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Quaternary geology of the Knife River Indian Villages National Historic Site

John Reiten
University of North Dakota

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QUATERNARY GEOLOGY OF THE KNIFE RIVER INDIAN VILLAGES NATIONAL HISTORIC SITE

by

Jon Reiten

Bachelor of Science, University of North Dakota, 1973

A Thesis
Submitted to the Graduate Faculty
of the
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Science

Grand Forks, North Dakota
May 1983
This thesis submitted by Jon Reiten in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School
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QUATERNARY GEOLOGY OF THE KNIFE RIVER INDIAN VILLAGES
Title NATIONAL HISTORIC SITE

Department Geology

Degree Master of Science

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The archeology of the Knife River Indian Villages National Historic Site is being studied by the University of North Dakota Anthropology Department. The age of the near surface sediment and depositional history of Quaternary sediments are useful to archeologists involved in locating and interpreting the cultural resources of this area.

There are eight river terraces within a 300 square kilometre area surrounding the Knife River Indian Villages National Historic Site near Stanton, North Dakota. The terraces are former river floodplains that have been preserved above the present floodplain. The elevation above river level of the Pleistocene terraces are listed: Riverdale Terrace (67 to 90 metres), Sakakawea Terrace (51 to 61 metres), and Stanton Terrace (8 to 15 metres). There are three Holocene terraces: A terrace (6 to 8 metres), B1 terrace (4 to 6 metres), and B2 terrace (0 to 5 metres). The Pleistocene terraces can be identified because of the relatively flat land surface at similar elevations above river level. Relative age of the Pleistocene terraces increases with increased elevation above river level. The Holocene terraces were identified by the flat land surface, elevation above river level, and stratigraphy. Radiocarbon dates from twelve wood and charcoal samples found within Holocene alluvial deposits ranged in age from about 4000 BP to the present.

Eight lithostratigraphic units are present in the study area. Unit One is fluvial sediment consisting of poorly lithified yellow, brown, gray and white sand, silt, silty clay, and clay. Unit One contains beds of lignite. Unit Two is a layer of glacial sediment consisting of
grayish-brown, pebbly clay-loam. Unit Three is fluvial, glacio-fluvial and beach deposits consisting of gray to reddish-brown, silty sand, silt and gravel. Unit Four is lake sediment consisting of flat-beded light-brown to grayish-brown fine-grained sand, silt, and clay. Unit Five is eolian, light-brown to very dark-brown, vaguely bedded, well sorted, very fine-grained, sandy silt. Unit Six is windblown sediment consisting of light-yellowish-brown to very dark-brown well sorted fine- to medium-grained sand. Unit Seven is alluvial sediment consisting of light-yellowish-brown interbedded calcareous clay, silt and sand. Unit One is part of the Paleocene Age Bullion Creek and Sentinel Butte Formations. Units Two, Three and Four are part of the Pleistocene Age Coleharbor Formation. Units Five, Six and Seven are of Late Wisconsinan to Holocene Age and are part of the Oahe Formation.

Climatic changes since the retreat of the Late Wisconsinan glaciers probably controlled deposition and erosion of the Oahe Formation and Holocene terraces. During cool, moist climates, soils developed and rivers incised their floodplains. During warm, dry climates, soil development decreased and river floodplains aggraded. From about 13 000 BP to 8500 BP a cool, moist climate caused rivers to incise and soil development to increase forming the dark colored Aggie Brown Member of the Oahe Formation. A warmer, drier climate from about 8500 BP to 4500 BP caused river floodplains to aggrade forming the lower A terrace alluvial fill. The light colored Pick City Member of the Oahe Formation was deposited. Since 4500 BP the climate has fluctuated from cool, moist conditions to warm, dry conditions. The A, B1 and B2 terraces were formed and the Riverdale Member of the Oahe Formation, composed of alternating layers of light colored and dark colored sediment, was deposited.
INTRODUCTION

The Knife River Indian Villages National Historic Site (herein referred to as the KNRI) is an area near the confluence of the Knife and Missouri Rivers in eastern Mercer County, North Dakota, which is being intensively studied for archeological resources. The KNRI is being developed by the National Park Service, with the Midwest Archeological Center and the University of North Dakota Anthropology Department conducting the research. Based on archeological studies along the Missouri River in North and South Dakota, the four major cultural/temporal periods of the Northern Plains are likely to be represented within the KNRI (Ahler 1978, p. 10). These are the Paleo-Indian Period (11 500 to 8000 BP), the Archaic Period (8000 to 2000 BP), the Woodland Period (2000 to 1000 BP) and the Plains Village Period (1000 to 100 BP). Village sites and associated artifacts of the Plains Village Period are the most abundant archeological materials in the KNRI.

This area was visited by European and American travelers as early as the 1700s. At that time many of the villages were occupied. Documents from these early travelers add historic significance to the cultural resources present.

Purpose

The purpose of this study was to determine the depositional history of Quaternary landforms and sediment within the KNRI by mapping,
stratigraphic investigations, and carbon-14 dating. The results of this study can be used to determine locations of certain classes of cultural material, to interpret evidence of Holocene climatic fluctuations, and to better understand the history of the Missouri River in central North Dakota.

Setting

The study area includes the KNRI and about 300 square kilometre surrounding the historic site (Figure 1). The study area was glaciated several times during late Cenozoic time. Topography of the region is dominated by two former meltwater trenches, eroded over 100 metres into Paleocene sediment. Two underfit streams, the Knife and the Missouri, flow in the former meltwater channels. This is one of the few sections of the Missouri River Valley not flooded by reservoirs. Although daily fluctuations of discharge at Garrison Dam have accelerated bank erosion, river control has eliminated both erosion and deposition formerly caused by flooding.

Three distinct physiographic regions are present in the study area. The highest is the upland, an undulating bedrock surface mantled with alluvial, eolian, and glacial sediment. Below this lies the valley slope with either steep, rugged badlands or nearly flat terraces and intervening terrace slopes. The third area is the valley bottom, a nearly flat surface made up of the modern floodplain and lower terraces.
FIGURE 1. Location of the Knife River Indian Villages National Historic Site and the study area in west-central North Dakota.
LANDFORMS

Two major types of landforms were identified in the study area. These are landforms developed by geological phenomena such as glacial and fluvial processes and landforms strongly influenced by biological activities of man and other large mammals.

Geological Landforms

Meltwater Channels

Meltwater channels are trenches that were cut into the land surface by streams carrying glacial meltwater. In central North Dakota the trenches contain underfit streams; the swales may be nearly filled with sediment or are completely filled channels having little or no surface expression (Meyer 1979, p. 64; Bluemle 1971, p. 32).

Fluctuation of base level and decrease of sediment load are two ways trenches could have been cut in this area. Base level variations could be caused by ponding of rivers by glacial ice and subsequent breaching of ice dams or by variations in a river's discharge. Variations in the sediment load of a river are commonly related to climatic and vegetational changes. In glaciated regions, the sediment load decreased as the glaciers declined in activity and retreated (Leopold and others 1964, p. 476).

It may be possible to determine the relative age of meltwater channels by analyzing their characteristics. Older channels have wide valleys and gentle valley slopes because of a longer time of exposure to
fluviatile and hillslope erosion. Where the water level within an old trench fluctuated through time, terraces occur at several different levels. Tributaries to older trenches have had a longer time to develop and therefore are relatively long. In contrast, young channels have relatively narrow valleys with rugged steep slopes, fewer and lower terraces, and shorter tributaries. A more complex combination of meltwater channel characteristics may exist if a filled or partly filled old trench is cut by a younger trench. Such a trench has properties of both young and old trenches.

Such contrasting properties are present in the Knife and Missouri trenches. The Knife River flows west to east along the axis of pre-glacial drainage (Carlson 1973, p. 49). The Knife River valley is wide, valley slopes are relatively gentle, tributaries are long, and series of paired terraces are present along the valley slopes indicating that the Knife River valley is an old meltwater channel compared to steep-sided segments of the Missouri River valley. The Missouri River valley trends north to south between Garrison Dam and Stanton (Figure 2). It cuts across the older Knife trench, and therefore characteristics of both old and young trenches are found on opposite sides of the valley. Near Garrison Dam the western slope of the Missouri River valley has properties of a young trench: rugged badlands, short tributaries graded to the lowest Pleistocene terrace, and absence of higher terraces. Farther south this north to south trench segment has more mature characteristics. In this area the east slope of the Missouri River valley is considerably different. Slopes are gentle, tributaries are long, and remnants of several terraces are present suggesting a longer history than for the western slope.
FIGURE 2. Drainage development in the KNRI area, west-central North Dakota.

EXPLANATION

1 ------- Preglacial (Pre-Wisconsinan) drainage.
2 -- -- -- Late Wisconsinan drainage.
3 ......... Last Late Wisconsinan drainage.

//////// Badlands Topography.

XXXXXXX Trenches bounded by the Riverdale Terrace.
Terraces

Terraces are flat to gently undulating surfaces located in the valley slope and valley bottom physiographic regions. The terraces identified in this study are interpreted to be former river floodplains, but one terrace may be a former strandline of a proglacial lake. In either case the terraces are two-dimensional surfaces representing an episode in which aggradation or planing produced a specific level surface. The former floodplains were preserved as terraces by incision of the valley bottoms during periods of downcutting.

Criteria used to identify and correlate the terraces are surface expression, elevation above river level, stratigraphy, and contact relationships between successive terraces. The terraces are interpreted to be of either Pleistocene or Holocene age based on distinctive properties that are discussed in the following section.

Five Pleistocene terraces were identified within the study area (Plate 1). I have named these, from highest to lowest, the Riverdale Terrace, Sakakawea Terrace, McKenzie Terrace, Hensler Terrace, and Stanton Terrace. Figure 3 shows the relationships between the Pleistocene terraces along the Knife River valley. Only four of the five terraces are present because the Stanton Terrace is generally unidentifiable along the Knife River. These terraces are paired and are commonly found as remnants dissected by streams. Where the terraces are underlain by thick alluvial fill, the fill is poorly sorted, consisting of sediment ranging from medium sand to coarse cobbles. Thickness of alluvial sediment, range of grain size, and color are as diverse within a specific terrace as between successive terraces. Thus, alluvial stratigraphy is not very useful for differentiating the Pleistocene
terrace surfaces can generally be used to identify terraces. However, considerable relief is possible on terrace surface as the result of reworking of surface sediment by later eolian activity, collapse of sediment deposited on stagnant ice, dissection of the surface by tributaries, and channels on the former floodplain. Elevations of the Pleistocene terraces at most places are within 10 metres of their designated levels. An exception is where tributaries are graded to a particular terrace level. Adjacent terraces are generally separated by steep slopes, which allows terrace contact to be easily identified.

Events occurring after a stabilization surface has formed may affect the surface and contacts with other stabilization surfaces. Contact between terraces are more obscure where hillslope erosion and depositional have subdued the terrace slope. Eolian sand may cover terrace slopes making contacts between terraces hard to define. Older stabilization surfaces are often less prominent than more recent surfaces due to the long-term effects of erosion and deposition. The highest terraces are commonly poorly defined due to deposition of post-stabilization glacial sediment.

Three lower terraces of Holocene age are present within the study area. These are named from the highest to lowest elevation, terrace A, terrace B1, and terrace B2. Terrace deposits B1 and B2 are discernible only in cross section and, therefore, are combined as the B terrace for mapping purposes. These terrace deposits are composed largely of fine-grained fill ranging from clay-sized fragments to medium sand.

Elevation differences between adjacent Holocene terraces are less than
FIGURE 3. Surface profile across Knife River valley five kilometres west of Stanton, showing four of the five Pleistocene terraces. The lowest Pleistocene terrace, the Stanton terrace, is not identifiable along the Knife River except near the confluence with the Missouri.
metres. Where eolian deposits or natural levee deposits occur on the B terrace, this surface may be elevated above the A terrace. Therefore, distinguishing between Holocene terraces by elevation differences is often impossible.

Contact relationships between adjacent Holocene terraces and the stratigraphy of the associated alluvium are useful in determining the relative age of alluvial fills and terraces. Two types of terrace fill contacts are found in the study area (Figure 4). Inset contacts (Figure 4a) indicate incision of a higher terrace followed by partial filling by alluvium. Overlap contacts (Figure 4b) indicate incision followed by renewed alluvial filling, which completely overlap the incised surface (Leopold and Miller 1954, p. 6).

Linear Ridges

Northeast to southwest trending linear ridges are located northwest of the KNRI in sections 17, 19 and 20, T. 145 N., R. 84 W. and sections 2, 10, 11 and 12, T. 145N., R. 85 W. (Figure 5). The ridges are from 0.4 to 1.8 kilometres long and are commonly less than 100 metres wide. Relief of the ridges is generally less than a few metres except where streams have eroded gullies in swales between the ridges. A gravel pit in the SE-1/4, SW-1/4, Sec. 1, T. 145 N., R. 85 W. exposes the sediment within the ridges. In this outcrop the sediment consists of 1 metre of glacial till over 1 metre of gravel over poorly lithified sandstone of the Sentinel Butte Formation. These ridges are interpreted to be subglacial in origin, formed by a glacier moving to the southwest.
FIGURE 4. Alluvial fill contact relationships in the KNRI. 

a. Second fill is inset into first. 

b. Second fill overlaps first. 

(After Leopold and Miller 1954, p. 6).
FIGURE 5. Northeast to southwest trending linear ridge, interpreted as being subglacial in origin indicating northeast to southwest movement of the glacier. United States Department of Agriculture aerial photograph number BAO-4V-52. Parts of sections 1, 2, 11, and 12, Township 145 North, Range 85 West are shown in this aerial photograph.
Meander Scars

Figure 6a is an aerial view of part of the Knife River floodplain showing several meander scars. The meander scars indicate former positions of river channels which were abandoned and then filled to the flood-plain level with alluvium. Meander scars are restricted to the modern flood plain and lowest terraces along the Knife and Missouri Rivers. The absence of meander scars on higher terraces may be the result of two different processes. Deposition of overbank or eolian sediment may have been of sufficient thickness to mask former meander scars, or, the river channel that formed the higher terrace surface may not have meandered.

Cutbanks

Cutbanks are nearly vertical bluffs adjacent to a river. They form in groundwater discharge areas as the result of spring sapping. The sapping caused sediment to be transported from the river bank by slumping and collapsing and subsequently removed during flooding. Cutbanks are usually located on outside edges of meanders or along straight reaches of the river. The cutbanks along the Knife and Missouri Rivers provide the only natural outcrops of the alluvial deposits. Cutbanks named for convenient reference include the Big Hidatsa Bluff (Figure 6b), the Madman Bluff (Figure 6c), the Elbee Bluff (Figure 6d), the Sakakawea Bluff (Figure 6e), and the Stanton Ferry Bluff (Figure 6f). These cutbanks best show the characteristics of the different alluvial units studied and are the locations of charcoal samples collected for carbon-14 analysis.
FIGURE 6. Aerial photograph near the confluence of the Knife and Missouri Rivers showing (a) meander scars on the Knife River floodplain and locations of named cutbanks, (b) Big Hidatsa Bluff, (c) Madman Bluff, (d) Elbee Bluff, (e) Sakakawea Bluff, (f) Stanton Ferry Bluff and locations of large Indian villages, (g) Big Hidatsa Village, (h) Sakakawea Village, (i) Lower Hidatsa Village. United States Department of Agriculture aerial photo BAC-3V-49. Aerial photograph shows parts of sections 21, 22, 23, 26, 27, 28, 33 34, and 35, Township 145 North, Range 84 West.
Albe, co: ri, of up, ch, ins: an
the sta, nor, sha, to inc.
Point
(Fig. bedi)
(Lec. ridge, area) the the
Alluvial Islands

Alluvial islands or braid bars are accumulations of predominantly bedload material located within a river channel. Alluvial islands are common in the Missouri River especially where tributaries flow into the river. An alluvial island originates as a submerged bar during periods of high flow. Bedload deposition causes the submerged bar to grow upward to about floodplain level and to grow downstream. Flanking channels become laterally unstable because of bar growth. This instability causes the flanking channels to deepen; the bar emerges as an island and often becomes stabilized by vegetation.

An example of a stabilized alluvial bar is found near the mouth of the Knife River. Figure 7 shows a large alluvial bar which is becoming stabilized by cottonwood and willow trees. Approximately 1 kilometre northwest of this island, the outline of a feature of similar size and shape is visible on the land surface. I have interpreted this feature to be a former alluvial island that has been attached and subsequently incorporated with the floodplain.

Point Bars

Point bars are common landforms along the Knife and Missouri River (Figure 8). They are lateral accretion deposits consisting largely of bedload sediment. Point bars occur on the inner banks of river curves (Leopold and Wolman 1960, p. 782). They are expressed as a series of ridges or scrolls trending nearly parallel to the river channel. The areal extent of point bars and the length of individual scrolls along the Knife River can be measured in tens and hundreds of metres. Along the Missouri River, individual scrolls are often several kilometres
FIGURE 7. (a) Missouri River alluvial island and (b) former Missouri River alluvial island which has become incorporated with the floodplain. Aerial photograph covers parts of sections 26, 27, 28, 33, 34, and 35 Township 145 North, Range 84 West.
FIGURE 8. Aerial view showing features on the Missouri River floodplain including (a) modern Missouri River point bars, (b) modern Knife River point bars, and (c) preserved scrolls of a former Missouri River point bar. United States Department of Agriculture air photo BAO-4V-42. Aerial photograph covers part of sections 15, 16, 21, 22, and 23 Township 145 North, Range 84 West.
long. Relief of the relatively young scroll bars near the Missouri River channel is up to 5 metres. Older, inactive scroll bars have negligible relief and are identified by long linear tonal variations on air photos. The decrease in relief of a series of scroll bars through time is primarily due to overbank deposition filling in swales between the ridges.

The modern point bars along the Knife and Missouri Rivers are composed largely of sand. Layers of silty clay and gravel are found but make up a small part of the modern point-bar deposits. Climbing-ripple crossbeds are the most common primary sedimentary structures within these point-bar deposits. Other sedimentary structures include flat bedding, large-scale and small-scale crossbedding, and distorted bedding. Driftwood and other organic debris were found both on and within point-bar deposits. Fossils associated with point bars include aquatic and terrestrial gastropods, bivalves, and bones of large mammals.

Sand Dunes

Three areas of sand dunes occur in the study area. The largest dune field covers about 15 square kilometres west and south of Stanton (Figure 9). A small dune field covers about 5 square kilometres in sections 12 and 13, T. 145 N., R. 84 W. The third area consists of small patches of dunes on active point-bar deposits. The dune field west of Stanton and the dune field east of the Missouri River have similar characteristics. Both have hummocks that are 5 to 10 metres high. Most of these dune fields are stabilized by prairie grass.
FIGURE 9. Stereo aerial view of stabilized longitudinal sand dune. White colored areas are blowout dunes. United States Department of Agriculture aerial photograph BAD-3V-35, 36. Aerial photograph covers the NW-1/4, Section Township 144 North, Range 85 West.
Longitudinal dunes trending northwest to southeast are the largest and most common dunes identified. Most of the longitudinal dunes are about 1 kilometre long, 200 to 300 metres wide, and up to 10 metres high. Active sand dunes are restricted to blowouts, which are usually developed in or near the stabilized longitudinal dunes.

The dunes are composed of well-sorted, fine-grained to medium-grained, light-yellowish-brown sand. Cobbles and pebbles are frequently found in deflated parts of blowouts. Most of these are artifacts.

Sedimentary structures in the dunes include flat bedding and large-scale crossbedding, but these structures are rare. More typically the sand deposits are massive, containing no preserved sedimentary structures.

In several areas paleosols have been exposed by the blowout dunes. Paleosols were found in at least two stratigraphic levels. They are very dark-brown, and the sand in them is not as well sorted as the normal dune sand. Several artifacts were observed adjacent to the highest paleosol and had apparently weathered out of it.

The northwest to southeast orientation of the stabilized longitudinal dunes can be used to determine past wind direction. These dunes indicate the prevailing wind was from the northwest at the time of formation, which is the same as today. The sand producing the dunes was probably derived from terrace and floodplain deposits. Increased dune activity was probably the result of a decrease in vegetation, which coincided with periods of decreased precipitation (David 1971, p. 299).
Blowouts are the typical eolian landform on the modern floodplain and lower terraces. The color, sorting, and grain size of the deposits in which the blowouts occur are similar to the sand of dunes on high surfaces. No paleosols were observed within the floodplain dunes. The occurrence of blowouts on point-bar deposits is probably due to the abundance of easily eroded sand of proper grain size to be transported by the wind.

**Biologically Influenced Landforms**

Indian Villages

Remains of Indian Villages that were occupied during the Plair Village Period are found throughout the Missouri River valley in North Dakota. The villages are conspicuous landforms from the air and a ground level (Figure 10). They are composed of clusters of circular depressions, which are the remains of individual earth lodges. The depressions are about 1 metre deep and range from 7 to 12 metres in diameter. Other surface features commonly associated with the village sites are earthen fortification, trails, and linear ridges of unknown origin.

Three large villages are located within the KNRI: the Big Hidatsa Village (Figure 6g) composed of about 100 houses, the Sakakawea Village (Figure 6h) composed of about 30 houses, and the Lower Hidatsa Village (Figure 6j) composed of about 40 houses.

Trails

Landforms consisting of both parallel and intersecting trenches are
FIGURE 10. Aerial view of Big Hidatsa Village. United States Department of Agriculture aerial photograph BAO-24-6. Aerial photograph covers the S-1/2 section 21, Township 145 North, Range 84 West. North is towards the top of the page.
conspicuous features from the air in the study area (Figure 11). Segments of the trenches up to 3 kilometres long were identified. More typically the trenches are about 1 metre deep, from 100 to 1000 metres long, and between 5 to 10 metres wide. Both isolated and grouped trench segments were found. When the trenches intersect drainages, the 1 metre deep trenches are usually replaced by ridges of similar dimensions. These trenches generally trend northwest to southeast and in this area most of them are located west of the Missouri River. The trenches in the KNRI area are similar to bison trails discussed by Clayton (1975) and are considered to be of similar origin.

Other trails having essentially the same properties as the bison trails are probably man made. Trails interpreted to be man made either radiate from or are located near village sites. A group of trails forms a swath about 0.5 kilometre wide extending north from the Big Hidatsa site for over 8 kilometres. Historical documents and native traditions state that the people living in the villages moved north to temporary villages on the Missouri River floodplain during the winter and moved back to the permanent villages by spring (Ahler 1978, p. 23, 30). This group of trails may be the route of such movement.

Other trail-like features are located near the Big Hidatsa and Lower Hidatsa sites. These ridges extend as far as 400 metres from the sites. Two cores, obtained with a Giddings Soil Probe, were taken from the ridge south of the Lower Hidatsa site. Based on cores C-4 and C-5 (appendix B), the ridge consists of 0.45 to 0.95 metres of brown, very fine to fine-grained sand, over 0.20 to 0.90 metres of pale-brown silt, over very hard, very pale-brown silt, in which the probe could make limited penetration. The silt and sand above the hard layer are well
FIGURE 11. Parallel linear troughs interpreted as bison trails. United States Department of Agriculture aerial photograph BAO-3V-52. Several trails in the W-1/2, Section 25, Township 145 North, Range 85 West are indicated by arrows.
sorted and unbedded, very similar to nearby eolian deposits. The shape and proximity of the ridge to the lower Hidatsa site suggests the ridge was man made. The ridge may represent a heavily used trail. Sand and silt accumulations are found near obstruction along the trail, similar to the accumulation of sand along the fence rows during the "Dirty Thirties". Test excavations will be required to help determine the origin of the ridge. A similar ridge extending from the Big Hidatsa Village was excavated in 1980. This ridge contains a core of light-yellowish-brown, silty loam rich in cultural material. The abundance of cultural material, mostly bone fragments, suggests that the core of this ridge was formed by material carried in and dumped.
DISCUSSION OF GEOLOGICAL MAP UNITS

Two major elements make up the geologic map of the study area (Plate 2). These are morphologic units, designated by patterns, and lithostratigraphic units, designated by unit numbers.

The lithostratigraphic map identifies the surficial sediment in the study area. The lithostratigraphic units include sediment deposited by glaciers, rivers, wind, slopewash and in lakes. Data for the lithostratigraphic map were obtained from outcrops, drill holes and soil maps of Mercer County (Wilhelm 1978) and McLean County (Brockmann 1979).

The morphologic map delineates terraces, unterraced uplands, slopes between terraces and areas modified by coal mining and large-scale construction. The morphologic map emphasizes areas interpreted to be former stabilization surfaces or terraces. These are two dimensional surfaces mapped on the basis of flatness of the surface, elevation, vertical distance above river level, and in some cases distinctive properties of the alluvium underlying the terraces. Identification of the different morphological units was accomplished by field mapping, air-photo mapping, and interpretation of topographic maps.

The composite morphologic/lithostratigraphic map differentiates between the river terraces and other surfaces while showing the distribution of the surface lithostratigraphic units throughout the study area.
Lithostratigraphic Units

Bullion Creek and Sentinel Butte Formations (undifferentiated)

All Paleocene deposits outcropping in the study area are included within the Bullion Creek and Sentinel Butte Formations. These formations are designated as Unit One in this study.

Unit One consists of poorly lithified yellow, brown, gray, and white sand, silt, silty clay, and clay, with some carbonaceous shale and lignite. It is largely fluvial in origin including channel, overbank, and marsh deposits (Jacob 1973).

Unit One is generally found along streams and hillslopes where younger material has been removed by erosion.

Coleharbor Formation

The Pleistocene deposits within the study area are included in the Coleharbor Formation (Bluemle 1971, p. 17). The Pleistocene deposits include map Unit Two (glacial till), Unit Three (fluvial and glaciofluvial sand and gravel), and Unit Four (lake silt and clay). Units Two, Three, and Four are frequently interlayed and overlie the Paleocene deposits. The Coleharbor Formation is up to 100 metres thick in the study area. The interbedded nature of the Coleharbor Formation has been interpreted to represent different episodes of glaciation (Benson 1952).
Unit Two

Unit Two consists of unbedded and unsorted gray to light-olive-brown, pebbly clay-loam containing occasional cobbles and boulders. Pebbles and cobbles of local and northern sources are common in this unit. No fossils were observed in Unit Two.

Unit Two is glacial sediment. Various units of glacial till have been differentiated by Ulmer and Sackreiter (1973) along the bluffs of Lake Sakakawea. No attempt was made to correlate units in this study with named subunits of the Coleharbor Formation.

Unit Three

Unit Three consists of light-gray, brown, and reddish-brown, silty sand, sand, and gravel. It is composed of a heterogeneous mixture of igneous, metamorphic, and sedimentary rock fragments. Sorting of Unit Three ranges from poorly sorted to moderately well sorted and it is bimodally sorted in one location. This unit is typically unbedded or flat bedded (Figure 12), locally containing high-angle, large-scale planar crossbedding and large-scale trough crossbedding and it is locally faulted and folded (Figure 13). At least part of this unit was deposited on ice, causing faulting and folding of the sand and gravel after the ice melted.

Unit Three contains sediment of fluvial, glaciofluvial, and beach origin which was deposited in river beds, meltwater channels, and along shorelines. Unit Three overlies Paleocene deposits (Unit One) and is interlayed with lake sediment (Unit Four) and glacial till (Unit Two). Unit Three is commonly found below terrace surfaces and is covered in many places with a thin layer of eolian or alluvial sediment of the Oahe Formation.
FIGURE 12. Flat-bedded fluvial sand and gravel deposit of Unit Three within the Stanton Terrace fill. Outcrop is about 5 metres high and is located in the SE-1/4 SE-1/4 Section 22, Township 145 North, Range 84 West.

FIGURE 13. Deformed bedding in a deposit of sand and gravel within the Hensler Terrace fill. Deformation was probably caused by melting of ice below the deposit. Shovel is about 1/2 metre long. Outcrop is a gravel pit located in the SE-1/4 SW-1/4 Section 36, Township 145 North, Range 85 West.
Thickness of Unit Three ranges from less than 1 metre in cut terraces to over 20 metres in fill terraces.

Unit Four

Unit Four consists of light-brown to grayish-brown interbedded, fine-grained sand, silt, and clay. It is flat bedded to unbedded and contains fine laminations in some outcrops. This unit is moderately well sorted within beds. Disturbed and convoluted beds of silt and clay occur within this unit. No fossils were observed in Unit Four.

Unit Four is interpreted to be offshore lake sediment deposited from interflow and underflow currents. For simplicity organic silt and clay layers deposited in more recent time in depressions on top of the lake sediment are included in this unit.

Unit Four is a surficial unit on the uplands and terraces where it is found in depressions in the glacial till or terrace gravels. In this setting it is often covered by postglacial marsh or slough sediment. It is also a major subsurface unit in the meltwater trenches, and it is exposed in some erosional remnants.

Oahe Formation

Unit Five (loess), Unit Six (eolian sand), and Unit Seven (alluvium and colluvium) are included within the Oahe Formation. These units make up the postglacial Late Wisconsinan and Holocene deposits in the study area. The units of the Oahe Formation are interbedded with each other and overlie the Coleharbor Formation, Bullion Creek Formation, and Sentinel Butte Formation. The original description of the Oahe Formation by Clayton and others (1976) restricted it to the silt of Unit Five. It has since been redefined (Clayton and Moran 1979, p. 338), and includes Units Five, Six and Seven of this study.
Unit Five

Unit Five consists of light-brown to dark-brown, well-sorted, very fine-grained sandy silt. It contains a few pebbles and cobbles, which are artifacts commonly composed of Knife River Flint. This unit is unbedded to vaguely bedded. Alternating bands of light-brown and dark-brown silt are found in Unit Five. The dark-colored bands are less well sorted and contain more organic material than the light-colored bands. Common fossils in Unit Five are terrestrial gastropods and bone fragments of large mammals. This unit is bioturbated and contains rodent burrows and other burrows, possibly made by insects.

Unit Five overlies Units One, Two, Three, Four and may be interlayered with Units Six and Seven. Maximum thickness of Unit Five is 5 metres. This unit is surficial sediment over much of the study area but is only mapped where it is at least 1 metre thick. Accumulations of Unit Five greater than 1 metre are restricted to flat-lying areas, such as terraces having slopes less than five degrees.

Unit Five is interpreted to be largely windblown silt. Parts of Unit Five may have been reworked by slopewash and floodwaters, but these deposits have the same properties as the rest of the unit.

Unit Five can be divided into four members based on color and stratigraphy (Figures 14 and 15). The lowest member is the Mallard Island Member, a very pale-brown silt. Overlying the Mallard Island Member is the Aggie Brown Member, composed of light-brown to very dark-brown silt. The Pick City Member, a light-gray to pale-yellow silt, overlies the Aggie Brown Member. The upper member is the Riverdale Member composed of three submembers of equal thickness, a
FIGURE 14. Outcrop of windblown silt unit (Unit Five) of the Oahe Formation. Oahe Formation overlying McKenzie Terrace gravel with the Mallard Island Member (MI), Aggie Brown Member (AB), Pick City Member (PC), and Riverdale Member (Rd) visible. Outcrop is about 1 metre high. Outcrop is a gravel pit located in the NE-1/4 Section 16, Township 145 North, Range 84 West.

FIGURE 15. Outcrop of the windblown silt unit (Unit Five) of the Oahe Formation. Oahe Formation overlying Stanton Terrace gravel with the Aggie Brown Member (AB), Pick City Member (PC), Lower Riverdale Submember (LRd), Middle Riverdale Submember (MRd), and Upper Riverdale Submember (URd) visible. Outcrop is about five metres high. Outcrop is part of the Stanton Ferry Bluff located in the NE-1/4 NE-1/4 Section 26, Township 145 North, Range 84 West.
lower grayish-brown silt, a middle light-grayish-brown silt, and an upper grayish-brown silt.

The age of Unit Five is Late Wisconsinan to Holocene. Although none of the four members has been adequately dated, the age of the members has been inferred by comparison with paleoclimatic and paleoecologic studies of the Holocene in this region. The Mallar Island Member was interpreted by Clayton and others (1976) to have been deposited during a cool, moist climate following the last glacial when wind eroded silt from the unstable meltwater channel floodplain and deposited it on the terraces and uplands. Other light color layers are interpreted to have been deposited during warm, dry climates when hillslopes were unstable due to sparse vegetation. During warm dry climates silt was removed from the unstable hillslopes and deposited as fallout. Cool, moist climates caused an increase in vegetative density, stabilizing hillslopes and forming dark-colored layers in the silt because of an increase in humic material.

Unit Six

Unit Six consists of light-yellowish-brown to very-dark-brown well-sorted, fine- to medium-grained sand. It is typically unbedded but may contain low-angle crossbedding and flat bedding. Dark-colored bands were observed in at least two stratigraphic levels within Unit S (Figure 16). The dark colored bands are paleosols representing former stable surfaces.

Unit Six forms both dune topography, as discussed under sand dunes in the landform section of this report, and a continuous sheet of sand which grades into silt of Unit Five.
Unit Six is up to 10 metres thick and is only mapped where it is greater than 1 metre thick. It is eolian sand which has been reworked from the terraces and floodplains.

Unit Six is largely Holocene sediment. Most of the sand probably accumulated during mid-Holocene time. According to David (1971, p. 299), in a study of sand dunes in southern Manitoba, dunes are stabilized by vegetation during periods of increased precipitation, and dry periods decrease vegetation density causing increased dune activity. Stabilization of the dune or sand sheet is represented in the stratigraphic section by paleosols.

The uppermost paleosol observed in Unit Six probably is contemporaneous with the paleosol of the Jules Stable Episode (Bickley 1972, p. 128). The age of this paleosol in Unit Six has been indicated by several different lines of evidence. The paleosol grades laterally into an organic, silty, sandy clay unit (Fischer 1980, p. 38, 39). A species of Populus found at the base of this organic deposit was dated at 325 BP. Trees within blowouts in Unit Six are commonly rooted in this paleosol, indicating a recent age. Artifacts which appear to have eroded out of this paleosol so far have not been datable, but they do suggest an age older than the late 1800's. This paleosol probably began forming roughly 325 BP and ceased in 1928 when the "Dirty Thirties" unstable episode began.

Unit Seven

Unit Seven is composed of silt, clay, sand, and gravel. Sediment of Unit Seven is variable in color, sorting, and thickness. Discussion of Unit Seven is eased by subdividing the unit into two general
FIGURE 16. Natural outcrop in a blowout of the windblown sand unit of the Oahe Formation (Unit Six). The dark colored band is a paleosol. Outcrop is located in the SW-1/4 Section 3, Township 144 North, Range 85 West.
subunits. These subunits are not differentiated on the map because they contain very similar sediment.

Part of Unit Seven is deposited in swales, intermittent stream valleys, and at the base of hillslopes. In such settings, it is largely colluvium.

The colluvial deposits of Unit Seven are similar to the source material upslope. Below steep slopes of Paleocene sediment the colluvium is brown to gray, silty clay. At the base of hillslopes composed of glacial till or gravel the colluvium is grayish-brown to dark-gray vaguely bedded pebble loam. Below loess covered slopes the colluvium is indistinguishable from Unit Five.

The major part of Unit Seven was deposited as alluvium in river channels and floodplains. It consists of light-yellowish-brown calcareous clay, silt, and very fine- to coarse-grained sand interlayered with up to 12 units of grayish-brown to dark-grayish-brown, calcareous clay, silt, and very fine- to fine-grained sand. A few gravel layers are also present in this part of Unit Seven. The silt and clay beds of this unit are diffusely bedded. Climbing ripple crossbeds, flat beds, large- and small-scale crossbeds, and diffuse beds are commonly found in the sand of Unit Seven. Secondary deposits such as carbonate nodules and iron stained siltstone nodules are found throughout Unit Seven. Unit Seven contains charcoal lenses and wood. Several of these samples were analyzed for radiometric age. Artifacts and fossils of terrestrial gastropods, aquatic gastropods, bison, elk, and other mammal bones were observed within Unit Seven.

This part of Unit Seven ranges in thickness from less than 1 metre to greater than 12 metres. Unit Seven alluvium underlies alluvial
terraces and the modern floodplain along the Knife and Missouri Rivers. These cut and fill terraces are located at different elevations above river level and are separated by erosional surfaces. Further explanation of these terraces is in the section discussing morphologic units.

Most Unit Seven alluvium was deposited by upper-flow-regime, lower-flow-regime, and stagnant water. Vertical accretion (overbank) deposits are represented in this unit by diffusely bedded sand, silt, and clay. Lateral accretion (point-bar) deposits consist of sand and silt containing climbing ripple crossbeds, large and small scale crossbeds, and thin clay layers. Channel-lag deposits are represented by beds of gravel and coarse sand. Parts of Unit Seven alluvium have been reworked by eolian and colluvial processes. Bioturbation by plants, earthworms, rodents, and man has disrupted most of the primary sedimentary structures of this unit.

Unit Seven is Holocene in age. Most of it was deposited within the last 8500 years and parts of Unit Seven continue to be deposited by nearly annual floods.

Morphologic Units

Uplands

The uplands consist of the region above the Missouri and Knife River valleys. This unit is characterized by rolling hills interspersed with closed depressions and sloughs. Hillslopes are generally less than 15 degrees. The uplands are an unterraced bedrock surface mantled with a thin layer of glacial, eolian, alluvial, and lacustrine sediment.
Drainage of the upland ranges from well-drained hillslopes to poorly-drained closed depressions.

The typical stratigraphic section contains paleocene sediments overlain by 0.5 to 3.0 metres of glacial till overlain by less than 1 metre of loess.

The uplands are differentiated from other units by topography, elevation, and the lack of associated fluvial sediment. The surface of this unit has more relief than the terraces but generally has lower relief than the slopes. The 600-metre contour marks the lower contact with the Riverdale Terrace or the slopes.

Slopes

The slopes consist of breaks between terraces or between the uplands and the highest terrace present. Included in this unit are rugged badlands (15 to 90 degree slopes) cut into Paleocene sediments and smooth breaks between fluvial terraces (less than 10 degree slopes). Surface sediment on the slopes is variable but most slopes are at least partially covered with colluvium. Age of the slopes is variable, but when associated with a terrace, the slopes are younger than the terrace immediately above them.

Massively Bioturbated Land

This unit consists of areas where the natural surface morphology and lithology have been altered by large-scale construction and coal mining. It includes unfilled pits, spoil piles, and reclaimed land associated with coal mining, and areas disturbed during the construction of Garrison Dam.
Riverdale Terrace

The Riverdale Terrace is the highest terrace mapped. It is named after the village of Riverdale which is located on this surface about 1 kilometre northeast of Garrison Dam. This terrace forms a flat to gently undulating surface gradually sloping towards the valleys. The Riverdale Terrace is generally well drained with slopes less than 5 degrees. The Riverdale Terrace is located between elevations of 579 to 600 metres in the study area, between 67 and 90 metres above river level.

The Riverdale Terrace is a cut terrace containing little or no fluvial sediment. Surficial sediment on this terrace consists of Paleocene fluvial sediment, glacial till, fluvial gravel, eolian sand, loess, lake sediment and colluvium. The typical stratigraphic section of the Riverdale Terrace contains Paleocene fluvial sediment overlain by 1 metre of gravel overlain by 1 to 2 metres of glacial till overlain by less than 1 metre of loess.

The Riverdale Terrace has less relief, better drainages, and more surface and near-surface fluvial sand and gravel than the uplands. It is difficult to differentiate from the uplands in many locations. Consequently, an arbitrary upper limit of the 600-metre contour was set for the highest contact between the Riverdale Terrace and the Uplands. The Riverdale Terrace can be distinguished from lower terraces by elevation. Terrace slopes grade into this and other terraces, but these can be differentiated because the slopes generally form escarpments between terraces.

The Riverdale Terrace is interpreted as a former fluvial floodplain
which was later incised to form the terrace. Subsequent deposition of glacial till and erosion by streams and slopewash has modified the original terrace surface, making it harder to identify than most lower terraces.

The Riverdale Terrace is the oldest terrace identified. The absolute age is unknown but it is probably pre-Wisconsinan and post-Pliocene.

Sakakawea Terrace

The Sakakawea Terrace forms a level surface at about the same elevation as the maximum pool level of Lake Sakakawea and therefore is named after the lake. The Sakakawea Terrace is located between elevations of 560 to 570 metres, between 51 and 61 metres above river level.

The Sakakawea Terrace consists of a flat to gently undulating surface sloping towards the valleys. It is well drained with slopes less than 5 degrees.

The Sakakawea Terrace is a cut terrace with little associated fluvial sediment. The range of surficial sediment and typical stratigraphy of the Sakakawea Terrace are the same as that associated with the Riverdale Terrace.

The Sakakawea Terrace is a former river floodplain which has been modified by glacial deposition and stream and slopewash erosion. This terrace is younger than the Riverdale Terrace and older than terraces located at lower elevations. It is probably pre-Wisconsinan in age.
McKenzie Terrace

The McKenzie Terrace is located at a mean elevation of 548 metres. Parts of this terrace are present between 33 to 42 metres above river level. The McKenzie Terrace is named after glacial Lake McKenzie which was filled during the Late Wisconsinan. This lake occupied parts of the Missouri valley and low areas in southcentral North Dakota east of the present location of Bismarck, near the town of McKenzie (Kume and Hanson 1965, p. 17). A minimum lake level of 533 metres above sea level was suggested by Bickley (1972, p. 117), based on lake silts occurring at this elevation. The elevation of 548 metres is reasonable considering that this lake's shoreline would be higher than the basin where offshore sediments were deposited.

The McKenzie Terrace is a flat to gently sloping, well-drained surface having slopes less than 5 degrees. This surface is preserved either as a terrace cut into Paleocene sediments or glacial till, or as a fill terrace underlain by sand or gravel. Much of the McKenzie surface is overlain by up to 10 metres of eolian sand or up to 5 metres of eolian silt.

About 500 metres north of the KNRI, gravel mining has exposed the McKenzie fill (Figure 17). At this point the terrace is composed of 2 metres of large-scale, high-angle, crossbedded gravel which is well sorted within individual beds and dips toward the valley wall.

The crossbedded gravels within the McKenzie fill are interpreted to be back-beach deposits, formed as a strandline of proglacial lake McKenzie. The McKenzie Terrace is differentiated from other morphologic units by its flat surface within its specific elevation limits. It is probably of Late Wisconsinan age but may be older.
Hensler Terrace

The Hensler Terrace is named after the village of Hensler which located on this surface about 19 kilometres southeast of the study area. The Hensler Terrace is located between elevations of 527 to 542 metres between 17 to 31 metres above river level. It forms a flat to gently undulating, well-drained surface with slopes less than 5 degrees. The Hensler Terrace is generally a fill terrace composed of up to 16 metres of fluvial sand and gravel. This terrace fill is capped by up to 10 metres of eolian sand or up to 5 metres of eolian silt.

Ten metres of faulted and folded gravel within the Hensler Terrace is exposed about 5 kilometres west of Stanton (Figure 13). The deformed sedimentary structures were probably caused by deposition of the Hensler fill on stagnant ice followed by melting of the ice and collapse.

The Hensler Terrace is differentiated from other morphologic units by having a relatively flat surface between its specific elevation limits. It is interpreted to have formed at two different times. The original Hensler floodplain probably formed during Late Wisconsin time. This surface was abandoned when glacial ice blocked the channel in south-central North Dakota and proglacial Lake McKenzie filled to the McKenzie Terrace level. The original floodplain was re-occupied when the ice dam was breached and the river returned to approximately its original Hensler surface.

Stanton Terrace

The Stanton Terrace is named after the village of Stanton which located on this surface. The Stanton Terrace is a flat, well-drain
FIGURE 17. High-angle, crossbedded gravel within the McKenzie Terrace fill, dipping towards the valley wall. The gravel is overlain by the Oahe Formation with Mallard Island (MI), Aggie Brown (AB), Pick City (PC), and Riverdale (Rd) Members marked. The pick handle is about 1 metre long. Outcrop is a gravel pit located in the NE-1/4, SW-1/4 Section 16, Township 145 North Range 84 West.
surface with slopes less than 5 degrees. It is located between elevations of 517 to 524 metres, between 8 to 15 metres above river level (Figure 18). Tributary terraces grading into the Stanton Terrace are mapped contiguous with the Stanton Terrace but commonly have steeper slopes and extend to higher elevation.

The Stanton Terrace is a fill terrace generally composed of over 2 metres of poorly-sorted, flat-bedded to unbedded sand and gravel (Figure 12a). This terrace fill is capped by up to 5 metres of eolian silt or sand which grades into and is interbedded with overbank silt and clay near tributaries. Upstream along the Knife River the Stanton Terrace is completely overlapped by younger alluvium.

The Stanton Terrace is the lowest Pleistocene terrace identified. It is younger than the Hensler Terrace and is probably Late Wisconsinan in age.

The Stanton Terrace is identified on the basis of its flat surface within the specific elevation limits. Where the surface is overlain by deposits of younger alluvial silt and clay it is difficult to differentiate the Stanton Terrace from the A terrace.

A Terrace

The A terrace is found between the 515 and the 522 metre contours, between 6 to 8 metres above the river level.

The A terrace is generally a fill terrace. The fill of the terrace can be divided into two major units (Figures 19 and 20). The lower unit contains light-brown to gray, fine- to medium-grained, silty sand and clay. Sedimentary structures within the lower A fill include high- and low-angle, small-scale crossbeds, climbing ripple crossbeds, and
Figure 18. Overview of the Stanton Terrace, view is to the east overlooking the northern part of the Stanton Ferry bluff.
horizontal beds. This sediment reaches thicknesses greater than 5 metres. The lower A fill coarsens downward. The lower A sand is largely lateral accretion sediment, most of which was deposited in channel margins as point bars.

Upper A sediment consists of pale-brown, clayey silt containing several layers of dark-grayish-brown silty clay, and is capped by up to 1 metre of grayish-brown silt. This unit is unbedded to diffusely bedded and contains discontinuous layers of charcoal, terrestrial gastropods, carbonate nodules, bones of large mammals, and artifacts. The upper A sediment is largely vertical accretion deposits that accumulated as fallout from overbank flood waters. Silt capping this fill is interpreted to be loess or loess slightly reworked by slopewash and flood water. The dark colored bands contain disseminated organic materials and are interpreted to be paleosols.

The discontinuous layers of charcoal were originally thought to be remains of man-made hearths. However, the presence of continuous sections several metres long and the lack of associated cultural materials suggest that the charcoal layers are the remains of floodplain forest fires that have been slightly reworked by slopewash and flood water.

The A terrace can be differentiated from other terraces by its elevation limits, escarpments between higher and lower terraces, lack of meander scars on the surface, and the characteristic stratigraphy consisting of a light colored sandy lower unit overlain by a darker-colored silty clay unit containing several paleosols.

The A terrace is restricted to the Knife River valley although material similar to upper A sediment underlies the Stanton Terrace
FIGURE 19. A terrace fill at Elbee Bluff showing the slope forming sand and clay deposit of the lower A terrace fill and the cliff forming silt and clay deposit of the upper A terrace fill containing several dark-colored layers. The top of the bluff is about 7 metres above river level.

FIGURE 20. A terrace fill at Big Hadatsa Bluff showing the slope forming sand and clay deposit of the lower A terrace fill and the cliff forming silt and clay deposit of the Upper A terrace fill containing several dark-colored layers. The top of the bluff is about 7 metres above river level.
surface along the Missouri River, especially near tributaries. In such settings the fill is considered part of the Stanton Terrace because no obvious escarpments occur between deposits of the alluvium and the loess, the alluvium is interbedded with the loess deposits, generally fluvial gravel makes up part of the Stanton fill but not the A fill, and the surface is part of an extensive terrace at the Stanton level. The absence of the A terrace along the Missouri River may be the result of its complete destruction by the meandering river. Basic differences in runoff into the two river systems may also have caused the formation of the A terrace in the Knife valley but not in the Missouri Valley. The larger area drained by the Missouri River than the Knife River and runoff from melting snow and small glaciers in the Rocky Mountains may have contributed sufficient water to prevent aggrading of the Missouri River floodplain to the A surface.

The A terrace is probably of Middle Holocene to Late Holocene age. Radiocarbon dates from charcoal within upper A sediment range from 2900 BP to 3900 BP. No datable material was found in the lower A fill, but it is older than 3900 BP and probably younger than about 8500 BP.

B Terrace

The B terrace is a composite of two fill terraces located from 0 to 6 metres above river level at elevations between 509 to 520 metres. The B1 surface ranges from 4 to 6 metres above river level and the B2 surface ranges up to 5 metres above river level and includes the modern floodplain. The B terrace is found along both the Knife and Missouri Rivers.

The surface of the B terrace is generally flat. Floodplain sand dunes, partially filled channels, and the present channel cause up to 6
metres of relief on this surface. Meander scars occur where former channels are nearly filled, making the B terrace easily identifiable from the air.

The B1 terrace fill unconformably overlies either lower A or upper A terrace fill. The lower 1 to 3 metres of the B1 alluvium consists of dark-gray silty clay. This sediment contains carbonate nodules, bones of large mammals, unidentified organic material, and terrestrial gastropods. Lower B1 fill is largely overbank fallout sediment and the dark color is a result of soil development. It ranges in thickness from less than 1 metre to more than 7 metres.

The upper B1 fill contains 1 to 5 metres of light-brown to pale-brown, silty clay. This sediment is generally unbedded but thin dark-colored bands make the sediment look diffusely bedded. The dark-colored bands contain lenses and layers of charcoal. Upper B1 fill is made up largely of a combination of lateral accretion (point bar) and vertical accretion (overbank) deposits.

The B1 terrace is generally identifiable only where the B1 fill outcrops. The B1 alluvial deposit is characterized by a light colored, sandy, upper unit overlying the dark colored silty clay unit (Figures 21 and 22).

The B2 terrace fill is inset into either the A terrace fill or the B1 terrace fill. Outcrop characteristics of the B2 fill are similar to those of the A fill (Figures 23 and 24). The lower several metres are composed of pale-brown to very light-brown, silty sand. This light colored unit contains climbing ripple crossbeds, small-scale crossbeds, flat beds, and convoluted beds. Fossils include terrestrial gastropod shells, aquatic gastropod shells, bivalve shells, large mammal bones, wood, and charcoal. Vertical iron stains, iron stained siltstone
nodules, and carbonate nodules are found in the lower B2 alluvium. This sediment is diffusely bedded to unbedded. The lower B2 fill is largely lateral accretion (point bar) deposits.

The upper B2 fill consists of dark-grayish-brown silty clay with a few thin layers of pale-brown to light-brown, silty clay. This sediment is diffusely bedded to unbedded. The upper B2 fill is largely overbank deposits and the dark-colored layers are probably paleosols.

The B2 terrace fill is Late Holocene in age. Radiocarbon dates on wood and charcoal within the B terrace fill range from 1100 BP to modern.
FIGURE 21. B1 terrace fill at Elbee Bluff, with the dark-colored, lower unit overlain by the lighter-colored upper unit. The top of the bluff is about 5 metres above river level.

FIGURE 22. B1 terrace fill at Madman Bluff showing the overlapping contact between the B2 terrace fill and the B1 terrace fill near the center of the photograph. The top of the bluff is about 5 metres above river level.
FIGURE 23. B2 terrace fill at Elbee Bluff showing the light-colored, lower B2 terrace fill overlain by the darker-colored banded, upper B2 terrace fill. The top of the bluff is about 4 metres above river level.

FIGURE 24. B2 terrace fill at Madman Bluff showing the light-colored, lower B2 terrace fill overlain by the darker-colored, banded upper B2 terrace fill. The top of the bluff is about 4 metres above river level.
Little data exists for determining the absolute age of the Pleistocene terraces identified in this study. No datable wood or charcoal was observed within the fill of these terraces and some of the terraces are probably older than the limits of radiocarbon dating. Only the relative chronology of the terraces can be determined. In general, the highest terraces are the oldest and the age of the terraces decreases with decreasing elevation (Ruhe 1975, p. 81). Based on this assumption, the relative age of these terraces from oldest to youngest is the Riverdale Terrace, Sakakawea Terrace, McKenzie Terrace, Hensler Terrace, and the Stanton Terrace.

The assumed chronology is probably valid in most cases. One exception is where evidence exists for glacial damming of the river. If a meltwater channel or river was dammed by an advancing glacier, it would be ponded, causing the water level to rise above the original floodplain and possibly effect higher terraces. If the lake persisted long enough to form a strandline, wave-cut benches could develop having similar properties as fluvial terraces. After the river breached the ice dam a diversion channel would develop and the lake would begin to drain. This drainage probably occurred rapidly. Because of positive feedback, the diversion channel would incise into the land surface causing more water to flow through the channel causing increased downcutting. Decreased down-cutting probably occurred as the river approached the pre-lake river gradient and it returned to approximately the former floodplain.
A major difference between fluvial terraces and strandline terraces is that the fluvial terraces slope downstream, whereas strandline terraces occur at a specific elevation throughout the basin. Therefore, along a valley segment containing both types of terraces, a strandline terrace would be higher above river level at the downstream end of the former lake and a fluvial terrace would probably be close to the same distance above river level along the same river segment. Over tens or hundreds of kilometres the slope difference between strandline terraces and fluvial terraces could cause confusion in identification and correlation in a valley containing both types of terraces. Figure 25 is an example of possible relationships between three fluvial terraces FT1, FT2, and FT3 and one strandline terrace ST1. In this example the strandline terrace could be confused first with FT1 then with FT2 and FT3 as the strandline terrace is traced downstream.

Since this area was glaciated several times during the Pleistocene, proglacial lakes could have formed several times. Therefore strandline terraces are possible at different levels in the Knife and Missouri River valleys. Within the study area the only terrace interpreted as a former shoreline is the McKenzie Terrace. This interpretation is based on the occurrence of late Wisconsin lake sediment east of Bismarck. According to Bickley (1972, p. 120), this sediment was deposited in pro-glacial Lake McKenzie which occupied the Missouri valley and low-lying areas outside the valley from south of Bismarck to north of Garrison Dam.

Other evidence for Lake McKenzie is found about 500 metres north of the KNRI. Here a gravel pit exposure of the McKenzie fill contains bimodally sorted, cross-bedded gravel dipping towards the valley wall.
FIGURE 25. Longitudinal view of a hypothetical valley segment showing possible relationships between three fluvial terraces FT1, FT2, and FT3 and a strandline terrace ST1.
This fill is interpreted to be backbeach sediment deposited at the shoreline of proglacial Lake McKenzie.

The Missouri River valley south of Bismarck is the narrowest valley segment in south-central North Dakota. This trench was probably incised by the draining of Lake McKenzie. The fact that the valley is not as rugged and narrow here as it is in diversion channels farther north does not necessarily reflect great age differences in trenching. It may be the result of changes in the resistance to erosion of the underlying formations. Diversion channels in central and western North Dakota are cut into more resistant Paleocene Formations. In the south central part of the state, less resistant Cretaceous formations have been incised. Another explanation is that Lake McKenzie drained into an older partially filled diversion channel which accounts for the relatively wide valley.

The best way to determine which glacial advance produced a terrace is to trace the terrace upstream to an outwash plain or other surface associated with a specific glacial advance. If the advance has been dated, the terrace can be assumed to be nearly the same age. Without dates the relative age of this terrace can still be determined if the relative chronology of the glacial advance has been established.

The Stanton Terrace is the only terrace that has been traced in this manner. According to Bickley (1972, p. 124), this terrace appears to correlate with surfaces related to the Lostwood Glaciation (latest Wisconsinan) along Painted Woods Creek in Burleigh and McLean Counties.

Terrace surfaces are generally overlain by 0.5 to 10 metres of sediment not related to the terrace deposits. This sediment is largely eolian silt, but considerable amounts of eolian sand, alluvium,
colluvium, and glacial till can also cover the surfaces. These deposits are not directly related to either the former floodplain or the incision of the surface, but were deposited after the river had entrenched the floodplain. If the material immediately capping the terrace fill can be dated, a minimum date of the terrace can be determined.

The Riverdale and Sakakawea Terraces are interpreted to be oldest because they are at the highest elevation. This interpretation is supported by the occurrence of glacial till over the terrace gravel. The equivalent till, although not positively identified, is probably relatively deep within the valley fill and it is covered by younger glaciofluvial and lacustrine sediment.

Eolian silt of the Oahe Formation capping the Hensler and Stanton Terraces can also be used to determine the age of these terraces. The lowest member of the Oahe Formation commonly found on the Stanton Terrace is the Aggie Brown Member. On the Hensler Terrace the Mallard Island Member is the lowest unit. These observations were used for evidence that while the Stanton Floodplain was occupied by meltwater, silt was blown up from it and deposited on the Hensler Terrace (Clayton and others 1976, p. 9). They suggested that the top of the Mallard Island Member probably coincides with the end of the late Wisconsinan glaciation, about 13,000 BP, in central and eastern North Dakota, which was followed by the incision of the Stanton floodplain.

Correlations of these terraces with other identified terraces along the Missouri River and its major tributaries in the Northern Great Plains are very speculative. Several problems are associated with attempts to correlate terraces along the Missouri River. Reservoirs on the Missouri River cover the terraces throughout much of North Dakota.
Areas where terraces have been studied are generally several hundred kilometres apart, and attempts to trace terrace surfaces over distances have been limited. Because of glacial diversion, segments of the valley are of different age and do not have the same sequential terraces. Relative elevation above river level is commonly the method to correlate the terraces and this is difficult to estimate when the river is dammed.

Keeping these qualifications in mind, a tentative correlation of Missouri River and tributary terraces is shown in Table 1, based largely on relative elevations above river levels. Data for this correlation comes from studies in western North Dakota (Alden 1932; Howard 1976; and Salomon 1976), in central North Dakota (Clayton and others 1976; Reiten, this study), in south central North Dakota (Kume and Hanf 1965), and in South Dakota (Coogan, personal communication, August 1979). The terraces have been traced for relatively long sections on the Missouri River and tributaries.

An alternative correlation between terraces in North and South Dakota can be made by studying the stratigraphy of the silty sediment overlying the terrace gravels. In central North Dakota these silts are part of the Oahe Formation and the lowest member overlying the Stanton Terrace is the dark-brown and dark-reddish-brown colored Aggie Brown member. In South Dakota the MT2 terrace gravels are directly overlain by silts having similar characteristics as the Aggie Brown Member (Coogan and Irving 1959). This interpretation would support correlating the Stanton Terrace with the MT2 terrace rather than with the MT1 terrace as shown in Table 1.
## TABLE 1

**TABLE 1. Tentative correlation of Missouri River terraces in North and South Dakota.**

<table>
<thead>
<tr>
<th>Missouri and Yellowstone Rivers</th>
<th>Central North Dakota Missouri and Knife River</th>
<th>South Central North Dakota Missouri River</th>
<th>South Dakota Missouri River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alden (1932)</td>
<td>Reiten &amp; others (this study)</td>
<td>Bluemle (1971)</td>
<td>Coogan (1979)</td>
</tr>
<tr>
<td>Howard (1960)</td>
<td></td>
<td>Kume &amp; Hanson (1965)</td>
<td></td>
</tr>
<tr>
<td>Salomon (1976)</td>
<td>Stanton (10 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crane Terrace (8-15 m)</td>
<td>Lower Terrace (12-15 m)</td>
<td>MT-1 (11 m)</td>
</tr>
<tr>
<td></td>
<td>Crane Terrace (11-21 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench 3</td>
<td>Hensler Terrace (17-31 m)</td>
<td>Middle Terrace (27 m)</td>
<td>MT-2 (33 m)</td>
</tr>
<tr>
<td>(? )</td>
<td>McKenzie Terrace (33-42 m)</td>
<td>D Upper Terrace (69 m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I Terrace (67 m)</td>
<td>MT-3 (65 m)</td>
</tr>
<tr>
<td></td>
<td>Sakakawea Terrace (51-61 m)</td>
<td>E Terrace (75 m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MT-4</td>
</tr>
<tr>
<td></td>
<td>Bench 2 Terrace (61 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cartwright Terrace (75 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cartwright Terrace (90 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Riverdale Terrace (67-90 m)</td>
<td>Custer Terrace (91 m)</td>
<td></td>
</tr>
</tbody>
</table>

79
The early Pleistocene History of central North Dakota is poorly understood. A tentative chronology of geologic events, named glacial deposits and river activity is shown in Figure 26. The area was probably glaciated several times before the Wisconsinan, but due to erosion, little evidence remains of the early glaciations. The southwesternmost glaciation (Dunn Glaciation) is identified by scattered boulders from the Canadian Shield (Clayton 1969). Evidence for a late pre-Wisconsinan glaciation (Verone Glaciation) consists of a large amount of Canadian Shield boulders covering the land surface (Bickle 1972).

These early glaciations undoubtedly diverted the preglacial drainages but evidence for this is, for the most part, lacking. Following the Dunn and Verone Glaciations a period of erosion and weathering removed most of the glacial sediment and incised the river valleys.

After the erosional event two periods of aggradation and erosion formed the Riverdale Terrace and Sakakawea Terrace. These terraces formed before or as a result of the Napolean Glaciation (earliest Wisconsinan?). The Napolean Glaciation diverted east flowing streams to the south and west. When the Napolean Glaciation reached its maximum extent, the meltwater was diverted into the Killdeer-Flasher Channel which trends southeast a few kilometres beyond the Napolean limit (Clayton and Moran, 1982). Napolean till was deposited on top of the Riverdale and Sakakawea Terraces, masking the terraces in some areas and completely obliterating them in others.
FIGURE 26. Tentative chronology of glacial and river activity in central North Dakota during the Pleistocene.
<table>
<thead>
<tr>
<th>Pre-Wisconsinan</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horseshoe Valley Formation</td>
<td>Snow School Formation</td>
<td>?</td>
<td>Lostwood Glaciation</td>
</tr>
<tr>
<td>Medicine Hill Formation</td>
<td>Napoleon Glaciation</td>
<td>?</td>
<td>Drainage of Lake McKenzie</td>
</tr>
<tr>
<td>Dozens of Glaciations Including Dunn and Verone</td>
<td>Incision</td>
<td>?</td>
<td>River Returns to Hensler Floodplain</td>
</tr>
<tr>
<td>Diversion, Alternating Aggradation and Incision</td>
<td>Aggradation to Sakakawea Terrace Level</td>
<td>?</td>
<td>Aggradation to Hensler Terrace Level</td>
</tr>
<tr>
<td>Incision</td>
<td>Diversion to Riverdale Terrace Level</td>
<td>Incision</td>
<td>Incision</td>
</tr>
<tr>
<td>Incision</td>
<td>Aggradation to Hensler Terrace Level, Diversion</td>
<td>Lake McKenzie</td>
<td>Aggradation to Stanton Terrace Level</td>
</tr>
<tr>
<td>Incision</td>
<td>Incision</td>
<td>?</td>
<td>Incision</td>
</tr>
</tbody>
</table>

Glaciations and Name Deposits

River Activity
Subglacial shearing formed northeast to southwest trending longitudinal ridges in the Napolean and older sediment.

The Napolean Glaciation was followed by an erosional event which removed much of the glacial sediment and incised the river valleys.

The Lostwood Glaciation was the next glacial advance into central North Dakota. The western limit of this glaciation is unclear. Sediment from this glaciation is generally not found west of the Missouri River.

Stagnant ice was present in the Knife River valley just prior to aggradation to the Hensler surface. This conclusion is based on the faulted and folded sedimentary structures within the Hensler fill. Whether the ice was a remnant of the Napolean Glaciation or the Lostwood Glaciation is unknown, but if late Wisconsinan ice crossed the Missouri River over the uplands, it probably occupied parts of low-lying Knife River valley. With the advance of the first Late Wisconsinan ice into central North Dakota, trenching of the diversion channel between Garrison Dam and Stanton was initiated and the valleys aggraded to the Hensler floodplain.

A local readvance of the Lostwood glacier into south-central North Dakota dammed the Missouri River which perhaps was flowing in the Strasburg channel (Bickley 1972, p. 117). Proglacial Lake McKenzie formed, depositing silt within the lake basin and developing wave-cut benches and beaches at the margin of the lake. The lake eventually breached the ice dam and a new channel was cut in the present position of the Missouri River valley. The incision progressed until the former gradient of the Hensler floodplain was reached. The Hensler floodplain was incised after the retreat of the first Lostwood glaciers.
The last Lostwood advance in central North Dakota probably did not reach the present Missouri River valley. Meltwater draining the glacier did, however, cause the valley bottom to aggrade to the Stanton floodplain. While this floodplain was occupied dust was blown up from the floodplain and deposited on flat-lying higher surfaces as the Mallard Island Member of the Oahe Formation.

The retreat of the last glacial ice caused a decrease of sediment load in the rivers, and they incised the Stanton floodplain to form the Stanton Terrace.
Three Holocene terraces, the A, B1, and B2 terraces, and their associated alluvial fills were identified in the study area. The relative age of these terraces and terrace fills was determined by elevation of terrace levels, occurrence of scarps between terraces, radiocarbon dates, and stratigraphy and sedimentology of the respective fills. A Holocene age was estimated for these lower terraces because of the fine-grained fill underlying them, in contrast to the coarse-grained fill underlying most higher Pleistocene terraces. This was confirmed by radiocarbon dates which indicated a Holocene age of the lower terraces.

The cut and fill relationships between terraces A, B1, and B2 are most evident at the Elbee Bluff (Figure 27). Several dark-colored bands are within the upper 3.5 metres of the A terrace at the Elbee Bluff (Figure 19). The A terrace can be traced southeast of the Elbee Bluff to the Sakakawea Bluff where the upper 3.5 metres of the fill also contains several dark bands (Figure 28). Although the A terrace cannot be traced from the Elbee Bluff to the Big Hidatsa Bluff similar stratigraphy and elevations of the terraces suggest they are remnants of the same terrace (Figure 20).

The B terrace complex, composed of the B1 and B2 terraces was traced in a similar manner. The B1 terrace at the Elbee Bluff forms a relatively flat surface 4 to 6 metres above river level. It is inset into the A terrace fill. The B1 fill is composed of 1 to 2 metres of light-colored, silty sand with very few dark bands (Figure 21). This
Figure 27. Cut and fill relationships between the A, B1 and B2 terraces at the Elbee Bluff. The center of the bluff is about 5 metres above the river level.
FIGURE 28. The A terrace fill at Sakakawea Bluff. The top of the bluff is about 5.5 metres above river level.
overlies 1 to 2 metres of dark-brown silty clay. The scarp between B1 and the B2 terraces at the Elbee Bluff can be traced north to the Madman Bluff (Figure 29). Here, the terrace 4 to 6 metres above river level contains fill which is similar to the B1 fill at the Elbee Bluff (Figure 22).

Surfaces identified as the B2 terrace range from 0 to 5 metres above river level. This includes the modern floodplain and several indistinct terraces above the floodplain. The fill underlying this terrace generally consists of 1 to 2 metres of dark-grayish-brown, silty clay overlying 0 to more than 3 metres of light-brown sand and silt. The B2 terrace can be traced by following the escarpment separating the B1 and B2 terraces from the Elbee Bluff north to the Madman Bluff. The B2 fill stratigraphy is similar at both of these cutbanks as well as most other cuts into this terrace along the Knife and Missouri Rivers (Figure 23 and 24).

In order to develop the chronology of the alluvial deposits, charcoal and wood from these deposits were analyzed for radiocarbon age. Table 2 summarizes the results. Six samples were analyzed by both the Institute for the Study of Earth and Man at Southern Methodist University and the Center for Applied Isotope Studies at the University of Georgia. Other samples collected from archaeological contexts within the study area were also analyzed by these two laboratories. Split examples, samples from the same stratigraphic level, and samples associated with artifacts identified from specific cultural phases were dated. Discrepancies of up to 500 years from duplicate samples were found between the two laboratories. The University of Georgia dates were generally younger than the Southern Methodist University dates.
FIGURE 29. Scarp between the B1 and B2 terraces north of the Elbee Bluff.
## TABLE 2
DATA ON C-14 SAMPLES FROM CUTBANKS ALONG THE KNIFE RIVER, KNRI

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location</th>
<th>Stratigraphic Position</th>
<th>Material</th>
<th>Age 5568 Halflife</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMU 708</td>
<td>Elbee Bluff</td>
<td>2.6m below</td>
<td>Charcoal</td>
<td>2974±66 BP</td>
<td>1. Dates upper charcoal layer within A terrace sediment.</td>
</tr>
<tr>
<td></td>
<td>A terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMU 786</td>
<td>Elbee Bluff</td>
<td>3.3m below</td>
<td>Charcoal</td>
<td>3942±300 BP</td>
<td>1. Dates lower charcoal layer within A terrace sediment</td>
</tr>
<tr>
<td></td>
<td>A terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMU 787</td>
<td>Elbee Bluff</td>
<td>3.3m below</td>
<td>Charcoal</td>
<td>3870±162 BP</td>
<td>1. Dates lower charcoal layer within A terrace sediment, same layer as SMU 786.</td>
</tr>
<tr>
<td></td>
<td>A terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UGA 3071</td>
<td>Elbee Bluff</td>
<td>2.6m below</td>
<td>Charcoal</td>
<td>35±320 BP</td>
<td>1. Dates upper charcoal layer within B1 terrace sediment.</td>
</tr>
<tr>
<td></td>
<td>B1 terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMU 710</td>
<td>Taylor Bluff</td>
<td>1.8m below</td>
<td>Charcoal</td>
<td>3431±74 BP</td>
<td>1. Dates charcoal with A terrace sediment.</td>
</tr>
<tr>
<td></td>
<td>A terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UGA 3075</td>
<td>Taylor Bluff</td>
<td>1.8m below</td>
<td>Charcoal</td>
<td>2965±75 BP</td>
<td>1. Dates charcoal layer with A terrace sediment, same layer as SMU 710.</td>
</tr>
<tr>
<td>Sample No.</td>
<td>Location</td>
<td>Stratigraphic Position</td>
<td>Material</td>
<td>Age 5568</td>
<td>Comments</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>------------------------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
</tr>
</tbody>
</table>
| UGA 3076  | Taylor Bluff | 4.5m below B terrace | Wood | 555±60 BP | 1. Dates wood with B terrace sediment.  
2. Terrace surface obscured by road construction.  
3. Stratigraphy obscured by slumping and vegetation. |
| SMU 709   | Madman Bluff | 2.2m below B1 terrace | Charcoal | 1132±87 BP | 1. Dates charcoal with B1 terrace sediment. |
| UGA 3072  | Madman Bluff | 2.2m below B1 terrace | Charcoal | 630±75 BP | 1. Dates charcoal layer with B1 terrace sediment, same layer as SMU 709. |
2. Stratigraphic relations are obscured by slumping, vegetation, and the absence of a clear contact with older units. |
| UGA 3073  | Madman Bluff | 4.0m below B2 terrace | Wood | Modern | 1. Dates wood within B2 terrace sediment.  
2. Stratigraphic relations are obscured by slumping, vegetation, and the absence of a clear contact with older units. |
| UGA 3074  | Madman Bluff | 4.2m below B2 terrace | Wood | 45±60 BP | 1. Dates wood within B2 terrace sediment.  
2. Split sample, same wood dated as }
A comparison of radiocarbon dates associated with cultural materials indicated internal inconsistencies within these University of Georgia dates (Ahler 1980). It was also noted that the cultural context dates from the University of Georgia were not consistent with cultural phases indicated by the artifacts. Therefore, caution should be used in interpretations based on these dates. The University of Georgia dates are included in this report with the qualification that they only show order of magnitude ages and general trends.

The wood and charcoal samples were collected using metal trowels and sealed in plastic bags in the field. The wood samples needed little cleaning, but the charcoal was commonly disseminated in the overbank silt and clay and it was concentrated by floatation in distilled water. All of the charcoal samples were found within specific stratigraphic horizons which could generally be traced for tens of metres. The wood samples appeared to be driftwood which had been deposited in the alluvium.

The stratigraphic position of radiocarbon dated samples within the Holocene terraces are shown in Figures 30, 31 and 32. At the Elbee Bluff (Figure 30) three charcoal samples from the A terrace alluvium were analyzed. SMU 708 (2974 ± 66 BP) dates a charcoal layer 2.6 metres below the terrace surface. SMU 786 (3942 ± 300 BP) and SMU 787 (3870 ± 162 BP) date a charcoal layer 3.3 metres below the terrace surface. A dark-colored layer 0.95 metres below the terrace surface appears to be equivalent to a similar dark band at the Elbee Site which contains preceramic artifacts, greater than 2000 years old (Ahler 1978, p. 15). These dates indicate that the upper 3.3 metres of A terrace fill
FIGURE 30. Sketch of Elbee Bluff, showing locations of radiocarbon samples, and relationships between the A, B1, and B2 terraces and the associated alluvial fill units.

EXPLANATION

<table>
<thead>
<tr>
<th>Lithologic Units</th>
<th>Radiocarbon dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 7 - dark-grayish-brown silty clay</td>
<td>UGA 3071 35 ± 320 BP</td>
</tr>
<tr>
<td>Unit 6 - pale-brown silty sand.</td>
<td>SMU 708 2974 ± 66 BP</td>
</tr>
<tr>
<td>Unit 5 - pale-brown silty sand.</td>
<td>SMU 786 3942 ± 300 BP</td>
</tr>
<tr>
<td>Unit 4 - dark-grayish-brown silty clay.</td>
<td>SMU 787 3870 ± 162 BP</td>
</tr>
<tr>
<td>Unit 3 - light-brown to dark-brown silt.</td>
<td></td>
</tr>
<tr>
<td>Unit 2 - light-brown to dark-grayish-brown silty clay.</td>
<td></td>
</tr>
<tr>
<td>Unit 1 - light-brown silty sand and gray silty clay.</td>
<td></td>
</tr>
</tbody>
</table>

/////  - paleosols.

.....  - thin sand layers.

-----  - thin clay layers.
FIGURE 31. Sketch of Madman Bluff, showing locations of radiocarbon samples, and relationships between the B1 and B2 Terraces and the associated alluvial fill units.

EXPLANATION

Lithologic Units

Unit 4 - dark-grayish-brown silty clay.

Unit 3 - pale-brown to light-yellowish-brown clayey silty and sandy silt.

Unit 2 - pale-brown to light-yellowish-brown sandy silt.

Unit 1 - yellowish-brown and light-gray silty clay.

--- grayish-brown silty clay

/// dark-grayish-brown silty clay (paleosols).

Radiocarbon Dates

SMU 791 - 327 ± 50 BP
UGA 3073 - modern
UGA 3074 - 45 ± 60 BP

SMU 709 - 1132 ± 87 BP
UGA 3072 - 630 ± 75 BP
FIGURE 32. Sketch of Big Hidatsa Bluff, showing locations of radiocarbon samples, and relationships between the A, B and the B1 Terraces and the associated alluvial fill.

EXPLANATION

Lithologic Units

Unit 4 - pale-brown sandy silt and silty clay

Unit 3 - gray silty sand and clay

Unit 2 - light-yellowish-brown silty clay
brown sandy silt.

Unit 1 - light-brownish-gray silty clay
and silty sand.

UGA 3076 - 555±60 BP
SMU 710 - 3431±74 BP
UGA 3075 - 2965±75 BP

/// Paleosols, dark-brownish-gray silty clay.
accumulated since about 3900 and the upper 0.95 metres of sediment were deposited since about 2000 BP.

A date within the B1 terrace fill at the Elbee Bluff UGA 3071, (3840 ± 320 BP) is not considered to be reliable because it was a small sample and because of the uncertainty associated with the University of Georgia dates.

Two charcoal samples were dated from 2.2 metres below the B1 surface at the Madman Bluff (Figure 31). Both samples, SMU 709 (1132 ± 87 BP) and UGA 3072 (630 ± 75 BP) were collected from a continuous layer of charcoal. The age differences are probably due to inconsistencies between the two laboratories. Since the Southern Methodist University dates are more internally consistent, the date of 1132 ± 87 BP (SMU 709) is considered to be the correct age of this horizon.

Dates within the B2 terrace fill from the Madman Bluff (Figure 31) include SMU 791 (327 ± 50 BP), UGA 3073 (modern), and UGA 3074 (45 ± 60 BP). SMU 791 is considered to be fairly accurate, and it indicates the sediment 4.2 metres below the B2 surface was deposited about 327 ± 50 BP.

Radiocarbon dates SMU 710 (3431 ± 74 BP) and UGA 3075 (2965 ± 75 BP) are from a charcoal layer 1.8 metres below the A terrace at the Big Hidatsa Bluff (Figure 32). Again, there are significant differences between the two radiocarbon laboratories and SMU 710 (3431 ± 74 BP) is considered the best.

The terrace surfaces below the A terrace at Big Hidatsa Bluff are difficult to identify because cutbank erosion has forced a county road to be re-built several times in the last fifty years. Wood samples from 4.5 metres below a surface, which is probably the B1 terrace, was dated
555 ± 60 BP (UGA 3076). Since the dates from the University of Georgia range from 300 to 500 years younger than the Southern Methodist dates, it is reasonable that UGA 3076 should date between 850 BP and 1100 BP.

All the radiocarbon dates considered to be reliable support the chronology of the three Holocene terraces and their respective fills. This indicates that correlation of the terraces by stratigraphy and elevation is valid within the study area.

Very few studies of Holocene alluvial terraces have been conducted in the Northern Plains. Therefore correlations of these terraces with terraces in other drainages is limited. However, climatic and geomorphic implications and the temporal relationships between alluvial and eolian deposits can be suggested.

A comparison of Holocene climatic fluctuations to the response of vegetation, soil development, eolian deposition, hillslope stability, and river activity is shown in Figure 33 (Bluemle and Clayton 1982). The timing of major climatic fluctuations during the Holocene was suggested by Bryson and others (1970). These climatic divisions have not been adequately dated in this region, but the response of eolian deposition (Clayton and others 1976), alluvial deposition (Hamilton 1967), and paleoecological changes (Wright 1970) appear to correspond with the suggested climatic changes.

Hamilton (1967) studied recent alluvial deposits along tributaries of the Little Missouri River in western North Dakota. The effect of climate on vegetation density was shown to have a major influence on the response of a streambed to climatic fluctuations. During periods of cool, moist climate, a thick sod cover develops, hillslopes are stable, and streambeds incise. Warm dry climates reduce the sod cover leaving
FIGURE 33. A comparison of Holocene climatic fluctuations to the response of vegetation, soil development, eolian deposition, hillslope stability and river activity in central North Dakota.
Climate - Increased Aridity
Vegetation - Increased Density
Slope Stability - Increased Stability
Soil Development - Increased Development
Eolian Activity - Increased Activity
River Activity - Aggradation Incision
the hillslopes susceptible to erosion. More sediment is washed into the valley bottoms than can be removed by the streams. Thus, streambeds aggrade in response to warm dry climates and incise during cool, moist climates. These observations agree with Schumm (1965, p. 785) who has shown that in humid and subhumid regions such as North Dakota, hillslope erosion occurs during dry periods and that vegetation stabilizes hillslopes during moist periods.

A cross-section of part of the Stanton Ferry Bluff is shown in Figure 34. This exposure is cut into the Stanton Terrace and exposes about 4 to 5 metres of fine-grained fill overlying the terrace gravel. The south end of this exposure consists of loess in which three members of the Oahe Formation can be identified. The lowest submember of the Riverdale Member of the Oahe Formation at this point consists of dark-brown silt which is equivalent to the Thompson Paleosol (Clayton and others 1976, p. 11). The dark-colored submember thickens and changes from largely silt to largely clay as it is traced to the north. This appears to indicate a change from eolian to overbank deposition and supports the interpretation that the dark-colored bands in alluvial deposits are paleosols. Overbank deposition and soil development at the Stanton Ferry Bluff was probably contemporaneous with the deposits contained in the upper part of the A terrace fill along the Knife River.

The Pick City Member of the Oahe Formation was probably deposited during the warm, dry mid-Holocene unstable episode. The lower A terrace fill, which contains very few paleosols, is probably contemporary with the Pick City Member. Although no organic materials were dated in this alluvium, radiocarbon dates within the fill immediately overlying it indicate the lower A terrace fill is older than about 3900 BP. Climatic
FIGURE 34. Sketch of the Stanton Ferry Bluff which is cut into the Stanton Terrace. This cross-section indicates three members of the Oahe Formation overlying terrace gravel. a. Lateral contact between silty clay unity (overbank deposits) and silt unit (windblown deposits) of the Lower Riverdale Member of the Oahe Formation. The eolian silt unit is located to the right of the contact. b. Pebbly, silty sand unit, probably representing a small channel cut into the top of the Lower Riverdale Member of the Oahe Formation.
Metres
Below
Surface
0
Stanton Terrace
Upper Riverdale Submember
1
Middle Riverdale Submember
2
Lower Riverdale Submember
3
Pick City Member
4
Aggie Brown Member
500 Metres

----

= Paleosols
and geomorphic implications of the warm, dry mid-Holocene unstable episode also suggest that much of the windblown sand found on the terraces is also contemporary with the Pick City Member of the Oahe Formation.
Climatic variations since the last Late Wisconsinan glacier retreated appear to have been a major factor controlling alluvial and eolian deposition. Figures 35 through 39 outline the postglacial history of deposition and erosion in the lower Knife River valley. Several climatic fluctuations occurred from the Late Wisconsinan to the Holocene. Only the major climatic changes are emphasized in the following discussion.

Incision of the Stanton floodplain commenced about 13,000 BP, after the retreat of the last glacier (Figure 35). The postglacial climate was cooler and more moist than the present climate in central North Dakota (Moran and others 1978, p. 153), and a spruce woodland migrated into this area (McAndrews 1967; Moir 1958; Bickley 1972; and Okland 1978). The paleosol of the Aggie Brown Member of the Oahe Formation began to develop. This forest soil continued forming until about 10,000 BP, when warming conditions caused replacement of the forests by prairie grasses and prairie soils developed. The climate remained relatively cool and moist until about 8,500 BP. Hillslopes were stable and little sediment was washed into the rivers. Consequently the sediment load of the Knife and Missouri Rivers was relatively small and the rivers continued to incise. Some floodplain aggradation probably occurred from about 10,000 BP to 8,500 BP, but little physical evidence supports this conclusion.
FIGURES 35 to 39. These five figures are idealized cross-sections illustrating the postglacial history of deposition and erosion in the lower Knife River valley. The symbols and unit numbers are described in the explanation listed below.

EXPLANATION

Lithology and Origin

- light-brown silty sand and clay, largely alluvial lateral accretion deposits.
- light-brown to dark-brown silt, largely eolian deposits.
- light-grayish-brown and dark-grayish-brown silt and clay, largely alluvial overbank deposits.
- brown to dark-brown silt, paleosols.
- Stanton Terrace gravel.

Oahe Formation Chronology

Unit 5 - 500 BP to present, Upper Riverdale Member.
Unit 4 - 2500 BP to 500 BP, Middle Riverdale Member.
Unit 3 - 4500 BP to 2500 BP, Lower Riverdale Member.
Unit 2 - 8500 BP to 4500 BP, Lower Riverdale Member.
Unit 1 - 13,000 BP to 8500 BP, Aggie Brown Member.
Unit 0 - Before 13,000 BP.

Scale: Figures are approximately 15 to 20 metres high and 100 to 200 metres wide.

FIGURE 35. 13,000 to 8500 BP. Incision of the Stanton Terrace. Development of the Leonard Paleosol in the Aggie Brown Member of the Oahe Formation. Cool and moist climate.
FIGURE 36. 8500 BP to 4500 BP. Valley filling. Pick City Member of the Oahe Formation deposited, active eolian sand dunes. Warm and dry climate.

FIGURE 37. 4500 BP to 2500 BP. Incision of the Middle Holocene valley fill and deposition of fine grained overbank sediment on floodplains. Several episodes of soil development (Thompson Paleosol) and floodplain forest fires. Lower Riverdale Member of the Oahe Formation deposited. Sand dunes stabilized. Cool and moist climate.
FIGURE 38. 2500 BP to 500 BP. Valley filling, occasional periods of deposition on floodplains and minor episodes of soil development. Middle Riverdale Member of the Oahe Formation deposited. Warm and dry climate.

The Middle Holocene unstable episode began about 8500 BP (Bickley 1972, p. 127). The climate became warmer and drier, causing a decrease in vegetation density. Reduction of the sod cover made the hillslopes unstable and decreased soil development. Sediment was removed from the hillslopes by slopewash and eolian activity. Flow in the Knife River was not great enough to remove the increased sediment load, and the streambed aggraded, depositing the lower part of the A terrace fill (Figure 36). Because of decreased precipitation, lower water table, and increased sediment supply, the Knife River was probably an ephemeral stream and may have been a braided stream during Middle Holocene time. The larger amounts of sand than clay in the lower part of the A terrace fill suggests that lateral accretion rather than vertical accretion was the dominant type of alluvial deposition.

The floodplain of the Missouri River probably aggraded at this time but the amount of runoff from the Rocky Mountains and other parts of its drainage basin was sufficient to rework most of the alluvium. Consequently no A terrace is preserved along the Missouri River today.

Eolian activity increased both on river floodplains and above them. Eolian silt of the Pick City Member of the Oahe Formation was deposited on the terraces and uplands. Eolian sand dunes formed on the floodplains and terraces where alluvial sand was available. The Middle Holocene unstable episode ended about 4500 BP. At this time the Knife River had aggraded to a position above the present river level.

From about 4500 BP to the present the climate fluctuated between relatively cool, moist conditions, similar to the present climate in North Dakota, to warm, dry conditions, similar to the "Dirty Thirties" (Clayton and others, 1976, p. 12).
About 4500 BP the climate became cooler and more moist. The increased precipitation raised the water table and increased vegetation density, causing soil development and hillslope stabilization. Flow in the Knife River increased and the river changed from an ephemeral, possibly braided stream to a meandering stream. Reworking of the Middle Holocene floodplain began at about this time. The decrease in sediment concentration into the Knife River caused the streambed to incise (Fig. 32). Fine-grained overbank deposits of the upper part of the A terrace fill accumulated on the old floodplain. Soils developed on the overbank sediment forming the dark colored bands and carbonate accumulations. Floodplain forests developed and sporadic fires left layers of charcoal in the overbank deposits. Floodplains reached elevations sufficient to flow over parts of the Stanton Terrace along both the Missouri and Knife Rivers. These floodwaters deposited fine-grained sediment similar to the upper part of the A terrace fill. This sediment covered most of the Stanton Terrace along the Knife River, but along the Missouri River only topographic lows were filled. Any accumulations of alluvium to the A terrace level remaining along the Missouri River were completely reworked during this period of cool moist climate.

The lower submember of the Riverdale Member of the Oahe Formation, named the Thompson paleosol by Bickley (1972, p. 128), accumulated at this time and sand dunes on the terraces and floodplains were stabilized. The time this cool moist episode ended is uncertain. Radiocarbon dates SMU 708 in the A terrace fill and SMU 709 in the B1 terrace fill indicate that incision, which is associated with cool moist climates, occurred between about 2974 ± 66 BP and 1132 ± 87 BP. A major
global climatic transition was determined to have occurred about 2500 BP (Wendland and Bryson 1974, p. 22). The climate change was probably to warmer drier conditions in this area. Therefore, the erosional surface between the A and B1 alluvial fills probably had formed by about 2500 BP.

With the change to warm, dry conditions, vegetation density decreased causing a decline in soil formation and hillslope stability. Eolian activity increased, sediment load of the Knife and Missouri Rivers increased, and the fill of the B1 terrace began to accumulate (Figure 33). The erosional surface between the B1 and B2 terrace fills developed between about 1132 ± 387 BP (SMU 709) and 27 ± 50 BP (SMU 791) (Figure 33). SMU 791 appears to be just above this erosional contact. This erosional surface may have formed at the start of the cool, moist Jules Stable Episode (Bickley 1972, p. 130). A species of Populus from the base of an organic silty clay deposit at the Stanton Site was dated at 325 ± 125 BP (Fischer 1980, p. 38). The similarity of this date with SMU 791 suggests the Jules Stable Episode began about 325 BP to shortly before 340 BP. An earlier date (850 BP) of this climatic transition is indicated by global-botanic and cultural discontinuities determined by Wendland and Bryson (1974, p. 20).

After this climatic transition, generally cool, moist conditions prevailed until the present. Much of the B1 floodplain was reworked (Figure 34). The B2 surface developed and is forming today as the rivers continue to meander, reworking older alluvial fill and depositing new alluvium.
GEOLOGIC AND GEOCHRONOLOGIC INTERPRETATIONS

Archeologists studying the history of man in the KNRI area have several questions that can be assessed by investigating the geological data in this report and in other Holocene studies from the Northern Plains. Some of the questions include: 1) What climatic changes have occurred since the last Late Wisconsinan glaciers retreated? 2) What was the relationship between the rivers and the villages when the villages were occupied? 3) Where would be the best locations to search for different classes of cultural materials?

The climatic changes since the start of the Holocene were discussed in the previous section. These are based on a variety of studies focusing on paleoecology, sedimentology, and geomorphology. More radiocarbon dates are needed to better define the timing and duration of specific climatic episodes. In general, present data indicate that the Holocene climate was similar to the present climate with fluctuations between warmer, drier conditions to cooler, more moist conditions.

The relationship between the former position of the Knife and Missouri River channels and the villages cannot be precisely defined based on available data. The system of preserved scroll bars east of the KNRI boundary has, in general, prograded towards the east. Therefore the three major villages, Sakakawea, Big Hidatsa and Lower Hidatsa, were probably closer to the Missouri River than they now are. The position of the river at the time of village occupation is still unclear. The location of three trails visible on aerial photographs and
mapped on Plate 3 appears to link Big Hidatsa village with former Missouri River channels. These trails are located in the north-central part of Plate 3. They extend southeast from Big Hidatsa village and end abruptly at obvious scroll bars. One ends at a scroll bar indicated by the contact between Unit Five and Unit Six and two others end at the contact between Unit Four and Unit Five. It seems reasonable to assume that these scroll bars were located at the edge of the river channel and the trails ending at the contact between Unit Four and Unit Five are somewhat older than the trail ending at the contact between Unit Five and Unit Six.

Specific depositional environments can be evaluated as possible locations of cultural activities and probably areas for preserving cultural remains. In the area of the KNRI, sedimentary deposits most likely to contain cultural materials are included in the Oahe Formation. These units are mapped on Plate 2 as Units Five (windblown silt), Six (windblown sand), and Seven (alluvium and colluvium).

In alluvial sediments, lateral accretion (point bar) deposits are unlikely locations for either cultural activities or preservation of cultural remains. Active point bars are generally flooded every year. Therefore, they are unlikely locations for other than temporary cultural activities. Any cultural materials deposited on point bars are likely to have been reworked and out of stratigraphic context.

Vertical accretion (overbank) deposits are more likely to contain cultural resources than lateral accretion deposits. These deposits are generally higher and subject to less intense flooding and are commonly locations of more permanent cultural activities than point bars. Cultural materials could be located throughout overbank deposits, but
concentrations are more likely to be within paleosols.

Deposits of windblown silt are likely locations for cultural activities and preservations of artifacts. These deposits are generally on flat areas that would have made good locations for permanent occupations. Although artifacts could be located throughout loess deposits, paleosols are the most likely stratigraphic horizons where cultural materials would be found. Windblown silt deposits are not commonly subject to intense reworking. Some mixing of this sediment is caused by rodents, but cultural materials deposited in loess are generally in place.

Artifacts are commonly associated with windblown sand deposits. Unfortunately, preservation of the original stratigraphy is often poor with concentrations of cultural materials frequently found in deflated areas of blowouts. Paleosols in windblown sand are likely locations of in-place artifacts.

The windblown and alluvial deposits often form a thin veneer overlying much older sediment. In such cases the older material is generally mapped as the surface sediment and the thin layer of alluvium or windblown sediment is ignored. In these settings the Holocene stratigraphy is compressed and stratigraphic markers such as paleosols have either coalesced and are indistinguishable, or one or more of the units have been removed by erosion. Therefore if the surficial geology in this area is mapped as pre-Holocene, there can be up to one metre of Holocene sediment at the surface. Although the stratigraphy of these thin deposits is often indistinguishable, cultural materials of pre-Holocene to present age are possible within or on these sediments.

Plate 3 is a geochronologic map of the KNRI and the immediate
surroundings. This map is divided into eight geochronologic units. These units are differentiated by the estimated age of the near surface sediments based on geomorphic, radiometric, and sedimentologic evidence.

Unit One refers to the Hensler Terrace deposits and sediment of the Oahe Formation that overlies the fluvial sand and gravel terrace deposits. Where a complete stratigraphic section of windblown silt of the Oahe Formation is present, the Mallard Island Member is the basal unit directly overlying the terrace sand and gravel. Unit One has the potential of containing deposits ranging in age from 22,000 BP to the present.

Unit Two contains Stanton Terrace deposits and the Oahe Formation overlying the terrace sand and gravel. The oldest member of the Oahe Formation likely to overlie these terrace deposits is the Aggie Brown Member. Unit 2 contains materials ranging in age from about 13,000 BP to the present.

Unit Three contains alluvial and eolian deposits of the Oahe Formation ranging in age from about 4500 BP to the present. This includes sediment forming the upper part of the A terrace. The maximum age of this Unit is based on radiocarbon dates in the upper A terrace deposits which range from about 3000 to 3900 BP.

Unit Four refers to alluvial and eolian sediment making up the B1 terrace. The age of this unit ranges from 2500 BP to present, based on the interpretation that the erosional surface between the A and B1 alluvial fills had formed by this time.

Unit Five refers to alluvial and eolian deposits making up the upper part of the B2 terrace. This includes sediment deposited after about 340 BP based on a radiocarbon date just above the erosional contact between the B1 and B2 alluvial fills.
Unit Six and Unit Seven are differentiated from other units strictly on the basis of geomorphology. Therefore only relative maximum age can be given for these units. A distinct scroll bar marks the contact between Unit Five and Unit Six, since the general trend of point bar development is to the east, Unit Six is somewhat younger than Unit Five. The contact between Unit Six and Unit Seven is marked by a similar scroll bar with Unit Seven being younger than Unit Six.

Unit Eight includes accretion land that was part of the river channel when the original survey was conducted in 1881. Therefore, this Unit contains sediment no older than about 100 years.
APPENDICES
APPENDIX A

DRILL - HOLE LOGS
DRILL - HOLE LOGS

Description of sediments in auger holes. Depth below surface is given in feet. Several samples of core and cuttings were analyzed for texture. Interval sampled is given in feet. Elevation is given in feet above mean sea level.

Depth (ft.)

DH-1
NWSWSWNE Sec. 33, T. 145 N.
El. 1737
Hensler Terrace

0-1  Silt, very fine, sandy; dark-brown.
1-2  Silt, very fine, sandy; brown.
2-5  Sand, fine; light-brown; coarsens downward
5-8  Sand, silt, and clay, interbedded; light-brown.
8-25 Gravel, sandy; dark-reddish-brown; poorly sorted.
25-42 Sand, very fine, silty; very pale-brown.
42-50 Silt, clayey; light-greenish-yellow; laminated.
50-57 Pebble-loam; light-yellowish-brown; pebbles of silt and clay, texture (52-57 feet), gravel 0.06%, sand 18.9%, silt 51.1%, clay 30%.

DH-2
NWSWSE Sec. 33, T. 145 N., R. 84 W.
El. 1700
Stanton Terrace

0-0.5 Silt, very fine sandy; dark-brown
0.5-1.5 Silt, very fine sandy; brown.
1.5-3 Silt, slightly clayey; very-dark-brown.
3-4 Gravel, coarse.
4-7 Pebble-loam; light-yellowish-brown.
7-17 Sand, very fine, silty; laminated very light-gray and very pale-brown.
17-18 Clay; pale-brown.
18-47 Sand, very fine, silty; pale-brown.
Depth

DH-3
NWSWSENE Sec. 33, T. 145 N., R. 84 W.
E1. 1690
A terrace

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
<td>Silt, clayey; very dark-brown.</td>
</tr>
<tr>
<td>0.5-1.5</td>
<td>Silt, clayey; light-brownish-gray.</td>
</tr>
<tr>
<td>1.5-2</td>
<td>Silty, clayey; very-dark-brown.</td>
</tr>
<tr>
<td>2-5</td>
<td>Silt, clayey; pale-brown.</td>
</tr>
<tr>
<td>5-6</td>
<td>Clay, silty; very-dark-brown.</td>
</tr>
<tr>
<td>6-7</td>
<td>Silt, clayey; pale-brown.</td>
</tr>
<tr>
<td>7-12</td>
<td>Sand, fine; light-yellowish-brown.</td>
</tr>
<tr>
<td>12-17</td>
<td>Sand, silt, and clay; interbedded; pale-brown mottled with gray; calcium carbonate nodules.</td>
</tr>
<tr>
<td>17-22</td>
<td>Sand?, silty; no returns.</td>
</tr>
<tr>
<td>22-29</td>
<td>Sandy silt and clay; yellow.</td>
</tr>
<tr>
<td>29-30</td>
<td>Silt and clay; laminated; yellow and gray; very hard.</td>
</tr>
</tbody>
</table>

DH-4
SWNESENE Sec. 33, T. 145 N., R. 84 W.
E1. 1698
Stanton Terrace

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>Silt, light-brown.</td>
</tr>
<tr>
<td>2-4</td>
<td>Gravel, sandy; brown.</td>
</tr>
<tr>
<td>4-19</td>
<td>Pebble-loam, silty; yellowish-brown; siltstone and claystone pebbles; very few pebbles.</td>
</tr>
<tr>
<td>19-21</td>
<td>Pebble-loam, silty; light-yellowish-brown; few pebbles.</td>
</tr>
<tr>
<td>21-27</td>
<td>Sand, very fine, silty; light-brownish-gray; slightly pebbly.</td>
</tr>
<tr>
<td>27-37</td>
<td>Pebble-loam, silty; light-yellowish-brown; contains Tertiary mollusk shell fragments. Texture, gravel 0.3%, sand 5.8%, silt 55.3%, clay 38.9%.</td>
</tr>
<tr>
<td>37-47</td>
<td>Silt, clayey; light-brownish-gray; few shells; slightly pebbly; sand layer at 42 feet.</td>
</tr>
</tbody>
</table>
Depth (ft.)

**DH-5**

NESENESE Sec. 33, T. 145 N., R. 84 W.
E1. 1690
A terrace

0-3  Silt; pale-brown.

3-4  Silt; clayey; gray.

4-5  Silt, clayey; pale-brown; calcium carbonate nodules.

5-6  Sand, very fine, silty; very-pale-brown; diffusely bedded.

6-15 Silt, pale-brown; interbedded with gray clay.

15-22 Pebble-loam, silty, sandy; light-brownish-gray.

22-26 Clay, silty; laminated light-brownish-yellow and light-gray; very fine laminations; hard drilling.

**DH-6**

SWSENESE Sec. 33, T. 145 N., R. 84 W.
E1. 1708
Stanton Terrace

0-5  Silt; pale-brown.

5-6  Silt; dark-brown.

6-7  Silt, sandy; pale-brown.

7-8  Gravel; poorly sorted.

8-10 Sand, medium to coarse; very-pale-brown.

10-12 Sand, medium to coarse; dark-reddish-brown; hard drilling; cobbles and gravel; lignitic.

12-27 Pebble-loam; light-olive-brown, mottled with dark-grayish-brown; pebbles of shale, dolomite, lignite, chert, and granite.

27-42 Clay, silty; light-olive-gray; cored through a vertical iron stained joint at 27 feet; manganese dioxide dendritic patterns.
Depth | DH-7  
--- | ---  
(ft.) | NWSWSE Sec. 28, T. 145 N., R. 84 W.  
| El. 1692  
| A terrace  
0-1 | Silt; dark-brown.  
1-3 | Silt; very-pale-brown.  
3-7 | Silt, slightly clayey; very-pale-brown.  
7-15 | Silt, clayey; interbedded yellowish-brown, very-pale-brown, and gray; calcium carbonate mottling; charcoal fragments from 8 to 10 feet.  
15-22 | Clay, silty; light-olive-brown; calcium carbonate nodules.  
22-24 | Sand; olive-gray; shell fragments.  
24-32 | Clay, silty; light-blue and green; brown plant debris.  
32-37 | Pebble-loam; olive-gray; texture (32 ft.), gravel 2.3%, sand 33.8%, silt 35.6%, clay 30.6%.  
37-42 | Pebble-loam; light-yellowish-brown; texture (42 ft.), gravel 1%, sand 37.8%, silt 26.5%, clay 35.7%.  

DH-8  
NWNW SE Sec. 28, T. 145 N., R. 84 W.  
El. 1685  
B1 terrace  
0-1 | Silt; yellowish-brown.  
1-2 | Silt; light-yellowish-brown.  
2-7 | Silt; very-pale-brown.  
7-17 | Clay, silty; light-olive-brown; calcium carbonate nodules.  
17-42 | Sand, silty; light-olive-brown; sand coarsens downward; contains several thin layers of blue-green silty clay.
Depth (ft.)  DH-9  
NENWSWNE Sec. 28, T. 145 N., R. 84 W.  
E1. 1682  
B2 terrace  
0-1  Silt, clayey; grayish-brown.  
1-1.5  Silt, clayey; pale-brown.  
1.5-2  Clay, bluish-gray.  
2-5  Silt, clayey; light-olive-brown.  
5-7  Clay, silty; very-dark-grayish-brown.  
7-9  Sand, silty; light-olive-brown.  
9-10  Silt, clayey; bluish-gray.  
10-12  Clay, silty; bluish-gray; organic debris.  
12-27  Sand, fine silty, slightly clayey; gray; soupy; poor recovery; contains a few thin clay layers.

DH-10  
SWNWSWSW Sec. 21, T. 145 N., R. 84 W.  
E1. 1693  
A terrace  
0-1  Silt; dark-gray.  
1-2  Clay; silty; gray.  
2-7  Silt; very-pale-brown.  
7-13  Silt; very fine sandy; very-pale-brown.  
13-13.5  Clay, silty; light-yellowish-brown; laminated.  
13.5-16  Sand, medium; pale-brown.  
16-17  Clay, silty; light-yellowish-brown; laminated.  
17-22  Sand, very coarse; dark-reddish-brown; pebbles.  
22-32  Sand?, no recovery; water at 20 feet; rocks at 25 feet; rocks at 30 feet.  

bit  Pebble-loam; gray; very pebbly; texture (32 ft.), gravel 18.3%, sand 55.2%, silt 26.2%, clay 17.6%.  

sample
Depth (ft.)

0-2.5  Silt, very fine sandy; pale-brown.
2.5-3.5  Sand, medium to coarse; light-brown.
3.5-4  Sand, very coarse; light-brown; granule gravel.
4-12  Sand, very coarse, gravelly; very-dark-brown; lignitic; rock at 11 feet.
12-15  Pebble-loam; light-olive-gray; texture (12 to 13 feet), gravel 7.1%, sand 41.4%, silt 37.1% clay 11.5%.
15-32  Pebble-loam; dark-gray; fewer pebbles below 25 feet; texture (17 to 18 feet), gravel 2.5%, sand 26.6%, silt 40.5%, clay 32.9%; texture (32 feet), gravel 0.2%, sand 11.3%, silt 37.5%, clay 51.2%.

DH-11
NWNWNWSW Sec. 21, T. 145 N., R. 84 W.
E1. 1739
Stanton Terrace

Slope

0-2.5  Silt, very fine sandy; pale-brown.
2.5-3.5  Sand, medium to coarse; light-brown.
3.5-4  Sand, very coarse; light-brown; granule gravel.
4-12  Sand, very coarse, gravelly; very-dark-brown; lignitic; rock at 11 feet.
12-15  Pebble-loam; light-olive-gray; texture (12 to 13 feet), gravel 7.1%, sand 41.4%, silt 37.1% clay 11.5%.
15-32  Pebble-loam; dark-gray; fewer pebbles below 25 feet; texture (17 to 18 feet), gravel 2.5%, sand 26.6%, silt 40.5%, clay 32.9%; texture (32 feet), gravel 0.2%, sand 11.3%, silt 37.5%, clay 51.2%.

DH-12
NWNESWSW Sec. 21, T. 145 N., R. 84 W.
E1. 1700
Stanton Terrace

0-1  Silt, very fine sandy; brown.
1-2  Silt, very fine sandy; very-pale-brown.
2-6  Sand, very fine, silty; very-pale-brown.
6-9  Sand, very fine, silty; light-brownish-gray.
9-10  Clay, silty; light-yellowish-brown.
10-12  Sand, fine to coarse; light-olive-brown; poorly sorted.
12-17  Sand, medium to very coarse; brown; poorly sorted.
17-19  Gravel, sandy; brown; poorly sorted.
19-27  Pebble-loam, silty; gray.
<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-13</th>
<th>SWSWNW Sec. 21, T. 145 N., R. 84 W. E1. 1796 McKenzie Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Silt, sandy; yellowish-brown.</td>
<td></td>
</tr>
<tr>
<td>1-4</td>
<td>Silt, sandy; pale-brown.</td>
<td></td>
</tr>
<tr>
<td>4-6</td>
<td>Silt, sandy; very-pale-brown.</td>
<td></td>
</tr>
<tr>
<td>6-10</td>
<td>Sand, coarse to very coarse; brown.</td>
<td></td>
</tr>
<tr>
<td>10-12</td>
<td>Gravel; reddish-brown.</td>
<td></td>
</tr>
<tr>
<td>12-22</td>
<td>Pebble-loam; light-olive-brown; lignitic; texture (12 feet), gravel 3.6%, sand 27.6%, silt 39.2%, clay 33.2%.</td>
<td></td>
</tr>
<tr>
<td>22-32</td>
<td>Sand, fine, clayey, silty; pale-olive.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-14</th>
<th>NWNESW Sec. 21, T. 145 N., R. 84 W. E1. 1770 Hensler Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Sand, medium, silty; dark-brown.</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>Sand, coarse; yellowish-brown.</td>
<td></td>
</tr>
<tr>
<td>2-7</td>
<td>Sand, coarse to very coarse; dark-reddish-brown.</td>
<td></td>
</tr>
<tr>
<td>7-9</td>
<td>Sand, fine; very-pale-brown.</td>
<td></td>
</tr>
<tr>
<td>9-12</td>
<td>Sand, very coarse, gravelly; dark-reddish-brown.</td>
<td></td>
</tr>
<tr>
<td>12-23</td>
<td>Gravel, very coarse sandy; dark-reddish-brown.</td>
<td></td>
</tr>
<tr>
<td>23-26</td>
<td>Pebble-loam; light-olive-brown.</td>
<td></td>
</tr>
<tr>
<td>26-27</td>
<td>Lignite; weathered.</td>
<td></td>
</tr>
<tr>
<td>27-28</td>
<td>Silt, slightly clayey; light-gray.</td>
<td></td>
</tr>
<tr>
<td>Depth (ft.)</td>
<td>DH-15</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NWSEENW Sec. 21, T. 145 N., R. 84 W.</td>
<td>E1. 1747</td>
</tr>
<tr>
<td></td>
<td>Hensler Terrace</td>
<td></td>
</tr>
<tr>
<td>0-2</td>
<td>Sand, coarse; brown.</td>
<td></td>
</tr>
<tr>
<td>2-4</td>
<td>Sand, coarse; very-pale-brown.</td>
<td></td>
</tr>
<tr>
<td>4-9</td>
<td>Sand, coarse; brown.</td>
<td></td>
</tr>
<tr>
<td>27-52</td>
<td>Sand, coarse to very coarse; very-dark-brown; poorly sorted; grain size increases with depth; lignitic.</td>
<td></td>
</tr>
<tr>
<td>52-72</td>
<td>Pebble-loam; dary gray; hard; lignite, carbonate, granite and chert pebbles; texture (52 feet), gravel 2.2%, sand 26.8%, silt 41.4%, clay 31.8%.</td>
<td></td>
</tr>
</tbody>
</table>

DH-16
NENWSW Sec. 21, T. 145 N., R. 84 W.
E1. 1693
A terrace

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Silt; dark-brown.</td>
</tr>
<tr>
<td>1-5</td>
<td>Silt; light-brown.</td>
</tr>
<tr>
<td>5-10</td>
<td>Silt, slightly clayey; very-pale-brown; abundant calcium carbonate; vaguely bedded.</td>
</tr>
<tr>
<td>10-12</td>
<td>Sand, fine to medium; reddish-yellow.</td>
</tr>
<tr>
<td>12-17</td>
<td>Sand, medium to coarse; reddish-yellow.</td>
</tr>
<tr>
<td>17-25</td>
<td>Sand, coarse to very coarse; grayish-brown; water at 17 feet.</td>
</tr>
<tr>
<td>25-42</td>
<td>Pebble-loam; gray; texture (25-27), gravel 5.8%, sand 30.7%, silt 43.4%, clay 25.9%.</td>
</tr>
<tr>
<td>42-47</td>
<td>Sand?; no returns.</td>
</tr>
<tr>
<td>Depth (ft.)</td>
<td>DH-17 SWNW Sec. 21, T. 145 N., R. 84 W. El. 1731 Hensler Terrace</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>0-1</td>
<td>Sand, medium; dark-grayish-brown.</td>
</tr>
<tr>
<td>1-2</td>
<td>Sand, coarse; dark-grayish-brown.</td>
</tr>
<tr>
<td>2-4</td>
<td>Sand, coarse; light-yellowish-brown.</td>
</tr>
<tr>
<td>4-6</td>
<td>Sand, coarse; dark-reddish-brown.</td>
</tr>
<tr>
<td>6-7</td>
<td>Sand, very coarse, gravelly; light-yellowish-brown.</td>
</tr>
<tr>
<td>7-9</td>
<td>Sand, very coarse, gravelly; dark-reddish-brown.</td>
</tr>
<tr>
<td>9-10</td>
<td>Sand, fine to medium; light-yellowish-brown.</td>
</tr>
<tr>
<td>10-15</td>
<td>Sand, medium to coarse; dark-reddish-brown.</td>
</tr>
<tr>
<td>15-17</td>
<td>Gravel; cobbles.</td>
</tr>
<tr>
<td>17-34</td>
<td>Sand, very coarse, gravelly; dark-reddish-yellow.</td>
</tr>
<tr>
<td>34-37</td>
<td>Pebble-loam; dark gray; texture (34-37 feet), gravel 4.4%, sand 30.9%, silt 41.4%, clay 27.7%.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-18 SEESW Sec. 21, T. 145 N., R. 84 W. El. 1740 Hensler Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>Sand, very coarse, gravelly; dark-brown.</td>
</tr>
<tr>
<td>1-2</td>
<td>Sand, very coarse, gravelly; very-pale-brown.</td>
</tr>
<tr>
<td>2-9</td>
<td>Sand, coarse, very dark-grayish-brown; pebbles.</td>
</tr>
<tr>
<td>9-11</td>
<td>Sand, medium; very-pale-brown.</td>
</tr>
<tr>
<td>11-17</td>
<td>Sand, very coarse, gravelly; very-dark-grayish-brown.</td>
</tr>
<tr>
<td>17-27</td>
<td>Sand, coarse, gravelly; brown.</td>
</tr>
<tr>
<td>27-37</td>
<td>Sand, fine, silt, and clay; laminated; pale-brown; lignite fragments.</td>
</tr>
</tbody>
</table>
Depth (ft.)  

DH-19  

E1. 1720  
Hensler Terrace  

0-1  Sand, very fine, silty; dark-grayish-brown.  
1-4  Sand, fine to medium, silty; very-pale-brown.  
4-7  Gravel, very coarse; cobbles.  
7-17  Gravel, fine; reddish-yellow; rock at 10 feet.  
17-27  Sand, coarse, gravelly; dark-brown.  
27-40  Pebble-loam; dark gray; shale, carbonate and lignite pebbles; texture (27-28), gravel 1.5%, sand 27.2%, silt 45.3%, clay 32.5%.  
40-44  Silt, slightly clayey; gray; laminated.  
44-47  Sand, fine; pale-brown.  

DH-20  

NENWSENE Sec. 33, T. 145 N., R. 84 W.  
E1. 1690  
A terrace  

0-1  Silt; dark-brown.  
1-2  Silt, slightly clayey; pale-brown.  
2-7  Silt, very fine sandy; very-pale-brown.  
7-9  Sand, very fine, silty; very-pale-brown.  
9-22  Silt, clayey; very-pale-brown; calcium carbonate nodules.  
22-27  Clay, silty; gray.  
27-32  Clay, silty; greenish-gray; abundant organics.
Depth (ft.) | DH-21
| SWSWSWSE Sec. 31, T. 145 N., R. 84 W.
| E1. 1716

0-1 | Sand, very fine, silty; pale-brown.
1-10 | Sand, very fine, silty; very-pale-brown.
10-23 | Sand, very fine, silty; pale-brown.
23-27 | Pebble-loam; dark gray; shale pebbles; texture (27-28); gravel 3.6%, sand 28.3%, silt 43%, clay 28.7%.

DH-22
NWNNWENW Sec. 2, T. 144 N., R. 85 W.
E1. 1697
A Terrace

0-5 | Sand, fine; pale brown.
5-12 | Silt, sandy, clayey; light-gray; laminated; dark-brown organic layers and reddish-brown iron-stained layers.
12-20 | Clay, silt, and sand, fine to medium, interbedded; light-yellow, light-gray, and pale-brown; shell fragments.
20-37 | Clay, silty; greenish-gray; bedded; a few thin sand layers.

DH-23
SWNWSNNW Sec. 4, T. 144 N., R. 85 W.
E1. 1705
A Terrace

0-2 | Sand, fine to medium; dark-brown.
2-10 | Sand, fine to medium; yellowish-brown.
10-15 | Silt, sandy, clayey; grayish-brown.
15-22 | Sand, fine to medium; yellowish-brown.
22-27 | Sand, coarse to very coarse; grayish-brown; water.
<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-24 SWSWSWSW Sec. 4, T. 144 N., R. 85 W. El. 1754 Hensler Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Sand, fine to medium, well-sorted; yellowish-brown.</td>
</tr>
<tr>
<td>10-18</td>
<td>Sand, fine to medium, silty; dark-brown, water at 12 feet.</td>
</tr>
<tr>
<td>18-24</td>
<td>Sand, fine to medium, poorly sorted; dark-brown; lignitic.</td>
</tr>
<tr>
<td>24-27</td>
<td>Silt, clayey; gray.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-25 SESESESWSW Sec. 5, T. 144 N., R. 85 W. El. 1760 Hensler Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td>Sand, fine to medium well-sorted; yellowish-brown.</td>
</tr>
<tr>
<td>4-5</td>
<td>Sand, fine to medium, slightly clayey, poorly sorted; very-dark-grayish-brown; a few cobbles; paleosol?</td>
</tr>
<tr>
<td>5-9</td>
<td>Sand, fine to medium; light-yellowish-brown.</td>
</tr>
<tr>
<td>9-11</td>
<td>Sand, fine to medium, poorly sorted; very-dark-grayish-brown.</td>
</tr>
<tr>
<td>11-14</td>
<td>Sand, medium; light-yellowish-brown.</td>
</tr>
<tr>
<td>14-15</td>
<td>Sand, medium; very dark-grayish-brown.</td>
</tr>
<tr>
<td>15-17</td>
<td>Sand, medium; light-yellowish-brown.</td>
</tr>
<tr>
<td>17-22</td>
<td>Sand, medium to coarse; very-dark-grayish-brown.</td>
</tr>
<tr>
<td>22-31</td>
<td>Sand, fine to coarse, poorly sorted; very-dark-grayish-brown; a few cobbles and thin layers of yellow clay.</td>
</tr>
<tr>
<td>31-37</td>
<td>Pebble-loam; dark-gray; lignite, agate, igneous, metamorphic, and carbonate pebbles.</td>
</tr>
</tbody>
</table>
Depth (ft.)  

DH-26  
NWSW NWSW Sec. 8, T. 144 N., R. 85 W.  
El. 1810  
McKenzie Terrace  

0-10  Sand, medium; yellowish-brown.  

10-12  Sand, fine; yellowish-brown; interbedded with very-dark-grayish-brown silty, fine sand.  

12-14  Sand, medium; yellowish-brown.  

14-16  Sand, fine, silty; laminated; alternating light and dark laminations.  

16-20  Sand, medium; yellowish-brown.  

20-21  Sand, fine, silty, clayey; dark-grayish-brown.  

21-27  Silt, very fine sandy; gray; hard; pyrite or marcasite concentrations.  

DH-27  
SWSW SWSW Sec. 17, T. 144 N., R. 84 W.  
El. 1940  
Slope  

0-5  Pebble-loam; grayish-brown.  

5-9  Sand, very fine, silty; very-pale-brown; laminated.  

9-12  Silt, very fine sandy; gray; hard; pyrite concentrations.  

DH-28  
NWSWW Sec. 17, T. 144 N., R. 85 W.  
El. 1880  
Riverdale Terrace  

0-4  Pebble-loam; pale-brown; vaguely bedded; texture (0-4), gravel 3.2%, sand 26.9%, silt 39.9%, clay 33.2%.  

4-22  Pebble-loam; dark-gray; unbedded; hard; texture (7-12 feet), gravel 2.4%, sand 26.1%, silt 41.1%, clay 32.8%; texture (12-17 feet), gravel 3.5%, sand 26.7%, silt 41.2%, clay 32.1%.  

22-25  Silt, very fine sandy, clayey; light-olive-brown.  

25-27  Silt, very fine sandy; gray.
<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>Depth</th>
<th>Section</th>
<th>Township</th>
<th>Range</th>
<th>E.1.</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>DH-29</td>
<td>SWMWNW</td>
<td>30</td>
<td>145</td>
<td>N.</td>
<td>R. 84 W.</td>
<td>McKenzie Terrace</td>
</tr>
<tr>
<td>1-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand, fine; dark-grayish-brown.</td>
</tr>
<tr>
<td>3-6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand, medium; yellowish-brown.</td>
</tr>
<tr>
<td>6-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand, medium; light-gray.</td>
</tr>
<tr>
<td>7-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand, medium; pale-brown.</td>
</tr>
<tr>
<td>9-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clay, silty; light-yellow.</td>
</tr>
<tr>
<td>12-13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shale; dark-brown; organic.</td>
</tr>
<tr>
<td>13-17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clay, silty; light-yellow.</td>
</tr>
<tr>
<td>0-1</td>
<td>DH-30</td>
<td>SWSW</td>
<td>19</td>
<td>145</td>
<td>N.</td>
<td>R. 84 W.</td>
<td>Sakakawea Terrace</td>
</tr>
<tr>
<td>1-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Silt, slightly clayey; brown.</td>
</tr>
<tr>
<td>3-27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gravel; pale-brown; calcareous.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pebble-loam; light-olive-brown; texture (3-7 feet), gravel 5.2%, sand 22.6%, silt 44.7%, clay 32.7%, texture (12 feet), gravel 1.1%, sand 27.5%, silt 40.1%, clay 32.4%.</td>
</tr>
<tr>
<td>0-7</td>
<td>DH-31</td>
<td>SWSW</td>
<td>18</td>
<td>145</td>
<td>N.</td>
<td>R. 84 W.</td>
<td>Sakakawea Terrace</td>
</tr>
<tr>
<td>7-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clay, silty; very-dark-gray.</td>
</tr>
<tr>
<td>9-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Silt; very-pale-brown; hard; finely bedded.</td>
</tr>
</tbody>
</table>
Depth
(ft.)

DH-32
SWNNW Sec. 34, T. 146 N., R. 85 W.
E1. 2030
Upland

0-1.5  Silt, very-dark-grayish-brown.
1.5-6  Silt; pale-brown.
6-7  Clay; gray; hard.

DH-33
NWNENW Sec. 17, T. 144 N., R. 85 W.
E1. 1880
Riverdale Terrace

0-2  Silt, very fine sandy; dark-reddish-brown.
2-7  Sand, fine; brownish-yellow.
7-8  Pebble-loam; pale-brown; vaguely bedded.
8-10  Pebble-loam; pale-brown; unbedded; texture (8-10 feet),
gravel 1.9%, sand 34%, silt 36.7%, clay 29.3%.
10-12  Pebble-loam; sandy; unbedded; pale-brown; texture (10-12 feet),
gravel 2.5%, sand 43.2%, silt 33%, clay 23.8%.
12-13  Sand, fine to medium, silty; very-pale-brown.
13-15  Sand, very fine, silty; light-gray; hard sandstone
concentration at 15 feet.

DH-34
NWNENW Sec. 21, T. 146 N., R. 84 W.
E1. 1755
Hensler Terrace

0-4  Silt; dark-brownish-gray.
4-8  Silt; very-pale-brown.
8-10  Silt; very fine sandy; yellow.
10-17  Gravel, coarse; reddish-brown.
17-44  Sand?; no returns; very easy drilling.
44-52  Pebble-loam; dark-gray; lignite, shale, carbonate, and
crystalline pebbles; texture (44-52 feet), gravel 2.3%, sand
25.7%, silt 45.9%, clay 28.4%.
<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>DH-35</th>
<th>SWSWSWSW Sec. 21, T. 146 N., R. 84 W.</th>
<th>E1. 1714</th>
<th>Stanton Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-7</td>
<td>Silt, slightly clayey; dark-grayish-brown.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-17</td>
<td>Silt, sandy, slightly clayey; light-brownish-gray; calcium carbonate layers.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-25</td>
<td>Sand, fine, silty; gray.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-27</td>
<td>Pebble-loam; gray; abundant pebbles; texture (25-27 feet), gravel 17.5%, sand 29.1%, silt 29.3%, clay 41.6%.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27-37</td>
<td>Pebble-loam; light-olive-brown; texture (27-32 feet), gravel 0.7%, sand 9.6%, silt 65.8%, clay 24.6%; texture (32-37 feet), gravel 8.2%, sand 27.5%, silt 42.4%, clay 30.1%; texture (37 feet), gravel 2.4%, sand 24.4%, silt 43.9%, clay 31.7%.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

LITHOLOGY OF CORES TAKEN WITH A GIDDINGS SOIL PROBE
LITHOLOGY OF CORES TAKEN WITH A GIDDINGS SOIL PROBE

Depth below the surface is expressed in metres. Elevation is given in metres above mean seal level.

Depth (metres) C-1

NENWSWSW Sec. 21, T. 145 N., R. 84 W.
E1. 516.5 metres
A terrace

0-0.85 Clay, silty; dark-grayish-brown.

0.85-1.20 Clay, silty; pale-brown; a few pebbles.

1.20-1.45 Silt, very fine sandy; pale-yellow.

1.45-1.60 Silt, very dark-grayish-brown.

1.60-2.80 Silt; pale-yellow; well-sorted.

2.80-4.00 Sand, silty; very-pale-brown; coarsens downward.

C-2

NENWSWSW Sec. 21, T. 145 N., R. 84 W.
E1. 518 metres
Stanton terrace

0-0.30 Silt, yellowish-brown.

0.30-0.95 Silt, very-pale-brown.

0.95-3.10 Silt, very fine sandy; very-pale-brown.

3.10-3.80 Silt, very fine sandy; pale-yellow.

3.80-4.00 Silt, very fine sandy; pale-brown.

4.00-4.30 Sand, coarse; light-gray; many pebbles.
Depth | C-3 | SENENWSW Sec. 21, T. 145 N., R. 84 W.
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>(metres)</td>
<td>E1. 521 metres</td>
<td>Stanton terrace</td>
</tr>
<tr>
<td>0-0.50</td>
<td>Sand, fine; dark-grayish-brown.</td>
<td></td>
</tr>
<tr>
<td>0.95-1.68</td>
<td>Sand, medium; pale-brown.</td>
<td></td>
</tr>
<tr>
<td>1.68-2.08</td>
<td>Sand, medium to coarse; light-gray and reddish-brown.</td>
<td></td>
</tr>
</tbody>
</table>

C-4
SENESWSE Sec. 33, T. 145 N., R. 84 W.
E1. 519.5 metres
Lower Hidatsa trail

| 0-0.45 | Sand, very fine, silty; very-dark-grayish-brown. |
| 0.45-0.55 | Silt, very fine sandy; contains unidentified bone fragments. |
| 0.55-0.65 | Silt; very-pale-brown; very hard. |
| 0.65-0.70 | Silt; very-pale-brown; a few iron-stained siltstone concretions. |

C-5
NESENWSW Sec. 33, T. 145 N., R. 84 W.
E1. 520.5 metres
Lower Hidatsa Trail

| 0-0.35 | Sand, fine; very-dark-grayish-brown. |
| 0.35-0.50 | Sand, very fine silty; brown. |
| 0.50-0.95 | Sand?, no recovery. |
| 0.95-1.15 | Silt, very fine sandy; brown. |
| 1.15-1.30 | Silt, pale-brown. |
| 1.30-1.53 | Silt, very fine sandy; brown. |
| 1.53-1.84 | Silt, very fine sandy; brown. |
| 1.84-1.92 | Silt, very fine sandy; very-pale-brown; hard. |
Depth (meters) C-6

NWSWSE Sec. 28, T. 145 N., R. 84 W.
E1. 1692
A terrace

0-0.22 Silt; very-dark-grayish-brown.

0.22-0.36 Silt, sandy; brown.

0.36-0.50 Silt, sandy; pale-brown.

0.50-0.80 Silt, sandy; pale-brown.

0.80-1.25 Silt, clayey; brown.

1.25-1.40 Sand, silty; very-pale-brown.

1.40-1.55 Clay, silty; grayish-brown; calcium carbonate mottles.

1.55-1.81 Silt, clayey, very fine sandy; pale-brown.

1.84-2.44 Clay, silty; brown; a few thin sand layers; calcium carbonate nodules.

2.44-2.54 Clay, silty, very fine sandy; light-yellowish-brown; calcium carbonate nodules.

2.54-3.17 Clay, silty, sandy; brown; a few thin sand layers; calcium carbonate nodules.

3.17-3.80 Clay, silty; mottled gray and brown; calcium carbonate mottling.

3.80-3.88 Clay, silty; mottled gray and brown; calcium carbonate mottling.

4.23-5.00 Clay, silty; mottled light-gray and light-yellowish-brown; a few thin sand layers.
Depth (metres) C-7

**SWSW** Sec. 28, T. 145 N., R. 84 W.
E1. 513.5 metres
B1 terrace

0-0.20 Sand, very fine; brown.
0.20-0.40 Sand, very fine; pale-brown.
0.40-1.81 Sand, very fine and fine; very-pale-brown.
1.81-2.06 Clay, silty; light-yellowish-brown.
2.06-2.26 Sand, fine; yellow.
2.26-2.44 Clay, silty; pale-brown.
2.44-2.80 Clay, silty, sandy; gray.
2.80-2.90 Sand, fine, silty; yellow.
2.90-2.95 Clay; gray.
2.95-3.05 Silt, clayey; yellow and gray.
3.05-3.17 Clay; gray.

C-8

**SWSW** Sec. 28, T. 145 N., R. 84 W.
B1 terrace

0-0.45 Sand, very fine, silty; yellowish-brown.
0.45-0.55 Clay, silty; gray.
0.55-1.05 Sand, very fine, silty; light-yellowish-brown.
1.05-2.61 Sand, very fine, silty, clayey; very-pale-brown; calcium carbonate mottles; a few thin brown clay layers.
2.61-2.75 Clay, silty; brown.
2.75-2.85 Sand, very fine; very-pale-brown.
2.85-2.93 Clay, silty; brown.
2.93-3.14 Sand, very fine, silty; very-pale-brown; a few thin brown clay layers.
3.14-4.08 Clay, silty; pale-brown; light-gray mottles, a few thin sand layers.
REFERENCES


Coogan, A., 1979, Personal communication: Department of Geology, Kent State University, Kent, Ohio.


PLATE I - SURFACE PROFILE ACROSS THE KNIFE AND MISSOURI RIVER VALLEYS.

J. Reiten - 1983

EXPLANATION

B terrace - tb
A terrace - ta
Stanton Terrace - tst
Hensler Terrace - th
McKenzie Terrace - tmc
Sakakawea Terrace - tsk
Riverdale Terrace - tr

ELEVATION IS GIVEN IN FEET AND METRES ABOVE MEAN SEA LEVEL.
GEOCHRONOLOGIC MAP OF THE
KNIFE RIVER INDIAN VILLAGES
NATIONAL HISTORIC SITE
MERCER COUNTY
NORTH DAKOTA

EXPLANATION

Unit 8 ~100 BP to present
Unit 7 Younger than Unit 6
Unit 6 Younger than Unit 5
Unit 5 ~340 BP to present
Unit 4 ~2500 BP to present
Unit 3 ~4500 BP to present
Unit 2 ~13,000 BP to present
Unit 1 ~22,000 BP to present

Symbols
Bison and Indian Trails
Indian Villages
Geochronologic Contact

PLATE 3
J. Reiten 1983