from the overlying 3Ab into the upper 3Cb is apparent in the calcium carbonate and pH curves in Figure 5:10, which indicate that carbonate content ranges from Stage I to Stage II and pH from 7.6 to 7.8 from the lower 3Ab to the upper 3Cb. Extensive illuviation of clay may be indicated by the silty clay loam layer mentioned above at a depth of 2.10 m. More likely, because of this layers proximity to other clay-rich deposits in Unit III, its presence is likely due to the overbank deposition of fine sediments rather than illuviation of clay.

The uppermost sedimentary unit at the Paschal Site is Unit I, which is a well-laminated and poorly-sorted deposit of essentially coarse and medium silt between 1.14 m and the surface. Figures 5:8 and 5:9 indicate that within the silty fill are a number of thin layers of fine-textured clay, approximately every .10 m that likely

accumulated as floodwaters waned. In the upper .15 m of Unit I the amount of fine sand in the fill increases appreciably, composing about 20 percent of the deposit (Figs. 5:8 and 5:9).

Featured within Unit I is a poorly-developed paleosol and the surface soil. The paleosol, which consists of an incipient 2Ab, 2ACb horizon, and thin 2Cb horizon, formed in the well-laminated silty fill in the center of the unit (Fig. 5:8). The 2Ab horizon is located between about .79 and .51 m, is light gray in color (5YR3/1) and is relatively high in organic content (5.1%). Radiocarbon-age determination on humates in the upper .05 m (.51-.56 m) of the 2Ab yielded a corrected age of 1,290±70 yrs B.P. The 2Ab grades into the 2Cb by way of the .15-m-thick 2ACb horizon (Appendix A). Stage I carbonates are present throughout the paleosol, but some illuviation is suggested by the slight increase in carbonate content in the 2ACb and 2Cb horizons. Soil pH, however, is consistently approximately 7.5 in each horizon of the paleosol (Fig. 5:10).

The surface soil formed in the slightly-sandier fill at the top of Unit I. This soil consists of a .42-m-thick A horizon that is light gray (5YR3/1) in color and contains about 4.5 percent organic matter. The A horizon grades into the C horizon via about a .10-m-thick AC horizon (Appendix A). In contrast to the poorly-developed 2Ab in the center of Unit I, the surface soil appears to be better developed. Figure 5:10 suggests that illuviation of carbonate has been much more extensive in the surface soil. At the surface only Stage I carbonates are present, but increase to Stage II in the AC horizon. Further evidence of illuviation lies in the peak in clay content in the AC and C horizons, although this likely reflects the

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deposition of fine sediments since clay content is highly variable throughout Unit I.

In summary, the Paschal Site is a 9.5-m exposure of late-Holocene alluvial fill that contains three sedimentary units about 2 km east of Luray. Radiocarbon and stratigraphic data taken from near the base of Unit III indicate that approximately 5,300 yrs B.P. the floodplain construction in the Wolf Creek basin was underway as indicated by the combination of lateral accretion of coarse gravels and overbank deposition of fine sediments. Between this time and about 1,800 yrs B.P., the remaining 5.3 m of Unit III accumulated. This unit, which consists of alternating layers of sediment in the silt loam and silt textural classes, likely accumulated during a number of intensive overbank floods since very little clay was left behind. This period of rapid deposition ceased about 1,800 yrs B.P. when a moderately-developed paleosol formed.

The upper 2.6 m of fill at the Paschal Site consists of Units II and I. Unit II contains the most clay of any sedimentary unit at the site and likely accumulated during a few low-intensity floods. Deposition of this unit ceased around 1,500 yrs B.P. when a moderately-developed paleosol formed in relatively clay-rich sediment. Deposition of Unit I, in contrast, appears to have been more sporadic, as the silty fill is punctuated by a number of thin clay deposits. Moreover, an incipient soil formed in the center of the unit, indicating that accumulation of sediment ceased or dramatically slowed for a brief period of time approximately 1,200 yrs B.P. Following this brief interval, the remainder of Unit I fill was deposited.

Schoen Site. The Schoen Site, named after landowner Richard Schoen, is a west-facing exposure on the outside of a tight meander bend about 8 km downstream from Lucas (Figs. 3:1 and 5:11). At this site, approximately 6.5-m of late-Holocene alluvial fill (Fill III) is exposed along a steep cutbank that underlies the T-2 terrace (Fig. 5:12).

Analyses of the alluvial fill at the Schoen Site indicates the fill has stratigraphy and texture similar to the Paschal Site, consisting largely of sediments in the silt, and silt loam textural classes and laminated medium to fine sands and silt that are generally very poorly to poorly sorted (Fig. 5.13 and 5.14). Three sedimentary units, Units III - I, are capped by two paleosols and the surface soil, in Fill III respectively, at the Schoen Site. In addition, an incipient paleosol similar to the one recognized in Unit I at the Paschal Site (Fig. 5:8) is present in Unit I at this locality (Fig. 5:12).

Along the base of the exposure below a depth of 5.82 m there is a deposit of poorly-sorted silt that is rich in organic matter (2.5%); this layer likely represents a slackwater deposit. A bulk sample collected from the upper .05 m (5.82-5.75 m) of this deposit yielded a C-13 corrected age of 2,970±80 yrs B.P. (Tx-6795). Above the organic-rich stratum, a 75-cm-thick deposit of alternating layers in the silt loam and silt textural classes that are weakly laminated and generally poorly sorted caps the basal deposit, suggesting the basal deposit was buried by alluviation. The laminae are reflected by the particle size trends (Fig. 5:13) and the peaks of the fifth and ninety-fifth percentile phi values between 5.05 and 5.82 m (Fig.

70
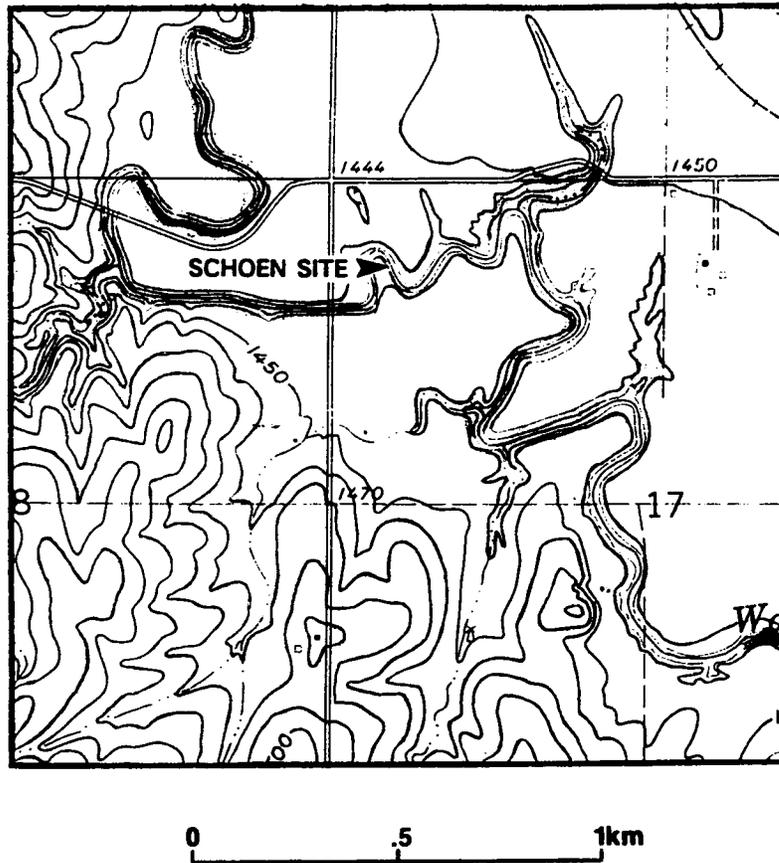
Figure 5:11 Topographic Map of the Schoen Site. The Schoen
Site is a west-facing exposure on the outside of a
tight meander bend in the NW 1/4, NW1/4, Sect. 17,
T12S, R10W, 6P.M., Sylvan Grove Quadrangle (1963).

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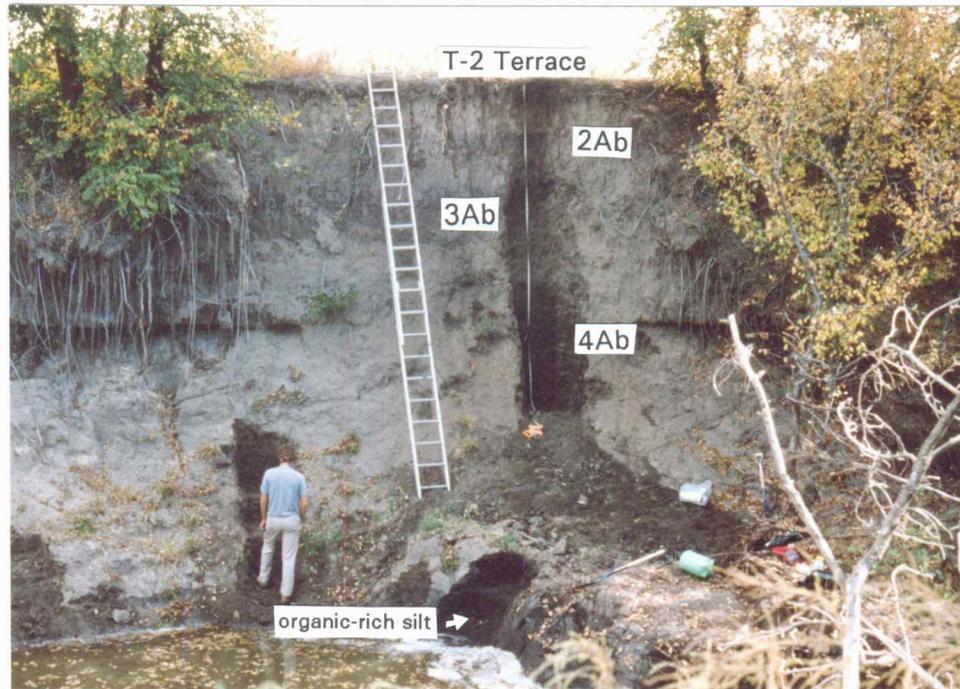
Figure 5:12   View of the Schoen Site that shows Wolf Creek, the
T-2 terrace and approximately 6.5 m of alluvial
fill. The fill at the Schoen Site is late-Holocene
(Fill III) in age and is composed of 3 sedimentary
units (Units III, II and I) that are generally silt
and silt loam in texture and are poorly sorted and
well laminated. Radiocarbon-age determinations on
an organic-rich silt layer at the base of the
exposure and the 4Ab and 2Ab yielded ages of
2,970±80 (Tx-6795), 1,750±70 (Tx-6959), and
1,250±60 (Tx-6960), yrs B.P., respectively.

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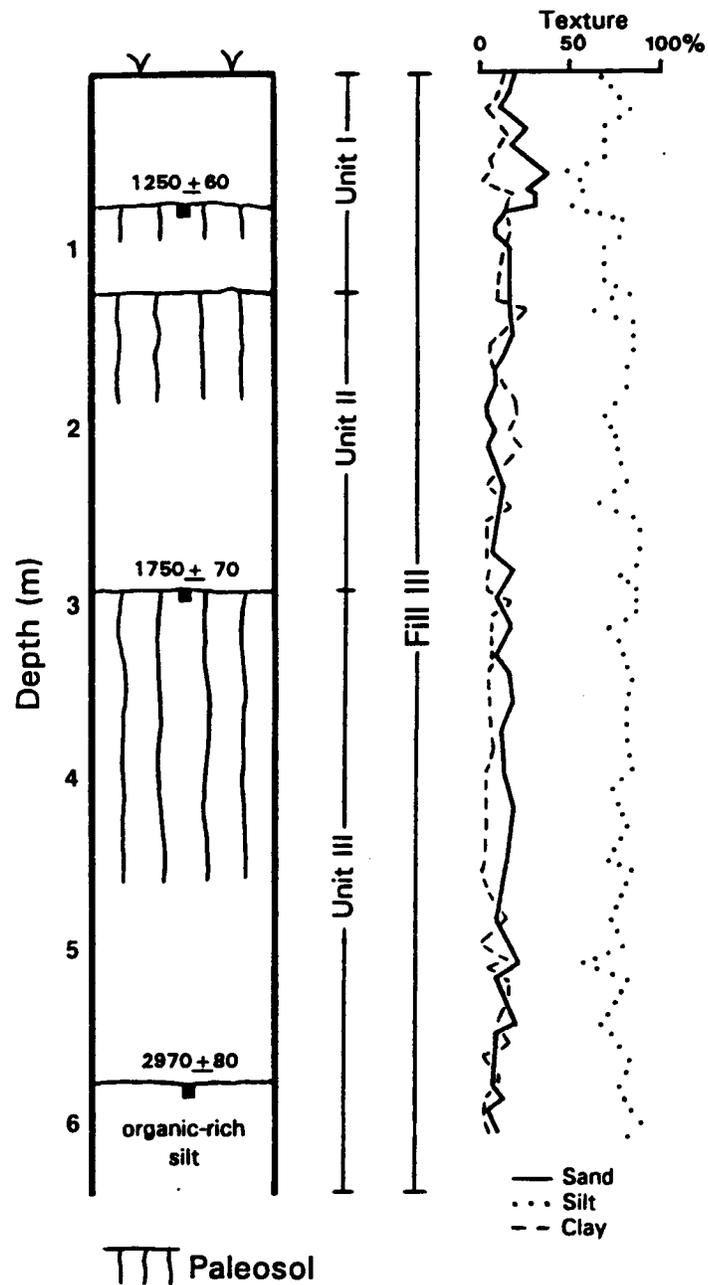
Figure 5:13 Stratigraphy and sediment texture of the Schoen
Site. Results indicate that three sedimentary units
exist in Fill III at this site. Each paleosol is
separated by well-laminated deposits of silt and
silt loam, suggesting that intensive overbank
deposition buried each formerly stable floodplain.
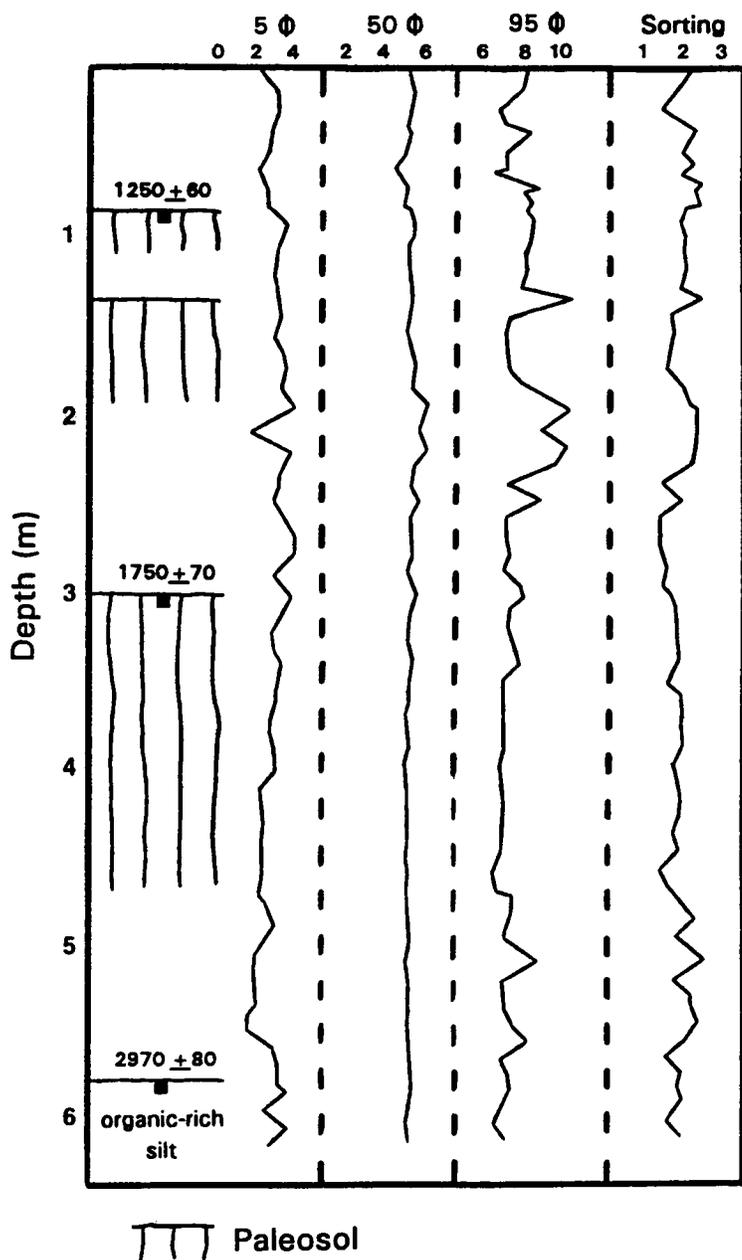
Figure 5:14 Graphical Statistics of the sediments at the Schoen
Site. Results indicate that the sediments are
generally poorly sorted and largely coarse silt in
texture, but that laminations containing fine sands
and clays are present.

5.14). The presence of sand stringers and thin clay deposits within many laminae may represent individual fining upward sequences. Calcium carbonate content in this portion of Unit III is low (Stage I), and soil pH is generally between 7.5 and 8.0 (Fig. 5:15).

Following the period of overbank deposition after about 3,000 yrs B.P., a period of relatively slow and steady aggradation occurred at the Schoen Site. This is reflected by the paleosol which developed in the texturally consistent deposits between a depth of about 5.05 and 3.02 m at the top of Unit III (Fig. 5:13). This paleosol features a cumulic 4Ab horizon that is black (5YR 3/1) between 3.02 and 4.42 m and dark gray (10YR 3/2) to its base at 4.74 m below the surface. Organic content is generally high (4.5%) from 3.02 to 4.42 m in the 4Ab horizon. Radiocarbon-age determination of soil humates in the upper .05 m (3.02-3.09 m) yielded a C-13 corrected age of 1,750±70 yrs B.P. (Tx-6959).

Between about 4.74 and 5.05 m the 4Ab horizon grades into the 4Cb horizon by way of a 4ACb that formed in a deposit that is silt loam in texture (Appendix A). Some illuviation is evident in the paleosol, since the curves for organic matter and calcium carbonate decrease in the lower 4Ab horizon and increase slightly in the 4ACb horizon (Fig. 5:15).

Following the episode of relative stability that ended about 1,800 yrs B.P., Unit II began to accumulate at the Schoen Site during a period of renewed flooding. Unit II consists of alternating deposits of moderately-sorted and finely-laminated silts with loam and silt loam textures that occur between a depth of 3.02 and 1.32 m. The particle size trends (Fig. 5:13) and fifth and ninety-fifth
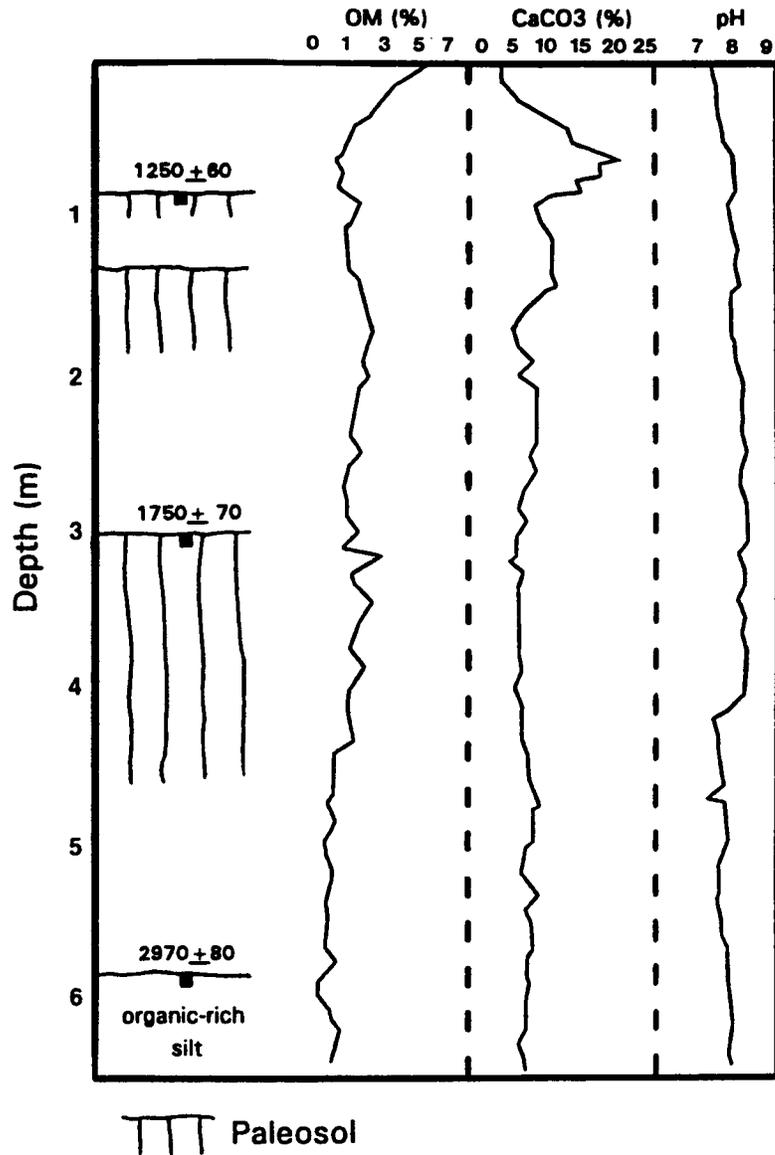
Figure 5:15 Chemical Analyses of the sediments at the Schoen
Site. Results indicate that organic carbon content
defines paleosol boundaries reasonably well.
Calcium carbonate content ranges from Stage I to
Stage III. Extensive illuviation of carbonate from
the surface soil is indicated by the steep peak
approximately .75 m below the surface. Soil pH
ranges from nearly 7.0 to 8.3.

percentile phi values (Fig. 5:14) further illustrate that these deposits are laminated and appear to, in general, fine upward. Like the Paschal Site (Fig. 5:8), a sharp contact is present at about 2.4 m that initiates a .50- m-thick deposit of relatively clay-rich (ca. 25%) alluvium. In the upper part of Unit II, clay content decreases to generally less than 10 percent in conjunction with an increase in silt and sand content (Fig. 5:13).

Contained within Unit II at the Schoen Site is a moderately-developed paleosol like the one recognized at the Paschal Site (Fig. 5:8); this soil formed in the silty deposits the top of the unit (Fig. 5:13). The paleosol features a black (10YR 2/1) 3Ab horizon rich in organic matter (3.3%) to a depth of 1.96 m and a dark gray (10YR 3/2) 3Bwb horizon between about 1.96 and 2.23 m (Appendix A). Although undated at the Schoen Site, a C-13 corrected radiocarbon age of 1,510±80 yrs B.P. (Tx-7076) was obtained from the upper .05 m of the paleosol at the Paschal Site. Since these soils are morphologically and stratigraphically similar (Appendix A), it is assumed that the Schoen soil is equivalent in age to the Paschal counterpart.

The data indicate that the 3Bwb horizon may be present because it formed in relatively clay-rich alluvium (Appendix A). At the Paschal Site, a similar stratigraphic relationship is present, but is clearly depositional in nature (Fig. 5:8). In addition, the calcium carbonate curve at the Schoen Site indicates that little illuviation of carbonate occurred in the paleosol here, since Stage I carbonates are present throughout the paleosol (Fig. 5:14).

Following the episode of landscape stability that ended about

1,500 yrs B.P., another period of relative rapid aggradation occurred at the Schoen Site. The episode of alluviation left behind the deposits of silt and finely-laminated silt in the loam and silt loam classes that comprise Unit I between 1.32 m and the surface. Within these deposits is an incipient paleosol and the surface soil that formed in the silty deposits of the unit (Fig. 5:13).

The paleosol, situated between a depth of about .82 and 1.02 m, consists of a dark gray (10YR 2/2) 2Ab horizon that contains 2.8 percent organic matter. Radiocarbon age determination of humates in the upper .05 m (.82-.87 m) of the paleosol yielded a C-13 corrected age of 1,250±60 yrs B.P.(Tx-6960), indicating that this paleosol represents the same brief interval of landscape stability recognized at a similar depth at the Paschal Site.

Once the brief period of relative stability at the Schoen Site terminated about 1,200 yrs B.P., another interval of aggradation occurred that formed the remainder of Unit I. Evidence suggests that alluviation at the Schoen Site at this time was apparently intense, consisting of a series of strong floods that deposited layers of moderate- to poorly-sorted silts that have a variety of textures. Textural (Fig. 5:13) and statistical analyses (Fig. 5:14) indicate that between .82 and .45 m the content of fine sand is generally over 20 percent, and peaks at nearly 50 percent at about .70 m. Calcium carbonate content is the highest (Stage II+) in this portion of the fill, reflecting the relative permeability of the deposit. In general, the fill in Unit I fines upward slightly at the top of the unit as the percentage of silt in the fill increases to nearly 65 percent. Calcium carbonate content decreases to 3 percent (Stage I)

in this part of Unit I (Fig. 5:15).

It is within this well-stratified deposit that the surface soil has developed. This soil features a very dark gray (10YR 3/1) A horizon to an approximate depth of .37 m. Between the A and C horizons is an AC horizon that formed between about .37 and .52 m (Appendix A). The calcium carbonate curve (Fig. 5:15) indicates that extensive illuviation of carbonate has occurred at the base of the surface soil at the Schoen Site.

In summary, detailed analyses of 6.5 m of late-Holocene alluvial fill (Fill III) at the Schoen Site indicates that the fill is stratigraphically and texturally similar to the fill at the Paschal Site, consisting largely of poorly- to very poorly-sorted sediments in the silt and silt loam textural classes. Recognized within Fill III at the Schoen Site are three sedimentary units that are capped by two paleosols and the surface soil, respectively. A third, poorly-developed paleosol is present within the deposits of Unit I. Separating these features are weakly- to moderately-laminated deposits that suggest a series of floods between intervals of stability.

Unit III is situated between approximately 6.5 and 3.0 m and generally consists of silty deposits that are better laminated in the lower third of the unit. Along the base of Unit III is an organic-rich, silty stratum that yielded a radiocarbon age of about 3,000 yrs B.P. Featured within the upper 1.25 m of the unit is an overthickened 4Ab that formed in remarkably texturally consistent sediments. Radiocarbon evidence suggests that pedogenesis in this paleosol terminated about 1,800 yrs. B.P. Unit II, between

approximately 1.3 and 3 m below the surface, consists generally of silty fill that is highly variable in clay content within the upper portion of the unit. A moderately-developed paleosol featured within Unit II correlates with the Paschal Site. Radiocarbon evidence from that site suggests that pedogenesis terminated in the 3Ab at the Schoen Site around 1,500 yrs B.P.

The uppermost sedimentary unit at the Schoen Site is Unit I, which formed between about 1.3 m and the surface. Contained within the lower third of the unit is a poorly-developed paleosol that was buried by sandy alluvium about 1,200 yrs. B.P. Since that time the surface soil has formed in the uppermost .80 m of Unit I.

Naylor Site. The Naylor Site, named after landowner Gerald Naylor, is a west-facing cutbank exposure in the upper reaches of the East Fork Wolf Creek (Figs. 3:1 and 5:16). In this portion of the Wolf Creek basin, the valley is only about 0.5 km wide (Fig. 5:16). Approximately 5.5 m high, the section is composed largely of deposits in the silt loam textural class separated intermittently by layers classified as silt, loam, and sandy loam. The site features both early (Fill II) and late-Holocene (Fill III) alluvial fills, as well as four sedimentary units and three paleosols (Fig 5:17).

The lowermost sedimentary unit at the Naylor Site is Unit IV which consists of early-Holocene fill exposed between about 5.53 and 4.10 m in depth. Along the base of Unit IV there is a 0.80-m-thick layer of poorly-sorted medium to coarse sand that fines upward into a stratum containing more silt and clay; this pattern is reflected by the particle size trends and the fifth and ninety-fifth percentile
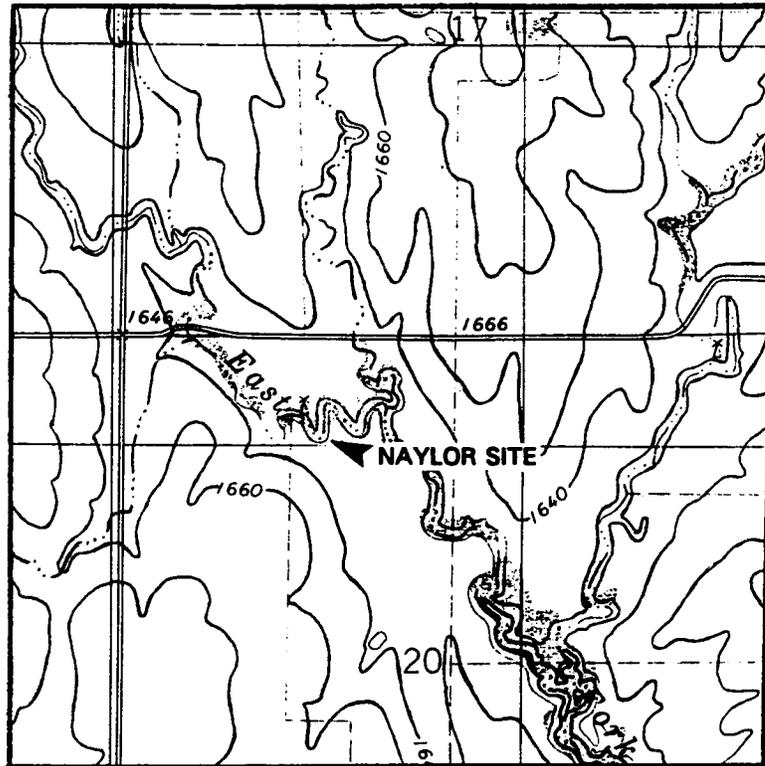
Figure 5:16 Topographic map of the Naylor Site. The Naylor
Site is a 5.5 m cutbank exposure on the outside of
a tight meander bend of the East Fork Wolf Creek in
the NW 1/4, NW1/4, Sect. 20, T10S, R11W, 6P.M.,
Meades Ranch Quadrangle (1978)

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Figure 5:17   View of the Naylor Site that shows the East Fork
              Wolf Creek, the T-2 terrace, and 5.5 m of alluvial
              fill. The fill is generally silt and silt loam in
              texture, poorly sorted, and well laminated. At the
              base of the exposure is nearly 1.5 m of early-
              Holocene (Fill II) fill that is buried by 4.0 m of
              late-Holocene (Fill III) alluvium. Radiocarbon-age
              determinations from the upper .05 m of the 4Ab,
              3Ab, and 2Ab horizons yielded ages of 6,770+110
              (Tx-6914), 1,880+60 (Tx-6962), and 1,460+60 (Tx-
              7076) yrs B.P., respectively.
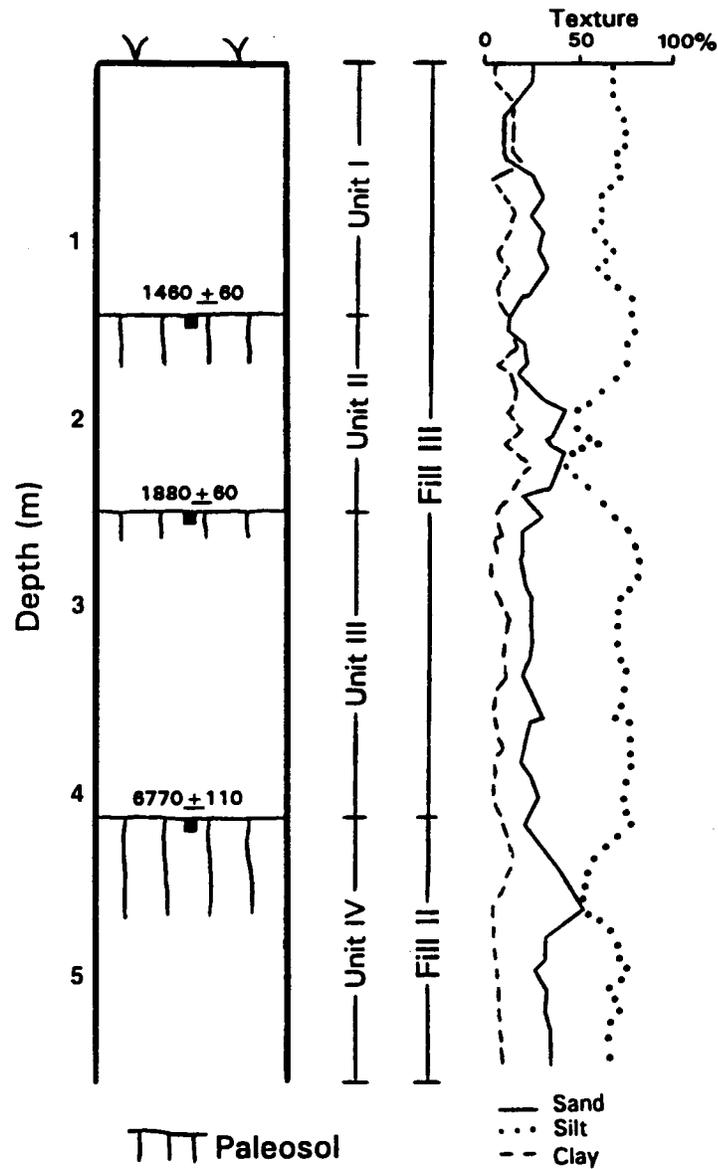
Figure 5:18 Stratigraphy and sediment texture from the Naylor Site. Results indicate that four sedimentary units are recognized in Fills II and III. The fill is generally silt and silt loam in texture. Note the laminations in Units II and I, indicating the soil formation was interrupted by intensive flooding.
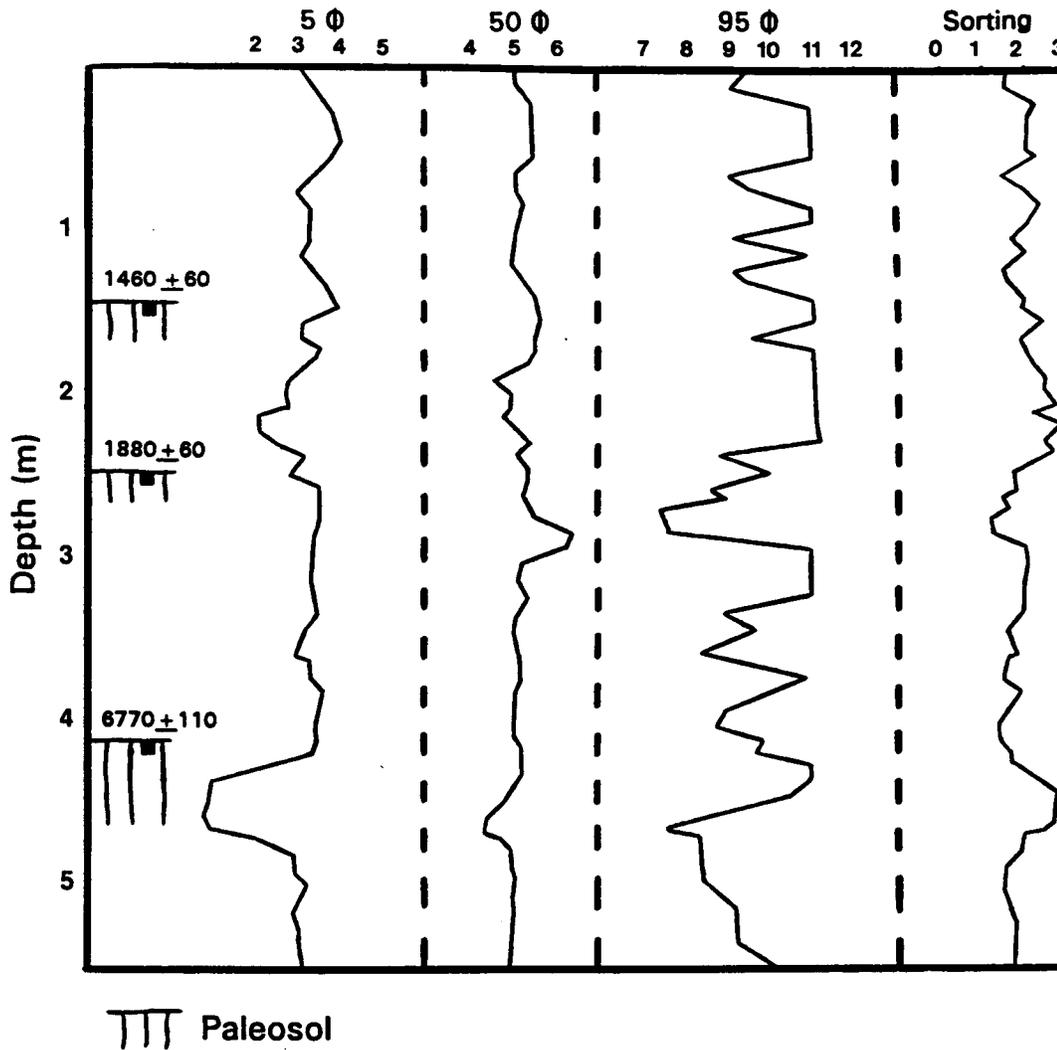
Figure 5:19 Graphical statistics from the sediments at the
Naylor Site. Results indicate that the fill is
poorly sorted and composed largely of coarse silt,
although deposits of fine sand and clay are
scattered throughout the fill.

phi values between a depth of 4.73 and 4.15 m (Figs. 5:18 and 5:19). This sequence of deposits may reflect the occurrence of less intensive overbank events or a change in sediment source area.

Unit IV contains a moderately-developed paleosol that formed within the deposits classified as sandy loam and silt loam in the upper 0.77 m of the unit (Fig. 5:18). The paleosol consists of about a 0.51-m-thick black (10 YR2/1), organic-rich (4.9%) 4Ab that grades into the 4Cb horizon by way of a 0.26-m-thick 4ACb (Appendix A). Radiocarbon-age determination on humates from the upper 0.05 m (4.15 - 4.20 m) of the 4Ab yielded a C-13 corrected age of 6,770+110 yrs B.P. (TX-6914). This is probably the same paleosol reported in Johnson and Martin (1987) that yielded an age of 10,580+140 yrs B.P. (Beta-2158) in 1980. Although the stratigraphy and location of this site are consistent with that described previously, the results were obviously not duplicated. This discrepancy may be a result of differences in sampling or age-determination procedures. The sample in this study was carefully collected (i.e., from deep within the verticle face) and cleaned to insure a reliable age, whereas documentation for the earlier sample was poor. Equally, the age acquired in 1980 is likely older since all of the fractions (i.e., humin, humate, base soluble) were assayed. In this study, only the base-soluble fraction was analyzed, which according to White and Valastro (1984) produces a more representative age. Lack of funds prevented another, potentially corroborating, age from being obtained at this site at this time. It is strongly believed, however, that the age obtained from the 4Ab at the Naylor Site in this study is accurate and should replace the age obtained in 1980.

Because the 4Ab formed in sediments that were relatively high in clay content, it has a distinct blocky structure, especially in the upper 4Ab. Although carbonate nodules are present throughout the paleosol, they are more numerous (Stage II +) in the upper 0.20 m of the 4Ab and the lower 0.40 m of the 4Cb horizon, suggesting the illuviation of carbonate occurred in the intervening .0.65 m of the paleosol (Fig. 5:20).

An unconformity separates the deposits in Unit IV from those in Unit III. A thin layer of coarse gravel caps the paleosol at the top of Unit IV, suggesting that the gravel was deposited following an erosional episode that removed a portion of the 4Ab. Further erosion of early-Holocene fill was likely retarded due to the relatively high clay content in the underlying paleosol.

Unit III consists of poorly-sorted and poorly-laminated deposits of mottled silt and fine sand between 4.14 and 2.46 m in depth. Capping the gravel layer on the top of the underlying 4Ab is a 0.36 m layer of fine sand that fines upward into coarse silt (Figs. 5:18 and 5:19). Carbonate nodules are common in the upper and lower portion (Stage II) of this layer, and increase to Stage II+ in the center of the deposit (Fig. 5:20).

Analysis of the fifth and ninety-fifth percentile phi values (Fig. 5:19) reveals that a sharp contact exists at a depth of 3.79 m, one that separates the underlying sandy fill from a finer-textured deposit above. This deposit, which lies between 3.79 and 3.59 m in depth, has a distinct subangular blocky structure due to its higher content of fine clay. Carbonate nodules are common (Stage II), but are not as numerous as in the underlying sandy fill (Fig. 5:20).
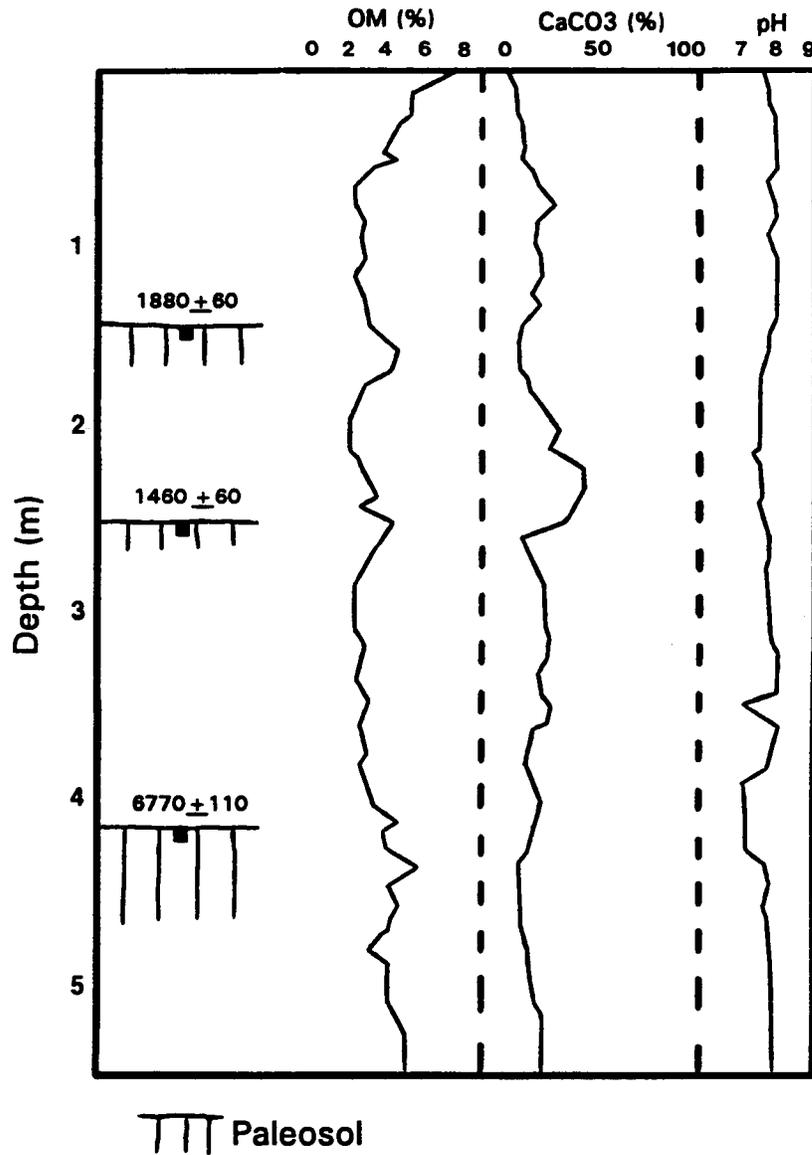
Figure 5:20   Chemical analyses of the sediments at the Naylor
Site. Results indicate that organic carbon content
defines paleosol boundaries reasonably well.
Calcium carbonate content ranges from Stage I to
Stage III. Soil pH is generally 7.5 throughout the
fill.

At a depth of 3.58 m another sharp contact exists in Unit III of the Naylor Site. Particle size trends (Fig. 5:18), and the fifth and ninety-fifth percentile phi values (Fig. 5:19) indicate that a 0.12-m-thick layer of medium sand covers the underlying fine-textured deposit. This layer, which is mottled, and contains iron oxide and carbonate nodules (Stage II+), likely represents an intensive flood event in this portion of the basin sometime during the late Holocene.

As floodwaters that deposited the medium sand mentioned above waned, a layer of finer-textured sediment accumulated in Unit III. The fiftieth and ninety-fifth percentile phi values (Fig. 5:19) indicate that this deposit, between a depth of 3.45 and 3.32 m, consists of medium silt and clay. At the top of this layer a well-developed lens of carbonate nodules exists, suggesting that the fine-textured nature of this deposit impaired the downward movement of illuviated carbonate (Fig. 5:20).

Between 3.32 and 2.95 m depth the amount of fine sand in Unit III increases and the amount of silt decreases (Fig. 5:18 and 5:19). Fine clay content remains about the same, and is reflected in the weak, subangular blocky structure of this layer. Isolated fragments of fine gravel underscore the poorly-sorted nature of this portion of Unit III. Iron oxide and carbonate nodules (Stage II+) are also common (Fig. 5:20).

The uppermost part of Unit III is between 2.95 and 2.46 m in depth. Figures 5:18 and 5:19 indicate that as this layer of Unit III accumulated, overbank events in this part of the basin must have varied in magnitude; individual fining upward sequences may be represented as well. Between 2.95 and 2.70 m depth is a layer of

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mostly medium silt. Capping this deposit is a thin clay layer, clearly illustrated in Figure 5:19. The amount of clay drops slightly in conjunction with a slight increase in fine sand content between 2.70 and 2.62 m, where another thin clay deposit can be identified. Between this layer, and the top of Unit III at 2.46 m, the amount of fine sand increases significantly, accompanying a dramatic drop in silt content (Figs. 5:18 and 5:19).

Featured within Unit III is a moderately-developed paleosol that formed in the variable deposits in the upper portion of the unit. This paleosol, which may have been partially truncated, consists of about a 0.14-m-thick dark gray (10YR3/1) 3Ab horizon that is granular to subangular blocky in structure and rich in organic-content (3.9%). A few, small nodules of calcium carbonate exist in the 3Ab, but, in general, carbonate content is Stage I + (Fig. 5:20). Radiocarbon-age determination on humates from the upper 0.05 m (2.46-2.51 m) of the 3Ab yielded an age of 1,880±60 yrs B.P. (TX-6962), indicating that it is the same paleosol as the 4Ab recognized downstream at the Paschal and Schoen Sites.

The 3Ab grades into the 3Cb horizon by way of a 0.12-m-thick 3ACb (Appendix A). Extensive illuviation of carbonate from the 3Ab is suggested by the significant increase in carbonate in the 3ACb (Stage II), and the underlying 3Cb (Stage II+) (Fig. 5:20). This degree of illuviation indicates that the paleosol formed during a significant interval of time, which is contradicted by the extremely thin 3Ab, suggesting, in turn, that a portion of the 3Ab was removed sometime after about 1,800 yrs B.P.

Because the upper portion of the 3Ab may have been eroded, an

unconformity separates Unit III from the overlying Unit II, which consists of well-laminated deposit between 2.46 and 1.34 m depth. That this sedimentary unit accumulated during a series of large floods is suggested by the generally very poorly sorted nature of this deposit; particle size trends (Fig. 5:18) and graphical statistics (Fig. 5:19) illustrate that peaks in sand and clay content mirror one another in most places.

Between a depth of about 2.46 and 2.15 m the amount of medium sand and fine clay increases significantly within Unit II, in conjunction with a 25 percent decrease in silt. Thin clay deposits are common in the lowermost 0.11 m of the unit. A sharp contact can be seen at a depth of 2.35 m, one that initiates a 0.25-m-thick layer of mixed coarse gravel, medium sand, silt, and fine clay that, in general, fines upward (Figs. 5:18 and 5:19). Figure 5:18 illustrates that clay content (15-20%) and carbonate content (Stage III) (Fig. 5:20) are highest in this very-poorly-sorted layer of Unit II.

Another sharp contact is seen at a depth of 2.10 m in Unit II. Figures 5:18 and 5:19 illustrate that an 0.08-m-thick deposit of coarse silt and medium sand. While sand and clay content both decrease in this stratum, the amount of sand does remain relatively high (30%) (Fig. 5:20).

Between a depth of 2.02 and 1.34 m, which is the top of Unit II, the deposits consist of generally well-laminated layers of silt in the loam and silt loam textural classes that fine upward. Figures 5:18 and 5:19 illustrate that fine sand content is highest (ca. 40%) between 2.02 and 1.85 m in depth. Above this layer, however, the amount of sand drops to about 10 percent at the top of Unit II. In

conjunction with the decrease in sand content is a significant change in the amount of silt; figure 5:13 illustrates that silt content increases from about 50 percent at 1.92 m to over 75 percent at 1.34 m in depth. The amount of clay remains generally consistent, but decreases are seen at 1.91 m and 1.67 m in depth. Calcium carbonate content decreases in this portion of Unit II from Stage II+ at 2.02 m to Stage I at the top of Unit II (Fig. 5:20).

Contained within the uppermost deposits of Unit II is a moderately-developed paleosol. This paleosol consists of a 2Ab horizon between about 1.34 and 1.70 m in depth that grades into the 2Cb horizon by way of an approximately 0.09-m-thick 2ACb horizon (Appendix A). The 2Ab has a granular structure, is dark-gray in color (10YR2/1), and is high in organic content (4.3%). Figure 5:20 illustrates that organic carbonate content clearly defines the boundaries of the 2Ab. Radiocarbon-age determination on the upper 0.05 m (1.34-1.35 m) of the 2Ab yielded a C-13 corrected age of 1,460±60 yrs B.P. (Tx-6960), indicating that it is the same paleosol recognized as the 3Ab downstream at the Paschal and Schoen Sites.

Figure 5:20 illustrates that calcium carbonate content is very low in the 2Ab (Stage I), and increases from Stage II in the 2ACb to Stage III in the 2Cb horizon, suggesting extensive illuviation in the paleosol. Further evidence of illuviation may lie in the low content of clay in the lower 2Ab and high content (25%) of clay in the 2ACb. More likely, the 2ACb formed in clay-rich sediment, since the 2Cb horizon contains as much as 30 percent clay at different depths.

The uppermost sedimentary unit at the Naylor Site is Unit I, which consists of a deposit with silt loam texture between 1.34 m and

the surface. Figure 5:18 illustrates that the deposits in Unit I are well laminated, and, in general, fine upward; in the lower one-half of the deposit fine sand comprise up to 30 percent of the deposit; sand content drops to as little as 10 percent in the upper one-half of the unit.

From the base of the Unit I to a depth of about 1.32 m is a layer of fine silt (Figs 5:18 and 5:19). Clay content decreases in conjunction with an increase in fine sand in the uppermost part of this layer (Fig. 5:18).

Capping the layer of fine silt is a well-laminated deposit of fine sand and clay, and medium silt between 1.32 and 0.63 m (Fig. 5:18 and 5:19). Thin silt and clay layers are common between the deposits of fine sand. Calcium carbonate content ranges between Stage II+ and Stage III in this part of Unit I (Fig. 5:20).

At a depth of 0.63 m, a sharp contact can be seen in the deposits of Unit I, one that initiates a sharp drop in sand content in conjunction with an increase of fine silt and clay (Figs. 5:18 and 5:19). In fact, between a depth of 0.55 and 0.30 m, the amount of clay in the fill is more than the sand content, the only stratum at the Naylor Site where this occurs. Stage II calcium carbonate content dominates in this layer of Unit I (Fig. 5:20).

In the uppermost 0.30 m of Unit I, the amount of sand increases from 10 to 25 percent in conjunction with a significant drop in clay content and a slight decrease in silt content (Fig. 5:18). In this part of Unit I calcium carbonate content is Stage I (Fig. 5:20).

Unit I contains the surface soil, which developed in the silt loam deposits in the upper portion of the unit. This soil consists

of an approximately 0.34-m-thick dark-gray (10YR2/1) organic-rich (5%) A horizon that overlies about a 0.19-m-thick gray (10YR2/2) Bw horizon and the 0.81-m-thick C horizon (Appendix A). Figure 5:20 illustrates that leaching of carbonate and fine clay (Fig. 5:18) has been relatively extensive. Calcium carbonate content ranges from Stage I in the A horizon to Stage II+ in the C horizon (Fig. 5:20). Similarly, clay content ranges from 5 percent in the A horizon to 18 percent in the Bw horizon (Fig. 5:18). It is possible that this horizon formed in clay-rich sediment, but the thickness of this stratum and consistent high clay content suggests pedogenic processes (i.e., illuviation) were active.

In summary, the Naylor Site consists of a 5.5-m-high cutbank in the upper reach of the East Fork Wolf Creek that exposes both early (Fill II) and late-Holocene (Fill III) alluvial fills. Contained within these fills are four sedimentary units that consist largely of deposits in the silt loam textural class that are poorly to very poorly sorted.

Fill II is exposed in Unit IV, which ranges in depth from 5.52 to 4.15 m and contains the highest percentage of sand at the site. Capping Unit IV is a moderately-developed paleosol that formed in clay-rich sediment; pedogenesis in this paleosol ceased about 6,700 yrs B.P., when rapid burial by overbank deposition occurred.

Capping Unit IV are three sedimentary units that comprise Fill III at the site. Unit III, which is the lowermost late-Holocene sedimentary unit, consists of poorly-laminated, silty deposits between 4.15 and 2.46 m, that contains numerous carbonate nodules. At the top of Unit III is a moderately-developed paleosol that may

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have been truncated. Radiocarbon-age determination on this paleosol suggests that pedogenesis ceased about 1,900 yrs B.P. when it was rapidly buried by overbank deposits.

Unit II, which is the coarsest sedimentary unit at the Naylor Site, lies between 2.46 and 1.34 m in depth. This unit appears to have accumulated rapidly during intensive flooding, as the deposits are generally very poorly sorted. Between 2.35 and 2.10 m, for example, the deposits consist of carbonate-rich coarse gravel mixed with a high percentage of sand, silt, and clay. Featured within Unit II is a moderately-developed paleosol. Radiocarbon-age determination indicated that pedogenesis in this paleosol ceased about 1,300 yrs B.P. after the paleosol was rapidly buried by overbank deposits.

The uppermost sedimentary unit at the Naylor Site is Unit I, which accumulated sometime after around 1,300 yrs B.P. This unit consists of silty deposits that are well laminated, poorly to very poorly sorted and generally fine upward. Contained within Unit I is the well-developed surface soil, consisting of an A and Bw horizon.

T-1 Terrace Complex

Approximately 1,000 yrs B.P. a major episode of erosion began in the Wolf Creek basin that formed the T-2 terrace. Since this phase of erosion began, the stream channels in the basin have entrenched about 5.0 m. Lateral erosion has generally been minimal, except for a 3-km reach below Luray where up to 25 percent of T-2 fill has been removed (Fig. 5:5). In this portion of the basin, lateral cutting in conjunction with more intensive entrenchment (nearly 6 m) has created the best developed T-1 terrace complex in the basin, consisting of

at least 4 surfaces (Fig. 5:21).

The uppermost terrace in the T-1 complex is a fill-strath terrace cut on the 4Ab (the upper .10 m of the paleosol contains a relative abundance of clay, resisting erosion) in Fill III alluvium. Fill IV, which consists of 3.5 to 5 m thick deposits of lateral accretion gravel and finer overbank sediments, directly underlies the remaining surfaces in the complex (Fig. 5:22). Figures 5:21 and 5:22 illustrate that Fill IV overlies the organic-rich, silty sediment in Fill III that was recognized in cores 1,2, and 4. Moreover, the stream is currently flowing on the same basal deposit in Fill III alluvium, suggesting that entrenchment is ongoing (Fig. 5:21).

T-0 (Floodplain)

Because the streams in the Wolf Creek basin have been largely entrenching the past 1,000 years, the modern floodplain (T-0) is poorly developed, consisting of isolated, narrow deposits adjacent to the present stream channel (Fig. 5:21). Fill IV underlies the floodplain, consisting of a thin veneer of fine-grained alluvium (post-settlement?) that overlies a coarse gravel deposit.

Late-Quaternary Valley History

Radiocarbon ages in conjunction with sedimentary and stratigraphic data have been employed to reconstruct the late-Quaternary valley history of the Wolf Creek basin. Ages on which the chronology is based are listed in Table 5:1.

Evidence indicates that sometime during the Pleistocene (pre-Wisconsin) Wolf Creek was a much different stream than during any time throughout the Holocene. The presence of upland gravel deposits

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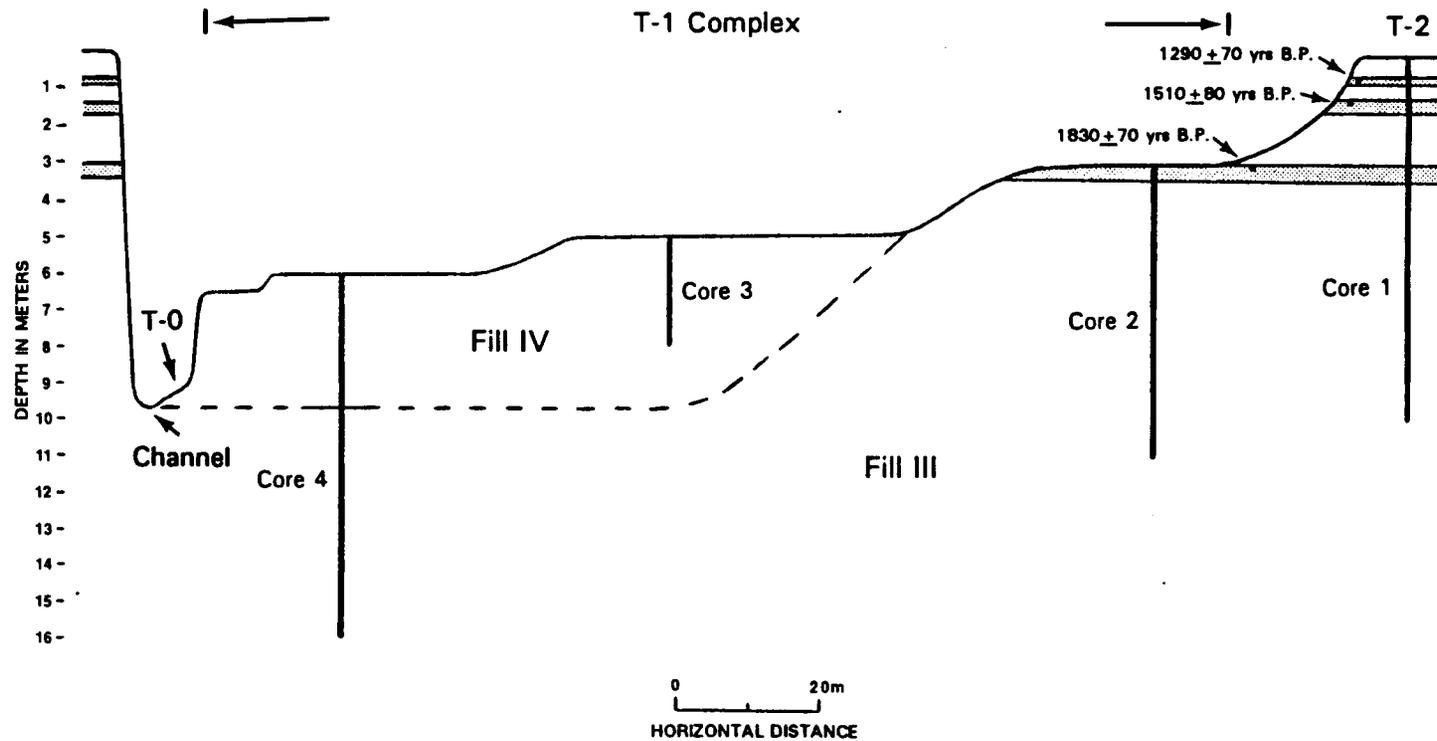
Figure 5:21   Cross-section of the T-2 terrace, T-1 terrace
               complex, and floodplain at the Paschal Site. The
               T-2 terrace is underlain by Fill III. The T-1
               terrace complex consists of at least 4 ill-defined
               surfaces created by stream entrenchment and lateral
               channel migration in the last 1,000 years. The
               uppermost surface in the T-1 terrace complex is a
               cut-terrace on Fill III alluvium, while the
               remaining surfaces are fill-top terraces underlain
               by Fill IV alluvium that caps Fill III.
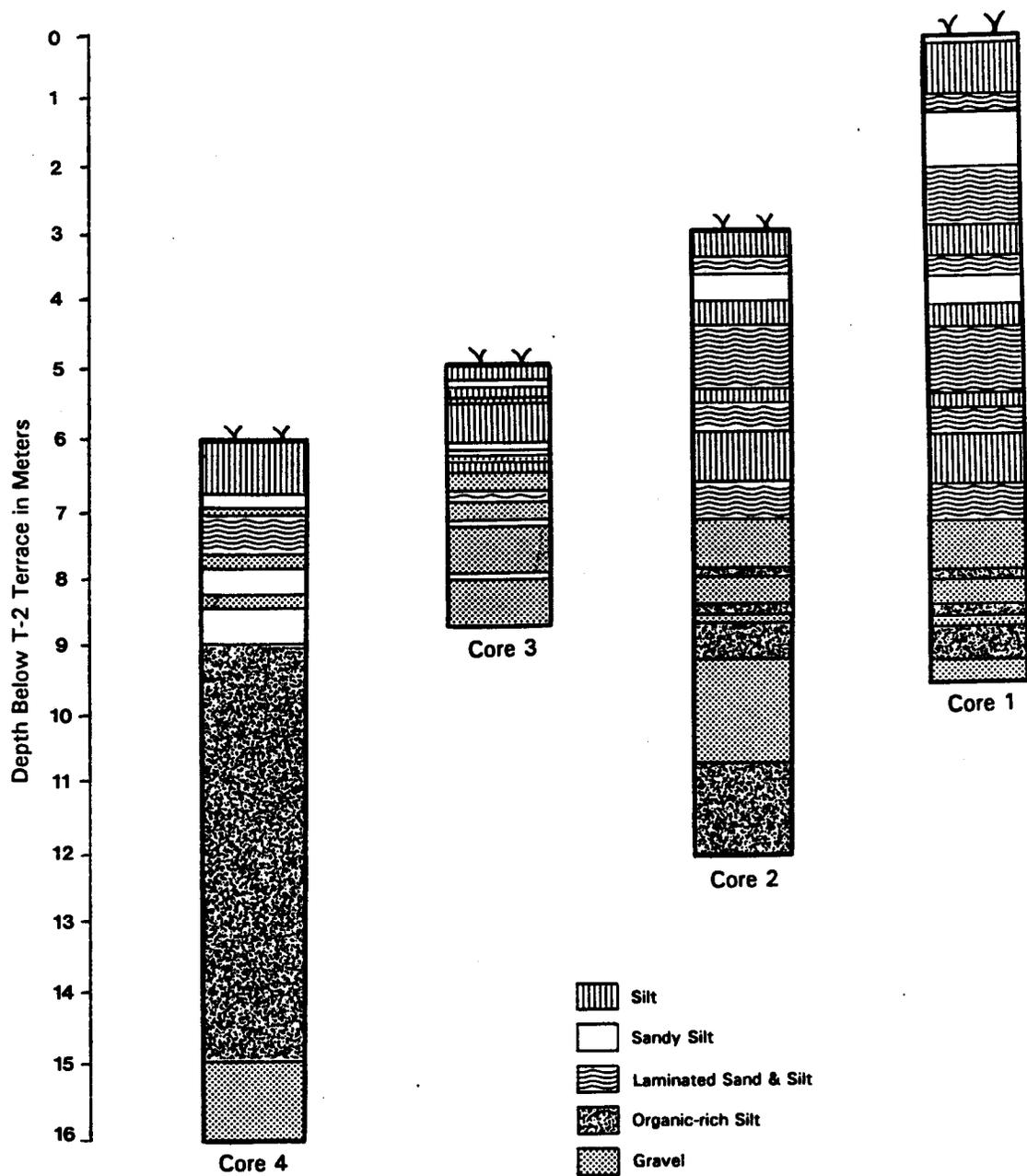
Figure 5:22   Stratigraphy of the T-2 and T-1 terrace complex at
the Paschal Site from cores illustrated in Fig. 20.
Fill III is exposed in Cores 1 and 2.   Core   3
consists of Fill IV deposits, which are alternating
layers of gravel and fine sediment. In Core 4, Fill
IV deposits are exposed from the surface to nearly
3 m, where the contact with the organic-rich silty
fill of Fill III is evident.

Table 5:1. Radiocarbon ages from the Wolf Creek basin (1).

Stream Site	Lab No.	C13 Corrected Age Age (RCYBP) (2)	Calibrated Age (3)	Source
*Luray Bridge	Beta-2162	2,060±160		Charcoal
*East Fork	Beta-2158	10,580±140		Humates (4Ab)
Sturgeon Site	Tx-6259	1,820±70	1,736	Humates (4Ab)
Paschal Site	Tx-7078	5,350±110	6,132	Organics
Paschal Site	Tx-7077	1,830±70	1,786	Humates (4Ab)
Paschal Site	Tx-7076	1,510±80	1,396	Humates (3Ab)
Paschal Site	Tx-7075	1,290±70	1,265	Humates (2Ab)
Schoen Site	Tx-6795	2,970±80	3,189	Organics
Schoen Site	Tx-6959	1,750±70	1,646	Humates (4Ab)
Schoen Site	Tx-6960	1,250±60	1,178	Humates (2Ab)
Naylor Site	Tx-6914	6,770±110	7,588	Humates (4Ab)
Naylor Site	Tx-6962	1,880±60	1,832	Humates (3Ab)
Naylor Site	Tx-7076	1,460±60	1,345	Humates (2Ab)

*Reported in Johnson and Martin (1987).

(1):   All ages from soils were obtained on the base soluble fraction
       soil humates of 2 kg samples, except for one soil sample
       analyzed at Beta Analytic in which total organics were
       assayed.

(2):   For a discussion of the C13 isotope correction procedure, see
       Stuiver and Polach (1977) and Taylor (1987)

(3):   Calibration from a conventional C13 corrected radiocarbon
       age to calibrated calendar years using a tree ring
       calibration curve. All calibrations reported here were based
       upon the 20-year atmospheric curve (see Linick et al. 1985,
       1986; Kromer et al. 1986; Mook 1986; and Stuiver et al.
       1986). Program used for calibration is discussed in Stuiver
       and Reimer (1986).

and sedimentary structures that are exposed in gravel quarries in the basin indicates that Wolf Creek functioned as a high-energy, braided stream during some of that time. Sometime toward the end of the Pleistocene, Wolf Creek entrenched up to 25 m as it eroded laterally. During this episode of erosion, most of the gravel fill was removed from the basin, leaving isolated fragments of the newly formed T-4 terrace on the valley wall and the T-3 strath terrace along the valley margins.

Still later, near the end of the Wisconsin or the beginning of the early Holocene, Wolf Creek began to fill its valley with generally coarse silt. Sedimentation of early-Holocene floodplains apparently was episodic with at least one period of stability and soil formation at about 6,700 yrs B.P.

During the middle Holocene (ca. 6,500 - 5,300 yrs. B.P.) lateral erosion in conjunction with stream entrenchment flushed most early-Holocene fill from the main valley of Wolf Creek and the lower reaches of the major tributaries. Although no early-Holocene fill is exposed in the larger valleys, it is likely preserved at depth beneath younger alluvium. In the extreme upper reaches of the basin's tributaries (e.g., Naylor Site), however, early- Holocene fill is exposed, suggesting that lateral migration was not as extensive in these parts of the basin as vertical entrenchment.

Following the interval of erosion during the middle Holocene, sediment began to accumulate again on floodplains in the basin between about 5,300 and 3,000 yrs B.P. Fill from this period of time is best exposed at the Paschal Site and indicates that floodplains during the early late Holocene formed by a combination of processes:

lateral accretion of gravel point bars and subsequent deposition of fine, often organic-rich, overbank sediments.

Between about 3,000 and 1,000 yrs B.P., alluviation in the main valley of Wolf Creek and the lower reaches of the major tributaries was episodic with intervening periods of floodplain stability and soil formation at about 1,800, 1,500, and 1,200 yrs B.P. Between these intervals of soil formation, alluviation in this portion of the basin (the sediment source was probably late-Pleistocene and Holocene loess) was extensive. Between approximately 3,000 to 2,000 yrs B.P., for example, nearly 3 m of alluvium accumulated at the Schoen Site.

In general, each of the three sedimentary units recognized in late-Holocene fill in the main valley of Wolf Creek is composed of well-laminated deposits of coarse silt and fine sand (Appendix A) that are poorly to very poorly sorted., suggesting that accumulation of these sediments occurred during intense overbank floods. Moderately-developed paleosols at about 1,800 and 1,500 yrs B.P. indicate that flooding was minimal for a relatively long period of time during those intervals. In contrast, a poorly-developed paleosol in the upper 1.0 m of late-Holocene fill suggests that a relatively brief period of stability occurred about 1,200 yrs. B.P. At the Schoen Site, this episode of soil formation was abruptly terminated when severe flooding buried the incipient paleosol with a thick layer of well-laminated sandy alluvium.

In the upper reaches of the small tributaries of the basin, periods of alluviation during the late Holocene were interrupted by both soil formation and erosion. Following the deposition of 1.5 m of late-Holocene alluvium at the Naylor Site, an episode of soil

formation occurred around 1,900 yrs B.P., when a moderately-developed soil formed. A short time after the soil developed, however, an interval of erosion occurred in this portion of the basin that removed the upper portion of the soil. Alluviation since that time and about 1,000 yrs B.P. was generally steady, interrupted only by an episode of soil formation approximately 1,300 yrs B.P. Like in the main valley of the basin, the sediments that compose the bulk of late-Holocene alluvium are well laminated and poorly to very poorly sorted, suggesting that alluviation in the upper reaches was due largely to intense overbank deposition during severe floods.

In the past 1,000 years the stream channels in the Wolf Creek basin have been entrenching. During this time, a complex of terraces has been created. The pervasive terrace in the basin, T-2, is underlain by Fill III. In places where channel entrenchment combined with extensive lateral channel migration (e.g., Paschal Site), at least four poorly-defined terraces (T-1 terrace complex) evolved beneath the T-2. The uppermost surface in the T-1 terrace complex is a fill-strath terrace while the remainder are fill-top terraces underlain by deposits of gravel and fine-grained alluvium (Fill IV). A poorly developed floodplain, underlain by a thin layer of fine-grained alluvium on a gravel bar, is currently being constructed adjacent to the stream channel.

Correlation with other results in the Kansas River basin

When comparing the late-Quaternary alluvial history of the Wolf Creek basin with the remainder of the Kansas River system, it is clear that broadly synchroneous events took place across the Kansas

River system as a whole, including the Wolf Creek basin. This pattern is similar to the one described by Knox (1983) and Johnson and Martin (1987) for the Midwest and for Kansas and adjoining states, respectively.

Like those studies, this correlation depends largely upon radiocarbon ages obtained from paleosols, which have long been recognized as discontinuities (e.g., Wendland 1982; Knox 1983; Johnson and Martin 1987), in valley fills of the Kansas River system. Figure 5:23 identifies the location of previous research localities in the Kansas River system, and Table 5:2 lists the radiocarbon ages that were obtained in those studies.

The oldest alluvial deposits in the Wolf Creek basin are the upland gravels exposed in quarries. Although the precise age of this fill is unknown, other research in the Kansas River system indicates they are likely pre-Wisconsin in age. Schultz and others (1951), for example, reported that upland gravels in the Lime Creek and Medicine Creek valleys were Kansan to early Illinoian in age. Similarly, the Menoken terrace, which is underlain by gravel fill in the lower Kansas River valley, was thought to be Kansan in age by Davis and Carlson (1952). Dort (1987) proposed that Menoken fill might consist, at least in part, of the Meade Formation. It appears that this gravelly fill was removed in the Wolf Creek basin in particular, and the Kansas River system in general, sometime during the late Pleistocene.

Because a number of radiocarbon ages have been obtained in the Kansas River system (Table 5:2), the patterns of alluviation, erosion, and soil formation during the Holocene have become
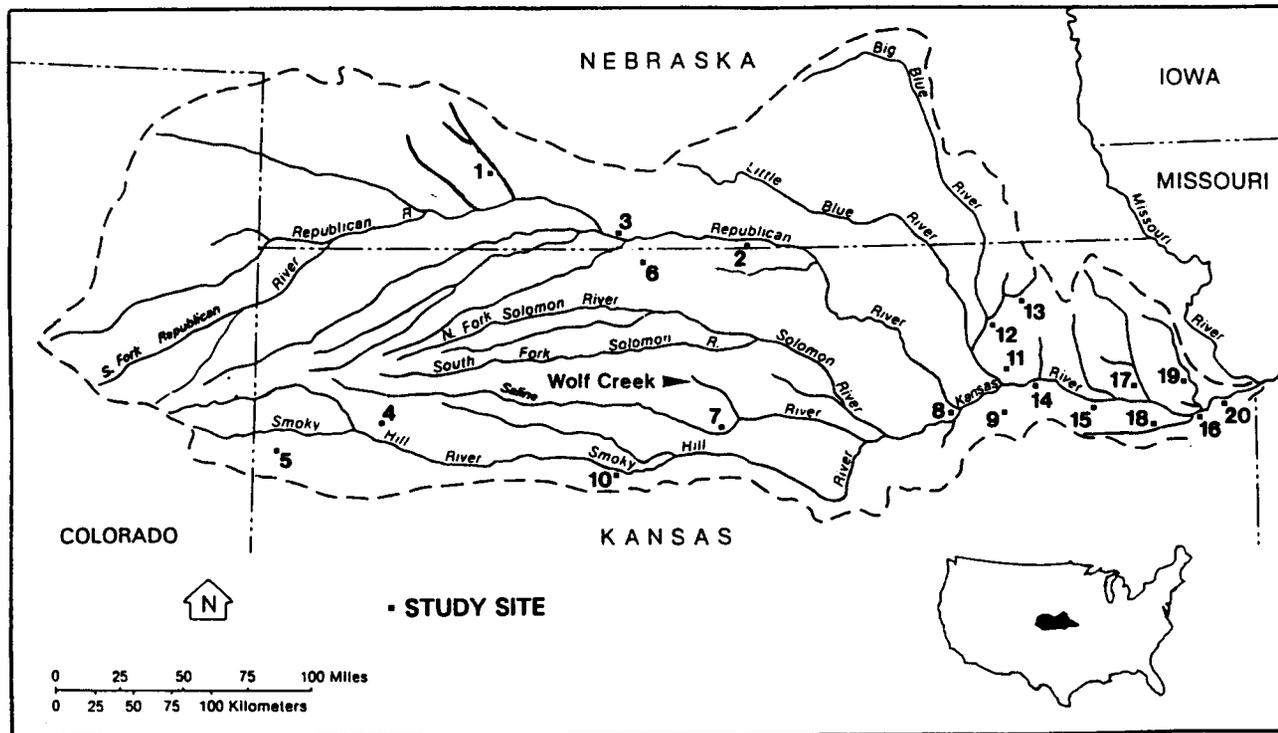
Figure 5:23   Map illustrating the locations of previous
              investigations with radiocarbon control of alluvial
              fills and terraces in the Kansas River system.

Table 5:2. Radiocarbon ages from alluvial deposits, Kansas River basin.

Map code*	Stream site	Age (RCYBP)	Source	Reference
1	Medicine Creek	10,493+1,500	charcoal	Schultz et
		9,880+670	charcoal	al. 1948
		9,167+600	charcoal	
		2,200+200	charcoal	
		420+160	charcoal	
1	Lime Creek	10,850+670	humates	May (pers.
		10,500+260	humates	comm.)
		10,090+450	humates	
		10,040+270	humates	
		9,120+510	humates	
		7,980+1000	humates	
		7,600+270	humates	
2	Louisa Creek	7,809+400	humates	Libby 1955
		7,426+600	humates	
		4,150+350	humates	
3	Harlan County Lake	3,050+60	humates	Martin 1990
		2,780+60	humates	
		2,020+60	humates	
4	12 Mile Creek	10,435+260	bone	Rogers and
		10,245+335		Martin 1984
5	Koehn-Schneider	11,170+170	humates	Johnson et
		11,050+180	bone	al. 1990
		9,800+120	humates	
		7,460+130	humates	
6	Deer Creek	4,120+270	humates	Johnson and
		1,890+90	charcoal	Martin 1987
7	Saline River (Wilson Lake)	5,090+60	humates	May 1986b
		1,740+70	humates	
8	Kansas River (Junction City)	1,210+100	humates	Johnson and Martin 1987
9	McDowell Creek	3,960+135	humates	
10	Smoky Hill River	5,110+70	humates	Mandel 1988
		4,490+80	humates	
		4,170+60	humates	
		3,680+60	humates	
		3,170+60	humates	
		2,620+80	humates	
		2,620+70	humates	
		2,090+60	humates	
		1,510+60	humates	
		930+60	humates	
		720+60	humates	
11	Elbo Creek	1,580+70	humates	Kurmann 1985
12	Big Blue River (14PO1)	6,285+145	charcoal	Schmits 1978
		5,850+135	charcoal	
		5,505+105	charcoal	
		5,355+70	charcoal	
		5,285+70	charcoal	

Table 5:2 (cont) Radiocarbon ages from alluvial deposits, Kansas River basin.

Map code*	Stream site	Age (RCYBP)	Source	Reference
12	Big Blue River	5,255+70	charcoal	Schmits 1978
	(14PO1)	5,240+70	charcoal	
		5,170+70	charcoal	
		5,160+70	charcoal	
		5,155+70	charcoal	
		5,140+65	charcoal	
		5,125+70	charcoal	
		5,080+65	charcoal	
		5,070+70	charcoal	
		5,030+65	charcoal	
		4,840+95	charcoal	
		2,480+55	charcoal	
		2,320+60	charcoal	
		1,090+80	charcoal	
13	Black Vermillion	5,320+790	charcoal	Schmits 1981
	River	4,215+180	charcoal	
		2,350+250	charcoal	
14	Kansas River	8,310+120	humates	Johnson and
	(Wamego bend)			Martin 1987
		7,250+110	humates	Bowman 1985
		4,950+120	charcoal	Johnson and
15	Kansas River	2,620+70	wood	Martin 1987
	(Meier sand pit)	1,670+55	wood	
16	Kansas River	785+130	wood	Dort 1987
	(Eudora bend)			
17	Delaware River	8,220+400	charcoal	Logan et al.
		5,710+100	charcoal	1989
		2,620110	charcoal	
		2,450+70	humates	
		1,200+60	charcoal	
		1,000+70	humates	
18	Wakarusa River	15,350+390	organics	Mandel 1988
19	Stranger Creek	4,260+50	wood	Logan 1985
20	(14LV1046)			
	Kansas River	10,430+130	humates	Holien 1982
	(Bonner Springs)	8,940+90	humates	Johnson and
				Martin 1987
		5,030+90	wood	Holien 1987
		4,290+310	humates	
		2,395+65	wood	
		1,210+50	humates	
		110+40	wood	

*See Figure 5:23 for the location of previous study sites in the Kansas River system.

relatively well established. Johnson and Martin (1987) recognized eight periods of floodplain stability in the large streams of the Kansas River system: 10,600-10,200, 8,900-8,300, 5,100-5,000, 4,300-4,000, 2,600-2,400, 2,100-1,600, and 1,200 yrs B.P. Only the periods of stability occurring at 10,600-10,200, 4,300-4,000 and 2,100-1,600 were recognized in both the large stream and small basins of the system. No periods of stability were recognized exclusively in the small basins of the system in their study. Table 5:3 illustrates how the radiocarbon ages obtained from paleosols in this study compare with those reported by Johnson and Martin (1987). Although some synchrony is realized between episodes of late-Holocene soil formation in the Wolf Creek basin and other localities in the Kansas River system, some differences are apparent (Table 5:3).

A number of variables must be considered when comparing radiocarbon ages from separate studies: was the soil truncated prior to burial; how was the paleosol sampled; how fresh was the sampled exposure; what fraction was dated; what radiocarbon laboratory was used; and was the age corrected for carbon 13 content? Each of the variables mentioned above may influence the age obtained from a paleosol. Of particular significance is the recent trend towards carbon 13 correction. Specifically, samples from soil humates that are uncorrected generally yield younger ages than those that have been corrected. For example, a sample was collected in this study at the Paschal Site from the upper .05 m of the 3Ab that yielded an uncorrected age of 1,390$\pm$80 yrs B.P. Upon correction, however, the age of the soil increased 120 years to 1,510$\pm$80 yrs B.P. (Tx-7076) (Table 6:1). Since many of ages obtained from the Kansas River

| From Johnson and Martin 1987 | | | This Study |
Large Streams	Tributaries	Both Positions	Wolf Creek
1,200			1,250±60
			1,460±60
			1,510±80
			1,750±70
		2,100-1,600	1,820±70
			1,830±60
			1,880±60
2,600-2,400			
		4,300-4,000	
5,100-5,000			
			6,770±110
7,250			
8,900-8,300			
		10,600-10,200	

Table 5:3   Time-space Distribution of Paleosols, RCYBP, Kansas
River system.   Range of ages in Large Streams,
Tributaries, and Both Positions are from Johnson and
Martin 1987

system are uncorrected (Johnson, personal communication), an age by age comparison may be biased at present.

Even though an absolute correlation thus far is uncertain, the results indicate that a valid comparison, based upon radiocarbon ages, of Holocene stream behavior in the Wolf Creek basin and the Kansas River system can be made. Evidence across the Kansas River system indicates that as stream systems filled their valleys during the early Holocene, episodes of soil formation occurred at 10,500 yrs B.P. in both the major streams and small tributaries and betweem 8,900 and 8,300 yrs B.P., and at 7,250 yrs B.P. in the major streams (Johnson and Martin 1987; Johnson and Logan 1990). A radiocarbon age of 10,580±110 yrs B.P. (Beta-2158) obtained in 1980 was reported in the Wolf Creek basin by Johnson and Martin (1987) but appears to be inaccurate since the same paleosol yielded an age of 6,770±110 yrs B.P. (Tx-6914) in this study. Regardless, the recognition of soil formation at about 6,700 yrs B.P., following an interval of alluviation, does indicate that events in the Wolf Creek basin during the early Holocene were roughly synchroneous with the remainder of the Kansas River system (Table 5:3).

Following the episode of valley filling in the Wolf Creek basin during the early Holocene, an intense interval of erosion occurred sometime during the middle Holocene that removed most of the early-Holocene fill in the basin, except for in the upper reaches of small tributaries. Several studies suggest that the middle Holocene was a time of stream-system instability in the Kansas River system (Johnson and Martin 1987).

According to Johnson and Logan (1986), for example, nearly all

of early-Holocene fill in Stranger Creek basin was removed during the middle Holocene. In that basin, isolated remnants of early-Holocene fill can be found in the lower reaches of small tributaries. Similarly, in the Republican River basin, Martin (1990) suggested that up to 10 m of entrenchment occurred in the vicinity of Harlan County Reservoir between 4,500 and 3,700 yrs B.P.

Although the period of mid-Holocene erosion has been recognized in the major streams of the Kansas River system (Johnson and Martin 1987), it was not nearly as severe in these streams. In the Medicine Creek drainage, for example, the Stockville Terrace, which is underlain by early-Holocene fill, is the most extensive terrace in that basin (Brice 1966). Similarly, the Newman Terrace, which is the T-2 terrace in the Kansas River valley, is well preserved throughout the lower portion of that valley. The youngest paleosol within Newman fill has yielded a radiocarbon age of about 4,900 yrs B.P., suggesting that all of the early-Holocene fill is preserved beneath the surface and that mid-Holocene erosion occured somewhat later in the Kansas River valley than the Wolf Creek basin.

Stratigraphic and radiocarbon evidence from the Wolf Creek basin indicates that, following the episode of mid-Holocene erosion, the basins valleys filled with sediment between about 5,300 and 1,000 yrs B.P., followed by stream entrenchment since that time. This episode of valley filling and entrenchment, which created the T-2 terrace, correlates well with events elsewhere in the Kansas River system.

According to Johnson (1985) and Johnson and Logan (1990), the Kansas River valley filled with sediment between about 4,300 and 1,000 yrs B.P., when entrenchment created the Holliday Terrace

Complex. In the Black Vermillion River basin, a tributary to the Big Blue River, Schmits (1981) suggested that sediment accumulated between 5,000 and 2,000 yrs B.P., when entrenchment created the T-1 terrace. Mandel (1988) reported that T-1 fill accumulated in major valleys of the Smoky Hill system, just south of the Wolf Creek basin, between 4,500 and 2,600 yrs B.P., and in small valleys betweeen 4,300 and 1,500 yrs B.P., when entrenchment elevated the former floodplain. To the north, the Republican River valley filled with sediment between 3,700 and 1,200 yrs B.P. Since that time, the Republican River has entrenched nearly 7 m (Martin 1990).

In other parts of the Kansas River system an episode of soil formation has been recognized in both major streams and tributaries at approximately 4,200 yrs B.P. (Johnson and Martin 1987), an episode not encountered in this study. This may not be surprising, since this period of stability was characterized by Johnson and Martin (1987) as moderate in intensity. An episode of soil formation at 2,500 yrs B.P., recognized exclusively in the major valleys thus far, was not encountered in this study.

According to Johnson and Martin (1987), a strong period of soil formation interrupted late-Holocene alluviation at about 1,800 yrs B.P. in both large streams and small basins in the Kansas River system. Table 5:3 illustrates that this episode of floodplain stability is recognized throughout the Wolf Creek basin, as samples collected at four localities yielded radiocarbon ages of approximately 1,800 yrs B.P. (Table 5:3).

Another episode of soil formation was recognized at two localities in the Wolf Creek basin at about 1,500 yrs B.P. (Table

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5:3). Although this episode of soil formation was not recognized by Johnson and Martin (1987) in other parts of the Kansas River system, it was reported by Mandel (1988) in small tributaries of the Smoky Hill River basin, suggesting that this interval of floodplain stability may be associated with small tributaries in the central Kansas River system.

The youngest episode of soil formation recognized in the Wolf Creek basin in this study was at 1,200 yrs B.P., at two localities (Table 5:3). Prior to this study, this interval of landscape stability was unrecognized in the small tributaries of the Kansas River system. The intensity of this event does appear to vary between major streams in the Kansas River system and those in the Wolf Creek basin, however. According to Johnson and Martin (1987), this episode of soil formation was characterized as strong in its intensity in the major streams of the system. In the Wolf Creek basin, in contrast, it was clearly weak in its intensity; moreover, it was completely unrecognized in the upper reaches of small tributaries in the basin.

In summary, although there is not an episode-to-episode correlation between events in the Wolf Creek basin and the rest of the Kansas River system during the late Quaternary, it is apparent that a general pattern in the timing of fluvial events is realized. In all parts of the Kansas River system, including the Wolf Creek basin, deposits of upland gravels accumulated and were largely removed during the Pleistocene. During the early Holocene, stream valleys across the basin apparently filled with sediment between episodes of soil formation. Sometime during the middle Holocene, a

period of lateral cutting and channel entrenchment removed a portion of early-Holocene fill in major valleys, and most of it in small tributaries such as Wolf Creek. Valley filling became pervasive again during the late Holocene between episodes of soil formation, some of which have been recognized in the Wolf Creek basin. Since about 1,000 yrs B.P., all of the channels in the Kansas River system, including those within the Wolf Creek basin, have been actively entrenching.

In short, the similarity in alluvial stratigraphic records across the Kansas River basin suggests that broadly similar activity occurred during the late Quaternary. The forces that may be responsible for these patterns may include the following possibilities: baselevel changes, tectonic activity, and climatic adjustments.

Stream Responses to Baselevel Changes

Aggradation and entrenchment in a drainage basin can be caused by raising and lowering of baselevel, respectively (Schumm 1977). Considerable research has focused on the relationship of baselevel fluctuations to stream behavior (e.g., Schumm and Parker 1973; Schumm 1977; Chorley et al. 1984). Schumm (1977) demonstrated that a drop in baselevel creates a knickpoint that rejuvenates the tributaries in the system as it migrates upstream. Schumm and Parker (1973) and Schumm (1977) have experimentally demonstrated that a drop in baselevel can result in progressive incision upstream, creating a terrace. Similarly, as eroded sediment fills higher order valleys, baselevel in those valleys rises, causing progressive alluviation in

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lower order drainages.

Although sea-level fluctuations probably did not affect stream systems this deep within the continental interior (Dort 1983), it is likely that the Wolf Creek basin was influenced by local baselevel changes due to complex responses (e.g., Schumm and Parker 1973; Schumm 1977) in the Saline River basin in particular, and the lower Kansas River system in general, during the late Quaternary. It is quite possible, in fact, that the extreme late-Pleistocene entrenchment(s) that produced the T-4 and T-3 terraces was baselevel related.

Stream Responses to Tectonism

Tectonism, including uplift, subsidence, lateral displacement, and warping of the earths crust, may produce channel incision, aggradation, and lateral channel migration (Schumm 1977). Generally, tectonic activity is not commonly considered, however, as a behavior-forcing variable in Great Plains stream systems since the rate of vertical movement of the crust averages less than 1mm/year (Schumm 1977).

Recent evidence indicates, however, that the Wolf Creek basin may have been affected to some extent by tectonic activity in the area during the late Quaternary. Specifically, the basin lies on the northeastern flank of the Central Kansas Uplift (Fig. 5:24), a buried Precambrian anticline in central Kansas (Merriam 1963; Steeples et al. 1990). According to Merriam (1963), a number of subsidiary structures are present along the crest and flanks of the uplift, including the Ellsworth Anticline, Fairport Anticline, Pawnee Rib,
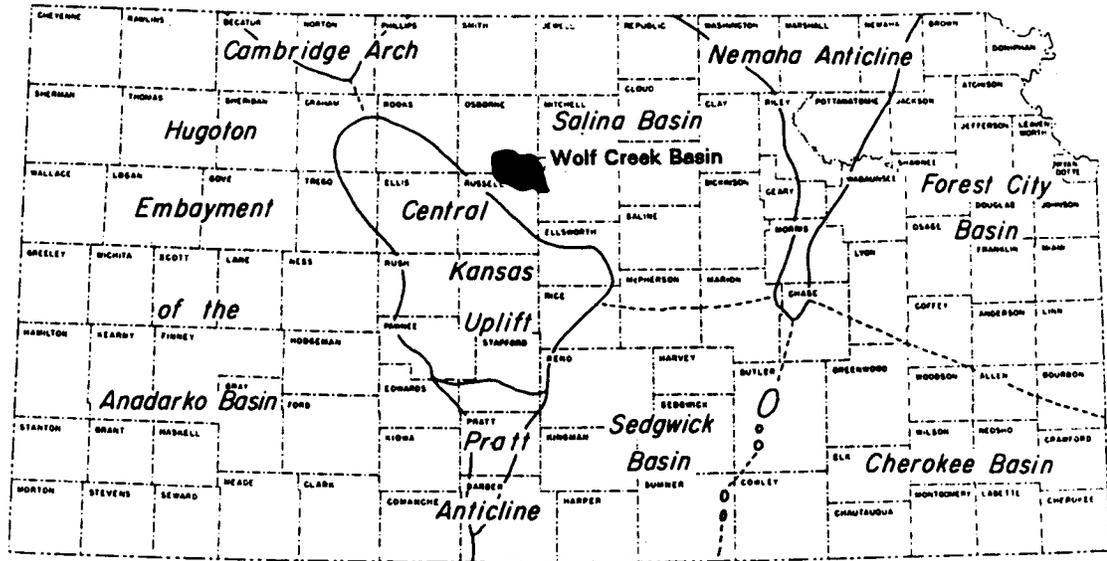
Figure 5:24   Location of the Central Kansas Uplift in the state
              of Kansas.   The Central Kansas Uplift is a buried
              pre-Cambrian anticline that is seismically active.
              The Wolf Creek basin is located on the northeastern
              flank of structure, suggesting that tectonism may
              be a factor in the development of the basin (from
              Merriam 1963).

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Rush Rib, and the Russell Rib.

Although the Nemaha Ridge, a buried anticline of similar age, structure, and lithology in eastern Kansas, has been the focus of most seismic research in the state (a felt earthquake in 1867 registered 5.5 on the Richter scale at Manhattan), Steeples and others (1990) suggested that the Central Kansas Uplift has not been properly recognized as a source of earthquake activity. In fact, they argue that the Central Kansas Uplift, like the Nemaha Ridge, is capable of generating a possible 6.5 magnitude earthquake every 1,000 years.

In support of this assertion, Martin (personal communication) has recognized at Harlan County Reservoir in Nebraska a fault in loess on the valley flank of the Republican River. At this locality, nearly 2 m of vertical displacement is observable in Late-Wisconsin loess.

From 1977 to 1989, the Kansas Geological Survey operated a microearthquake seismograph network in portions of Kansas and Nebraska, including the area of the Central Kansas Uplift. Results indicate that earthquakes along the structure range in magnitude from 0.8 to 4.0 (Steeples et al. 1990). Although most of the events occurred in adjacent Ellis, Rooks, and Graham Counties, several were recorded in the vicinity of the Wolf Creek basin (Fig. 5:25).

Despite the suggested incidence of tectonism in the vicinity of the Wolf Creek basin throughout the late Quaternary, the degree of influence upon the basin cannot be determined. According to Steeples (personal communication), tectonic activity may have contributed to the abandonment of the "Wilson Channel" when an ancestor of Wolf
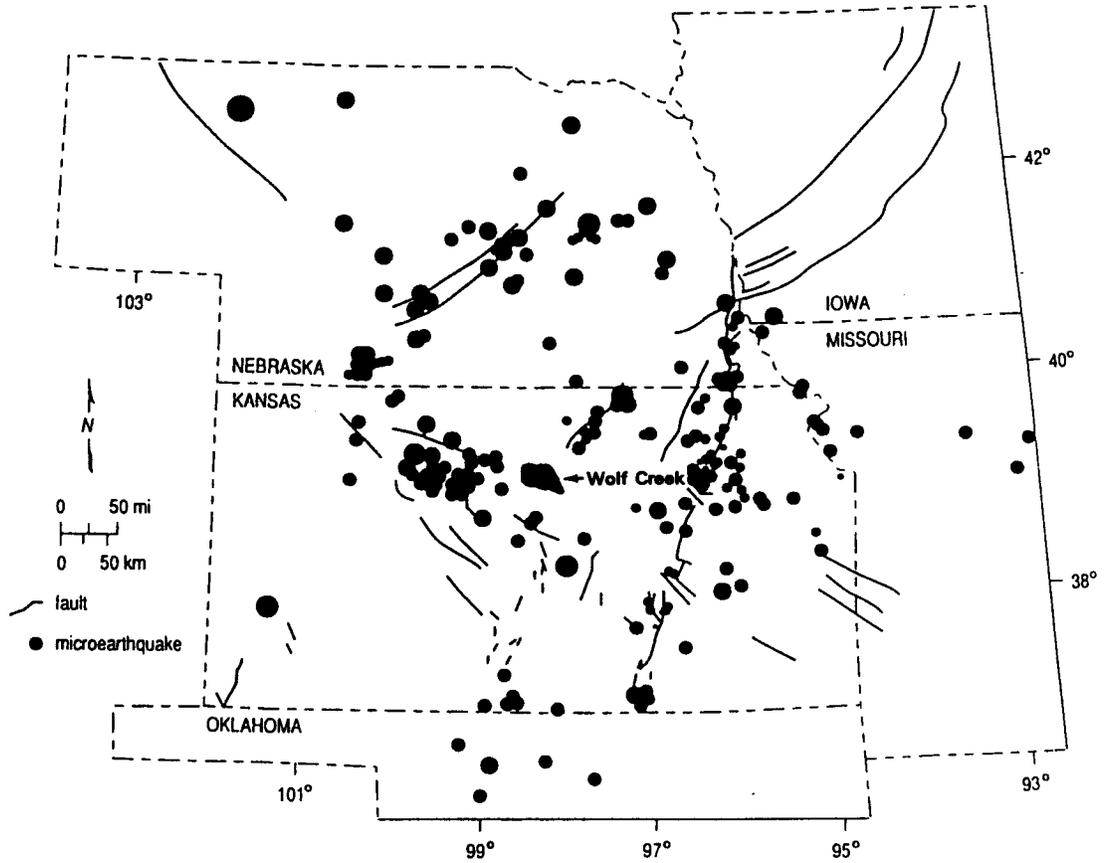
Figure 5:25 Microearthquakes in Kansas and Nebraska, 1977-1989. Results indicate that several earthquakes, ranging in magnitude from 0.8 to 4.0, occured along the Central Kansas Uplift (from Steeples et al. 1990).

Creek captured the Saline River sometime during the early Pleistocene.

Stream Responses to Climate Change

Since excess water is removed from a drainage basin via stream systems, it logically follows that they are sensitive to the amount and frequency of precipitation imposed upon the system. According to Knox (1983), the evolution of late-Quaternary river systems can be evaluated in relation to both the direct effects of climatic events and the indirect effects of vegetation as it controls runoff and erosion. Specifically, it is apparent that the combined effects of climate and vegetation influence the portion of runoff in a drainage basin derived from overland flow (surface runoff), which is the principal contributor to flood flow and is the main factor responsible for erosion and sedimentation in river systems.

The ability of streams to maintain an equilibrium state, for example, depends upon the recurrence interval of floods, especially large floods (Knox 1976). Specifically, cross-sectional areas of alluvial channels tend to be most strongly related to the water volume during frequently recurring flood flows (Wolman and Miller 1960; Knox 1983). Because the Wolf Creek basin is a relatively small system (i.e., one severe storm can blanket the entire drainage), it was likely very susceptible to variations in flood magnitude during the late Quaternary.

Another climate-driven variable is the annual and seasonal distribution of rainfall that falls in a basin. Langbein and Schumm (1958) recognized that variability around a 30 cm mean in average

annual precipitation greatly influences the amount of surface runoff and sediment yield. Since the Wolf Creek basin lies at the western edge of the tall grass prairie community, severe decreases in annual rainfall during the late Quaternary probably influenced vegatative cover and therefore sediment yields a great deal. Specifically, a decrease in annual precipitation decreased vegetative cover, which, in turn, increased surface runoff and sediment yields in the drainage basin.

Growing evidence indicates that long-term changes in climate during the late Quaternary, specifically the Holocene, have been common (e.g., Bryson and Wendland 1967; Wendland and Bryson 1974; Knox 1983; Kutzbach 1985; COHMAP Members 1988). Early research (e.g., Antevs 1955) proposed that changes in late-Quaternary climates since the late Wisconsin followed a tripartite division: cool and moist during the early Holocene, warm and dry during the middle Holocene, and cool and moist during the late Holocene. According to Wendland and Bryson (1974), this subdivision of climate change is much too simplistic since atmospheric circulation patterns are constantly in flux. Instead, they suggested that changes in Holocene climates in North America were common, were separated by rapid transitions, and correlated well with the Blytt-Sernander chronology (Fig. 5:26) described by Zuener (1952).

Although the focus of this study is not a detailed chronology of late-Quaternary climates, a general treatment of climate change with specific references to the Blytt-Sernander chronology is appropriate as it relates to the Wolf Creek basin. A number of reports (e.g., Wendland and Bryson 1974; Knox 1983; Kutzbach 1985; COHMAP Members
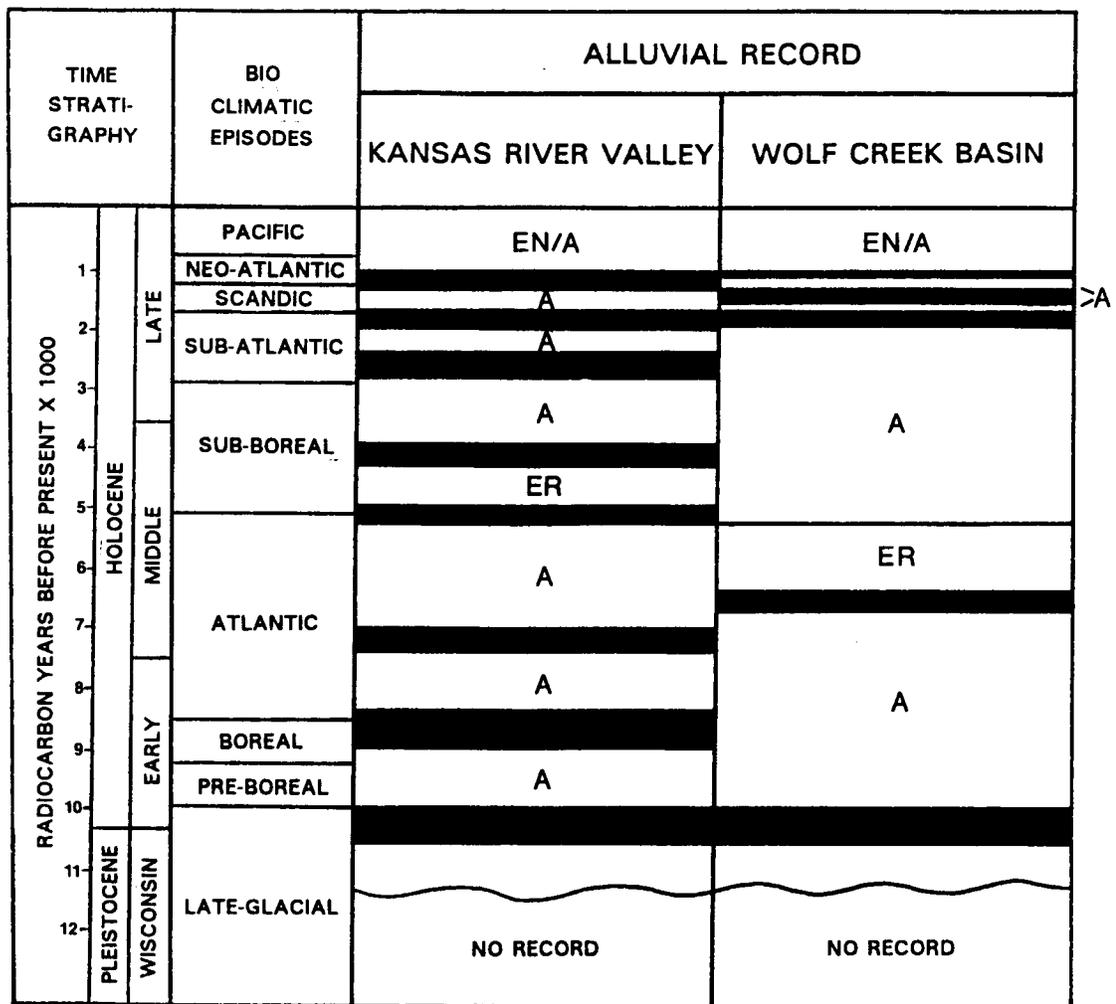
Figure 5:26   Bio-climatic episodes of the Blytt-Sernander
chronology and the geomorphic record of the Kansas
River valley and the Wolf Creek basin.

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1988) indicate that late-Quaternary climates can be generally viewed in two parts: (1) a phase during the late-Wisconsin and early Holocene when atmospheric circulation was influenced by the presence and subsequent disintegration of the Laurentide ice sheet and (2) the time (middle and late Holocene) since the Laurentide ice sheet was the dominant influence upon atmospheric ciruculation patterns in North America.

Atmospheric general circulation models (AGCM's) indicate that between the late-Wisconsin glacial maximum at 18 ka and and its retreat about 9 ka the Laurentide ice sheet was the dominant surface feature influencing the North American climate. From 18 to 15 ka there was essentially no change in atmospheric circulation patterns (Kutzbach 1985, 1987; COHMAP members 1988). During that time, the westerly jet stream was split to the north and south of the ice sheet in both summer and winter by a strong glacial anticyclone (Fig. 5:27). As a result, upper atmospheric airflow, which would have affected the Wolf Creek basin, consisted of relatively cool and dry air from Canada (Knox 1983). According to Kutzbach (1981, 1987), the presence of pluvial lakes in the Southwest during this time indicates that storm tracks responsible for frequent high-intensity rains were pushed far to the south at that time.

Between 15 and 9 ka, a number of variables (e.g., increased tilt of the earth, less surface albedo, July perihelion) increased summertime solar radiation sufficiently that the Laurentide ice sheet decreased in size. In turn, the westerly jet stream weakened in summer, and was no longer split, even in winter (Kutzbach 1985; COHMAP members 1988). The circulation over the Wolf Creek basin

Figure 5:27   Atmospheric circulation patterns in North America
              at 18,000 yrs B.P.   During this time, a strong
              glacial anticyclone was present over the Laurentide
              Ice Sheet, forcing a split in the westerly jet
              stream that resulted cool and dry Canadian air over
              the Wolf Creek basin (modified from COHMAP members
              1988).

became dominantly zonal during this time, as Canadian air was replaced by dry Pacific air (Fig. 5:28). Under these conditions, infrequent but intense convective storms produced severe flash floods in the basin (Knox 1983). Because vegetative cover was reduced, sediment yields were high, resulting in the general alluviation in the basin during the early Holocene.

By 9,000 yrs B.P., a major shift in climate was underway in the Wolf Creek basin. Perihelion was in July, and this, in conjunction with a decrease in the earth's tilt (obliquity 24.23°), increased summer solar radiation at the top of the atmosphere to about 8 percent greater than at present (Kutzbach 1981, 1985, 1987).

As the Laurentide ice sheet continued to waste, the steep north-south temperature gradient continued to weaken, prompting further zonal flow dynamics (Knox 1983). These factors triggered the generally warm and dry conditions of the Altithermal that prevailed in the central United States from about 8,000 to 5,000 yrs B.P. (Antevs 1955; Knox 1983; Kutzbach 1985, 1987; COHMAP members 1988). A period of soil formation in the Wolf Creek basin was recognized during this time, around 6,700 yrs B.P, which, according to Wendland and Bryson (1974) correlates with a minor discontinuity in the Atlantic bioclimatic episode of the Blytt-Sernander chronology (Fig. 5:26).

By about 6,000 yrs ago, mean summer temperatures in the Wolf Creek basin were 2° to 4°C higher than at present (COHMAP members 1988). In addition, annual precipitation was much as 25 percent less than today (Bartlein et al. 1984; Kutzbach 1987). These factors taken together caused prairies to expand to their maximum in the
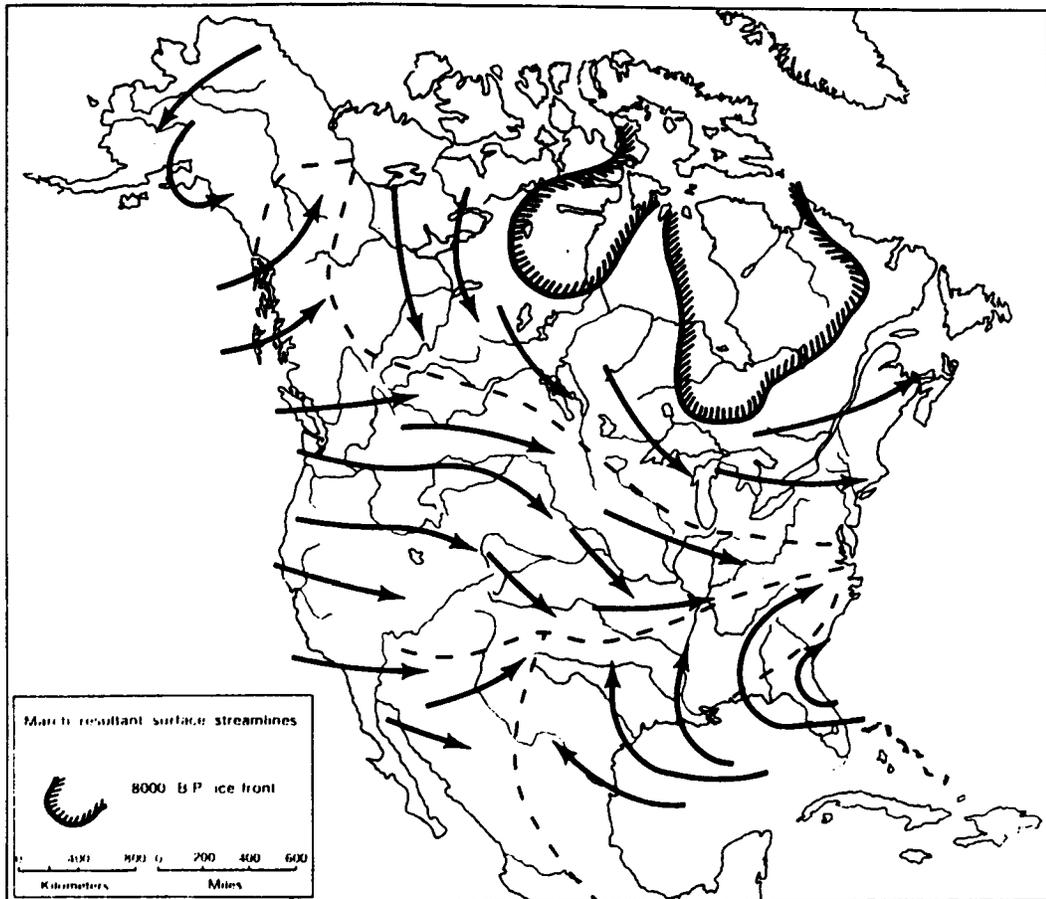
Figure 5:28   Atmospheric circulation patterns in North America
               between 15,000 and 9,000 yrs B.P. Retreat of the
               Laurentide Ice Sheet caused the westerly jet stream
               to merge, resulting in dominantely zonal flow over
               the Wolf Creek basin (from Knox 1983).

Midwest (Webb et al. 1987; COHMAP members 1988). Moreover, the data suggest that stream systems throughout the Midwest were inherently unstable during this period (Knox 1983; Johnson and Martin 1987).

As a result, the middle Holocene probably represents the most unstable episode in the Wolf Creek basin during the Holocene. This hypothesis is supported by the lack of a recognizable period of soil formation during that time, a void that may be explained by the following cause: a small basin such as Wolf Creek could be entirely covered by a single, but infrequent convective storm that caused massive erosion along channelways, high sediment concentrations from poorly protected hillslopes, and subsequent alluviation in stream valleys.

After about 6,000 yrs B.P., the influence of the Laurentide ice sheet on North American atmospheric circulation patterns disappeared completely (Kutzbach 1987; Webb et al. 1987; COHMAP members 1988). As a result, the steep north-south temperature gradient that had prevailed during the early Holocene, and somewhat less in the middle Holocene, was replaced by a more moderate one that prompted deeper penetration (i.e., meridional flow) of both polar and tropical air masses into the continental interior (Fig. 5:29; Knox 1983).

According to Knox (1983), the increased dominance of meridional flow in the Midwest during the late Holocene frequently resulted in the development of intense cyclones and long-duration storms as contrasting air masses collided over the region. Mean annual precipitation and frequency of large floods probably increased dramatically in the Wolf Creek basin when the frontal zone was
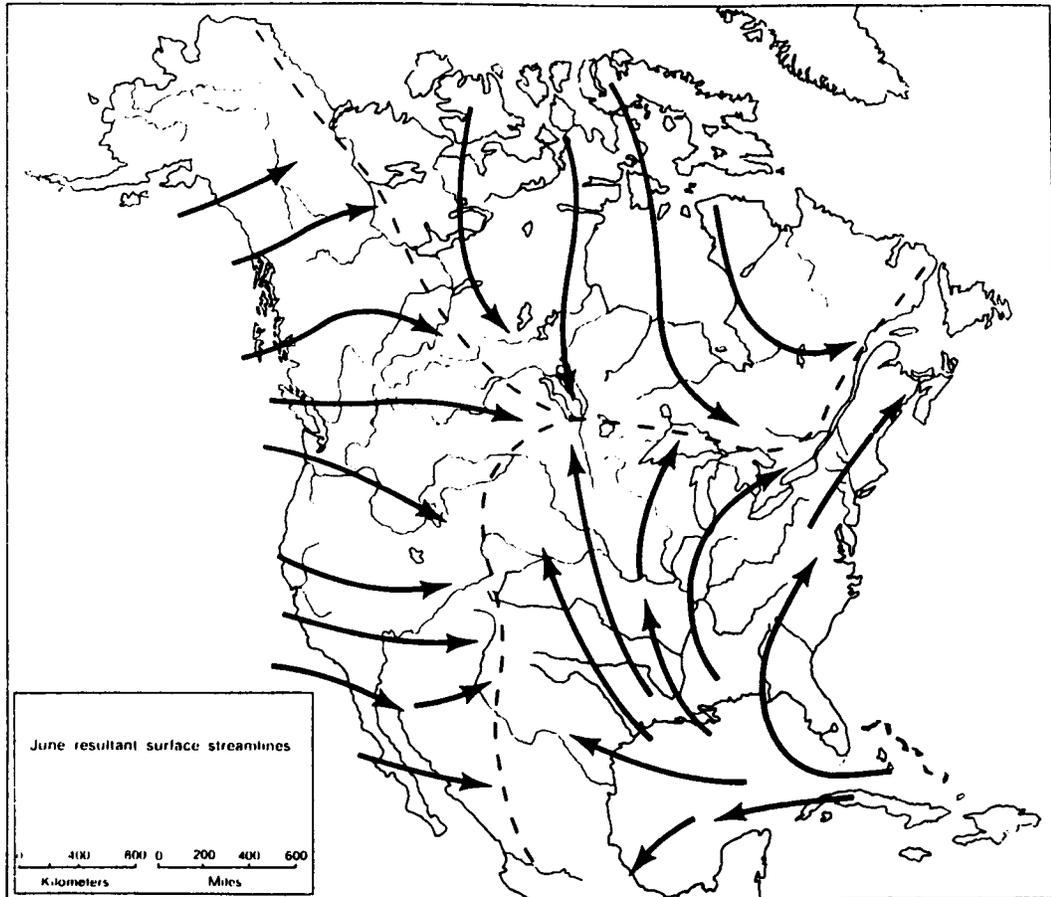
Figure 5:29   Atmospheric circulation patterns in North America
from 6,000 yrs B.P. to present. As the Laurentide
Ice Sheet disappeared, circulation became more
meridional, resulting in the collision of cool and
dry Canadian air with air from the Gulf of Mexico
over the Wolf Creek basin (from Knox 1983).

overhead, causing significant adjustments within the system.

Moreover, the change from the dominantly xeric conditions of the middle Holocene to the more mesic environments of the late Holocene likely caused a shift from short- or mid-grass to tall-grass prairie; consequently, hillslopes were better protected. As a result, upland sediment yields were significantly reduced and erosion was accomplished by lateral channel migration and vertical incision (Knox 1983). These changes probably accounted for the extensive erosion and flushing that occurred in the Wolf Creek basin at the end of the middle Holocene.

Although late-Holocene climates can be generally characterized as relatively cool and moist, Wendland and Bryson (1974) suggested that some short-term fluctuations did occur. According to Knox (1983), periodic shifts to relatively drier conditions could have induced the waves of extensive valley filling, punctuated by floodplain stability, seen in the Wolf Creek basin between 5,300 and 1,000 yrs B.P. Not coincidently, episodes of soil formation at about 1,800, 1,500, and 1,200 yrs B.P. correlate reasonably well with the end of the Sub-Atlantic and Scandic bioclimatic episodes, of the Blytt-Sernander chronology, respectively (Fig. 5:26).

A study conducted by Hall (1990) in Oklahoma supports the assertion that short-term fluctuations in climate occurred during the late Holocene, although somewhat different results were obtained. He reported that the Copan Paleosol developed during slow alluviation within a relatively moist period between 2,000 and 1,000 yrs B.P. Following soil development, a 200-year period of regional valley entrenchment occurred, which Hall (1990) postulates was a response to

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drier conditions.

In summary, the evidence strongly suggests that late-Quaternary events within the Wolf Creek basin were largely controlled by the direct and indirect effects of climatic variability. According to Knox (1983), the general pattern of regional synchrony in midwestern alluvial chronologies during the Holocene reflects the influence of climate as an external variable on those systems. Although events in the Wolf Creek basin were not completely in phase with other localities in the Kansas River system, this study has clearly demonstrated that a pattern of synchrony is present throughout the Kansas River system as a whole, including the Wolf Creek basin. Any differences that exist can likely be attributed to short-term fluctuations in local climate and the complex response of drainage basins within the Kansas River system and inconsistencies in chronology development.

CHAPTER VI
SUMMARY

Geomorphic research in the Wolf Creek basin indicates that late-Quaternary events in this small drainage correlate reasonably well with other localities in the Kansas River system. Although short-term discontinuities (i.e., soil formation) were not always in phase, long-term periods of fluvial behavior (i.e., alluviation, erosion) are similar. This unmistakeable pattern of regional synchrony, similar to that described by Knox (1983), strongly suggests that Wolf Creek responded to the same long-term fluctuations in climate that affected the Kansas River system as a whole during the late Quaternary. Short-term variability, in contrast, was likely a function of local climate changes and/or the complex response of Wolf Creek to other events within the Kansas River system.

This study recognizes four valley fills and terraces in the Wolf Creek basin. Fill I consists of upland gravel deposits that underlie the T-4 terrace which likely accumulated before the Wisconsin when Wolf Creek functioned as a high-energy braided stream. Sometime toward the end of the Pleistocene, Wolf Creek entrenched up to 25 m, when the T-4 terrace became a terrace and the T-3 surface, which is a strath terrace on Dakota Sandstone along the valley margins, was created.

During the very beginning of the Holocene, the valleys in the Wolf Creek basin began to fill with silty alluvium (Fill II). This episode of alluviation, which has been well documented in other streams in the Kansas River system (Johnson and Logan 1990), continued until between 6,700 and 5,300 yrs B.P., but was interrupted

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by at least one episode of soil formation that terminated around 6,700 yrs B.P.

Sometime during the middle Holocene (6,700 - 5,300 yrs B.P), an extensive interval of erosion occurred in the Wolf Creek basin, one that removed most of Fill II from the large streams in the basin, and left only scattered remnants exposed in the upper reaches of small tributaries. This intensive erosional interval correlates well with the Altithermal that has been recognized at other localities in the Kansas River system (e.g., Johnson and Martin 1987; Johnson and Logan 1990; Martin 1990).

Following the erosional interval of the middle Holocene, a period of extensive, but episodic, alluviation began in the basin that lasted from about 5,300 to 1,000 yrs B.P.; this basin-wide alluviation has been recognized at other localities in the Kansas River basin (e.g. Schmits 1980; Johnson and Martin 1987; Mandel 1988). Approximately 5,300 yrs B.P., floodplains in the basin were constructed by a combination of processes: lateral accretion of coarse point bar gravels that were subsequently buried by fine overbank sediments. As alluviation proceeded, up to 9 m of silty alluvium (Fill III) filled the valleys of the Wolf Creek basin. Alluviation was interrupted by three episodes of brief floodplain stability, reflected by moderate to poorly formed soils, about 1,800, 1,500, and 1,200 yrs B.P. Following each period of relative stability, intensive flooding and alluviation rapidly buried the formerly stable land surfaces.

Since about 1,000 yrs B.P., the streams in the Wolf Creek basin have been rapidly entrenching in much the same fashion as other

streams in the Kansas River system (e.g. Schmits 1980; Johnson and Martin 1987; Mandel 1988; Martin 1990). As entrenchment has progressed in conjunction with some lateral channel migration, the T-1 terrace complex, which consists of at least four ill-defined surfaces, has been forming on the insides of meander bends. The uppermost of these surfaces is a fill-strath terrace underlain by Fill III. The remaining surfaces are fill-top terraces that are underlain by the reworked gravels and silts (Fill IV) from Fill III deposits, indicating that floodplain construction in the last 1,000 yrs has been through the combination of lateral accretion and overbank deposition. Because the streams in the basin have largely entrenched the past 1,000 years, a poorly developed floodplain has developed adjacent to the stream in isolated locations.

Future Research

The results of this study in the Wolf Creek basin have raised some interesting questions regarding the direction of future research. The following discussion examines how this study could be applied to further work, specifically from both a geomorphic and archeological perspective.

Geomorphic Research

Because previous geomorphic research in small tributaries of the Kansas River system was generally site specific (e.g., archeologically oriented, one or more short reaches of a stream), a detailed correlation of small and large streams in the drainage was impossible. Thus, a primary goal of this study was to compare the findings from the Wolf Creek basin with those from other localities

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in the Kansas River system. As a result, this study may serve as benchmark for the late-Quaternary behavior of small streams in the Kansas River system.

Beyond this study, further comparison is necessary between small tributaries and large streams in the Kansas River system for the relationships between these systems to be better understood across the drainage. According to Johnson and Logan (1990), it appears that alluvial fills in stream valleys of the Kansas River system decrease in age upstream. A better understanding of this pattern might emerge if a series of small basins, similar in size to Wolf Creek, were studied across the Kansas River system. For example, a previously unreported paleosol in small tributaries of the Kansas River system at 1,200 yrs B.P. was recognized in the Wolf Creek basin; this paleosol has been recognized in other small basins in the central United States (e.g., Hall 1990; Mandel 1990). If a series of small basins were studied across the Kansas River system, it might be determined if and where this paleosol disappears in the western portion of the drainage.

In an effort to better correlate the alluvial chronology in the Kansas River system, future research should be based upon radiocarbon ages that have been corrected for C-13 content. In Chapter 5 of this study it was stated that a variety of factors can influence the accuracy of a radiocarbon age derived from a paleosol (e.g., truncation, sampling strategy, fraction dated, radiocarbon laboratory). In particular, the recent trend towards routine carbon 13 correction raises some concerns regarding the reliability of age by age comparisons if some are uncorrected.

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A total of 12 samples in this study were age-determined; each was corrected for carbon-13 content (Table 6:1). Results indicate that the variability in the corrected versus the uncorrected ages ranges from 1.2 to 10 percent, with a mean difference of 8 percent. As the sample becomes older (>2,000 yrs B.P.), the amount of variability is relatively insignificant. For a young (<2,000 yrs B.P.) sample, however, the degree of difference between the uncorrected and corrected ages is significant. Any future research of this kind in the Kansas River basin, therefore, should take this into consideration.

Archeological Research

From an archeological perspective, the research that was conducted in the Wolf Creek basin should contribute to the refinement of the geoarcheological model for the Kansas River basin proposed by Johnson and Logan (1990). Results of that study indicated the cultural record in the Kansas River basin ranges from Paleo-indian through Historic, and there is a high probability of locating these cultural components buried in situ beneath certain alluvial surfaces. Because the complete record from a small basin such as Wolf Creek was unknown at that time, however, the spatial and temporal distributions of cultural and geomorphic features were biased toward the large streams of the Kansas River system and the uncorrected radiocarbon ages obtained from deposits in the system.

The results obtained from the Wolf Creek basin, therefore, have significant implications regarding preservation of the archeological record, specifically Paleo-indian and early to middle-Archaic

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Table 6:1. Uncorrected and C13 Corrected Radiocarbon ages from the Wolf Creek basin.

Stream Site	Lab No.	Uncorrected age	C13 corrected age
Sturgeon site	Tx-6259	$1,670\pm70$	$1,820\pm70$
Paschal site	Tx-7078	$5,220\pm110$	$5,350\pm110$
Paschal site	Tx-7077	$1,730\pm70$	$1,830\pm70$
Paschal site	Tx-7076	$1,390\pm80$	$1,510\pm80$
Paschal site	Tx-7075	$1,170\pm70$	$1,290\pm70$
Schoen site	Tx-6795	$2,870\pm80$	$2,970\pm80$
Schoen site	Tx-6959	$1,630\pm70$	$1,750\pm70$
Schoen site	Tx-6960	$1,140\pm60$	$1,250\pm60$
Naylor site	Tx-6914	$6,690\pm110$	$6,770\pm110$
Naylor site	Tx-6962	$1,760\pm60$	$1,880\pm60$
Naylor site	Tx-7076	$1,330\pm60$	$1,460\pm60$

cultural components, in similar sized basins in the Kansas River system and should be considered as future surveys are conducted. Certainly, the focus of any future archeological research should concentrate on paleosols, which represent the best potential for cultural artifact concentrations (Ferring 1986) in basins of this size.

In short, any future archeological research in the Wolf Creek basin or a similar sized basin in the Kansas River system should consider the following: 1) while Paleo-indian and early to middle-Holocene Archaic sites were likely eroded in small basins of the Kansas River system sometime between about 6,700 and 5,300 yrs B.P.,the results of this study indicate that they may exist, deeply buried in upper reaches of small tributaries, 2) since most of the alluvial fill in the Wolf Creek basin is late-Holocene in age, the likelihood of preservation of Late Archaic and other late-Holocene Plains Woodland and Plains Village sites is much greater than it is for earlier sites throughout most of the Wolf Creek basin, and 3) subsequent removal of some late-Holocene sites, and further erosion of older cultural components, has most certainly occurred in portions of these small basins due to lateral migration and channel entrenchment in the last 1,000 years.

REFERENCES CITED

Antevs, E., 1955. "Geologic-climatic dating in the West:" American Antiquity, v. 20, pp. 317-335.

Berry, D.W., 1952. "Geology and groundwater resources of Lincoln County, Kansas:" Kansas Geological Survey Bulletin, no. 95, 96 p.

Bettis, E.A. III, and D.M. Thompson, 1981. "Holocene landscape evolution in western Iowa - concepts, methods, and implications for Archaeology:" in Selected Papers from the Mankato Conference, ed., S.F. Anfinson, Occasional Publications in Minnesota Anthropology, Minnesota Archaeological Society, St. Paul.

Baker, V.R., and Penteado-Orellana, M.M., 1977. "Adjustment to quaternary climatic change by the Colorado River in central Texas:" Plains Anthropologist, v. 29, pp. 211-226. Bettis and Thompson, 1981.

Bass, N.W., and Rubey, W.W., 1925. "Geology of Russell County." Ks.:" Kansas Geological Survey Bulletin no. 10, 86 p.

Barker, W.L., and Hamilton, V.L., 1985. "Soil survey of Lincoln County, Ks.:" United States Department of Agriculture, Soil Conservation Service.

Bartlein, P.J., T. Webb III, and E. Fleri, 1984. "Holocene climatic change in the northern Midwest: Pollen derived estimates:" Quaternary Research, v. 22, pp. 361-374.

Baughman, R.W., 1961. Kansas Post Offices, Kansas State Historical Society, Topeka, Ks.

Beck, H.V., 1959. "Geology and groundwater resources of Kansas River valley between Wamego and Topeka vicinity:" Kansas Geological Survey Bulletin v. 135, 88 p.

Benson, M.A., 1962. "Evolution of methods for evaluating the occurence of floods:" U.S. Geological Survey WSP, 1543-A, 30 p.

Birkeland, P.W., 1984. Soils and Geomorphology, Oxford University Press, Oxford.

Boison, P.J., and Patton, P.C., 1985. "Sediment storage and terrace formation in Coyote Gulch basin, southcentral Utah:" Geology, v. 13, pp. 31-34.

Bowman, M.W., 1985. "A disparity in the rate of lateral channel cutting between two reaches of the Kansas River." Unpublished M.S. thesis, Department of Geography, University of Kansas,

Lawrence.

Brakenridge, G.R., 1980. "Widespread episodes of stream erosion
    during the Holocene and their climatic cause:" Nature v. 283,
    pp. 655-656.

            , 1981. "Late Quaternary flood plain sedimentation
    along the Pomme de Terre River, southern Missouri:" Quaternary
    Research, v. 15, pp. 62-76.

Brice, J.C., 1964. "Channel patterns and terraces of the Loup Rivers
    in Nebraska:" U.S. Geological Survey, Professional papper 422-D,
    pp. D1-D41.

            1966. "Erosion and deposition in the loess-mantled
    Great Plains, Medicine Creek drainage basin, Nebraska:U.S.
    Geological Survey Professional Paper 352-H.

Bryson, R.A., and W.M. Wendland, 1967. "Tentative climatic patterns
    for some late-glacial and post-glacial episodes in central North
    America:" in Life, Land and Water, ed., W.J. Mayer-Oakes, Univ.
    of Manitoba Press, Winnipeg, pp. 271-298.

Bucher, W.H., 1935. "'Strath' as a Geomorphic Term:" Science, v. 75,
    pp. 130-131.

Burkham, D.E., 1972. "Channel changes of the Gila River in Stafford
    Valley, Arizona, 1846-1970:" U.S. Geological   Survey
    Professional Paper 655-G.

Chorley, R.C., S.A. Schumm, and D.E. Sugden, 1984. Geomorphology,
    John Wiley and Sons, New York.

COHMAP Members, 1988. "Climatic changes of the last 18,000 years:
    Observations and model simulations:" Science, v. 241, pp. 1043-
    1052.

Condra, G.E., 1907. "Geology and water resources of the Republican
    River valley and adjacent areas, Nebraska:"U.S. Geological
    Survey Water-Supply and Irrigation Paper 216.

Dana, J.D., 1863. Manual of Geology. Theodore Bliss, Philadelphia.

Day, P.R., 1965. "Particle fractionation and particle-size analysis;"
    in, Methods of Soil Analysis Part I: Physical and Mineralogical
    Properties, Including Statistics of Measurement and Sampling,
    ed. C.A., Black, Madison: American Society of Agronomy, pp. 545-
    567.

Davis, E.M., and Schultz, C.B., 1952. "The archaeological and
    paleontological salvage program at the Medicine Creek Reservoir,
    Frontier County, Nebraska:" Science, v.115, pp. 288-290.

Davis, S.N., and Carlson, W.A., 1952. "Geology and groundwater of the Kansas River valley between Lawrence and Topeka, Kansas:" Kansas Geological Survey Bulletin v. 96, pt. 5. pp. 201-276.

Davis, W.M., 1902. "Base level, grade and peneplain:"Journal of Geology, v. 10, pp. 77-111.

Dean, W.E., Jr., 1974. "Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by Loss on Ignition: comparison with other methods:" Journal of Sedimentary Petrology, v. 44, p. 242-248.

Dort, W., Jr., 1983. "Sea level changes and midcontinent fluvial terraces:" Ter-Qua Annual Meeting Program and Abstracts Lawrence, Ks. p. 193

_____ 1987. "Type Descriptions of Kansas River Terraces." inQuaternary Environments of Kansas, ed. W.C. Johnson, Kansas Geological Survey, Guidebook Series 5, Lawrence, Ks. pp. 103-107.

Dunne, T. and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman and Co., San Francisco.

Dury G.H., 1973. "Magnitude-frequency analysis and channel morphometry:" in M.E. Morisawa ed.,Fluvial Geomorphology: a Proceedings Volume of the Fourth Annual Geomorphology Symposia Series, Publications in Geomorphology, State University of New York, Binghamton, 314 p.

Elks, J.E., 1979. "Air-photo interpretation of floodplain features; A means of determining Kansas River history"M.S. thesis: Lawrence, University of Kansas, 79 p.

Ferring, C.R., 1986. "Rates of fluvial sedimentation; implications for archaeological variability:" Geoarchaeology, v. 1, pp. 259-274.

Fleming, E.F., 1977. "Soil survey of Osborne County, Ks.:" United States Department of Agriculture, Soil Conservation Service.

Folk, R.L., and Ward, W.C., 1957. "Brazos River Bar: a Study in the Significance of Grain Size Parameters:" Journal of Sedimentary Petrology, v. 27, p. 3-26.

Foster, C.N., and Topley, W., 1865. "On the superficial deposits of the valley of the Medway, with remarks on the denudation of the Weald:" Quarterly Journal of the Geological Society of London, v. 21, pp. 433-475.

Fournier, M.F., 1949. "Les facteurs climatiques de l"erosion du sol:" Bul. ASsn. Geogr. Francois 203, pp. 97-103.

137

Geil, S.A., 1987. "Significance of the age and identity of a volcanic ash near DeSoto, Kansas, with respect to the enclosing terrace deposits:" M.S. Thesis, Lawrence, Kansas, 169 p.

Gilbert, G.K., 1900. "Rythms in geologic time:" Proceedings of the American Association for the Advancement of Science, v. 49, pp. 1-19.

Hall, S.A., 1990. "Channel trenching and climatic change in the southern Great Plains:" Geology, v. 18, no. 3, pp. 342-345.

Hattin, D.E., 1978. "Guidebook upper Cretaceous stratigraphy and depositional environments of western Kansas;" Kansas Geological Survey, Guidebook Series 3, University of Kansas, Lawrence, Ks.

Hereford, R., 1984. "Climate and ephemeral-stream processes: Twentieth-century geomorphology and alluvial stratigraphy of the Little Colorado River, Arizona:" Geological Society of America Bulletin, v. 95, pp. 654-668.

Holien, C.W., 1982. "Origin and geomorphic significance of channel-bar gravel of the lower Kansas River:" M.S. thesis, University of Kansas, Lawrence, 128 p.

Hoover, W.F., 1936. "Petrology and distribution of highly weathered drift in the Kansas River valley:" Journal of Sedimentary Petrology, v. 6, pp. 143-153.

Howard, A.D., R.W., Fairbridge, and J.H. Quinn, 1968. "Terraces, fluvial-Introduction:" in R.W. Fairbridge, ed. Encyclopedia of Geomorphology, Reinhold Book Corp., New York, pp. 1117-23.

Hull, E., 1878. Physical geology and geography of Ireland. Edward Stanford, London.

Jantz, D.R., Owens, H.D., and Wehmueller, W.A., 1982. "Soil survey of Russell County, Ks.: " United States Department of Agriculture, Soil Conservatin Service.

Jaumann, P.J., Johnson, W.C., and Fredlund, G.G., 1985. "Wisconsin full-glacial vegetation record from south-central Kansas (abs):" Institute for Tertiary-Quaternary Studies, 4th Annual Symposium, Lawrence, Kansas, Program with Abstracts, p. 18.

Jewett, J.M., 1949. "Oil and gas in eastern Kansas:" Kansas Geological Survey, Bulletin 77.

Jewett, J.W., O'Conner, H.G., and Seevers, W.J., 1965. "Hydrology of the lower Kansas River valley; Guidebook to field trip of Geological Society of America and associated societies:" Kansas Geological Survey, 45 p.

Johnson, A.E., 1971. "The Bridwell Site-continuity in exploitative

patterns in a micro-environmental setting:" Paper presented at the 29th Plains Conference, Lincoln, Nebraska.

　　　　1973. "Archaeological investigations at the Budenbender Site, Tuttle Creek Reservoir, northcentral Kansas, 1957:" Plains Anthropologist v. 18, no. 62, Parts 1-2.

Johnson, W.C., 1981. "Geomorphic and archeologic evidence of late-holocene stream system change in the central plains:" Meeting of the Association of American Geographers, Los Angelas, Program and Abstracts, p. 205.

　　　　1985. "Revision of terrace chronologies along the Kansas River and tributaries:" Lawrence, Kansas, Proceedings of the Institute for Tertiary-Quaternary Studies, pp. 21.

Johnson, W.C., and Logan, B., 1990. "Geoarchaeology of the Kansas River basin, central Great Plains:" in, Geological Society of America Centennial Special Volume 4, pp. 267-299.

Johnson, W.C., and Martin, C.W., 1987. "Holocene alluvial-stratigraphic studies from Kansas and adjoining states of the East-Central Plains:" in, Kansas Geological Survey, Guidebook Series 5, Lawrence, Ks. pp. 109-121.

Johnson, W.C., Martin, C.W., and Cheney, Nadine, 1990. "Koehn-Schneider Mammoth Site of western Kansas:" Current Research in the Pleistocene, v. 7 (in press).

Johnson, W.D., and Adkinson, W.L., 1967. "Geology of eastern Shawnee County, Kansas and vicinity:" U.S. Geological Survey Bulletin, 1215-A.

Knox, J.C., 1972. "Valley alluviation in southwestern Wisconsin:" Annals of the Association of American　　　Geographers, v. 62, pp. 401-410.

　　　　1976. "Concept of the graded stream;" in, Theories of Landform Development, W.N. Melhorn and R.C. Flemal, ed.:State University of New York, Binghamton, pp. 169-198.

　　　　1983. "Responses of river systems to holocene climates;" in, Late Quaternary Environments of the United States, the Holocene, H.E., Wright, Jr., ed.: University of Minnesota Press, Minneapolis, v. 2, p. 26-41.

　　　　1985. "Response of floods to holocene climatic change in the upper Mississippi valley:" Quaternary Research, v. 23. 287-300.

Kolb, C.R., and J.R. Van Lopik, 1958. "Geology of the Mississippi River deltaic plain, southeastern Louisiana:" U.S. Army Corps of Engineers, Waterway Exp. Sta. Rept., 3-483, Vicksburg.

Kopsick, P.R., 1980. "Geology and geomorphic history of the lower May Brook valley;" in, The May Brook Site, Jackson County, Missouri, L.J. Schmits, ed.: Report submitted to the City of Lees Summit and the Environmental Protection Agency, p. 70-75.

Kromer, B., M. Rhein, M. Bruns, H. Schock-Fischer, K.O. Munnich, M. Stuiver, and Becker, B., 1986. "Radiocarbon calibration data for the 6th and 8th Millennia BC:" Radiocarbon, v. 28, pp. 954-960.

Krumbein, W.C., and F.A. Graybill, 1965. An Introduction to Statistical Models in Geology, McGraw-Hill, New York.

Kuchler, A.W., 1974. "A new vegetation map of Kansas:" Ecology v. 55, pp. 586-604.

Kutzbach, J.E., 1981. "Monsoon Climate of the Early Holocene: Climate Experiment with the Earth's Orbital Parameters for 9,000 Years Ago:" Science, v. 214, pp. 61.

_____ 1985. "Modeling of Paleoclimates:" Advances in Geophysics, v. 28A pp. 159-196.

_____ 1987. "Model simulations of the climatic patterns during the deglaciation of North America:" in W.F. Ruddiman, H.E. Wright Jr., ed: North America and Adjacent Oceans during the Last Glaciation, v. K-3.

Kurmann, M.H., 1985. "An opal phytolith and palynomorph study of extant and fossil soils in Kansas (U.S.A.):" Paleogeography, Paleoclimatology, Paleoecology, v. 45, pp. 217-235.

Langbein, W.B., and Schumm, S.A., 1958. "Yield of sediment in relation to mean annual precipitation:" Transactions of the American Geophysical Union, v. 39. pp. 1076-1084.

Leopold, L.B., 1976. "Reversal of erosion cycle and climatic change:" Quaternary Research, v. 6, pp. 557-562.

Leopold, L.B., Wolman, W.G., and Miller, J.P., 1964. Fluvial processes in geomorphology. W.H. Freeman and Co., San Francisco.

Lewin, J., 1978. "Floodplain geomorphology:" Progress in Physical Geography, v. 2, pp. 408-437.

Lewis, W.V., 1944. "Stream trough experiments and terrace formation:" Geology Magazine, v. 81, pp. 241-253.

Libby, W.F., 1955. Radiocarbon Dating, Chicago, Illinois, University of Chicago Press, 175 p.

Linick, T.W., H.E. Suess, and B. Becker, 1985. "La Jolla measurements of radiocarbon in south German oak tree-ring chronologies:" Radiocarbon, v. 27, pp. 20-32.

Linick, T.W., A. Long, P.E. Damon, and C.W. Ferguson, 1986. "High-precision radiocarbon dating of bristlecone pine from 6554 to 5350 BC:" Radiocarbon, v. 28, 943-953.

Logan, Brad, 1985. "O-Keet-Sha-Culture history and its environmental context-the archeology of Stranger Creek basin, Northeastern Kansas:" Ph.D. Dissertation, University of Kansas, Lawrence, 439 p.

Logan, B., M.J. Adair, S, Bozarth, M. Dunlap, M. Fosha, W.C. Johnson, W.B. Lees, and B. Loosle, 1989. Archaeological investigations in the Perry Lake project area, northeastern Kansas national register evaluation of 17 sites, an archaeological project conducted for the Kansas City District, U.S. Army Corps of Engineers Contract No. DACW41-88-C-0084, 314 p.

Logan, B., and Johnson, W.C., 1986. "Geoarchaeological investigations in the lower Kansas River basin:" Current Research in the Pleistocene, v. 3, pp. 84-85.

Lyell, C., 1871. Student's Elements of Geology. John Murray, London.

Mackin, J.R., 1937. "Erosional history of the Big Horn basin, Wyoming:" Geological Society of America Bulletin, v. 48, pp. 813-893.

Mandel, R.D., 1985. "Geomorphology on the Little Blue drainage basin;" in, Prehistory of the Little Blue River Valley, Western Missouri-Archaeological Investigations at Blue Springs Lake, L.J. Schmits, ed.: Shawnee Mission, Kansas, Environmental Systems Analysis, Inc., Project no. 1063.

_____ 1987. "Geomorphology of the Wakarusa River valley, northeastern Kansas;" in ed., Brad Logan, Archaeological Investigations in the Clinton Lake Project Area, Northeastern Kansas: National Register Evaluation of 27 Prehistoric Sites, Kaw Valley Engineers Contract Report, report submitted to the U.S. Army Corps of Engineers, Kansas City District.

_____ 1988. "Geomorphology of the Smoky Hill River valley at Kanopolis Lake;" in ed., L.J. Schmits, An Archaeological and Geomorphological Survey of Kanopolis Lake, Northcentral Kansas, Environmental Sysltems Analysis, Inc., Cultural Resource Management Report, submitted to the U.S. Army Corps of Engineers, Kansas City District.

_____ 1990. "Morphology of holocene-age buried paleosols developed in valley fill of the Pawnee River, southwestern Kansas:" Association of American Geographers Programs and

<u>Abstracts</u>, Toronto, Canada.

        1990. "Holocene landscape evolution in the Pawnee
River valley, southwest Kansas:" <u>Ph.D. Dissertation</u> University
of Kansas, Lawrence, Ks.

Martin, C.W., 1990. "Late Quaternary sedimentation and paleo-
    environmental change in the Repulican River basin, southcentral
    Nebraska:" <u>Ph.D. Dissertation</u>, University of Kansas, Lawrence,
    210 p.

May, D.W., 1986a. "Holocene alluvial fills in the South Loup valley,
    Nebraska:" <u>Quaternary Research</u>, v. 32, pp. 117-120.

        1986b. "Geomorphology:" in, <u>Along the Pawnee Trail:</u>
<u>Cultural Resource Survey and Testing at Wilson Lake, Kansas,</u>
ed., D. J. Blakeslee, R. Blasing, and H. Garcia, pp. 72-86.
Report submitted to the U.S. Army Corps of Engineers, Kansas
City District.

McCrae, R., 1954. "Geomorphic effects of the 1951 Kansas River
    flood:" <u>Unpublished M.S. thesis</u>, Department of Geology,
    University of Kansas, Lawrence.

Merriam, D.F., "The Geologic History of Kansas:" <u>Kansas Geological</u>
    <u>Survey, Bulletin,</u> 162.

Mook, W.G., 1986. "Business meeting: recommendations/resolutions
    adopted by the twelfth international radiocarbon conference:"
    <u>Radiocarbon</u>, v. 28, p. 799

Morisawa, M., 1985. <u>Rivers: Form and Processes</u>. Longman, New York.

Muilenburg, G., and Swineford, A., 1975. <u>Land of the Post Rock</u>.
    University of Kansas Press, Lawrence, Ks.

Nanson, G.C., 1986. "Episodes of vertical accretion and catastrophic
    stripping: A model of disequilibrium floodplain development:"
    <u>Geological Society of America Bulletin</u> v. 97, pp. 1467-1475.

Newell, N.D., 1935. "The geology of Johnson and Miami Counties:<u>Kansas</u>
    <u>Geological Survey Bulletin</u>, v. 21, pp. 7-150.

The North American Commission on Stratigraphic Nomenclature, 1983.
    "North American Stratigraphic Code," in <u>The American Association</u>
    <u>of Petroleum Geologists Bulletin</u>, v. 67, no. 5.

O'Conner, H.G., 1960. "Geology and groundwater resources of Douglas
    County, Kansas:" <u>Kansas Geological Survey Bulletin 148</u>, 200 p.

        1971. "Geology and groundwater resources of
Johnson County, northeastern Kansas:" <u>Kansas Geological Society</u>
<u>Bulletin 203</u>, 68 p.

Patton, P.L., and Schumm, S.A., 1981. "Ephemeral-stream processes: implications for studies of quaternary valley fills:" Quaternary Research, v. 15, pp. 24-43.

Prante, M.C., 1989. "Grain Size: A program to aid pedologic particle size analysis:" University of Kansas, Department of Geography (unpublished).

Richards, K., 1982. Rivers - form and process in alluvial channels. Methuen, London.

Richmond, G.M., and D.S. Fullerton, 1986. "Introduction to Quaternary Glaciations in the United States of America:" in V.Sibrava, D.Q. Bowen, and G.M. Richmond, eds., Quaternary Glaciations in the Northern Hemisphere: Report of the International Geological Correlation Programme, Quaternary Science Reviews, v. 5, 514 p.

Ritter, D.F., 1986. Process Geomorphology. Second edition, W.C. Brown Publishers, Dubuque.

Rogers, R.A., 1984. "Kansas prehistory: An alluvial geomorphological perspective:" Unpublished Ph.D. dissertation, Department of Anthropology, University of Kansas, Lawrence, Ks.

Rogers, R.A., and Martin, L.D., 1984. "The 12 Mile Creek Site-a reinvestigation:" American Antiquity, v. 49, p. 757-764.

Saunders, J., 1984. "A reassessment of certain archeological sites in the Candy Lake area, Oklahoma:" Archeological Research Associates Research Report no. 22, University of Oklahoma, 226 p.

Schmits, L.J., 1978. "The Coffey site: Environmental and cultural adaptation at a prairie plains border Archaic site:" Midcontinent Journal of Archaeology, v. 3, pp. 69-185.

1980. "Holocene fluvial history and depositional environments at the Coffey Site, Kansas; in A.E. Johnson ed., Archaic Prehistory on the Prairie-Plains Border:" University of Kansas Publications in Anthropology, v. 12, Lawrence.

1981. "Archaeological and geological investigations at the Coffey Site, Tuttle Creek Lake, Kansas:" ed., T.A. Witty, Jr., Kansas State Historical Society, Anthropological Series, no. 8, Topeka, Ks.

Schmits, J.J., Donahue, J.a., and Mandel, R., 1983. "Archeological and geomorphological inventory and evaluation at the proposed Fort Scott Lake Project, southeast Kansas-draft report:" Report submitted to the Kansas City District, U.S. Army Corps of Engineers, Kansas City, Missouri, Environmental Systems Analysis, Inc., Cultural Resources Division, Overland Park, Kansas, 135 p.

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Schmits, L.J., Mandel, R.D., McKay, J., and Hedden, J.G., 1987. "Archaeological and historical investigations at Tuttle Creek Lake, eastern Kansas:" Publications in Archaeology, no. 3, Environmental Systems Analysis, Inc., submitted to the U.S. Army Corps of Engineers, Kansas City District.

Schultz, C.B., and Frankforter, W.D., 1948. "Preliminary Report on the Lime Creek Sites: New Evidence of Early Man in southwestern Nebraska:" Bulletin of the University of Nebraska State Museum, v. 3, no. 4, Part 2, pp. 43-62.

Schultz, C.B., Lueninghoener, G.C., and Frankforter, W.D., 1948. "Preliminary geomorphological studies of the Lime Creek Area: "Bulletin of the University of Nebraska State Museum, v. 3, no. 4, Part 1, pp. 31-42.

                                                              1951.
"A graphic resume of the Pleistocene of Nebraska with notes on the fossil mammalian remains:" Bulletin of the University of Nebraska State Museum, v. 3, no. 6, pp. 1-41.

Schumm, S.A., 1973. "Geomorphic thresholds and complex response of drainage systems;" in, Fluvial Geomorphology, Marie Morisawa, ed.: Binghamton, New York, Proceedings Volume, 4th Annual Geomorphology Symposium, p. 299-310.

         ., 1977. The Fluvial System, John Wiley & Sons, New York, 338 p.

Schumm, S.A., and Lichty, R.W., 1963. "Channel widening and floodplain construction along the Cimmaron River in southwestern Kansas:" U.S. Geological Survey Professional Paper 352-D.

Schumm, S.A., M.P. Mosley, and W.E. Weaver, 1987. Experimental Fluvial Geomorphology, John Wiley and Sons, Inc. 402 p.

Schumm, S.A., and Parker, R.S., 1973. "Implications of complex response of drainage systems for quaternary alluvial Stratigraphy:" Nature (Physical Science) v. 243, pp. 99-100.

Selby, M.J., 1985. Earth's Changing Surface. Oxford University Press, Oxford.

Sissons, J.B., 1979. "The Later Lakes and associated fluvial terraces of Glen Loy, Glen Spean and vicinity:"Transactions of the Institute of British Geographers, New Series, v. 4, pp. 12-29.

Soil Survey Staff, 1972. "Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples, U.S.D.A. - S.C.S., Soil Survey Investigation Report no. 1, U.S. Government Printing Office, Washington, D.C.

　　　　　　　　　1987. "Keys to Soil Taxonomy," Agency for
International Development, U.S. Department of Agriculture, Soil
Management Support Service, SMSS Technical Monograph no.6,
Cornell University, Ithica, New York.

Sorenson, C.J., Sallee, K.H., and Mandel, R.D., 1987. "Holocene and
    Pleistocene soils and geomorphic surfaces of the Kansas River
    valley," in W.C. Johnson, ed., Quaternary environments of
    Kansas, Kansas Geological Survey Guidebook Series 5, pp. 93-
    102.

Steeples, D.W., B.C. Bennett, C. Park, R.D., Miller, R.W. Knapp,
    1990. Microearthquakes in Kansas and Nebraska 1977-1989, Kansas
    Geological Survey, University of Kansas, Lawrence; prepared for
    the U.S. Nuclear Regulatory Commission, 14 p.

Stene, L.P., 1980. "Observations on lateral and overbank
    deposition - evidence from Holocene terraces, southwestern
    Alberta:" Geology, v. 8, pp. 314-317.

Stuiver, M., and H.A. Polach, 1977. "Reporting of 14C data:"
    Radiocarbon, v. 19, pp. 355-363.

Stuiver, M., G.W. Pearson, and T. Braziunas, 1986. "Radiocarbon age
    calibration of marine samples back to 9,000 cal. yr B.P.:"
    Radiocarbon, v. 28, pp. 980-1021.

Stuiver, M., and P.J. Reimer, 1986. "A computer program for
    radiocarbon age calibration:" Radiocarbon, v. 28, pp. 1022-1030.

Taylor, R.E., 1987. Radiocarbon dating: an archaeological
    perspective, Orlando, Florida: Academic Press.

The World Book Encyclopedia, 1988. World Book, Inc., Chicago

Webb, T.III, P.J. Bartlein, J.E. Kutzbach, 1987. "Climatic change in
    eastern North America during the past past 18,000 years;
    comparisons of pollen data with model results:" in W.F.
    Ruddiman, H.E. Wright Jr., North America and Adjacent Oceans
    During the Last Glaciation, v. K-3.

Wendland, W.M., 1982. "Geomorphic responses to climate forcing
    factors during the Holocene:" in, Space and Time in
    Geomorphology, C.E. Thorn, ed.: London, Allen and Unwin Ltd.,
    p. 355-371.

Wendland, W.M., and R.A. Bryson, 1974. "Dating climatic episodes of
    the Holocene:" in Quaternary Research, v. 4, pp. 9-24.

Wolman, M.G., and Leopold, L.B., 1957. "River flood plains: Some
    observations on their formation:" U.S. Geological Survey
    Professional Paper 1286.

White, S.E., and Valastro, S. Jr., 1984. "Pleistocene Glaciation of Volcano Ajusco, Central Mexico, and Comparison with the Standard Mexican Glacial Sequence:" Quaternary Research, v. 21, pp. 21-35.

Wolman, M.G. 1960. "Magnitude and frequency of forces in geomorphic processes:" Journal of Geology, v. 68, pp. 54-74.

Womack, W.R., and Schumm, S.A., 1977. "Terraces of Douglas Creek, northwestern Colorado: An example of episodic erosion:" Geology, v. 5, pp. 72-76.

Zuener, F.E., 1952. Dating the Past: an Introduction to Geochronology. Methuen and Co. LTD., London, 515 p.

APPENDIX A: TEXTURAL AND CHEMICAL DATA OBTAINED FROM ALLUVIAL FILLS
AT THE PASCHAL, SCHOEN, AND NAYLOR SITES

This appendix contains the textural and chemical data and soil
horizonation (1st sample from horizon indicated) from the sites that
were intensively studied in this project, and the location from which
the samples were taken. All measurements are given as depths (in
meters) below the banktop at the sampled section.

Paschal Site

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
0.00-0.02	17.77	74.67	7.55	8.3	5.0	6.7	Ap
0.10-0.12	21.13	76.12	2.75	5.5	9.0	7.2	
0.20-0.22	9.16	89.98	.86	3.8	14.0	7.5	A
0.30-0.32	7.27	83.71	9.01	3.1	15.0	7.5	
0.40-0.42	5.33	87.42	7.25	3.1	13.0	7.7	AC
0.45-0.47	7.41	90.30	2.29	3.2	12.3	7.6	C1
0.51-0.53	5.61	85.71	8.68	4.1	13.5	7.6	2Ab
0.56-0.58	5.65	84.30	10.05	4.3	10.0	7.7	
0.66-0.68	6.71	88.36	4.93	4.1	12.0	7.6	
0.76-0.78	5.89	87.13	6.98	5.1	13.0	7.5	
0.80-0.82	5.14	93.41	1.44	3.2	13.0	7.6	2ACb
0.91-0.93	8.51	85.45	6.04	2.4	12.0	7.6	
0.94-0.96	8.98	86.43	4.59	2.3	15.0	7.8	2C1b
1.02-1.04	11.56	76.68	11.76	2.8	16.5	7.7	
1.12-1.14	12.51	81.98	5.50	2.2	16.0	7.8	
1.17-1.19	14.26	78.50	7.24	3.6	17.0	7.6	3Ab
1.30-1.32	12.72	73.17	14.11	6.0	11.0	7.2	
1.40-1.42	12.27	76.95	10.78	4.1	11.0	7.1	
1.50-1.52	23.20	74.73	2.17	3.4	12.5	7.3	
1.60-1.62	11.45	84.14	4.41	3.4	15.0	7.0	
1.62-1.64	15.92	81.35	2.82	3.5	10.0	7.5	3ACb
1.72-1.74	16.27	77.21	6.52	2.6	11.6	7.5	
1.76-1.78	17.11	76.97	5.92	2.2	13.8	7.5	3C1b
1.86-1.88	19.60	69.79	10.61	2.3	15.4	7.5	
1.96-1.98	13.43	72.86	13.71	2.3	12.8	7.5	
2.06-2.08	9.88	59.10	31.12	2.5	11.5	7.5	
2.16-2.18	6.01	78.12	15.87	2.8	11.4	7.5	
2.20-2.22	7.28	69.61	23.11	2.7	12.4	7.5	3C2b
2.32-2.34	10.33	78.24	11.43	2.9	12.5	7.5	
2.34-2.36	20.43	63.32	16.35	2.2	16.5	7.6	3C3b
2.43-2.45	24.50	63.67	11.93	2.1	15.5	7.6	
2.53-2.55	27.32	67.17	6.61	2.5	15.5	7.6	
2.63-2.65	24.88	66.50	8.72	2.5	13.0	7.6	
2.68-2.70	17.96	63.32	18.82	2.8	9.9	7.6	4Ab
2.78-2.80	14.49	65.09	20.41	3.2	11.3	7.6	
2.88-2.90	17.92	79.25	2.83	3.2	9.9	7.6	
2.98-3.00	20.11	73.82	6.17	3.2	10.3	7.6	
3.08-3.10	11.90	73.34	14.86	2.9	11.1	7.6	
3.18-3.20	13.81	75.74	10.55	2.7	9.2	7.6	
3.20-3.22	16.85	76.84	6.31	3.9	9.2	7.5	
3.27-3.29	14.72	72.66	12.63	4.2	10.8	7.5	

Paschal Site

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
3.37-3.39	17.31	76.88	5.81	3.7	11.8	7.5	4Ab
3.40-3.42	13.33	80.29	6.38	3.0	12.3	7.7	
3.50-3.52	15.14	79.06	5.80	2.7	12.2	7.7	
3.60-3.62	14.39	79.62	5.99	3.1	12.0	7.6	
3.70-3.72	10.07	84.99	4.94	3.1	10.0	7.6	4ACb
3.80-3.82	12.74	80.37	6.89	8.0	12.2	7.6	
3.90-3.92	12.47	82.09	5.44	4.0	12.0	7.6	
3.93-3.95	9.10	86.53	4.37	2.7	14.3	7.7	4C1b
3.99-4.01	12.98	81.02	6.00	2.9	13.6	7.6	
4.09-4.11	11.47	83.20	5.33	3.3	11.0	7.8	
4.19-4.21	8.22	85.60	6.18	3.0	11.0	7.6	
4.29-4.31	11.47	83.37	5.16	3.4	11.5	7.6	
4.39-4.41	10.85	83.58	5.58	3.0	10.6	7.6	
4.49-4.51	9.77	85.85	4.38	2.5	11.3	7.6	
4.54-4.56	10.78	83.39	5.80	3.2	12.7	7.7	
4.58-4.60	3.75	90.01	6.24	3.7	12.3	7.8	
4.65-4.71	20.27	78.84	.88	2.7	12.0	7.7	
4.79-4.81	20.15	75.08	4.77	2.7	12.7	7.6	
4.82-4.84	28.25	68.92	5.83	2.0	15.0	8.0	
4.91-4.93	7.69	84.67	7.65	2.5	17.4	8.0	
5.01-5.03	9.13	82.70	8.11	2.3	13.1	8.2	
5.11-5.13	20.64	73.77	5.59	2.2	15.0	8.2	
5.21-5.23	24.62	69.32	6.06	2.0	16.7	8.3	
5.25-5.27	18.32	65.93	5.75	2.2	13.4	8.2	4C2b
5.30-5.32	19.59	74.97	5.44	2.1	13.1	8.2	
5.40-5.42	21.08	73.22	5.70	2.0	13.8	8.2	
5.50-5.52	23.37	70.63	6.00	2.3	15.3	8.2	
5.60-5.62	27.07	67.73	5.20	2.4	14.3	8.3	
5.70-5.72	24.42	70.38	5.20	2.4	13.1	8.3	
5.80-5.82	16.69	70.83	5.48	2.3	12.6	8.2	
5.90-5.92	13.81	80.24	5.92	2.7	13.4	8.4	
6.00-6.02	10.22	83.79	5.99	2.4	11.2	8.3	
6.10-6.12	14.21	79.62	6.17	2.2	12.9	8.5	
6.20-6.22	27.02	67.41	5.57	2.2	16.0	8.5	
6.30-6.32	22.64	72.24	5.12	2.3	15.3	8.5	
6.40-6.42	25.56	68.81	5.63	2.2	17.0	8.6	
6.50-6.52	15.76	78.39	5.85	2.3	15.0	8.5	
6.54-6.56	11.49	81.59	6.92	2.5	14.0	8.5	4C3b
6.61-6.63	23.58	69.76	6.66	1.7	14.6	8.2	
6.71-6.73	14.34	77.96	7.70	2.1	13.5	8.1	
6.81-6.83	20.28	71.04	8.68	2.1	21.2	8.2	
6.85-6.87	23.61	68.06	8.33	2.0	19.6	8.3	4C4b
6.95-6.97	15.82	76.07	7.48	2.7	15.8	8.2	
7.05-7.07	26.65	67.67	5.68	1.9	16.0	8.6	
7.15-7.17	19.66	73.47	6.81	1.6	12.7	8.3	
7.25-7.27	16.72	75.47	7.81	1.8	10.0	8.3	
7.31-7.33	17.76	74.09	8.12	2.1	11.5	8.4	4C5b
7.40-7.42	20.07	71.28	8.65	2.2	14.3	8.4	
7.50-7.52	12.90	79.53	7.57	2.1	10.5	8.2	
7.60-7.62	11.85	79.34	8.78	2.5	11.2	8.2	

Paschal Site (cont)

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
7.70-7.72	10.96	79.27	9.77	2.5	10.5	8.2	4C5b
7.76-7.78	18.06	74.64	7.30	2.3	17.5	8.4	
7.81-7.83	13.60	80.03	6.10	2.8	10.5	8.3	
7.92-7.94	6.47	69.79	23.74	3.9	15.0	8.1	
8.60-8.62	17.10	74.09	8.81	2.3	8.4	7.9	4C7b
8.73-8.75	30.27	61.99	7.74	2.2	10.0	8.0	
9.14-9.16	13.50	80.52	5.98	2.3	6.5	8.1	4C9b
9.22-9.24	15.98	78.15	5.87	2.2	6.0	8.2	4C10b
9.49-9.51	25.79	66.69	7.54	2.6	14.8	8.2	4C11b

Schoen Site

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
0.03-0.05	20.18	66.28	13.54	6.7	3.0	7.3	Ap
0.13-0.15	13.41	75.06	11.53	5.8	3.0	7.5	
0.23-0.25	11.82	84.22	3.96	3.9	5.7	7.5	A
0.33-0.35	23.82	66.83	9.36	2.5	11.0	7.5	AC
0.37-0.39	16.87	67.91	15.22	2.3	12.8	7.6	C
0.47-0.49	26.36	68.81	8.83	2.0	13.9	7.7	
0.57-0.59	41.45	48.17	10.38	1.8	21.0	7.9	
0.60-0.62	38.36	55.65	5.99	2.1	17.5	8.0	
0.69-0.71	25.91	57.94	16.15	2.4	13.5	7.9	
0.72-0.74	33.97	52.81	13.22	2.5	14.0	8.0	
0.78-0.80	33.83	50.76	15.41	2.9	15.0	8.0	
0.81-0.83	18.72	67.90	13.38	3.1	10.0	7.9	2Ab
0.88-0.90	8.47	76.33	15.20	2.8	8.2	7.8	
0.98-1.00	11.73	73.34	14.93	2.5	9.0	7.8	
1.02-1.04	15.79	69.25	14.76	2.2	10.0	7.8	
1.07-1.09	16.56	70.38	13.05	2.1	11.0	7.9	2C1b
1.17-1.19	17.52	68.90	13.58	2.2	11.0	8.1	
1.27-1.29	14.31	74.69	11.00	2.5	10.5	8.0	
1.32-1.34	13.33	61.82	24.85	2.9	11.6	8.1	3Ab
1.42-1.44	13.37	77.58	9.05	3.0	9.0	7.9	
1.52-1.54	16.67	75.38	7.95	3.5	7.0	7.8	
1.62-1.64	11.01	80.89	8.14	3.9	5.5	7.9	
1.72-1.74	8.49	76.98	7.32	5.0	6.0	7.9	
1.82-1.84	10.81	77.83	11.36	3.2	8.5	7.9	
1.92-1.94	4.74	71.14	24.11	3.6	6.0	8.0	3Bwb
1.96-1.98	5.69	67.37	26.94	3.2	9.0	8.2	
2.08-2.10	11.68	70.55	17.85	3.0	9.0	8.2	
2.18-2.20	6.63	68.95	24.42	2.8	9.0	8.2	
2.28-2.30	10.48	69.84	19.67	2.7	9.0	8.2	3C1b
2.38-2.40	12.36	80.05	7.59	3.5	8.3	8.3	
2.48-2.50	11.06	69.02	19.92	2.6	9.0	8.2	
2.58-2.60	8.80	84.32	6.88	2.5	7.0	8.2	
2.68-2.70	5.15	87.15	7.70	2.5	6.0	8.3	
2.78-2.80	5.79	85.32	8.88	2.5	7.5	8.4	
2.88-2.90	15.38	77.22	7.32	3.3	6.0	8.3	
2.98-3.00	8.05	84.52	7.42	2.3	6.0	8.3	

Schoen Site (cont)

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
3.02-3.04	7.77	80.34	11.88	4.8	5.0	8.2	4A1b
3.10-3.12	10.44	80.96	8.60	2.8	7.0	8.3	
3.20-3.22	16.43	74.94	8.62	3.3	6.0	8.3	
3.30-3.32	14.47	76.19	9.34	4.3	6.0	8.2	
3.40-3.42	10.96	78.48	10.56	3.0	6.0	8.3	
3.50-3.52	13.73	81.02	5.24	3.3	6.0	8.2	
3.60-3.62	14.45	77.73	7.81	3.0	6.0	8.3	
3.70-3.72	16.69	76.08	7.73	3.8	6.5	8.3	
3.80-3.82	12.70	78.73	8.57	3.2	6.0	8.3	
3.90-3.92	12.49	78.32	9.19	2.9	7.0	8.3	
4.00-4.02	13.02	81.60	5.38	3.1	7.0	7.3	
4.10-4.12	17.81	75.93	6.26	3.4	7.0	7.5	
4.20-4.22	18.76	73.78	7.46	2.4	8.0	7.6	
4.30-4.32	16.04	77.85	6.11	2.5	8.0	7.7	
4.40-4.42	16.67	78.62	4.70	2.4	9.0	7.8	
4.50-4.52	18.78	74.32	6.89	2.1	10.0	7.8	4A2b
4.60-4.62	15.58	81.97	2.45	2.5	9.4	7.8	
4.70-4.72	16.71	79.30	3.99	2.2	9.0	7.9	
4.74-4.76	14.34	78.55	7.11	1.8	9.0	7.9	4ACb
4.89-4.91	11.58	74.00	14.42	2.3	8.0	7.7	
4.99-5.01	15.12	79.27	5.63	2.4	7.5	7.7	
5.03-5.05	19.43	73.36	7.21	2.3	8.5	7.7	
5.13-5.15	23.04	59.88	16.48	2.0	10.0	7.7	4C1b
5.23-5.25	10.27	82.64	7.08	4.6	8.0	7.8	
5.33-5.35	9.23	77.25	13.52	2.1	9.0	7.7	
5.38-5.40	11.99	74.05	13.76	2.0	9.0	7.9	
5.48-5.50	20.73	68.97	10.29	2.8	8.5	7.9	
5.58-5.60	9.25	75.92	14.83	1.7	8.0	7.9	
5.68-5.70	9.77	85.96	4.27	1.8	8.5	8.0	
5.78-5.80	9.71	81.23	9.06	2.6	8.0	8.0	
5.84-5.86	6.26	77.20	8.39	2.6	8.2	8.1	4C2b
5.94-5.96	13.33	80.75	5.92	3.1	8.0	8.1	
6.04-6.06	7.58	89.80	2.61	2.6	7.0	8.0	
6.14-6.16	10.73	82.07	7.19	2.5	8.0	8.1	

Naylor Site

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
0.02-0.04	26.04	68.24	5.71	7.1	2.8	7.5	Ap
0.12-0.14	26.81	67.47	5.01	5.2	6.1	7.7	
0.22-0.24	15.59	68.93	15.47	5.2	6.8	7.7	A
0.30-0.32	11.09	74.22	14.61	4.4	9.5	7.8	
0.45-0.47	10.00	75.25	14.75	3.6	10.7	7.8	AC
0.47-0.49	10.52	70.63	13.61	4.4	9.2	7.7	
0.53-0.55	12.83	69.89	17.28	3.0	13.5	7.8	C
0.63-0.65	25.22	71.15	3.63	2.2	16.0	7.7	
0.73-0.75	30.56	60.82	8.62	2.2	25.0	7.8	
0.83-0.85	23.64	61.02	15.34	2.6	16.0	7.8	
0.93-0.95	30.37	57.73	11.90	2.4	15.6	7.6	

Naylor Site (cont)

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
1.03-1.05	27.51	67.42	5.03	2.7	17.3	7.8	C
1.13-1.15	32.55	57.34	10.11	2.1	18.2	7.8	
1.25-1.27	24.96	70.01	5.03	2.6	13.0	7.8	
1.31-1.33	16.39	78.06	5.76	2.7	16.8	7.7	
1.40-1.42	11.32	76.92	11.76	2.8	9.5	7.7	2Ab
1.45-1.47	10.63	77.81	11.48	3.6	6.3	7.7	
1.55-1.57	20.20	63.17	16.63	4.3	5.2	7.6	
1.65-1.67	20.77	72.87	6.36	3.7	6.0	7.5	
1.72-1.74	16.11	69.90	13.90	2.6	11.0	7.4	2ACb
1.80-1.82	25.34	58.65	16.00	2.2	13.5	7.5	2C1b
1.90-1.92	41.08	47.80	11.12	1.7	21.0	7.4	
2.01-2.03	36.49	46.30	17.20	1.6	26.0	7.4	
2.08-2.10	32.06	59.38	8.55	1.6	21.0	7.4	
2.12-2.14	40.07	42.69	17.24	2.2	38.0	7.3	2C2b
2.21-2.23	38.08	39.97	21.95	2.5	37.0	7.5	
2.32-2.34	33.57	53.18	13.25	3.1	33.5	7.5	
2.37-2.39	19.96	59.46	20.61	2.2	30.0	7.5	2C3b
2.47-2.49	29.87	65.87	4.26	3.9	5.0	7.5	3Ab
2.56-2.58	17.14	75.00	7.86	3.3	7.0	7.5	
2.61-2.63	18.71	77.47	3.82	2.9	11.0	7.6	3ACb
2.69-2.71	17.19	77.67	5.14	2.6	13.0	7.7	
2.73-2.75	16.83	81.47	1.70	2.3	14.0	7.6	3C1b
2.83-2.85	18.02	78.65	3.33	1.9	17.0	7.7	
2.93-2.95	24.15	69.50	6.35	1.9	17.0	7.7	
3.03-3.05	22.13	67.12	10.75	1.9	17.0	7.7	
3.13-3.15	23.47	67.02	9.51	2.4	20.0	7.7	
3.23-3.25	22.62	68.13	9.25	2.1	19.0	7.8	
3.33-3.35	17.49	73.21	9.30	1.8	13.5	7.8	3C2b
3.43-3.45	23.74	71.73	4.53	2.6	15.0	7.8	
3.47-3.49	26.85	66.02	7.13	2.3	22.0	7.0	3C3b
3.56-3.58	29.88	66.46	3.66	2.2	19.0	7.9	
3.60-3.62	22.12	73.98	3.90	2.2	12.0	7.7	3C4b
3.74-3.76	18.51	73.84	7.65	2.4	7.0	7.8	
3.81-3.83	17.58	75.42	3.72	2.1	8.0	7.8	3C5b
3.91-3.93	22.65	72.40	4.95	2.4	12.5	7.0	
4.01-4.03	25.72	70.13	4.15	2.6	15.0	7.0	
4.10-4.12	21.37	71.76	6.87	4.2	12.0	7.0	
4.16-4.18	19.24	74.11	6.45	3.2	10.0	7.0	4Ab
4.25-4.27	25.21	64.29	10.49	3.4	8.0	7.0	
4.35-4.37	31.23	55.97	12.80	4.9	3.0	7.5	
4.45-4.47	39.42	50.96	9.62	3.4	3.5	7.6	
4.57-4.59	47.05	48.66	4.28	3.7	3.0	7.5	
4.63-4.65	49.59	47.33	3.08	3.4	3.0	7.6	
4.69-4.71	38.77	57.33	3.90	3.0	4.0	7.6	4ACb
4.79-4.81	29.38	66.66	3.96	2.3	6.0	7.7	
4.89-4.91	29.04	66.86	4.10	3.5	7.3	7.6	
4.95-4.97	24.22	71.30	4.02	3.3	8.5	7.7	4C1b
5.05-5.07	30.11	64.99	4.90	3.3	9.0	7.7	
5.15-5.17	28.20	65.97	5.88	3.8	13.5	7.7	
5.25-5.27	31.68	62.45	5.87	4.2	14.0	7.7	

Depth (m)	%Sand	%Silt	%Clay	%Organic Carbon	%CaCO3	pH	Soil Horizon
5.35-5.37	31.07	62.91	6.01	4.1	13.9	7.7	
5.45-5.47	30.37	62.52	7.10	4.3	12.0	7.5	3C1b

APPENDIX B: PHI CALCULATIONS AND STATISTICAL PARAMETERS USED IN THIS STUDY

Phi Calculations

This appendix contains the formulas and statistical tests used in the analysis of sediments in the Wolf Creek basin. As noted in Chapter IV, particle size data were converted to the logarithmic phi scale using a computer program developed by Prante (1990). This program constructed a cumulative frequency distribution for the particle size distribution of a given sample, and then read the desired phi value from it. In this manner, the fifth, fiftieth, and ninety-fifth phi values were derived. Two additional parameters, the mean phi value (Mean Φ) and the degree of sorting ($\sigma\Phi$), were also calculated using the following equations (Folk and Ward 1957):

$$\text{Mean} = \frac{16\Phi + 50\Phi + 84\Phi}{3}$$

$$= \frac{84\Phi - 16\Phi}{4} + \frac{94\Phi - 5\Phi}{6.6}$$

The degree of sorting represents the dispersion of sediment sizes around the mean phi value. Folk and Ward (1957:13) designate the following qualitative descriptions of the degree of sorting based on the calculated value of $\sigma\Phi$:

$$< 0.35 = \text{Very Well Sorted}$$
$$0.35 - 0.50 = \text{Well Sorted}$$
$$0.50 - 1.00 = \text{Moderately Sorted}$$
$$1.00 - 2.00 = \text{Poorly Sorted}$$
$$> 4.00 = \text{Extremely Poorly Sorted}$$