QUATERNARY GEOLOGY OF THE MISSOURI RIVER VALLEY AND ADJACENT AREAS IN NORTHWEST-CENTRAL NORTH DAKOTA

52nd Midwestern Friends of the Pleistocene Field Conference
Bismarck, North Dakota
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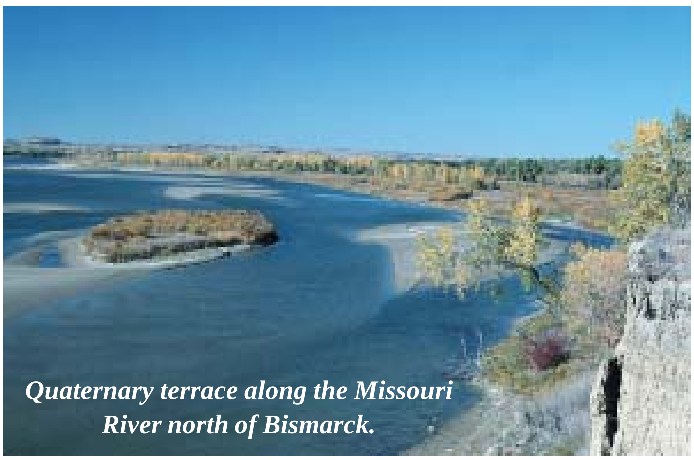

Quaternary terrace along the Missouri River north of Bismarck.

Ice-walled-lake plain near Stanley.

Glaciotectonic ice thrust near Anamoose.

GEOLOGIC INVESTIGATIONS NO. 24
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2006

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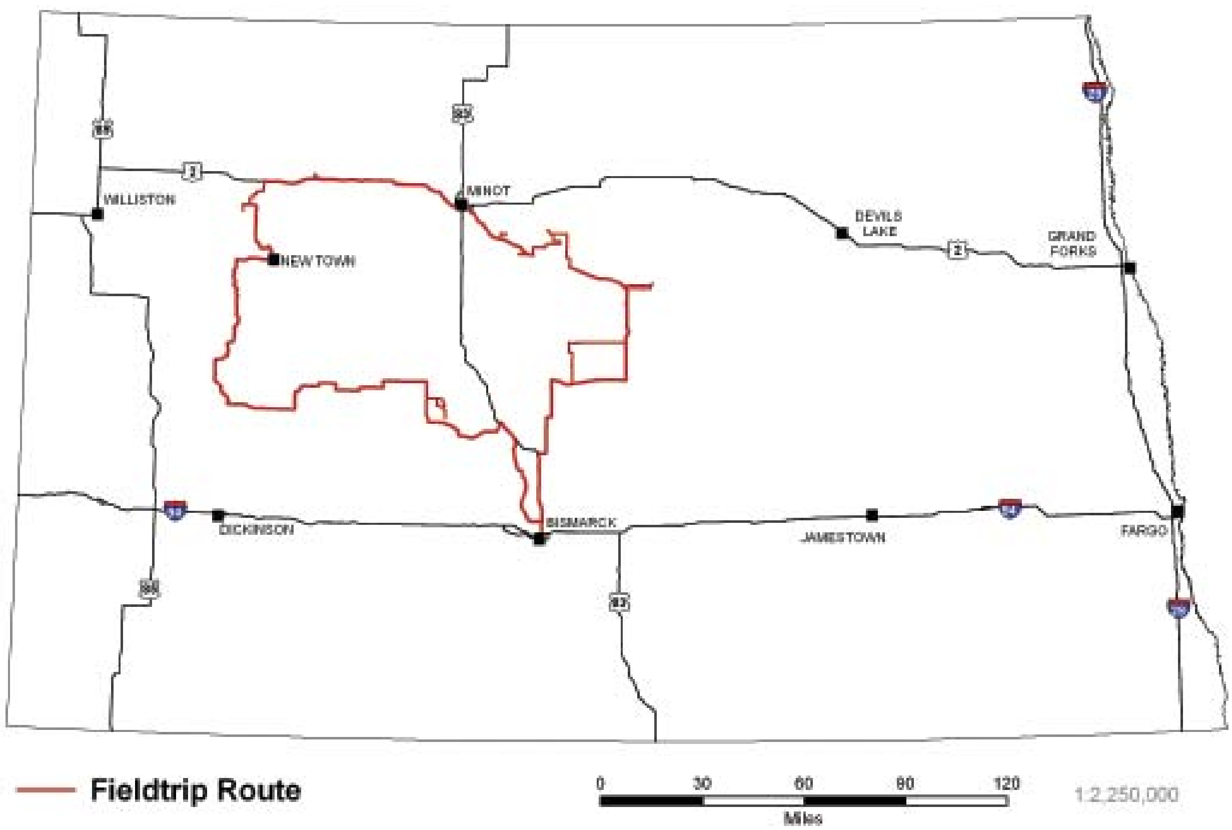

WILLISTON
MINOT
DEVILS LAKE
GRAND FORKS
NEW TOWN
DICKINSON
BISMARCK
JAMESTOWN
FARGO
Fieldtrip Route
0 30 60 90 120
Miles
1:2,250,000

Day 1

Tertiary and Quaternary Geology Along the Missouri River Valley from Bismarck to New Town

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North Dakota Geological Survey, Bismarck, ND

Introduction

This portion of the Friends of the Pleistocene fieldguide is based on a book that we co-authored, *Geology of the Lewis and Clark Trail in North Dakota,* published by Mountain Press Publishing Company in 2003. The purpose of that book was to provide a geologic guide for those traveling the Lewis and Clark Trail during the Bicentennial of the Corps of Discovery and the years beyond. Lee Clayton, having reviewed portions of our book, suggested that we lead a FOP fieldtrip in 2004 to coincide with the start of the bicentennial. But we could not work it into our schedule at that time having committed to giving over 40 presentations on the expedition around the state, about a dozen book signings, and co-leading a two-day fieldtrip in conjunction with the Lewis and Clark Signature Event in Bismarck. Instead, we were able to schedule this FOP fieldtrip to coincide with the end year of the Corps of Discovery Bicentennial.

The first day of this trip will focus on the Missouri River Valley and the sites that were seen and recorded by Lewis and Clark as well as other early travelers to this area. This theme has been reinforced by accompanying articles submitted by both geologists and archaeologists that have worked in this part of North Dakota. We are supplying each fieldtrip registrant with a copy of our book on the Lewis and Clark Trail. We have left most of the information presented in our book out of this fieldguide to avoid repetition and copyright infringements. Those that purchase this fieldguide in the future, and would like more information on the expedition, are referred to our book and the litany of fine books and articles that are referenced therein.

The Lewis and Clark Expedition crossed into present-day North Dakota on October 14, 1804. They reached the Bismarck-Mandan area, where our fieldtrip begins, on October 21, 1804. The Corps of Discovery wintered at Fort Mandan near Washburn from November 1, 1804 to April 7, 1805. The expedition passed by the New Town area, where we will end this portion of the fieldtrip, on April 15, 1805. On their return trip from the west coast, they entered the New Town area on August 11, 1806 and reached the North Dakota/South Dakota border on August 20, 1806.

North Dakota Heritage Center Parking Lot
Mile: 0

Turn off to NDGS office - Calgary Ave 2.0 miles

The roadguide begins at the North Dakota Heritage Center on the State Capitol Grounds.
Turn left onto US Highway 83 and proceed north, turn left at the intersection of ND Highway 1804 (mile 4.5) and proceed west (fig. 1).

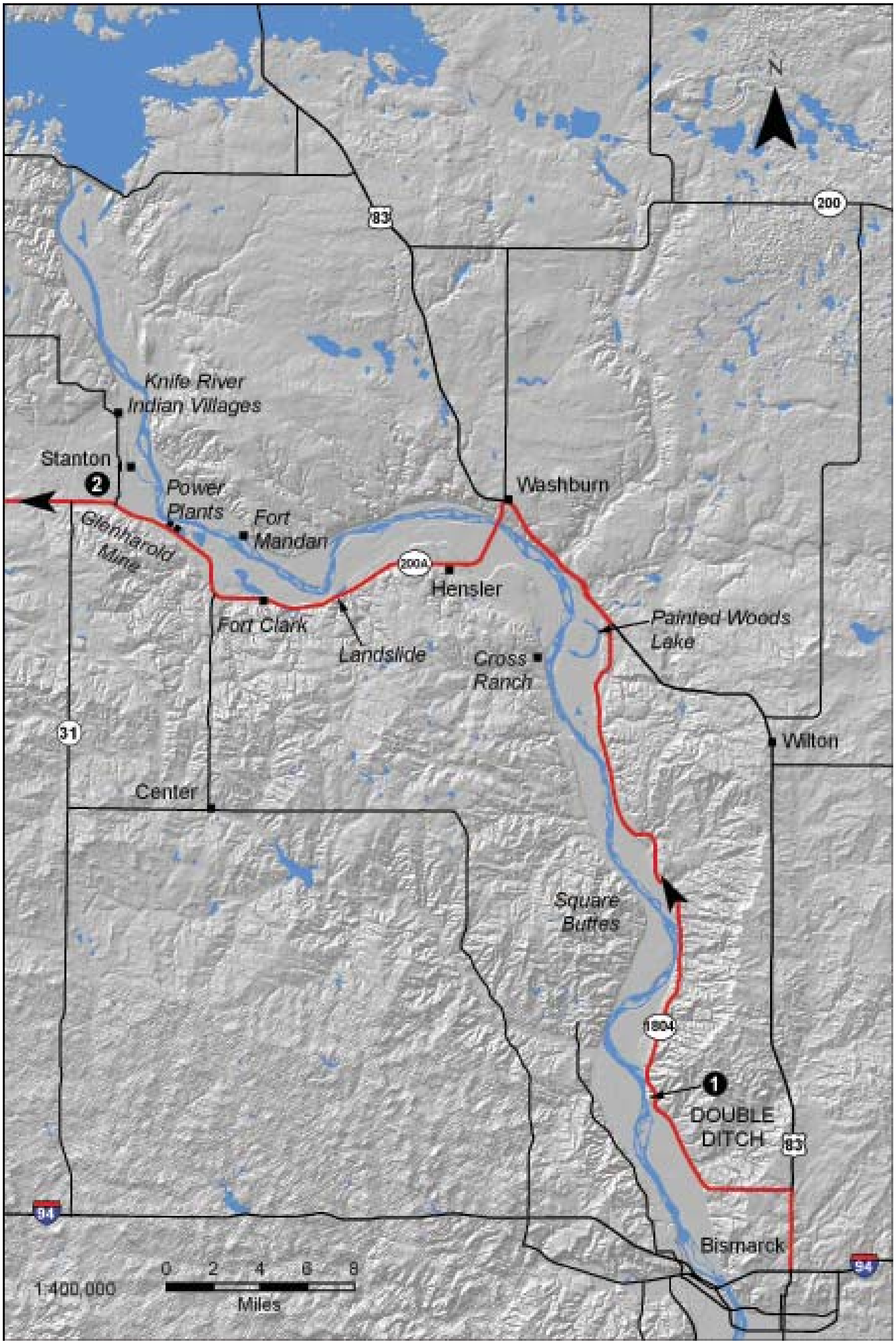

Figure 1. The fieldtrip route (in red) for day one from Bismarck to Stanton.

Abandoned Gravel Pit
Mile: 8.4

An abandoned gravel pit is present to the right (north) of ND Highway 1804. Terraces of the ancestral Missouri River are important sources of gravel in this area. As is all too common throughout the country, urban sprawl will make it difficult to utilize many of the gravel deposits in the Bismarck-Mandan area.

STOP 1: Double Ditch Indian Village State Historic Site
Mile: 12.5 (4.1)

Turn left into gravel turnaround

The Double Ditch Indian Village State Historic Site is located on an upper terrace of the Missouri River (fig. 2). Approximately 20 feet (6 m) of alluvium overlies marine mudstone of the Cannonball Formation (Paleocene) at this site.

Figure 2. When the Corps of Discovery passed by the abandoned village at Double Ditch on October 22, 1804, William Clark wrote in his journal *"and a small island at the head of which is a bad place, an old Village on the S.S. and the Upper of the 6 Villages the Mandans occupied about 25 years ago."* Clark called it a bad place because numerous sand bars split the channel making it difficult to navigate.

Turn left (north) onto ND Highway 1804.

A Brief History of Settlement Change at Double Ditch Village

Stanley A. Ahler[1], Phil R. Geib[2], W. Raymond Wood[3], and Fern E. Swenson[4]

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Double Ditch Village is a spectacular archaeological site on a high bluff on the east bank of the Missouri River about 11 miles upstream from Bismarck, North Dakota. The settlement is one of seven or more traditional villages of the Mandan tribe clustered near the mouth of the Heart River that were occupied simultaneously from late prehistoric times until late in the eighteenth century. The site is so named for two fortification ditches visible at the surface that partially or completely encircle the community. Viewed from the air (fig. 1) or on the ground, one is also struck by numerous large earthen mounds that ring the settlement and myriad earthlodge-size and larger depressions and basins that occur inside the two ditches. Double Ditch is perhaps the most spectacular of a dwindling number of Plains Village sites still intact in North and South Dakota – a true national treasure. Purchased by the state of North Dakota in 1936, the site is managed by the State Historical Society of North Dakota (SHSND).

Until recent research at Double Ditch Village beginning in 2001, little was known about the site. Integral to recent studies have been remote sensing surveys conducted in 2001-2004 and small-scale excavations at 44 locations throughout the village conducted in 2002-2004. Placement of many excavations was guided precisely by the geophysical results. This research program is sponsored by the SHSND and involves collaboration among the Society, PaleoCultural Research Group, Kvamme's team at the University of Arkansas, the University of Missouri-Columbia, and Tommy Ike Hailey at Northwestern State University, Louisiana. One research goal has been to understand the chronology of the settlement and how the structure and organization of the settlement – its houses and ancillary features, residential areas, and defensive systems – changed throughout its history.

Many first-time visitors to Double Ditch Village find themselves lost and disoriented somewhere within its 22+ acres of mounds, ditches, and depressions. In a site this complex, maps of all kinds are the key to planning and executing research and also to interpreting the findings. Building on a surprisingly

Figure 1. Aerial photograph of Double Ditch Village by Tommy Ike Hailey, June 2004. View SSW.

accurate site plan map published in 1906 and a 1995 photogrammetric, 25-cm interval contour map, Ken Kvamme's site-wide and detailed maps from several remote sensing methods provide many remarkably informative views of the settlement (see Ken Kvamme, this guidebook). A key finding from geophysical surveys is, of course, the discovery of two previously unknown fortification ditches well outside the outermost ditch visible on the surface. Figure 2 shows all four ditches, numbered 1 through 4 from inner to outer, and also earthen mound features (A1, B, C1, etc.) and prominent basins in the site surface. These are superimposed on a 10-cm interval contour map produced by Kvamme's team using a DEM derived from robotic total station data and reanalyzed data from the 1995 contour map. Figure 3 is a graphic summation of the history of the settlement that we discuss in detail below.

Data from 21 radiocarbon dates, densities of trade artifacts that began to appear at the village shortly after A.D. 1600, and historic records, tell us that the village was continuously occupied for nearly three centuries – from about A.D. 1490 until shortly after a devastating smallpox epidemic swept the region in A.D. 1781-1782. Ditches 3 and 4 are the oldest in the village, but their ages cannot be distinguished from one another using radiocarbon dates or artifact content. We believe Ditch 4, the outermost, was built first, surrounding the founding community at Double Ditch. Ditch 4 includes several prominent bastions very similar to bastions at Shermer (Sperry 1968) and Huff (Wood 1967) villages that date ca. A.D. 1350-1460, slightly before the founding of Double Ditch. Ditch 4 enclosed about 7.71 ha (19 acres). Using a density of about 21 houses/ha (based on Huff Village), Ditch 4 protected a settlement of about 160 houses and perhaps 1600-2000 residents. The earliest houses were likely rectangular in form (like those at Huff and Shermer), although we have so far been unable to confirm this through excavation. We believe Ditch 3 to be somewhat more recent than Ditch 4, constructed in the A.D. 1500s. It reflects a fallback to a slightly smaller community as well as a simpler ditch system in terms of fewer bastions. The few, small bastions in Ditch 3 were matched with larger bastions in Ditch 4, indicating a close conceptual linkage between the two concentric fortification systems.

By the late A.D. 1500s, Ditches 3 and 4 were both abandoned and several earthen mounds were created over these ditches. A few small mounds overlie Ditch 4 (L, N, V) and several much larger early mounds overlie Ditch 3 (I1, F, E, D1, C1) or both ditches (A3 and A1) (fig. 2). Some of these mounds were composed mostly of accumulated trash and others were built from borrowed and transported earth. These mounds were built in the late A.D. 1500s and early 1600s. High mounds would have served the same purpose that bastions did in abandoned Ditches 3 and 4 – as strong points in a defensive system that might have included wooden palisades linking or skirting the mounds. Around A.D. 1625-1650, the village would have been perhaps 20% smaller than its founding size, or about 6.1 ha in area.

The next discernable changes in settlement pattern were the addition of earth to at least two mounds (C1 and D1), construction of several new mounds (some quite large; B, I2, JJ, and P1) to the interior of several of the older mounds, and then construction of Ditch 2, still partially visible on the present site surface (figs. 2, 3). Based on trade artifact densities, construction of these mounds and Ditch 2 occurred late in the A.D. 1600s or early 1700s. The latest iteration of Ditch 2 skirted outside Mounds JJ, B, P1, and apparently I2. We interpret this configuration as mounds used in combination with both a ditch and palisade to form the village defense. About 4.8 ha (12 acres) were enclosed within Ditch 2, meaning a village of 90-100 houses.

The final phase of settlement organization in the period A.D. 1725-1785 involved construction of Ditch 1 and confinement of most, if not all, of the occupied dwellings to the 1.6 ha (4 acre) core residential area within Ditch 1 (figs. 2, 3). It appears that mounds had largely been dropped from village defenses, replaced by weakly developed bastions. Only 32 or 33 possible or fairly certain circular or elongated house depressions occur within Ditch 1. At 12 persons per lodge, the village that began its life with nearly

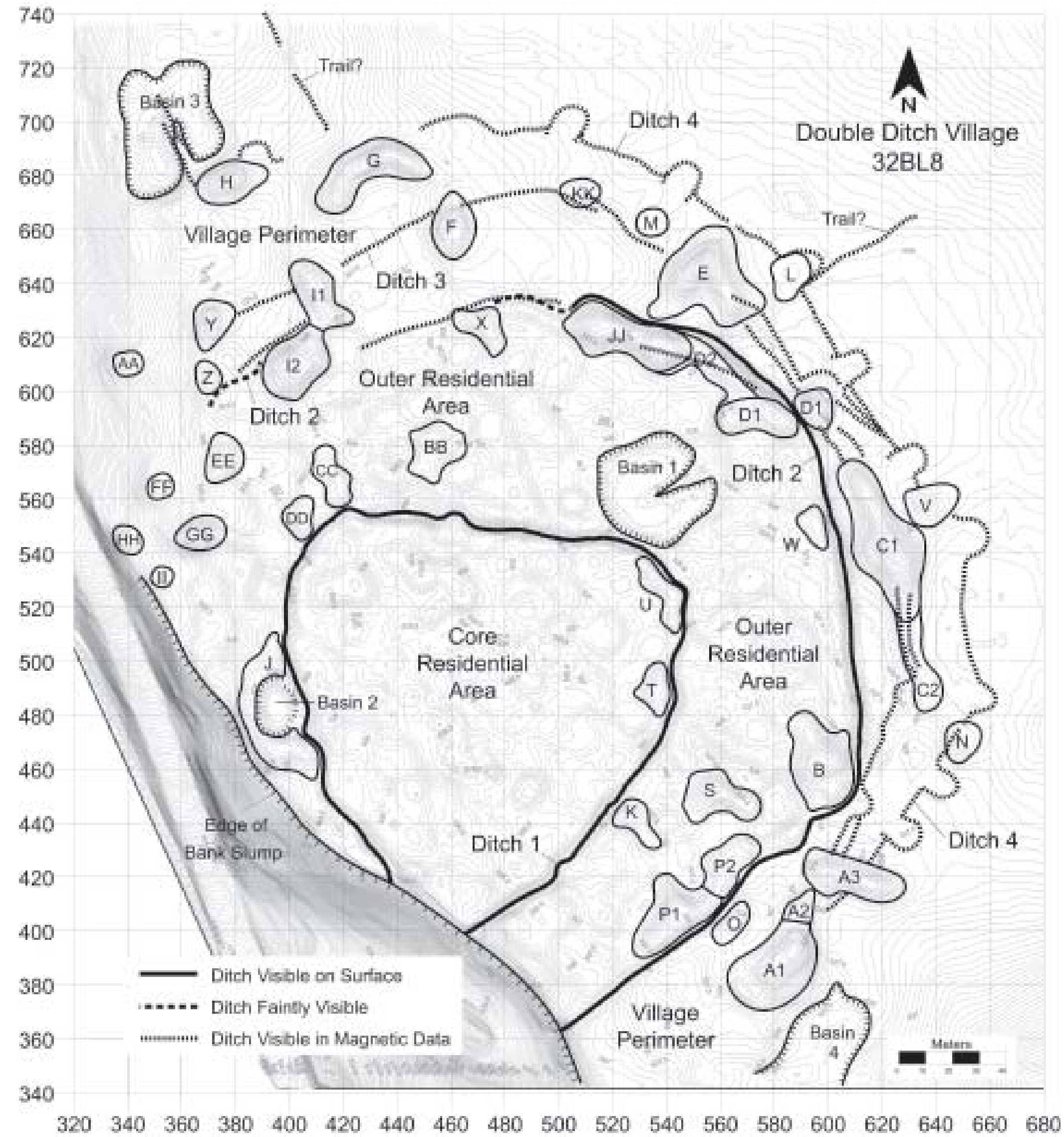

Figure 2. Contour map of Double Ditch Village by Ken Kvamme and associates using 1995 KBM, Inc. map data and 2004 microtopographic map data, showing an overlay of major features visible at the surface and Ditches 3 and 4 based on magnetic survey data. 10 cm contour interval.

2000 residents around A.D. 1490 ended with fewer than 400 residents when it was abandoned in the late A.D. 1700s.

Another very unexpected discovery at Double Ditch Village involves earthmoving on a large spatial scale (see Frey, Miles and Wood this guidebook). Several mounds were comprised wholly or in part of massive layers of earth charged with artifacts, apparently consisting of reexcavated fill and domestic refuse dug elsewhere and hauled to the mounds. This process was especially clear in Mound B, which was built laterally and rapidly, with no discernable time depth. Mound E was also constructed in this manner. If fill was hauled to the mounds, then borrows, or sources for fill, can be expected. There is no shortage of such borrow locations at Double Ditch. Based on excavations at a few locations and careful inspection of the surface topography, we interpret many large, deep, and irregularly shaped surface depressions as borrow basins. Other evidence of extensive borrowing occurs. Mound B and several

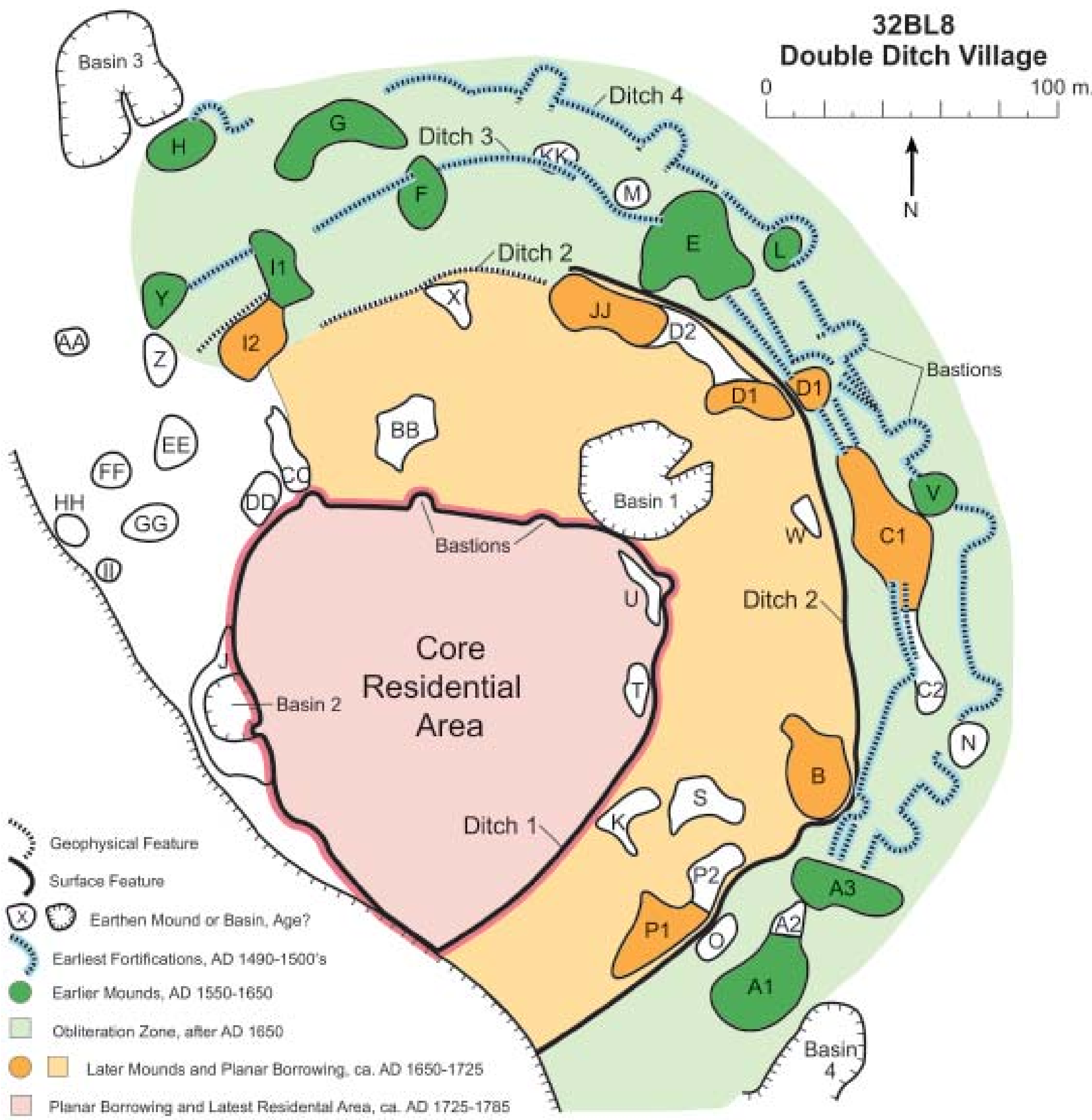

Figure 3. Plan map of Double Ditch Village showing major cultural features and changes in settlement plan and structure through time. Adapted from Figure 10.23 in Ahler and Geib (2006).

other mounds inside Ditch 2 were constructed on a truncated, C horizon surface. Most telling, we discovered that the A horizon and most of the B horizon had been removed beneath each of four houses tested within the village core. These latest house floors rested directly on a truncated surface only 20-25 cm below the present surface. Multiple house floors do not exist. We have found only a shallow layer of sheet midden anywhere in the village.

It is clear that nearly the entire site surface between Ditches 1 and 2, as well as the area inside Ditch 1, was severely altered by systematic removal of the A horizon and substantial sediment beneath it (fig. 3). We have called this process "planar borrowing." Removal of sediment from these areas undoubtedly obliterated many older house remains that once existed there, and this is especially true of the area between Ditches 1 and 2. Extensive borrowing inside Ditch 2 began before Ditch 2 was constructed and continued right up to the time of village abandonment. We surmise that much of the borrowed sediment found its way into earthen mounds. An activity that was apparently so extensive and thorough, occurring at locations far removed from the mounds, suggests a compelling desire to cleanse or renew the whole village, perhaps in the aftermath of major epidemics.

Finally, there is the question of why there are no visible house features or borrow features outside Ditch 2 and why Ditches 3 and 4 are invisible at the surface in that area. Excavation at widely dispersed locations indicates consistent stratigraphy with a 40 to 100-cm layer of homogenized, featureless sediment overlying the basal parts of ditches and deep storage pits. Our present interpretation is that this area, once part of the early village but abandoned as the village contracted, was severely altered by activities of the later village residents (fig. 3). We believe the most probable degrading activity was gardening and cultivation on this surface. Late in the history of the settlement, horses may have been hobbled in this area, further contributing to a "feedlot" environment and total obliteration of all older, shallow cultural features.

In sum, we have assembled a rather striking picture of settlement contraction and change at Double Ditch Village over the course of nearly 300 years (fig. 3). Fortification systems evolved through several variations that first used bastions, then mounds, and again bastions for strong points, first in combination with, then without, and again with ditches. By abandonment, the village had shrunk to a community 20% of its original size. The villagers themselves, through a combination of extensive earthmoving and secondary impacts, obliterated much of the archaeological record at the site. Several other traditional Mandan sites at Heart River contain large earthen mounds like those at Double Ditch. New fieldwork at those sites may soon reveal multi-community patterns of settlement change in the Mandan homeland at Heart River.

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Integrated Remote Sensing at Double Ditch State Historic Site, North Dakota

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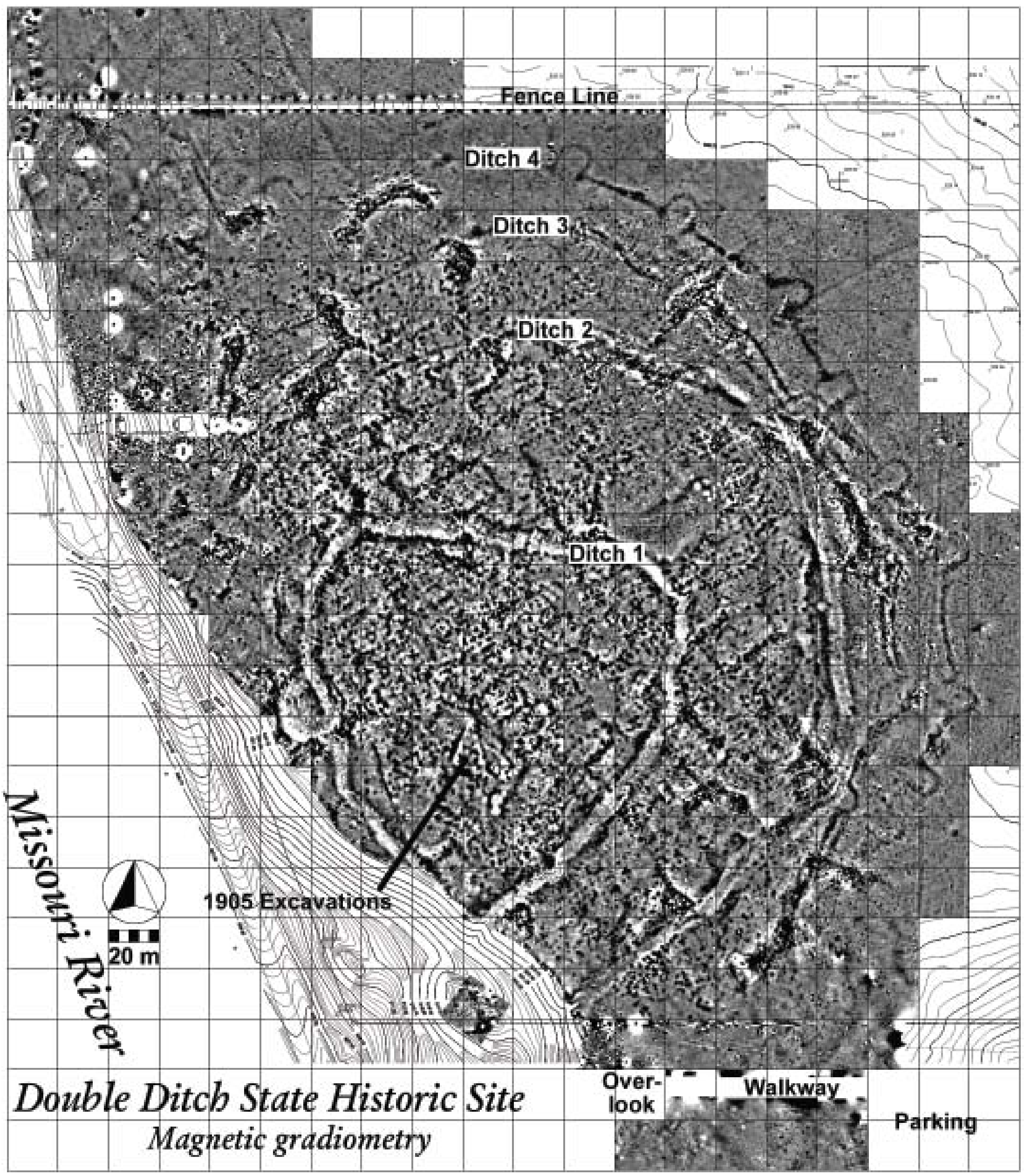
Double Ditch (32BL8*) is one of the largest and best preserved of the earthlodge villages that once populated the high terraces of the Missouri River trench in the Northern Great Plains. (The earthlodge in the historic period was a dome-shaped dwelling about 9-13 m in diameter, made of a stout timber frame covered with 25-35 cm of earth). It is also distinctive in the size and number of its large mounds and middens (areas where refuse was discarded), some over 2 m tall, its apparent double fortification system of ditches that were once associated with palisades, and its nearly 100 shallow depressions, 5-50 m in diameter. The last signify the locations of former lodges or earth-borrowing pits—places where soil was borrowed for covering earthlodges or mound building. Historically, Double Ditch is noteworthy for two reasons. Lewis and Clark visited this ancestral Mandan village in 1804, where they learned from a nearby group of Teton Sioux that a smallpox epidemic in the 1780s had forced its abandonment. A century later, in 1905, Double Ditch became the site of one of the earliest professional archaeological excavations in the Northern Great Plains; several trenches from that work remain visible in the surface. It now is protected by the state, the Double Ditch State Historic Site, near present-day Bismarck, North Dakota.

In 2001, the State Historical Society of North Dakota, in league with the PaleoCultural Research Group of Flagstaff, Arizona, the Department of Anthropology of the University of Missouri, and the ArcheoImaging Lab of the University of Arkansas, initiated a four-year project to further study this important site. A distinctive characteristic of this project was its reliance on the techniques of remote sensing to document the state of the site's surface and subsurface within an area that ultimately encompassed over 11 hectares. Recent advances in remote sensing permit the accurate detection of large and small subsurface archaeological features, and their identities frequently can be classified to likely types (e.g., hearths, storage pits, houses, bastions, ditches). The use of multiple remote sensing techniques permits different dimensions of the subsurface to be probed, providing additional information that helps produce secure identifications of subsurface elements. More remote sensing techniques have been applied at Double Ditch than at any other archaeological site in North America.

Two forms of remote sensing were employed: ground-based geophysical surveys and aerial imaging. Magnetic gradiometry is generally the most productive geophysical method used in archaeology. At Double Ditch it revealed countless subterranean corn storage pits, hearths, and two previously unknown fortification systems that vastly increase the settlement's area and projected population to perhaps 2000 individuals. This result is illustrated in the figure, where the two ditches visible in the ground surface may be seen (labeled Ditch 1 and Ditch 2), as well as the two newly discovered ditches that exhibit a series of bastion loops at intervals (labeled Ditch 3 and Ditch 4). These ditches are visible to a magnetometer because they were filled purposely or by erosion with a greater thickness of topsoil, which is generally more magnetic than subsoil.

Other remote sensing methods were also insightful. Electrical resistivity helped define middens, other depositional areas, houses, and earth-borrowing pits. An electromagnetic induction survey offered magnetic insights that discriminate between anomalies representing hearths and storage pits. Ground-penetrating radar yielded details about ditch, house, and mounded midden interior forms. Aerial survey from a powered parachute acquired high-resolution digital color and thermal infrared imagery. The former distinguished houses, borrow pits, and ditches from middens and fill areas by changes in vegetation; the latter did the same through temperature variations that also highlighted historic excavations. The remote sensing program reduced costs of on-going excavations by allowing specific archaeological features of interest to be accurately targeted. The excavations confirmed anomaly identifications made by remote sensing and established a chronology that documents late-fifteenth century origins to an ultimate contraction in the eighteenth century, with abandonment after a smallpox outbreak about A.D. 1785.

* This number is the official site number of Double Ditch in the system of the Smithsonian Institution. Most states use this system as an official archaeological designation, to avoid the confusion of multiple site names. North Dakota is the 32nd state (alphabetically-minus Hawaii & Alaska), BL represents Burleigh County, and 8 indicates it was the eighth site recorded by the state in that county.



Soil Characteristics at the Double Ditch State Historic Site

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Introduction

The Double Ditch State Historic Site is situated on a high terrace on the east side of the Missouri River. The soil is mapped as Mandan silt loam, level (taxonomic classification is coarse-silty, mixed, superactive, frigid Pachic Haploborolls), and has developed in loess (primarily silt and very fine sand). Hoganson and Murphy (2003) observed approximately 6 m (20 ft) of alluvium in a terrace cut beneath the village site. This soil formed in portions of the Holocene Oahe Formation (type location at the Riverdale Section, Lake Sakakawea) which consists of four members. The Riverdale Member occurs on the surface (approximately 0 to 1 m at the type location); the Pick City Member underlies this (approximately 1 to 2 m); it is followed by the Aggie Brown Member (approximately 2 to 2.25 m), which contains the Leonard Paleosol, remarkable for its distinctively dark surface horizon; and the Mallard City Member (to approximately 3 m depth) (Clayton and others, 1976).

The upper portion of the Oahe Formation developed during the middle to late Holocene (ca 8,000 B.P. to present), characterized by alternating stable and unstable climate. The Aggie Brown Member dates to the early Holocene (ca 10,000 to 8,000 B.P.), a period of stable climate and slow warming, allowing strong development of the soil. The glacial material is Late Wisconsinan (> 10,000 B.P.), and on this site appears to be primarily water-worked sands.

Objectives, Materials and Methods

One of the objectives of the study at Double Ditch is to obtain baseline characterization data for the Leonard Paleosol and the overlying loess material. Thirty-nine soil cores 7 cm in diameter and approximately 2 to 3 m in depth were obtained using a Giddings hydraulic probe during the summers of 2003 and 2004. A control transect of twelve cores was sampled in relatively undisturbed soil along the northern edge of the State Historic Site perpendicular to the Missouri River (fig. 1). This transect provides information on variations in soil characteristics with distance from the source of the loess. The remainders of the soil cores are located throughout the village (fig. 1), and will help to assess the magnitude of earth-moving activities during occupation by the Mandan.

Results and Discussion

Pedon descriptions reveal up to four separate deposits of loess above the Leonard Paleosol. The presence and overall thickness of each deposit is variable, and may be related to local erosion and deposition activity, or to earth-moving activity of the Mandan. Laboratory analysis of the soil will aid in identification of the various deposits. The total depth to the paleosol appears to decrease with distance eastward from the Missouri River (Table 1). On the west end of the control transect (T1) is pedon T1-1, approximately 150 m east of the river and near the edge of the high terrace. It has 1.5 m of loess overlying the paleosol, less than other cores in the transect, perhaps due to erosional activity near the slope break. Pedons T1-2 through T1-8 (170 to 270 m east of the river) have 2 to 2.5 m of loess over the paleosol. There is a slight decrease in thickness in T1-12 (370 m from the river), with 1.9 m of overlying loess. Within the village proper, depths to paleosol are highly variable, dependant on cultural features. The largest borrow feature has a shallow depth of 60 cm. One pedon (T2 – 11) located between earth lodge

Figure 1. Soil core locations at Double Ditch.

TRANS. & SAMPLE	DISTANCE (m) FROM MISSOURI RIVER	ELEVATION (m) OF SURFACE	DEPTH (cm) TO PALEOSOL SURFACE
T1 – 1	150.499	523.905	142.240
T1 - 2	170.457	524.001	218.440
T1 – 3	190.499	524.534	256.540
T1 - 4	210.404	525.425	262.670
T1 - 5	230.429	526.159	259.080
T1 - 6	250.457	527.214	259.080
T1 - 7	270.476	527.863	243.840
T1 - 8	290.441	527.952	248.920
T1 - 9	310.574	528.083	213.360
T1 – 10	330.575	528.195	205.740
T1 - 11	350.515	528.435	193.040
T1 - 12	370.473	528.875	128.270
T2 - 1	409.250	527.937	269.240
T2 - 2	393.641	527.788	217.170
T2 - 3	383.545	527.598	274.320
T2 - 4	360.371	527.313	114.300
T2 - 5	342.332	526.285	63.500
T2 - 6	325.162	527.002	182.880
T2 - 7	311.548	526.564	172.720
T2 - 8	305.293	526.017	154.940
T2 - 9	293.794	526.801	220.980
T2 - 10	275.267	526.266	193.040
T2 - 11	259.810	526.672	231.140
T2 - 12	228.429	525.812	218.440
T2 - 13	204.643	524.452	151.130
T3 - 1	202.810	525.322	304.800
T3 - 2	201.357	525.247	182.880
T3 - 3	202.365	525.471	172.720

Table 1. Depth to Leonard Paleosol surface horizon with distance from the Missouri River.

depressions has 230 cm of material above the paleosol, and contains great artifact density, probably indicative of trash dumping.

It would be expected to find textural trends in particle size, such as fining with distance from the Missouri River. While some fining in size has been observed, it does not appear to be significant (Tables 2-4). This is probably due to the length of the control transect, a mere 370 m total distance from the river. Texture in the loess that overlies the paleosol is silt loam throughout all horizons. In the paleosol, the surface A-horizon is silt loam, with the underlying B-horizon somewhat finer in texture with greater clay content.

One of the most interesting features noted in several soil cores lies below the Leonard Paleosol. A deposit of non-eolian soil has characteristics of water-worked material (Table 2). Primarily sandy in texture, this deposit exhibits sharp contrasts in particle size and frequent, thin banding. Inspection under a microscope has revealed the rounded and relatively smooth nature of the sand grains.

HORIZON	DEPTH, cm	% CLAY	% SILT	% SAND	% VF SAND	% F SAND	% MED SAND	% C SAND	% VC SAND	TEXT. CLASS
A	0 – 3	12.8	64.8	22.4	20.2	1.3	0.2	0.3	0.4	SIL
Bw1	3 – 12	9.7	64.1	26.2	24.7	1.1	0.1	0.1	0.2	SIL
Bk1	12 – 22	11.8	57.0	31.2	27.1	2.9	0.5	0.4	0.3	SIL
Bk2	22 – 27	15.8	57.8	26.4	22.6	3.0	0.3	0.2	0.3	SIL
Bk3	32 – 39	13.8	62.9	23.3	20.9	1.8	0.2	0.2	0.1	SIL
Bk4	47 – 58	14.1	62.1	23.8	20.6	2.5	0.4	0.2	0.1	SIL
Bk5	65 – 72	14.4	60.9	24.7	20.8	3.2	0.4	0.2	0.1	SIL
BCk	79 – 86	15.5	61.7	22.8	19.8	2.5	0.2	0.2	0.1	SIL
Ck1	86 – 96	14.6	63.0	22.4	20.3	1.8	0.2	0.1	0.0	SIL
Ck1	118 – 124	12.3	63.0	24.7	22.9	1.6	0.1	0.1	0.0	SIL
Ck2	133 – 137	11.9	68.8	19.3	17.7	1.4	0.1	0.1	0.0	SIL
Ck2	137 – 142	12.0	67.7	20.3	18.3	1.8	0.2	0.0	0.0	SIL
2Ak1	**147 – 152**	**14.2**	**60.9**	**24.9**	**19.5**	**4.6**	**0.7**	**0.1**	**0.0**	**SIL**
2Ak2	**157 – 162**	**13.9**	**64.1**	**22.0**	**18.5**	**3.1**	**0.3**	**0.1**	**0.0**	**SIL**
2Ak/Bk	162 – 169	16.5	64.8	18.7	16.4	2.0	0.2	0.1	0.0	SIL
2Bk6	169 – 179	16.3	47.3	36.4	32.1	4.0	0.2	0.1	0.0	L
2Bk7	179 – 188	11.2	39.0	49.8	38.4	9.8	1.4	0.2	0.0	L
3Bk8	188 – 198	9.6	34.3	56.1	40.1	14.4	1.3	0.3	0.0	VFSL
3Bk9	204 – 210	9.4	36.3	54.3	45.2	8.4	0.6	0.1	0.0	VFSL
3Bk10	215 – 222	10.1	30.0	59.9	39.6	17.6	2.3	0.4	0.0	VFSL
3BCk	230 – 237	9.8	24.6	65.6	33.8	26.9	4.3	0.6	0.0	VFSL
4C	258 – 262	3.2	11.4	85.4	17.3	53.5	13.0	1.6	0.0	LFS
4Bk/Ck	276 – 282	8.2	27.8	64.0	38.4	20.3	4.7	0.6	0.0	VFSL
4Bk'1	282 – 298	9.4	37.2	53.4	36.7	15.1	1.3	0.2	0.1	VFSL
4Bk'2	298 – 310	10.9	40.7	48.4	34.0	12.6	1.6	0.2	0.0	L
5A	322 – 325	8.4	29.4	62.2	20.2	19.9	17.0	5.0	0.1	FSL
5Bk13	328 – 331	8.7	29.8	61.5	30.2	21.6	8.4	1.3	0.0	VFSL
5C1	331 – 333	2.3	5.2	92.5	6.0	46.7	35.4	4.4	0.0	S
6Bw2	339 – 345	6.5	17.7	75.8	43.6	30.2	1.9	0.1	0.0	VFSL
6Bw3	345 – 346	43.9	35.6	20.5	14.6	5.4	0.4	0.1	0.0	C
6C2	346 – 368	6.7	17.6	75.7	40.4	30.1	4.5	0.4	0.3	VFSL

Table 2. Pedon T1-1 particle size data (note that not all horizons are presented). Horizons in bold are Leonard Paleosol A-horizon. Water-worked material begins at 188 cm. Textural Classes: SIL (silt loam); L (loam); LFS (loamy fine sand); FSL (fine sandy loam); VFSL (very fine sandy loam); S (sand); C (clay).

In the cool and semi-arid climate of North Dakota, calcium carbonate features are ubiquitous in the soil. Carbonates increase in concentration and degree of expression with depth, from 30 cm to approximately 2.75 m; a gradual decrease is observed below that depth. Carbonates occur as filaments, nodules, coatings on structural faces and pebbles (if present), and as nodules.

Preliminary analysis of organic carbon indicates an average of 3.3% in the surface A-horizon (range 1.3 to 6.4%). Organic carbon in the A-horizon of the Leonard Paleosol contains an average of 0.61% (range 0.39 to 0.85%), a slight increase (0.1 to 0.4%) from the overlying C-horizon. Soil pH (in 0.01 M $CaCl_2$) increases from near neutral (6.5 to 7.5) in the surface horizon to a maximum of 8.0 to 8.3 at a depth of 2.5 m.

Summary

One objective of this study is to obtain descriptions and characterization data for the Holocene-age loess and the underlying paleosol. With this information it should be possible to confirm the identity of the paleosol and delineate the several loess deposits, as well as further our understanding of the soil-forming environment. It appears that there are 2 to 4 unique episodes of loess deposition at the Double Ditch State Historic Site, the variability perhaps related to local topography and erosion/deposition episodes. Characteristics of the paleosol, such as its dark A-horizon and finer-textured B-horizon, indicate its formation in a cooler and wetter environment than that of the present. The ubiquitous nature of carbonates in the loess points to a drier climate since the early Holocene. The presence of water-worked, coarser textured material below the paleosol implies the area may have been a strath terrace on the margins of glaciation in the Late Wisconsinan.

HORIZON	DEPTH, cm	% CLAY	% SILT	% SAND	% VF SAND	% F SAND	% MED SAND	% C SAND	% VC SAND	TEXT. CLASS
A	2 - 7	11.6	59.6	28.8	22.5	3.0	0.8	1.0	1.5	SIL
E	7 - 16	10.6	59.6	29.8	26.7	1.9	0.2	0.3	0.7	SIL
Bk1	20 - 27	11.6	59.1	29.3	25.4	2.2	0.3	0.3	1.1	SIL
Bk2	34 - 42	12.2	63.0	24.8	21.5	2.3	0.3	0.3	0.4	SIL
Bk3	42 - 49	12.4	64.9	22.7	19.5	2.2	0.5	0.3	0.2	SIL
Bk3	56 - 66	12.5	66.2	21.3	19.5	1.3	0.2	0.2	0.1	SIL
Bk4	66 - 73	13.3	67.6	19.1	17.3	1.4	0.2	0.1	0.1	SIL
Bk5	73 - 80	14.1	67.4	18.5	17.0	1.2	0.2	0.1	0.0	SIL
Bk5	88 - 95	14.5	65.4	20.1	18.2	1.6	0.2	0.1	0.0	SIL
Ck1	95 - 101	14.3	66.1	19.6	17.7	1.6	0.2	0.1	0.0	SIL
Ck1	121 - 128	11.8	68.0	20.2	18.7	1.3	0.1	0.1	0.0	SIL
Ck1	151 - 158	10.6	68.3	21.1	20.0	1.0	0.1	0.0	0.0	SIL
Ck1	171 - 178	10.9	67.4	21.7	19.9	1.6	0.2	0.0	0.0	SIL
Ck2	185 - 192	11.6	61.2	27.2	23.9	2.8	0.4	0.1	0.0	SIL
Ck2	208 - 218	11.3	54.3	34.4	30.9	2.4	0.4	0.5	0.2	SIL
Ck2	228 - 238	11.6	58.8	29.7	26.8	2.2	0.4	0.2	0.1	SIL
2A2	**270 - 278**	**17.7**	**62.1**	**20.2**	**15.7**	**3.2**	**1.0**	**0.3**	**0.0**	**SIL**
2Bk6	278 - 283	17.9	54.2	27.9	21.0	5.0	1.6	0.3	0.0	SIL
2Bk7	288 - 294	14.3	40.7	45.0	31.7	10.3	2.6	0.4	0.0	L
2Bk7	301 - 308	12.8	37.5	49.8	34.5	12.6	2.2	0.3	0.2	L
2Bk8	314 - 320	11.8	32.4	55.7	37.1	15.8	2.4	0.3	0.0	VFSL
3Ck3	333 - 343	9.3	23.9	66.8	26.6	19.7	16.5	3.9	0.1	FSL
3Ck3	351 - 361	8.2	17.8	74.0	31.0	32.3	9.4	1.2	0.0	FSL

Table 3. Pedon T1-6 particle size data (note that not all horizons are presented). Horizon in bold is Leonard Paleosol A-horizon. Water-worked material begins at 333 cm. Textural Classes: SIL (silt loam); L (loam); FSL (fine sandy loam); VFSL (very fine sandy loam).

HORIZON	DEPTH, cm	% CLAY	% SILT	% SAND	% VF SAND	% F SAND	% MED SAND	% C SAND	% VC SAND	TEXT. CLASS
A	0 - 3	10.9	64.2	24.9	20.8	2.2	0.5	0.8	0.6	SIL
Bw1	3 - 9	10.0	63.3	26.7	25.0	1.2	0.1	0.2	0.2	SIL
Bw1	9 - 13	12.1	60.9	27.0	25.1	1.5	0.1	0.1	0.2	SIL
2A3	18 - 24	13.3	42.2	44.5	40.0	3.6	0.1	0.2	0.6	L
2A4	24 - 30	14.0	52.8	33.2	29.4	2.9	0.3	0.2	0.4	SIL
3Bk1	36 - 41	14.8	65.4	19.8	17.1	1.9	0.2	0.2	0.4	SIL
3Bk1	41 - 46	14.8	65.3	19.9	17.7	1.5	0.2	0.2	0.3	SIL
4A5	46 - 51	14.2	65.3	20.5	18.4	1.4	0.2	0.2	0.3	SIL
4Bk2	51 - 55	15.1	66.7	18.2	16.4	1.3	0.1	0.2	0.2	SIL
4BkCk	60 - 68	15.1	68.5	16.4	14.8	1.2	0.2	0.1	0.1	SIL
4Ck1	68 - 74	14.9	69.0	16.0	14.6	1.1	0.2	0.1	0.0	SIL
4Ck2	79 - 86	16.1	67.2	16.7	15.0	1.2	0.2	0.2	0.1	SIL
4Ck2	93 - 100	17.4	65.5	17.1	15.3	1.4	0.2	0.1	0.1	SIL
4Ck2	107 - 114	16.5	66.0	17.5	15.8	1.4	0.1	0.1	0.1	SIL
4Ck2	121 - 127	13.9	68.5	17.6	16.5	0.9	0.1	0.1	0.0	SIL
4Ck2	133 - 142	11.7	68.4	19.9	18.8	0.8	0.1	0.1	0.1	SIL
5A6	142 - 145	12.3	67.3	20.4	19.3	0.9	0.1	0.1	0.1	SIL
5Bk3	145 - 152	12.9	68.0	19.1	18.0	0.9	0.1	0.1	0.0	SIL
5Bk3	159 - 165	14.1	61.6	24.3	21.4	2.6	0.3	0.0	0.0	SIL
5Bk3	170 - 177	13.2	62.9	23.9	22.3	1.4	0.1	0.1	0.0	SIL
5Bk3	177 - 185	12.8	62.8	24.4	22.9	1.4	0.1	0.0	0.0	SIL
5Bk4	185 - 192	13.1	62.2	24.7	23.2	1.3	0.1	0.1	0.0	SIL
5Bk4	199 - 206	13.6	66.5	19.9	18.2	1.6	0.1	0.0	0.0	SIL
5Bk4	206 - 210	12.8	66.8	20.4	18.4	1.7	0.2	0.1	0.0	SIL
5C	210 - 223	12.8	66.6	20.6	18.4	1.9	0.2	0.1	0.0	SIL
6A7	**223 - 230**	**15.3**	**62.9**	**21.8**	**19.1**	**2.3**	**0.3**	**0.1**	**0.0**	**SIL**
6A8	**230 - 239**	**16.7**	**60.7**	**22.6**	**18.7**	**3.4**	**0.4**	**0.1**	**0.0**	**SIL**
6A9	**239 - 253**	**17.9**	**60.1**	**22.0**	**19.5**	**2.1**	**0.3**	**0.1**	**0.0**	**SIL**
6Bk5	253 - 273	17.6	55.8	26.6	24.9	1.6	0.1	0.0	0.0	SIL
6Ck3	273 - 281	12.3	48.4	39.3	36.4	2.6	0.2	0.1	0.0	L
6Ck3	281 - 289	12.3	42.6	45.1	38.4	5.7	0.9	0.1	0.0	L
7Ck4	289 - 296	11.7	33.9	54.4	38.3	12.6	3.2	0.3	0.0	VFSL
7Ck4	303 - 317	9.9	27.4	62.7	33.9	22.5	5.7	0.6	0.0	VFSL

Table 4. Pedon T1-12 particle size data (note that not all horizons are presented). Horizons in bold are Leonard Paleosol A-horizon. Water-worked material begins at 289 cm. Textural Classes: SIL (silt loam); L (loam); VFSL (very fine sandy loam).

By using the Leonard Paleosol as a stratigraphic marker, it will be possible to measure the "ground surface to paleosol" depth within the village perimeter. An estimate of the magnitude of planar borrowing, the practice of somewhat uniform and widespread earth removal practiced by the Mandan, can then be determined.

References

Clayton, L., S.R. Moran, and W.B. Bickley, Jr., 1976, Stratigraphy, origin, and climatic implications of Late Quaternary upland silt in North Dakota: North Dakota Geological Survey Miscellaneous Series No. 4.

Hoganson, J.W., and E.C. Murphy, 2003, Geology of the Lewis and Clark Trail in North Dakota: Missoula, Mt., Mountain Press Publishing Co., 247 p.

Square Buttes
Mile: 18.3 (5.8)

The Square Buttes are some of the most prominent geographic features along a 50-mile stretch (80 km) of the Missouri River from Bismarck to Washburn. Although visible for a distance of 20 miles (32 km) both up and down river, they were not noted in the journals of William Clark nor the Corps of Discovery sergeant's. Clark also failed to plot them on his map of the area.

Square Buttes stand approximately 300 feet (91 m) above the surrounding countryside and consist of alternating nonmarine beds of claystone, sandstone, siltstone, mudstone, and lignite of the Fort Union Group (Paleocene). Mudstones and sandstone of the Cannonball Formation (a Paleocene marine unit) are exposed in the drainages around the buttes.

In North Dakota, three-fourths of the Missouri River Valley is inundated with flood waters from the Garrison and Oahe reservoirs. There are only two stretches in the state where the valley is still occupied by a river, the longest of which is from Bismarck-Mandan to Riverdale. The other stretch is from Williston to the Montana line.

Wogansport (Wogan's Port Ditches)
Mile: 19.6 (1.3)

In 1886, Frank Russo Simons, a native of Schenectady, New York arrived in the area with his brother. For the next 40 some years, Simons dug triangular ditches by hand for the purpose of establishing irrigation ditches for a nursery (fig. 3). It has been reported that he may have spent time in an insane asylum. Most ditchwork is oriented north-south and is approximately 200 feet (61 m) long.

Many of the ditches have become obscured over time. However, prior to the examination of aerial photographs, we mistook a segment of Simon's ditch for soil creep, an erosional process that is otherwise prevalent in the hillsides in this area (see page 88, Hoganson and Murphy, 2003).

Figure 3. A 1957 aerial photograph (BAB -5T-90) of the Wogansport area. The area depicted is approximately 3,300 feet by 3,300 feet (1006 x 1006 m).

Painted Woods Lake
Mile: 32.1 (12.5)

The Lewis and Clark Expedition passed by the area near present day Painted Woods Lake on October 24, 1804. At that time, Painted Woods Lake was an oxbow lake (fig. 4). Clark noted in his journal that the river cutoff in this area had taken place seven years prior to the expedition. He arrived at this conclusion based upon a map by John Thomas Evans which showed that this meander was an active river channel in 1797 (fig. 5).

Figure 4. Landsat 7 imagery of the Painted Woods Lake area. The oxbow lake is located in the center of the photograph. The white line along the Missouri River is the border between Oliver and McLean counties. Modified from a map produced by the U.S. Geological Survey.

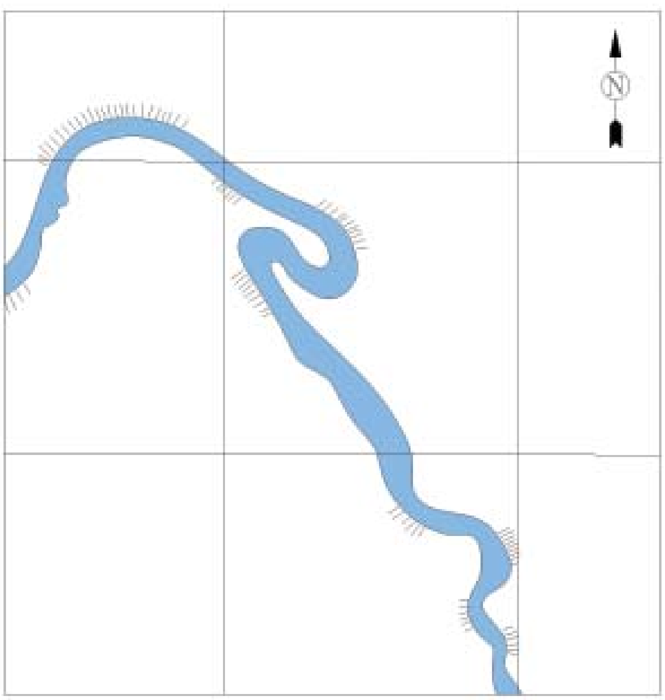

Figure 5. A simplified drawing of J.T. Evan's map of 1797 showing a meander in the Missouri River that became an oxbow (Painted Woods Lake) prior to the fall of 1804. Drawing modified from Moulton (1983). Information on John Thomas Evans and other early explorers in this area can be found in Wood and Thiessen (1985) and Wood (2001).

Turn left (north) onto US Highway 83 at mile 35.2 (3.1)

Turtle Creek
Mile: 38.8 (3.6)

Stratigraphy of Three Archaeological Sites at the Turtle Creek and Missouri River Confluence

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In 2000 Metcalf Archaeological Consultants, Inc. (MAC) conducted excavations of sites 32ML902, 32ML903 and 32ML914, overlooking the Missouri River at Turtle Creek south of Washburn, North Dakota. Excavations revealed almost continuous human occupation at the site ranging from 11,188 ± 80 B.P. to the present. The occupations were broken down into four analytic units corresponding to the soil stratigraphy (figs. 1 and 2).

The date ranges applied to the analytic units for this project's three sites are based on the previous research that has been conducted in and around the Missouri River trench in North Dakota. The results of the previous research were considered in combination with the radiocarbon dates returned from the 32ML903/32ML914 samples. The application of the cultural period designations to this project's analytic units fits well – not only with the previous research and the radiocarbon dates, but also with the diagnostic projectile points that were recovered in the artifact assemblage.

Analytic Unit 1 (A Horizon, plow zone and uppermost portion of the undisturbed Riverdale Member of the Oahe Formation) is assigned to the Late Plains Archaic up to the present including Late Prehistoric or the Plains Woodland time periods. Upland instability between 3,000 and 1,000 B.P. (Van Nest 1995:4:64) supports the idea that these deposits are a mix of modern and old deposits. No radiocarbon samples were attributed to this analytic unit, therefore stratigraphic data was relied on for dating purposes. Additionally, no diagnostic materials were recovered from AU1. This designation therefore is based on the chronology developed by Clayton et al. (1976) for the Oahe Formation in conjunction with radiometric dates from the slightly earlier AU2 sediments at 32ML903/32ML914. This unit is represented at the sites by shallow deposits that have been disturbed by agricultural activities, with no intact features encountered during excavation.

Analytic Unit 2 (A/B and B_w Horizon of the Riverdale Formation) is assigned to the Middle Plains Archaic time period. This designation is based on the chronology developed by Clayton et al. (1976) for the Oahe Formation in conjunction with radiometric dates from 32ML903/32ML914. Analytic Unit 2

Figure 1. View of Trench 3, note dark band is Leonard Paleosol.

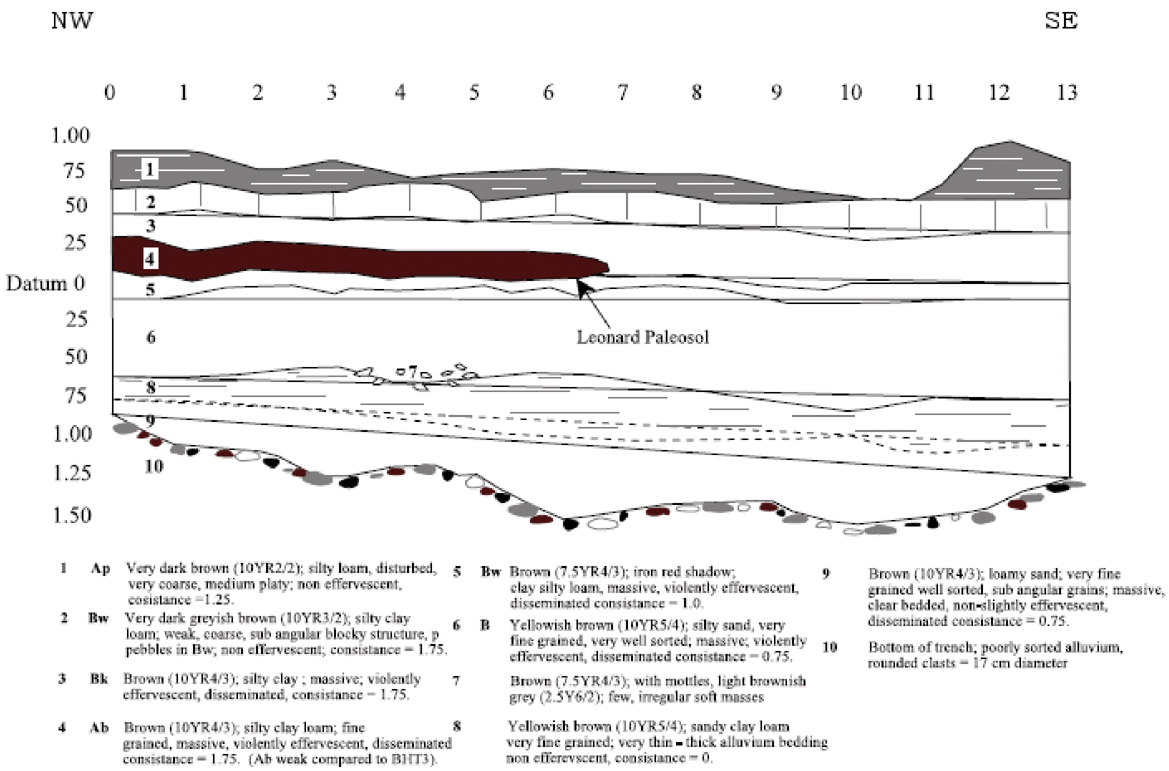

Figure 2. Illustration of the northeastern wall profile of Backhoe Trench 4 at ML903/32ML914 (September 20, 2003, profile drawn by M. L. McFaul).

encompasses an early date of 5,000 B.P. with a terminal date of 2,000 B.P. A Duncan projectile point fragment, FS204, is the only temporally diagnostic chipped stone tool from AU2. It was found adjacent to Feature 118, a hearth. Duncan points are solidly dated to the Middle Plains Archaic period where they have been found in good context (e.g. Frison 1978). There appears to be some overlap in the assigned date ranges of the Middle and Late Plains Archaic periods between the radiocarbon date, the cultural periods, and the analytic units. Based on the evolving nature of cultural period designations, the increased precision and accuracy of radiocarbon dating, and the recovered diagnostic projectile points, MAC concludes that assignment of cultural period designations to this analytic unit is valid.

Analytic Unit 3 (Pick City Member of the Oahe Formation) is assigned to the Early Plains Archaic time period. Analytic Unit 3 encompasses an early date of 7,000 B.P. with a terminal date of 5,000 B.P. Of the eleven projectile point/point fragments recovered from AU3, seven are temporally diagnostic, with two assigned to named types. The radiocarbon dates were from materials at the bottom of the AU3 sediments, directly above the Leonard Paleosol, while the points were recovered at or above these radiocarbon samples and therefore do not predate them.

The projectile points were within the Pick City Member of the Oahe Formation, which has been dated geologically to the Early Plains Archaic period. In support of this time frame, two ^{14}C dates from excavated Features 1 and 3 had recorded dates of 5,433 ± 62 B.P. (ETH-26160) and 6,980 ± 50 B.P. (BETA-175674). The shape of the projectile points (particularly FS44, FS203, and FS205) are similar to the descriptions for triangular side-notched projectile points at the Itasca (Shay 1971:55-56) and Medicine Crow sites (Ahler and Toom 1995:46, 85 to 87) and are most likely Simonsen points. Based on the dates from both the soil and the carbon samples, and also the shape of the projectile points, AU3 seems to be accurately placed within the Early Archaic.

While considered part of the Early Plains Archaic in the *State Plan* (SHSND 1990:B.23), there is evidence that the Oxbow Complex occurred at the terminal Early Archaic *and* the early Middle Archaic (Frison 1978: 45). Dates for the Oxbow Complex are suggested, in the *State Plan* to be 3,300 to 2,500 B.C. Frison suggests a similar time period of 5,000 to 4,000 B.P. and says some sites suggest Oxbow and McKean mixing (Frison 1978:45). This mixing was also encountered at 32MH94 (Stine et al 2001:247-248). Simonsen points have associated dates closer to the 6,000 to 8,000 years B.P. range. It appears that, based on the presence of an Oxbow point and Simonsen points, there are at least two distinct occupations at 32ML903/32ML914 during the Early Archaic.

Analytic Unit 4 (Leonard Paleosol) is assigned to the PaleoIndian time period. Analytic Unit 4 encompasses any cultural expression older than 8,800 B.P. Field Specimen 31, a fragment of a Cody Knife, was produced from KRF and was recovered from a depth of 118-128 cm below datum. Cody Knives are a diagnostic artifact type of the Cody Complex based on the recovered artifact assemblages at the Horner type-site in Wyoming (Frison and Todd 1987). Cody Complex age artifact assemblages have also been recorded at the Hell Gap, Carter/Kerr-McGee, Medicine Lodge Creek, Finley, and Claypool sites. Cody Knives are bifacial implements with a transverse lower edge and a distinctly shouldered stem (Bradley and Frison 1987:220), creating a distinct asymmetrical outline noted for having antecedents in the earlier Agate Basin and Hell Gap PaleoIndian assemblages (Bradley and Stanford 1987:429 to 431). The established date range for Cody Complex sites is 8,800 to 9,300 B.P. (Frison et al. 1996:15).

Two projectile point fragments were recovered during the excavations. One is similar to points from the Hell Gap complex and the second is an Alberta-Cody point (Bradley and Frison 1987:207). The two points are fragments, making identification tentative. Field Specimen 32 is the base of a point and while it fits within the Hell Gap it is slightly asymmetrical and may more properly be considered a second Cody Knife fragment. Field Specimen 30, the blade portion of a point, most closely fits the profile of an Alberta-Cody point. It should be noted that this point is also consistent with Alberta points, Cody varieties, and the extreme range of Hell Gap points.

Discussion of Analytic Unit Development

With the exception of AU1, diagnostic materials found within each analytic unit support the findings of the natural and cultural stratigraphy as well as the radiocarbon dates for each analytic unit. Our goals in outlining the analytical units in this manner were threefold. First, it aided in outlining the cultural time periods for this area, solidifying the appropriate application of the Missouri River trench cultural stratigraphy. Second, through utilization of radiocarbon dating, justification of the date ranges applied to each analytic unit was accomplished. Third, the regional context for these sites in the broader regional framework was accomplished, creating a reliable base for cultural materials found within the same stratigraphic context in the future.

The identification and subsequent radiocarbon dating of two features found within the Leonard Paleosol is the most significant contribution of this project to the regional chronology. The two hearth features represent two distinct occupation periods, one significantly older than initially expected based on the diagnostic projectile points found within the general matrix. Excavations at nearby sites such as Alkali Creek have recovered artifacts from multiple components (i.e. Goshen, Hell Gap, Early Archaic, etc.) with radiocarbon dates obtained from soil matrices surrounding cultural material, but not from distinct feature fill as is the case here.

A gap in the occupation sequence at this location is evident between 7,000 and 8,800 B.P., making the break between AU3 and AU4 significant. No diagnostic tools or radiocarbon dates were discovered relating to this time period. The AU3 radiocarbon dates taken from immediately above the Leonard Paleosol fell well within the Early Archaic time period, while the diagnostic tools from within the Leonard date to the PaleoIndian period. This gap may reflect an absence of cultural occupation during this time or could reflect the taphonomic processes at work on the site. A combination of these two scenarios could also be possible.

Overview of Geologic Processes for Site Area's Formation

West of the Missouri Coteau, the study area is within the glaciated Missouri Plateau section of the Great Plains province (Fenneman 1931). Geology in the area consists of Paleocene Cannonball and Bullion Creek Formations mantled or altered by Pleistocene glacial deposits of the Coleharbor Formation and late Pleistocene-Holocene Oahe Formation loess (Bluemle 1971; Clayton 1980). Unnamed Holocene alluvial deposits mantle the Turtle Creek and the Missouri River floodplains (fig. 3).

Older Holocene-pre Wisconsin alluvial terrace sediments are on the right bank (west) of the Missouri west of the Turtle-Missouri confluence (Clayton et al. 1980). Clayton (1980) notes exposures of both the Cannonball and Bullion Creek Formations in the moderately steep segments of the Turtle Creek meltwater trench. There are at least two meltwater trenches in the area. The positions of the meltwater trenches infer they were cut in the waning phases of the last glacial advance. Clayton et al. (1976:10-11) suggest that by 13,000 B.P. the Missouri River was no longer carrying meltwater. This implies that trench incision began approximately at this time. Work in the Des Lacs drainage channel suggests that by 9,700 ± 120 B.P. incision of the meltwater trench ended (McFaul and Holmes 2000; McFaul and Elmendorf 2002).

The geomorphic and geologic setting of the study area provides the foundation for understanding the sites' potential to yield buried cultural materials. The relatively flat alluvial sands and cobbles of the paleo-floodplain (Pleistocene Coleharbor Formation) are probably too old to yield cultural materials within the accepted age range for human occupation. They also represent a depositional environment that did not favor human habitation or the in situ preservation of cultural materials. Clovis materials are, however, associated with cobble bars in braided stream, latest Pleistocene, South Platte River alluvium (Zier et al. 1993).

The oldest described sediments at the locality are sand and cobble facies of the Pleistocene Coleharbor Formation (see Bluemle 1971; Clayton et al. 1980:14-15).

The reconstruction for 32ML902 and 32ML903/32ML914 begins in Late Wisconsinan time with the opening of the modern Missouri River and the subsequent retreat of glacial ice from the study area (ca.<14,000 B.P. Clayton et al. 1980:68). The absence of collapsed river sediment suggests the construction of the Turtle Creek meltwater floodplain followed the ice retreat to the Missouri Coteau. Rounded, cobbly fan deposits were carried to the study area ca. 14,000-12,000 B.P. via the Turtle Creek meltwater trench. Although not as harsh as the full-glacial, the climate at the end of the Late Wisconsinan glaciation was probably cooler and wetter than today (Clayton et al. 1976). Terrains outside the active floodplain were colonized by a spruce-aspen forest (Clayton et al. 1976:10).

By ca. 12,000 B.P. the meltwater drainage was diverted from the Turtle Creek drainage to the James River Valley (Clayton et al. 1980). The upward-fining sediment sequence above the cobbly meltwater at the study area suggests a relatively orderly transition from meltwater to overbank alluviation prior to the creation of the meltwater trench. The small coulee that divides the sites dates from this event. Work in the Des Lacs channel implies both Turtle Creek incision and coulee cutting ended by 9,700 B.P. (McFaul and Elmendorf 2002).

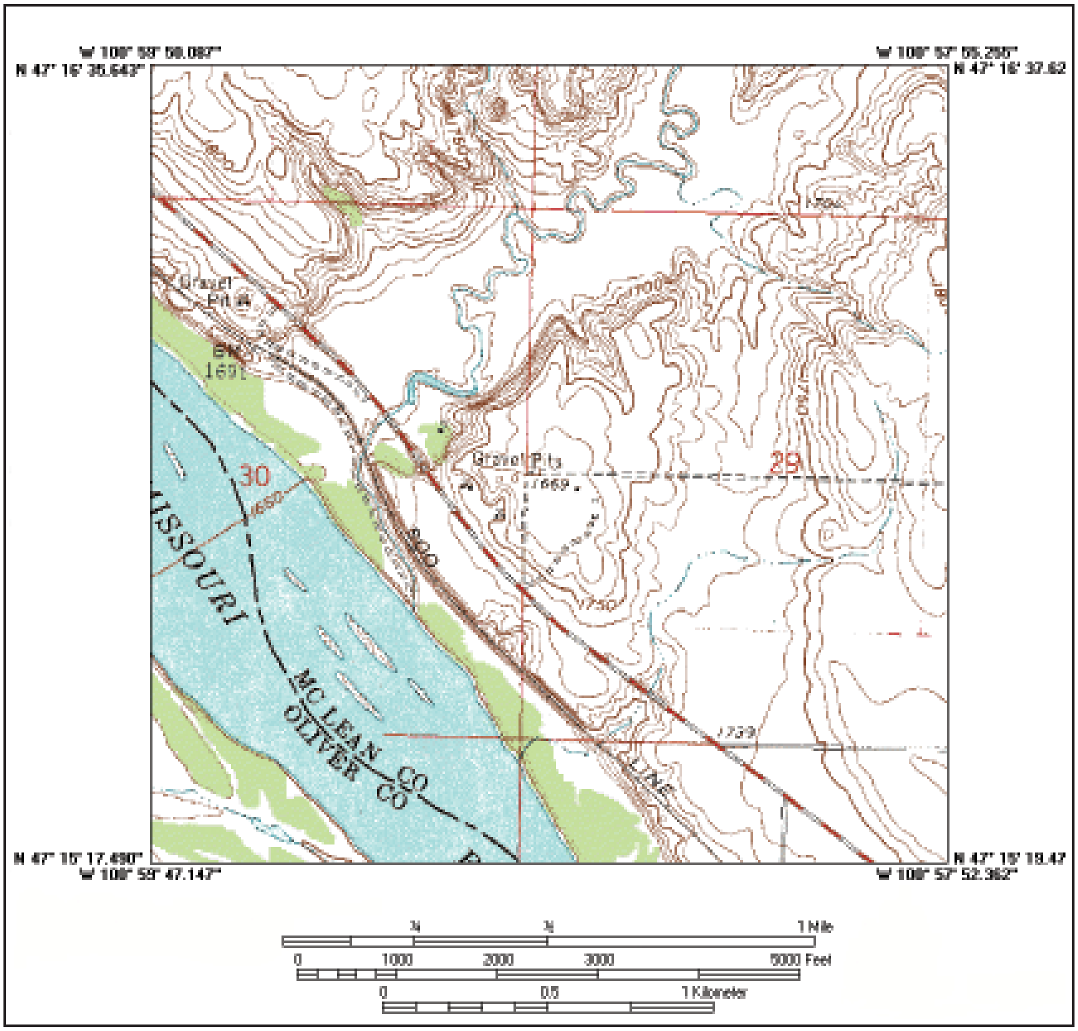

Figure 3. Map of project area based on USGS 7.5' Turtle Creek SW (1961) quadrangle map.

Beginning with the abandonment of the paleo-floodplain and ending with cutting of the meltwater trench, the construction of the modern landscape, sans loess, was complete. Initial eolian deposition resulted in the formation of a low-relief dune on the segment of abandoned meltwater floodplain that overlooks the Turtle Creek meltwater trench near the Missouri River. Development of the dark, organic-enriched Leonard Paleosol (AU4) marks the conclusion of the initial loess event. Clayton and others (1976) suggest the spruce-aspen forest had given way to prairie grassland by this time and that the climate had become more like today (cool and humid). Results of this study show development of the Leonard Paleosol beginning by 11,186 ± 80 B.P. (ETH-26157; wood charcoal; $*^{13}C/^{12}C = -26.6 \pm 1.2‰$) and continuing through 10,235 ± 76 B.P. (ETH-26159; charcoal; $*^{13}C/^{12}C = -24.3 \pm 1.2‰$). Although there are considerations regarding sample preparation that appear to make its ^{14}C ages younger, results of a previous study at the materials pit imply formation of the Leonard continued to ca. 9,000 B.P. (C. Vance Haynes Jr., written communication January 30, 2003).

Renewed eolian deposition followed development of the Leonard Paleosol. Clayton and others (1976:11) suggest the deposition of the Pick City Member correlates with increasing dry and warm conditions that resulted in slope instability and an increase in sediments available for eolian transport. Pick

City age sediments (AU3) appear to be more extensive than those of the Aggie Brown, but they also thin to the southeast (BHT 2, 32ML903/32ML914). Soil development during this time consists of a carbonate enrichment that is associated with semi-arid grasslands (Clayton et al. 1976:12). The age of a cultural hearth within the Pick City sediments, suggests relatively xeric conditions at 6,980 ± 50 (BETA-175671 charcoal, *^{13}C/^{12}C = -26.4‰) and continued through 5,433 ± 62 B.P. (ETH-26160; charred silt; *^{13}C/^{12}C = -23.7 ± 1.2‰).

The absence of a soil A horizon with the calcareous Pick City sediments implies an erosional event may have preceded deposition of the most recent and extensive loess (Riverdale Member). Although climatic fluctuation (warm-dry/cool-wet) is associated with the Riverdale event, the Riverdale sediments (AU2) at the study area show continued deposition followed by soil formation. Position and age of a cultural feature suggests on-going eolian deposition as early as 3,900 ± 60 (BETA-175673, charcoal, *^{13}C/^{12}C = -25.0‰) and continuing through 2,335 ± 56 B.P. (ETH-26158; wood charcoal; *^{13}C/^{12}C = -23.8 ± 1.2‰).

Summary

The examination of archaeological sites 32ML902 and 32ML903/32ML914 has provided insights about two important and understudied periods in North Dakota prehistory, the PaleoIndian period and the Early Archaic period. They also provide insight into Late Wisconsinan-Holocene terrain evolution, environmental events, and human/land interaction along the Missouri River. Cultural materials at the sites are associated with Holocene loess deposits that mantle a Late Wisconsinan meltwater floodplain. This association with loess is significant. The relatively gentle and continuous nature of loess deposition results in stratigraphic separation and in situ preservation of individual cultural components and possibly individual occupations. Because the loess units are members of the Holocene Oahe Formation, they have soil/sediment characteristics that are helpful in evaluations of site age, extent, and paleoenvironments. The Leonard Paleosol is a readily apparent example.

Research at these multi-component localities provides insight into the understanding of Missouri River Trench geoarchaeology. For example, the state geologic map (Clayton 1980) shows numerous terrains in the region mantled with Oahe Formation sediments. However, across the region why are there so few multi-component sites? It appears the locality's view, together with its potable, eatable, and lithic resources influenced repeated human occupation.

Summary of Temporal Data for All Sites

Cultural Period	Time Period	Radiocarbon Dates	Projectile Points	Analytic Unit
Late Plains Archaic/ Late Prehistoric	2000 B.P.-present	None	None	1
Middle Plains Archaic	5000-2000 B.P.	2335 ± 56 B.P. 3620 ± 80 B.P. 3650 ± 110 B.P. 3900 ± 60 B.P.	Duncan Point	2
Early Plains Archaic	7000-5000 B.P.	5433 ± 62 B.P. 6980 ± 50 B.P.	Early Archaic (n=4) Simonsen (n=2) Oxbow (n=1)	3
PaleoIndian	older than 8800 B.P.	11,186 ± 80 B.P. 10,235 ± 76 B.P.	Cody Knife (n=2*) Alberta-Cody	4

*While attributed to the Cody Complex, FS32 may be a Hell Gap projectile point fragment.

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Washburn
Mile: 40.8 (2)

Turn West at Washburn onto ND Highway 200A at mile 42.3. *(1.5)*

Washburn was an early river town. A ferry operated across the Missouri River at Washburn for many decades, until a highway bridge was built at this locality in the 1960s. The Lewis and Clark Interpretive Center is located on the north side of town. A scale-replica of Fort Mandan, occupied by the Lewis and Clark Expedition from November 1, 1804 until April 7, 1805, is located about five miles northwest of the interpretive center (fig. 6). The actual location of Fort Mandan is believed to be about 12 miles west-northwest of Washburn. Although scientists have attempted in recent years to discover the remains of the fort, it likely succumbed long ago to the migrating channel of the Missouri River.

Figure 6. A scale-replica of Fort Mandan was built in the 1970s. The winter at Fort Mandan was a harsh one for the members of the Corps of Discovery. When the temperature fell to -12 ^{0}F on December 8, 1804, Ordway wrote in his journal *"the weather is 12 degrees colder this morning than I ever new it to be in the States."* It would get much colder. The coldest temperature recorded that winter is, depending upon the journal entry, either - 43 or - 45 ^{0}F.

Missouri River Terraces in the Hensler Area
Mile: 45.5 (3.2)

There are three well-developed terraces in the Missouri River Valley in the Hensler area (fig. 7). The two lower terraces have relatively flat surfaces while the older, upper terrace is not as well defined because it has a more undulating surface. Only about 10 feet (3 m) of elevation separates the two lower terraces while the upper terrace is about 50 feet (15 m) higher than the middle one.

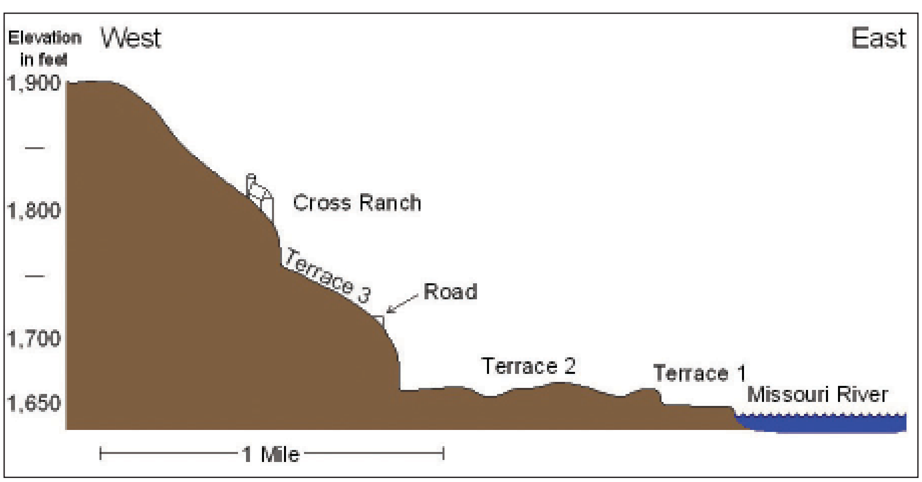

Figure 7. A profile of three terraces in the Missouri River Valley near Hensler.

Cross Ranch State Park
Mile: 46.8 (1.3)

Cross Ranch State Park is located approximately five miles southeast of Hensler. The park was originally part of a 11,000-acre purchase made by A.D. Gianes, a professor of classical literature, in 1879. Gaines came to the Dakota Territory as a land agent for the Northern Pacific Railroad. He acquired Teddy Roosevelt's Maltese Cross brand. The nearby town of Sanger, originally named Bentley, was also established at that time. Once a thriving town with a railroad depot and steamboat service, it briefly served as the Oliver County seat. After the Sanger depot closed in 1952, the town slowly died and all that remains today are a handful of abandoned buildings. In 1956, ownership of the Gaines Ranch passed to Bob and Gladys Levis, who renamed their land Cross Ranch. The Nature Conservancy subsequently purchased the ranch. Both the Conservancy and Burlington Northern Railroad donated land to create Cross Ranch State Park. The Conservancy manages the remaining land, some 6,000 acres, as a dedicated state nature preserve. Hiking trails now connect the park and preserve (information modified from the North Dakota State Park website).

Landslide Along Highway 200A
Mile: 51.8 (5.0)

In recent years, ND Highway 200A has been damaged in this area by landslides, in this case rotational slumps (fig. 8). The scarp of one of the slumps is visible above the roadway. As is typical of most slope failures in North Dakota, there have been several episodes of movement (fig. 9). An inspection of the railroad cut, originally excavated in the late 1800s, revealed disturbed strata indicating that the slope had initially failed prior to construction of both the railroad and the highway. The original or ancestral landslide, visible on aerial photographs, was likely caused when a meander of the Missouri River eroded the toe of the slope. The younger slides are superimposed upon the slide material. At least one of these slides can likely be attributed to removal of material at the toe by the railroad cut.

Typically, an unstable slope is stabilized by the removal of material from the head of the slide, thereby reducing the driving force, or by the placement of additional material at the toe of the slide to counterbalance the driving forces. Corrective measures such as these are difficult at this site because of the steep slope above the roadway and the presence of railroad tracks near the toe of the slope beneath the roadway. The position of the tracks makes it virtually impossible to buttress the slope below the roadway.

Figure 8. Highway 200A crosses an old landslide at Clark's "High Hill" just west of Mandan Lake. Note that the toe of the old slide extends towards the river beneath the roadway. The prominent railroad cut in the photograph exposes distorted strata within the body of the old landslide (arrow). View is towards the northeast.

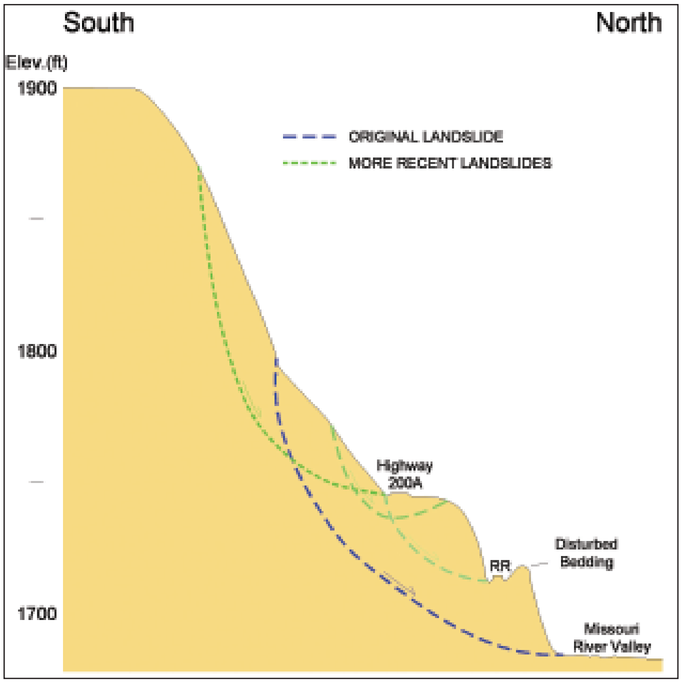

Figure 9. Profile of the unstable slope along ND Highway 200A at Clark's "High Hill" east of Fort Clark. There have been several episodes of slope failure at this locality.

Concretion
Mile: 53.4 (1.6)

A large, round concretion was excavated in the 1970s during construction of a small, manmade lake adjacent to the highway and placed on display at a highway turnout. The round concretion is not typical of those found in the nonmarine strata of the Fort Union Group. More typically, Fort Union concretions are elongated and are often referred to as log concretions.

Fort Clark
Mile: 56.2 (2.8)

Fort Clark Trading Post State Historic Site is one of the most important archeological sites in the state because it provides a record of the fur trade era. More than 150 years ago, it was the scene of devastating smallpox and cholera epidemics that decimated most of the inhabitants of a Mandan and later an Arikara Indian village. The historic site protects the archeological remains of the large earthlodge village, cemetery, and two fur trade posts (Fort Clark Trading Post and Primeau's Post).

The story of the site begins in the summer of 1822 when the Mandan built a village of earth-covered homes on the bluffs of the west bank of the Missouri River at the confluence of Chardon Creek and Clark's Creek. They called their new home Mitu'tahakto's (pronounced me-toot-ahank-tosh), meaning first village or east village. The community overlooked gardens tended by the village women who grew crops of corn, beans, squash, pumpkins, and sunflowers. The men were primarily responsible for hunting bison and other game. After the fall harvest of these crops, the villagers moved to a winter village sheltered in the wooded Missouri River bottom. In the spring, they returned to Mitu'tahakto's to plant their crops.

In 1830-1831, James Kipp, an employee of the American Fur Company, built Fort Clark Trading Post south of a Mandan village with hopes of enhancing trade with the Indians. The rectangular fort measured 120 feet by 160 feet and was protected by a palisade. The fort contained a bourgeois house, where the head trader Francis A. Chardon lived, and other buildings. Between 1834 and 1839, Chardon kept a journal of his life at Fort Clark, which records the tragic history of the site.

The first steamboat to journey to the Upper Missouri, the *Yellow Stone*, arrived at Fort Clark in 1832 and delivered trade goods and 1,500 gallons of liquor. It returned to St. Louis carrying 100 packs of beaver pelts and bison robes from the fort. Important visitors to the site included artists Karl Bodmer and George Catlin and German scientist and explorer Prince Alexander Philipp Maximilian of Weid-Neuweid.

Although steamboat traffic was important in transporting goods and visitors to the site, it also brought disease. On June 19, 1837, the steamboat *St. Peters* docked at Fort Clark carrying passengers infected with smallpox. Soon the disease swept through the Mandan village, killing about 90 percent of the inhabitants. In mid-August, at the height of the smallpox epidemic, the Mandan survivors fled to join the Hidatsa near the mouth of the Knife River, abandoning the village at Fort Clark.

Although also devastated by the 1837 epidemic, approximately 50 percent of the Mandan's neighbors, the Arikara, survived. In 1838 they moved into the abandoned Mandan village to trade at Fort Clark and to grow their crops. Tragically, an outbreak of cholera in 1851 and another of smallpox in 1856 further reduced their population. The Arikara used the village as their summer home until they moved to Star Village near Fort Berthold in 1862.

Meanwhile, another fur trade post, Primeau's Post, had been constructed on the south side of the Arikara village in 1850 by a competitor, Harvey Primeau and Company of St. Louis. The fort was located between Fort Clark and the Arikara village. Charles Primeau, a former employee of the American Fur Company, started the competing company.

After the south half of Fort Clark burned in 1860, the owners purchased Primeau's Post, which they operated until 1861. Later that year, Primeau's Post and the Arikara village were abandoned after an attack by the Dakota. Passing steamboats scavenged firewood from the abandoned fort until at least 1865 (modified from the State Historical Society of North Dakota website on Fort Clark http://www.state.nd.us/HIST/ftClark/ftClark3.html).

Coal-Fired Power Plants
Mile: 59.6 (3.4)

Two coal-fired electric generating stations are present on the right (north) side of ND Highway 200A (fig. 10). The Stanton Station was built in 1966 as one lignite-fired unit rated at 202,000 kilowatts. Unit One of the Leland Olds Station is rated at 210,000 kilowatts and was also built in 1966. Unit Two of this plant was built in 1975 and is rated at 440,000 kilowatts. The plants were located adjacent to the Missouri River to take advantage of the abundant water as a coolant.

Earlier this year, Basin Electric Power Cooperative announced that it will spend $300 million to install scrubbers on both coal-based generating units at the Leland Olds Station to reduce emissions of sulfur dioxide. Amendments to the Clean Air Act approved by Congress in 1990 required that plants like the

Leland Olds Station that were built prior to 1977 would eventually be required to meet more stringent air quality requirements.

The Deapolis Village was occupied by the Mandans between about 1787 and 1822, and then intermittently as late as 1856 (Wood, 1886). Lewis and Clark visited this village while occupying Fort Mandan during the winter of 1804-05. The initial residents came from the Heart River area where they were driven from the area by a smallpox epidemic in the mid-1770s and another in 1780-81. The village site was partially destroyed during construction of a river elevator and by a gravel operation that mined the area between 1958 and 1960. The Stanton Station destroyed the remainder of the historic site when it was constructed in 1966.

Figure 10. The UPA's Stanton Station and Basin Electric Cooperative's Leland Olds Station are located on terrace deposits of the Missouri River. The Missouri River Valley is 2.5 to 3 miles (4 -4.8 km) wide in this area. The approximate location of Fort Mandan is noted by an **X**. The Stanton Station is the closest of the two, view is to the southeast.

Glenharold Mine
Mile: 60.0 (0.4)

To the left (south) of Highway 200A are the reclaimed spoils of the old Glenharold surface coal mine. The mine operated from 1964 to 1990. From 1977 on, state and federal laws required the mining company to separate and stockpile the soil and subsoil while mining. Upon completion of mining, the spoils were leveled and the ground surface returned to the approximate original contour and the subsoil and soil respread. Most of the uplands south of the highway between ND Highway 31 and Stanton were mined and reclaimed. The absence of both woody draws and outcrops of layered strata of the Fort Union Group is one of the ways to differentiate reclaimed land from unmined lands. The coal that was mined in this area was a 12-foot-thick lignite that was present at a depth of approximately 100 feet.

Intersection with road to Stanton and Knife River Indian Village Site at mile 63.4. (3.4)

Oahe Formation

In 1971, John Bluemle noted the presence of thick (15-20 feet, 5-7 meters) eolian silt deposits exposed in the bluffs adjacent to Lake Sakakawea in McLean County. These deposits commonly contained two paleosols. The following year, Lee Clayton (1972), introduced the terms Oahe Formation and Aggie Brown Member for a group of silt deposits near the town of Killdeer. In 1976, Clayton and others, formally named this unit the Oahe Formation and established a type section (center of section 22, T.147N., R.84W.) near the town of Riverdale in McLean County (figs. 11 and 12). The Oahe Formation was described as unlithified silt that varies across North Dakota from silt, to silty loam, to loam. At the type section, the Oahe Formation was determined to be 75 percent silt, 15 percent clay, and 10 percent sand. The silt of the Oahe Formation typically exhibits vertical columnar jointing when exposed along steep, dry slopes. The Oahe Formation was subdivided into four members based primarily on color differences recognizable in the field. The members are (in ascending order): Mallard Island, Aggie Brown, Pick City, and Riverdale (Clayton et al., 1976).

The Mallard Island Member (MI, figs. 11 and 12) is the basal member of the Oahe Formation and is typically pale brown to light yellowish brown and ranges in thickness from 0.3 to 6.5 feet (0.1 to 2 m). Clayton and others (1980) suggested that much of this member was deposited during the Late Wisconsinan.

The Mallard Island Member is overlain by the Aggie Brown Member (AB, figs. 11 and 12), a black to dark gray or dark brown paleosol. The Aggie Brown Member ranges in thickness from 0.3 to 5 feet (0.1 to 1.5 m). Clayton and others (1976) further divided the Aggie Brown Member into two submembers. The upper submember of the Aggie Brown Member is the darkest colored horizon within the Oahe

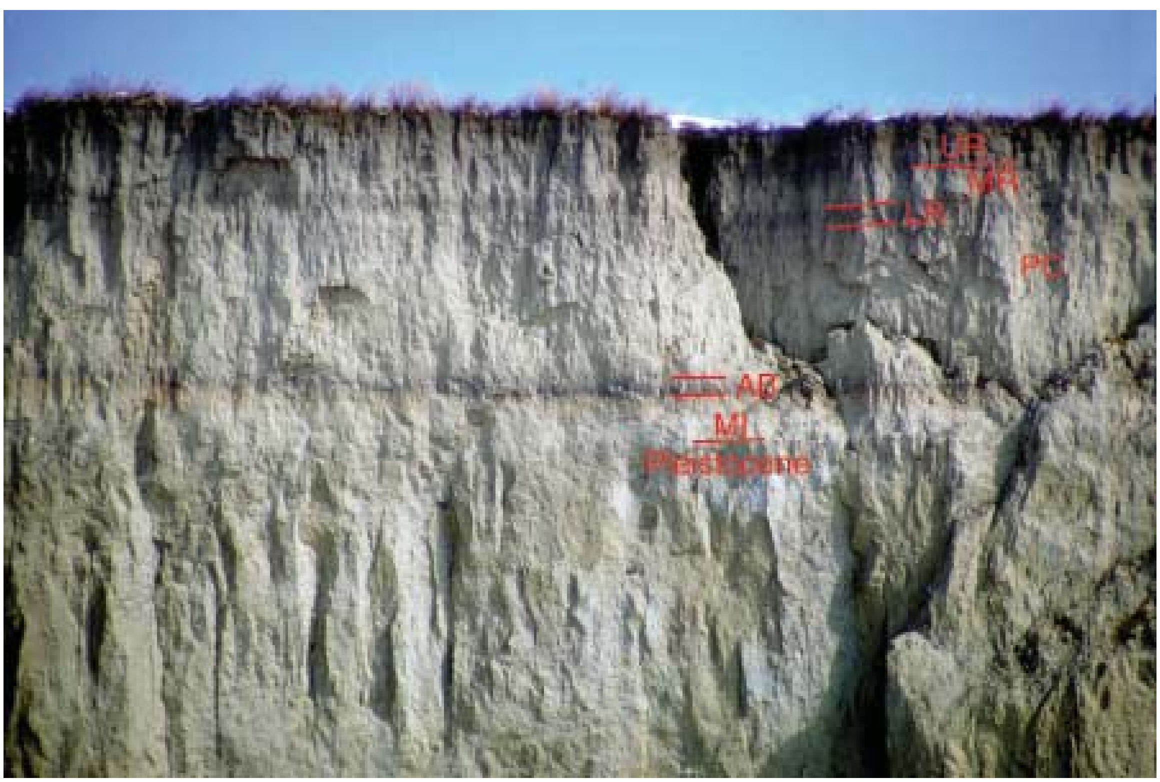

Figure 11. Type section of the Oahe Formation in the center of section 22, T.147N., R.84W., near the town of Riverdale in McLean County. Photo courtesy of Lee Clayton, circa 1975.

Figure 12. A recently excavated face of the Oahe Formation. John Cherry (University of Waterloo) for scale. The Aggie Brown Member is the prominent paleosol just above John's arm and the upper Riverdale Member is the organic-rich layer at the top of the cut. Photo courtesy of Lee Clayton, circa 1975.

Formation and was termed the Leonard Paleosol following Bickley's (1972) initial recommendation. Clayton and others (1980) interpreted the lower submember of the Aggie Brown Member to be a fossil forest soil and the Leonard Paleosol to be a fossil prairie soil. Clayton and others (1976) arbitrarily placed the Wisconsinan\Holocene boundary at the base of the Leonard Paleosol.

The Pick City Member (PC, figs. 11 and 12) is typically light gray to light grayish brown in color and is approximately 3 feet (1 m) thick (Clayton et al., 1976). The Pick City Member was likely deposited between 8,500 and 5,000 years BP and is bounded by paleosols (Clayton et al., 1980).

The Riverdale Member is about 3 feet (1 m) thick and ranges in color from light brownish gray to dark grayish brown (Clayton et al., 1976). The member has been divided into three submembers, the middle submember (MR, figs. 11 and 12) is a light brownish gray and the upper (UR) and lower (LR) submembers are darker colored. The lower or basal submember is a paleosol and was termed the Thompson Paleosol by Bickley (1972). The Riverdale Member was deposited in Late Holocene time, sometime after 5,000 BP (Clayton et al., 1980).

Clayton and others (1980) noted that, in general, the contacts between the Coleharbor Group, Mallard Island Member, Aggie Brown Member, and Pick City Member become older from the northeast to the southwest in North Dakota. Conversely, the contact between the Pick City and Riverdale Members generally becomes younger from the northeast to the southwest (fig. 13).

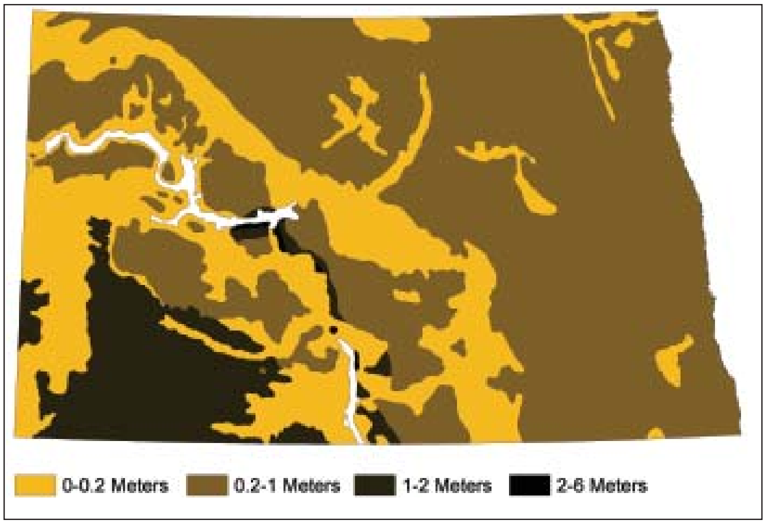

Figure 13. Thickness of the Oahe Formation in North Dakota (from Clayton and others, 1976).

Postglacial History of the Stanton Area

Jon Reiten
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Climatic variations since the last Late Wisconsinan glacier retreated appear to have been a major factor controlling alluvial and eolian deposition. Figures 1(a-d) and 2 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 B.P., after the retreat of the last glacier (fig. 1a). The postglacial climate was cooler and moister than the present climate in central North Dakota (Moran and others 1978, p. 153). A spruce woodland migrated into this area (McAndrews 1967; Moir 1958; Bickley 1972; and Okland 1978) and the paleosol of the Aggie Brown Member of the Oahe Formation began to develop. This forest soil continued forming until about 10,000 B.P., 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 B.P. 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 B.P. to 8,500 B.P., but little physical evidence supports this conclusion.

The Middle Holocene unstable episode began about 8,500 B.P. (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 (fig. 2). 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 4,500 B.P. At this time the Knife River had aggraded to a position above the present river level (fig. 1b).

From about 4,500 B.P. 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).

d. 2,500 B.P. to 500 B.P. Valley filling, occasional periods of deposition on floodplains and minor episodes of soil development. Middle Riverdale Member (**MR**) of the Oahe Formation deposited. Warm and dry climate.

c. 4,500 B.P. to 2,500 B.P. 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 (**LR**) of the Oahe Formation deposited. Sand dunes stabilized. Cool and moist climate.

b. 8,500 B.P. to 4,500 B.P. Valley filling. Pick City Member (**PC**) of the Oahe Formation deposited, active eolian sand dunes. Warm and dry climate.

a. 13,000 B.P. to 8,500 B.P. Incision of the Stanton Terrace. Development of the Leonard Paleosol in the Aggie Brown Member (**AB**) of the Oahe Formation. Cool and moist climate.

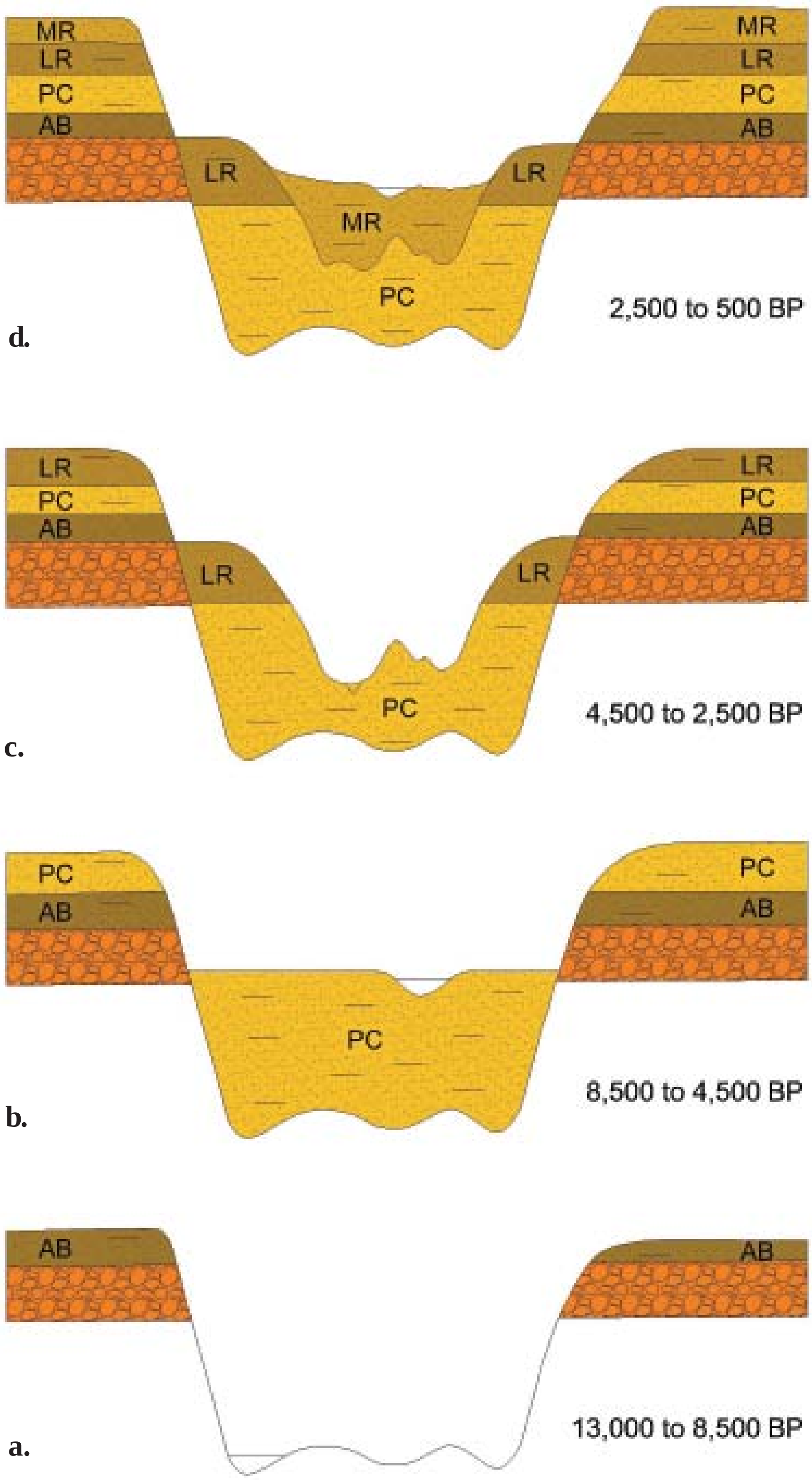

Figure 1. These are idealized cross-sections illustrating the postglacial history of deposition and erosion in the lower Knife River Valley. The lower, unnamed unit was deposited prior to 13,000 B.P. The profiles are approximately 15 to 20 meters thick and 100 to 200 meters wide.

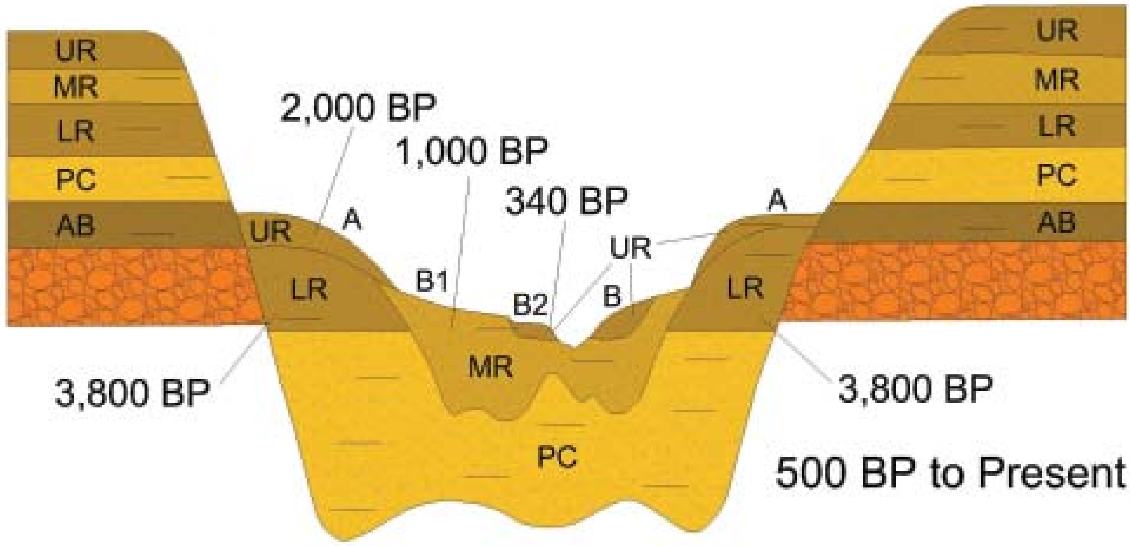

Figure 2. **500 B.P. to present.** Alternating periods of valley filling and incision. Upper Riverdale Member (**UR**) of the Oahe Formation deposited. Several episodes of soil development (Jules Paleosol). Minor climatic fluctuations ranging from cool and moist to warm and dry. Capital letters on cross-section refers to the named Holocene Terraces. A = A terrace, B1 = B1 terrace, B2 = B2 terrace, B = B1 and B2 terraces undifferentiated.

About 4,500 B.P. 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. 1c). Fine-grained overbank deposits of the upper part of the A terrace fill accumulated on the old floodplain (fig. 2). 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 in the A and the B1 terrace fill indicate that incision, which is associated with cool moist climates, occurred between about 2,974 ± 66 B.P. and 1,132 + 87 B.P. A major global climatic transition was determined to have occurred about 2,500 B.P. (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 2,500 B.P. (fig. 2).

With the change to warm, dry conditions, vegetation density decreased causing a decline in soil formation and hill slope stability. Eolian activity increased, sediment load of the Knife and Missouri Rivers increased, and the fill of the B1 terrace began to accumulate. The erosional surface between the B1 and B2 terrace fills developed between about 1,132 ± 387 B.P. and 27 ± 50 B.P. (fig. 2). The latter date 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 B.P. (Fischer 1980, p. 38). The similarity of these dates suggests the Jules Stable Episode began about 325 BP to shortly before 340 B.P. 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 (figs. 1d, 2). The B2 surface developed and is forming today as the rivers continue to meander, reworking older alluvial fill and depositing new alluvium.

The archaeology of the Knife River Indian Villages National Historic Site was investigated by the University of North Dakota Anthropology Department during the late 1970s and early 1980s. The age of the near surface sediment and depositional history of Quaternary sediments are useful to archaeologists involved in locating and interpreting the cultural resources of this area.

There are eight river terraces within a 300 square kilometer 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 elevations above river level of the Pleistocene terraces are listed: Riverdale Terrace (67 to 90 meters), Sakakawea Terrace (51 to 61 meters), and Stanton Terrace (8 to 15 meters). There are three Holocene terraces (fig. 2): A terrace (6 to 8 meters), B1 terrace (4 to 6 meters), and B2 terrace (0 to 5 meters). 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 B.P. to the present.

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Geologic and Geochronologic Interpretations and their Impact on the Preservation of Cultural Features

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Archaeologists studying the history of man in the Knife River Indian Villages (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 a previous article. 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 figure 1 appears to link Big Hidatsa village with former Missouri River channels. These trails are located in the north-central part of figure 1. 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 probable 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 figure 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.

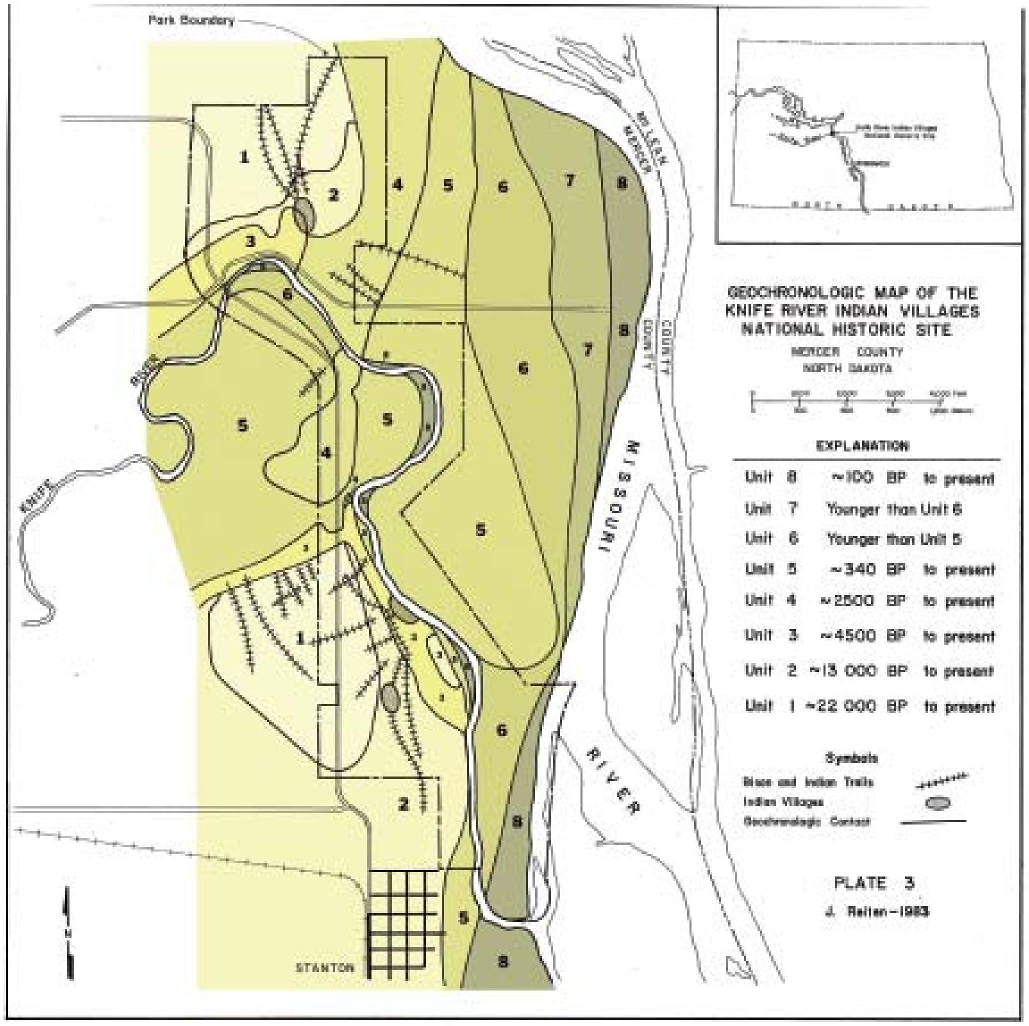

Figure 1. A geochronologic map of the Knife River Indian Villages National Historic Site area. This map is divided into eight geochronologic units. These units are differentiated by the estimated age of the near surface sediments based on geomorphic, radiometric, and sedimentologic evidence. **Unit One** 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 B.P. 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 B.P. to the present. **Unit Three** contains alluvial and eolian deposits of the Oahe Formation ranging in age from about 4,500 B.P. 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 3,000 to 3,900 B.P. **Unit Four** refers to alluvial and eolian sediment making up the B1 terrace. The age of this unit ranges from 2,500 B.P. to the 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 B.P. 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. Unit Six is somewhat younger than Unit Five because the general trend of point bar development is to the east. 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.

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 meter 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.

Small-Format Aerial Photography for Archaeologic Applications: Knife River Indian Villages NHS

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Small-format aerial photography

Small-format aerial photography (SFAP) is based on 35- and 70-mm film cameras or compact digital and video cameras to acquire airphotos from manned or unmanned platforms (Warner, Graham and Read 1996). Such airphotos, taken from low height, have large-scale and high-spatial-resolution that depict ground features in surprising detail (Light 2001). SFAP has become employed widely in recent years for documenting all manner of natural and human resources (Bauer et al. 1997).

Many types of unmanned lifting platforms may be utilized, such as model airplane (Quilter and Anderson 2000), balloon (Miyamoto et al. 2004), and hot-air blimp (Marzolff and Ries 1997). With assistance of several colleagues, I have developed unmanned SFAP techniques based on kites (Aber et al. 1999) and a small helium blimp (Aber 2004) for lifting various types of film and digital cameras. Initially we used 35-mm film cameras for both natural-color and color-infrared photographs (Aber, Aber, and Leffler 2001). Beginning in 2001, we started using compact digital cameras along with film cameras, and since 2005 have employed only high-resolution digital cameras for our work (fig. 1).

Photographs are taken using radio-controlled camera rigs from heights of 30-150 m (fig. 2). The camera may be tilted (vertical to horizontal) and rotated (360°) in order to provide all possible viewing angles in relation to the ground target. Single, vertical photographs typically have ground resolution of 2-10 cm (linear pixel size) and cover ground areas up to one hectare, which is suitable for detailed mapping and analysis of archaeologic sites in the scale range, 1:100 to 1:1000.

Figure 1. *Canon Digital Rebel* camera rig for kite or blimp aerial photography. The six-megapixel SLR camera is radio-controlled from the ground. It can pan (0-360°) and tilt (0-90°) to provide views in all orientations relative to the study site. The camera shutter is activated via a remote plug-in interface (*). Camera rig built by Brooks Leffler; taken from Aber et al. (2006, fig. 3).

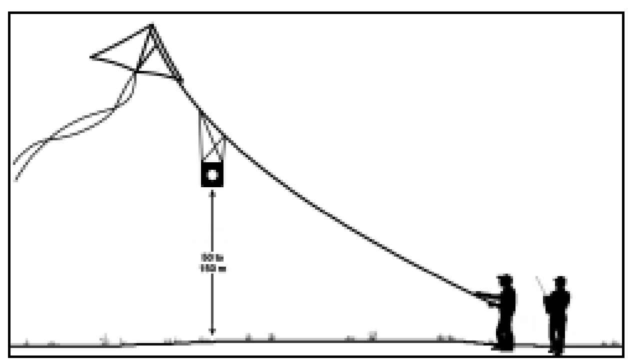

Figure 2. Cartoon showing the basic setup for kite aerial photography. The camera rig is attached to the kite line, and a radio transmitter on the ground controls operation of the camera rig. Not to scale. Adapted from Aber, Zupancic and Aber (2003, fig. 1).

Unmanned kite and blimp aerial photography has several advantages compared with conventional manned airphotos. These include relatively low cost of equipment and operation, rapid deployment and ease of field logistics, and no need for a trained pilot. The most important advantages have to do with height range and viewing angles. In the United States, conventional manned aircraft are normally restricted to airspace at least 500 feet (150 m) above the ground or 1000 feet (300 m) in urban areas. Unmanned, tethered platforms (kite, balloon or blimp), conversely, are limited to less than 500 feet height without filing a flight plan with the nearest airport. In other words, kite and blimp aerial photography exploits a height range that is difficult, if not impossible, to reach by other means. This leads, in turn, to large-scale and high-resolution imagery.

Standard aerial photographs are acquired in nadir (vertical) views in sequences that provide for stereoscopic viewing of overlapping pairs. Such airphotos are invaluable for general survey mapping and archaeologic applications (e.g. Avery and Berlin 1992). However, the fixed nadir view is a rather limited means for visualizing the landscape. Our approach allows for all possible viewing angles in relation to the ground target – vertical, low oblique and high oblique (fig. 3). Furthermore, flexibility of camera position means that oblique images may be acquired in various look directions relative to the sun and ground shadows. This leads to special lighting conditions at certain positions, such as sun glint from water bodies and the hot spot (fig. 4). The overall result is that more visual information is collected through a combination of vertical and oblique views, which could lead to recognition of subtle archaeologic features on the ground.

Figure 3. Viewing angles for small-format aerial photography with examples from Knife River Indian Villages NHS. (A) high-oblique view, tilted with the horizon visible. Northern portion of Big Hidatsa Village in lower portion of view. (B) low-oblique view, tilted with the horizon not visible. Knife River to left; mowed portion of Awatixa Village site to right. (C) vertical (nadir) view looking straight down. Note shadows of two people standing on the path in lower left part of scene. Small trees and brush to left of path; mowed portion of Awatixa Village site to right.

Figure 4. Hot spot is the bright patch just below scene center. It appears at the antisolar point, the position on the ground in direct alignment with the camera and sun. Because no shadows are visible here, the spot appears overexposed. Northern portion of Big Hidatsa Village.

Knife River Indian Villages NHS

Knife River Indian Villages National Historical Site (NHS) is located adjacent to the Knife River close to its junction with the Missouri River in central North Dakota. These Hidatsa and nearby Mandan villages were settled beginning around A.D. 1300. Five hundred years later, they figured prominently with the Corps of Discovery, which spent the winter of 1804-05 close by at Fort Mandan. Sakakawea (Sacagawea) and her husband Toussaint Charbonneau came from the Awatixa Hidatsa village. The presence of Sakakawea and her son with the Corps proved crucial for peaceful reception during the subsequent journey westward, as no Indian war party traveled with women and children.

At the time of Lewis and Clark's visit, the Mandan and Hidatsa villages were the focus of a trading network that encompassed a vast region between the Great Lakes and the northern Rocky Mountains. Rich bottomland soil sustained agriculture (corn, beans, squash and sunflowers), and the adjacent uplands teemed with buffalo herds. Hidatsa and Mandan traded their agricultural produce along with Knife River Flint, which was collected from local gravel deposits. This flint was highly prized for making stone tools across North America.

During the winter, the Mandans and Hidatsas lived in shelters within the wooded terrain on the floodplains of the Knife and Missouri valleys. When summer came, however, they moved into substantial earth lodges on the adjacent, higher terrace (fig. 5). Here, they escaped the dangers of floods and mosquitoes, and were exposed to cooling breezes. Remains of these earth lodge locations are well preserved at the Knife River Indian Villages NHS.

Kite aerial photographs

Kite aerial photographs, taken in October 2003, clearly depict remnants of earth lodges, which are revealed by shadows and distinctive vegetation. The remains of hundreds of earth lodges are preserved as circular depressions, each about 30 to 40 feet (~9 to 12 m) in diameter (fig. 6). The positions of the earth lodges are still quite distinct, in spite of several decades of agricultural land use during the late 19th and early 20th centuries.

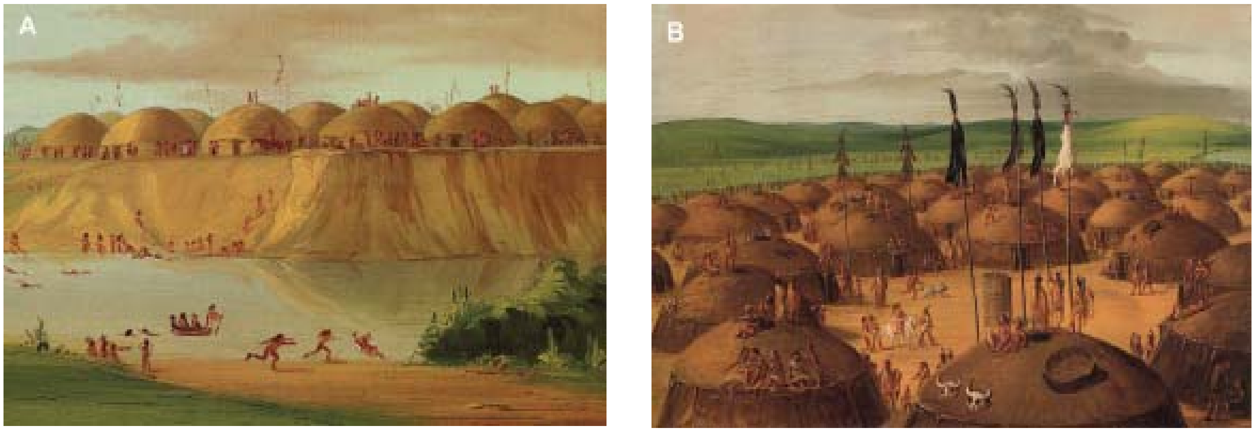

Figure 5. Portions of two oil paintings of the Mandan village by George Catlin. (A) view from across the Knife River showing position of the village on a terrace (1832). (B) Overview of village center depicting the arrangement of earth lodges around a central plaza (1837-39). Adapted from Dippie et al. (2002).

Figure 6. Southward view over the Big Hidatsa Village site showing several dozen earth-lodge remains in the mowed portion. Kite flyers are standing in upper right corner of the scene. Note: some people see raised bumps instead of depressions; this is a common optical illusion.

Slight depressions mark the former interior floors of lodges, which were built at ground level (not dug out). Surrounding each depression is a subtle raised rim composed of material that fell off the lodge wall and roof. Some portions of the site are mowed, so the lodge remains can be seen easily on the ground (fig. 7). Other portions are covered by prairie grass, shrubs and woods. Earth lodges in these unmowed portions are not obvious from the ground, but are quite evident from above because of circular patterns in vegetation cover (fig. 8).

The success of kite aerial photography for revealing archaeologic remains at this site was enhanced by seasonal conditions. In early October, vegetation is in transition, as photosynthesis declines and deciduous leaves begin to display autumn color. This happens in stages during the fall, depending on plant types. Thus, vegetation is more distinct at this time than during any other season. Vegetation reflects variations in microtopography, soil type, soil moisture, and other factors that are, in turn, influenced by former human occupation of the site.

Another important seasonal factor is sun angle above the horizon and resulting shadows on the ground. Shadows are important visual clues, particularly for interpreting vertical airphotos. In this case, shadows help to define the circular rim-and-depression features (fig. 7). When the sun is high in the sky,

Figure 7. Vertical shot of earth-lodge remains at Awatixa Village. Circles are about 9-10 meters across and mark the floors of former lodges. A distinctive mowing pattern crosses the lodge remains, and small white patches are animal burrows (gophers and squirrels). Erosion by the Knife River (lower right) has removed part of this village site.

Figure 8. View southward from the Awatixa Village site. Mowed portions in left foreground (Awatixa Village) and center background (site headquarters). The intervening unmowed prairie displays circular vegetation patterns that indicate many dozens of earth-lodge remains. Kite line cuts across the scene center.

shadows are minimized; conversely, low sun produces too much shadowing on the ground. Given the latitude of North Dakota, mid-day in early autumn provides optimum sun angle and shadowing for this situation.

On the basis of our preliminary imagery and interpretation, it appears that the entire terrace surface at Knife River Indian Villages NHS is covered by earth-lodge remains. This includes both the mowed portions as well as intervening unmowed tracts of the site. The total number of earth lodges is unknown, but must be at least several hundred. This saturation coverage of earth lodges may represent the cumulative effects of villages that shifted or migrated in location during several centuries of site occupation. This suggests that historical observations of village settlements in the late 18th and early 19th centuries represent only a temporal slice of overall, long-term site utilization by prehistoric inhabitants.

Acknowledgements

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STOP 2: DUNE FIELD WEST OF STANTON
Mile: 65.3 (1.9)

Stabilized sand dunes occupy an area of approximately six square miles (15.5 square km) and overlie terrace deposits south and west of the confluence of the Knife and Missouri Rivers (figs. 14 and 15). The crests of the dunes are 15 to 30 feet (4.6 to 9.1 m) high and extend for upwards of one half mile (0.8 km). The dunes formed during dry periods over the last five hundred years (Reiten, 1983). The longitudinal dunes are oriented northwest to southeast, paralleling today's prevailing wind direction. The source of the sand and silt are the adjacent terrace deposits of the Knife River. The dunes are underlain by 150 to 250 feet (46-76 m) of channel fill deposits which consist primarily of Pleistocene sand, gravel, and till.

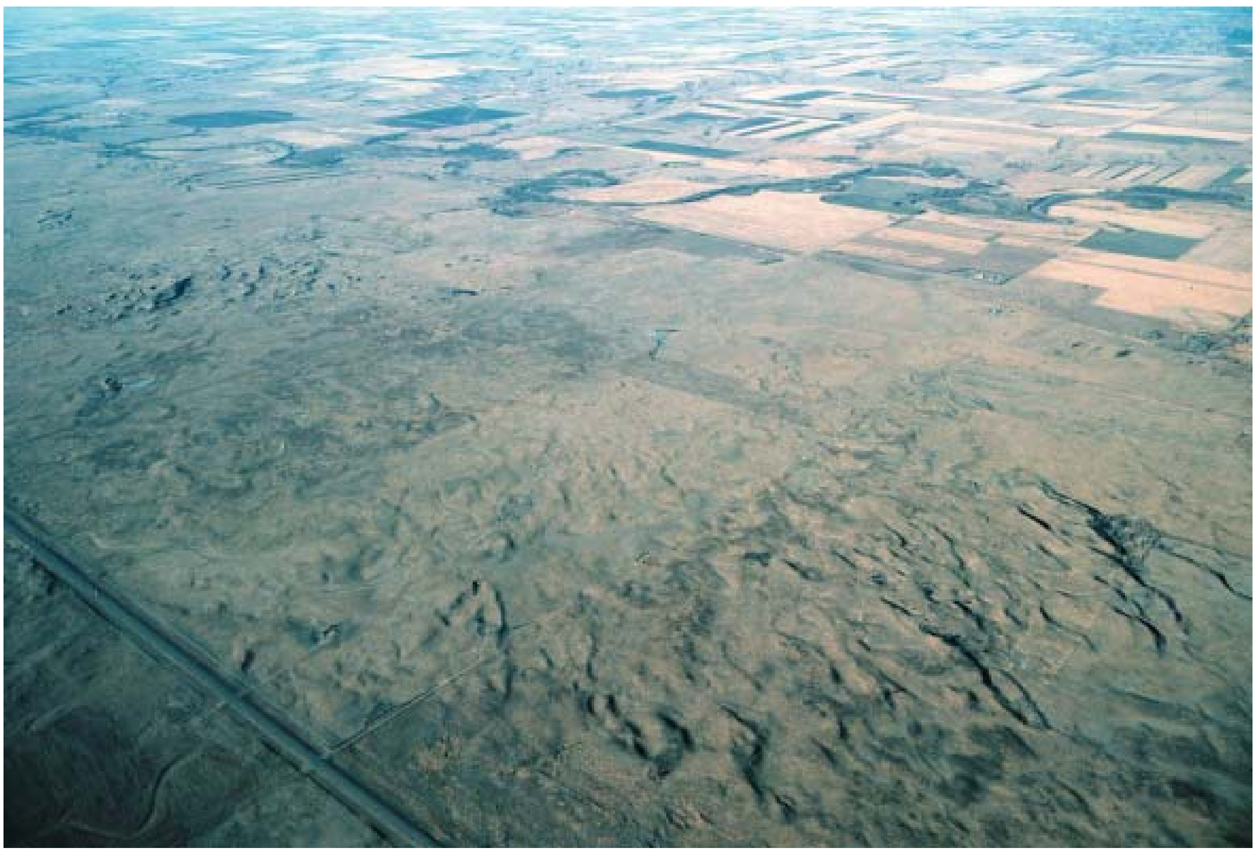


Figure 14. Stabilized dune field extending for approximately six square miles (15.5 square km) along the Knife River Valley west of Stanton. View to the northwest.

Turn right (north) on ND Highway 200N at mile 68.3. (3.0)
Turn left (west) on ND Highway 1806 at mile 80.5. (12.2)
Turn right (north) on gravel road into Beulah Bay at mile 92.6. (12.1)

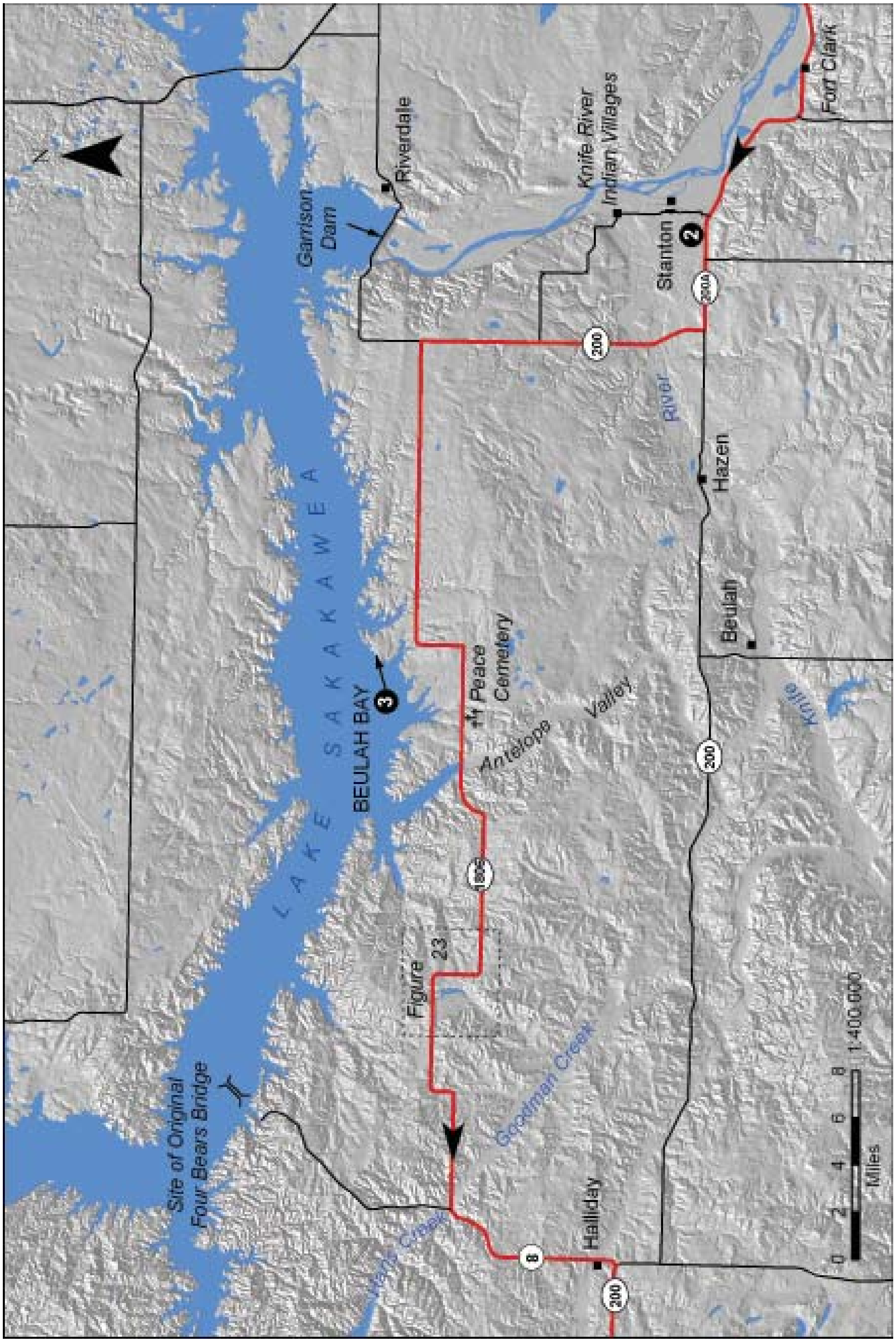


Figure 15. The fieldtrip route (in red) for day one from Fort Clark to Halliday.

STOP 3: BEULAH BAY
Mile: 95.5 (2.9)

The Corps of Discovery arrived in the Beulah Bay area on April 10, 1805. Meriwether Lewis observed a seam of coal burning along the face of an outcrop and commented *"the bluff is now on fire and throws out considerable quantities of smoke which has a strong sulphurious smell"* (Moulton, 1987b).

Construction was completed on Garrison Dam in 1954. Lake Sakakawea, the reservoir of Garrison Dam, extends over an area of approximately 180 miles (290 km) almost reaching the Montana border. The shoreline of the lake extends for approximately 1,300 miles (2,092 km), one of the largest man made lakes in the United States. The lake is four miles (6.4 km) wide in the Beulah Bay area. The normal pool height for the reservoir is 1850 feet (564 m), the lake is projected to be at an elevation of 1815 feet (553 m) in June, 2006.

Fifty years of wave erosion has, in places, created 100-foot (30 m) high vertical cliffs along the shores of the reservoir (figs. 16a and 16b). These cliffs offer a unique opportunity to examine the relationships between Paleocene, Pleistocene, and Holocene deposits. The cliffs along Beulah Bay are an excellent place to view Holocene and Pleistocene sediments and to trace the contacts of these deposits and the exposed lithologies through an area of nearly continuous exposures.

Several studies of the Quaternary deposits have been conducted on the exposures surrounding Lake Sakakawea since Bluemle (1971) first noted the thick silt deposits. These include investigations by Bickley (1972), Sackreiter (1973), Ulmer (1973), Ulmer and Sackreiter (1973), Kornbrath (1975), Clayton et al. (1976), Reiten (1983), Hartman et al. (1998), and Beck (1998). A number of bank erosion studies have also generated information on the stratigraphy of these bluffs: Reid and Millsop (1984), Millsop (1985), Reid et al. (1986), Sandberg (1986), and Elliot (1991). In addition, several archaeological investigations have also been conducted within the Holocene deposits exposed around the perimeter of Lake Sakakawea.

Seven geologic sections were measured across a linear distance of approximately 2000 yards (1830 m) to illustrate lithologic variations in Quaternary deposits in the Beulah Bay area (fig. 16b). The Paleocene or bedrock stratigraphy in the Beulah Bay area consists of alternating beds of sandstone, siltstone, claystone, mudstone, clinker, and lignite of the Sentinel Butte Formation. This strata is well exposed in the lower portions of the cliff faces. On average, the Sentinel Butte Formation contains about 60-70% mudstone and claystone, 20-30% sandstone, and 5-10% lignite. Two, three-foot-thick lignites can be traced through parts of this area. All four of the mines currently operating in North Dakota (excluding the two leonardite mines) are mining lignite from the Sentinel Butte Formation. In addition, the Beulah Bay area is noted for the abundance of large and well preserved petrified wood specimens weathering out of the Sentinel Butte Formation.

The lithologies and thickness of the Coleharbor Group (Pleistocene\Holocene) is variable in Beulah Bay. These deposits are 5 to 30 feet (1.5-9 m) thick in this area and consist of till, gravel, and leonardite (figures 17 and 18). Till was the dominant lithology of the Coleharbor Group in measured sections 1-3, 6, and 7, but is absent in sections 4 and 5. Gravel is 1-3 feet (0.3-0.9 m) thick in sections 4-7, but is absent in sections 1-3. The gravel in measured section 5 contains lenses and pebbles of lignite and leonardite. Leonardite is oxidized or weathered lignite which has a high content of humate or humic acid. It is often powdery and greasy to the touch. Leonardite is present as a thin layer above an existing coal bed in measured sections 3-5 (fig. 17). In Beulah Bay, the upper portion of the coal was exposed prior to, or during, the Pleistocene and weathered to leonardite. Gravel overlying the coal in section 5 incorporated pieces of the underlying leonardite and lignite. Clayton and others (1976) observed that a layer of lag gravel commonly underlies the Oahe Formation. While the gravel in this area may typically be of a lag origin, the pebbles in sections 5 and 6 appear to be oriented suggesting fluvial deposition.

Figure 16. a) Oblique aerial photograph of Beulah Bay looking east. b) Oblique aerial photograph of Beulah Bay looking east. The locations of measured sections 1-7 are plotted on the photo. Photograph obtained in the fall of 2002 when the level of Lake Sakakawea was approximately 1820 feet (555 m) above sea level.

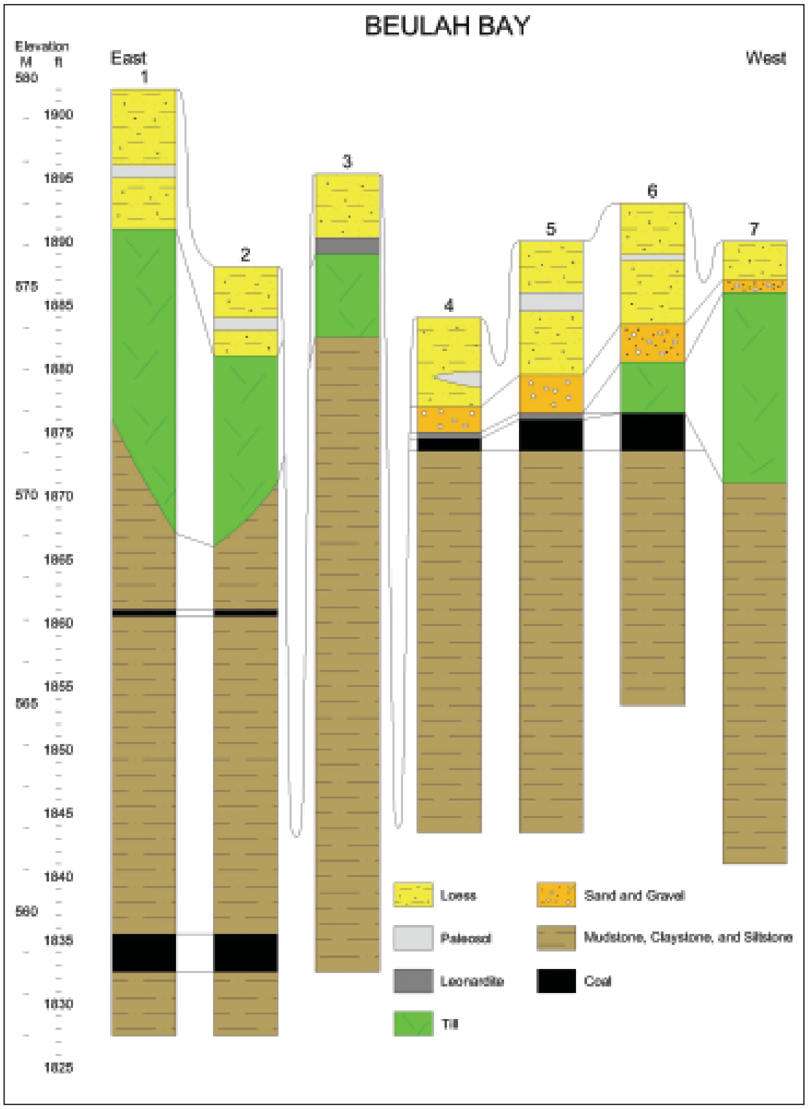


Figure 17. Lithologic columns of seven measured sections at Beulah Bay.

The Oahe Formation is defined primarily as unlithified silt (Clayton et al., 1976). Loess of the Oahe Formation is up to ten feet (3 m) thick in the Beulah Bay area. Because the loess is exposed at the top of vertical cliff faces, it is difficult, and often impossible, to closely examine it without using climbing gear or a ladder. A well-developed paleosol is present within the loess about five feet (1.5 m) from the top of the exposures in all but one of the measured sections. The stratigraphic sections presented here were measured along north-facing cliff faces at Beulah Bay during an overcast day in late November of 2005. Under these low-light conditions, the colors of the Oahe Formation blended together and the only distinguishable member was the Aggie Brown (a moderately to weakly developed paleosol) that occurred near the midpoint of the unit. However, when the digital photographs were enhanced (brightened) the color differences between the four members became readily apparent (fig. 18). As previously noted in the chapter on the area around the Knife River Indian Village Site, the Oahe Formation has been subdivided into four members (Clayton et al., 1976).

The Mallard Island Member, the basal member of the Oahe Formation, is light yellowish brown in this area and typically is about three feet (1 m) thick. It is the thickest of the four members at this site. The Aggie Brown Member is about one foot (0.3 m) thick. It was generally difficult to subdivide the Aggie Brown Member in this area. The Pick City Member is approximately 1.5 feet (0.5 m) thick and is somewhat difficult to discern from the overlying Riverdale Member which is about three feet (1 m) thick. The Thompson paleosol at the base of the Riverdale Member is also not very distinct in these outcrops (fig. 18).

At measured section 3, leonardite is present between the loess (Oahe Formation) and the underlying till (Coleharbor Group). The leonardite was placed within the Oahe Formation at this locality because it appears to be incorporated into the bottom of the loess. The source of the coal for the leonardite at this section is unknown.

Beulah Bay is a great place to study wave erosion. Waves have undercut the banks and created steep cliff faces during periods of high water. Wave action has also eroded coal beds and deposited chunks of lignite on the beaches (fig. 19). In addition, waves have removed the poorly cemented mudstones and sandstones leaving behind concretions. This has resulted in an excellent opportunity to study the size and distribution of concretions in three dimensions (fig. 20).

Return on gravel road to the intersection with ND Highway 1806 and turn right (west) at mile 98.8. (3.3)

Turn right (west) and proceed along ND Highway 1806 at mile 101.8. (3.0)

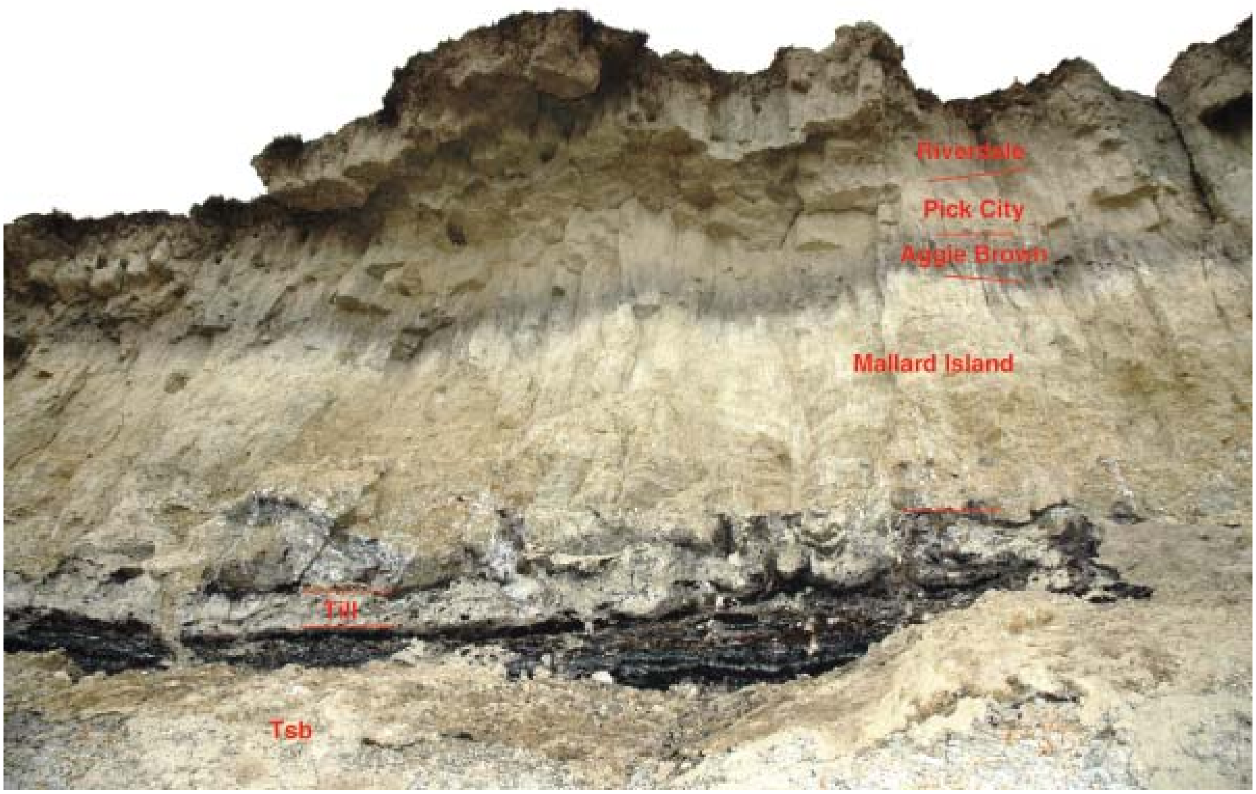


Figure 18. Measured section 4 at Beulah Bay. Four members of the Oahe Formation (Mallard Island, Aggie Brown, Pick City, and Riverdale) are exposed in the upper portions of the vertical cliff faces in Beulah Bay. This exposure is 17 feet (5.2 m) thick

Figure 19. Chunks of lignite have washed up on “Black Beach” at Beulah Bay. Most of the chunks in this photograph are six to eight inches (15 to 20 cm) thick. Petrified wood and concretions are also mixed in with this deposit.

Figure 20. Wave erosion has winnowed the less resistant rock leaving behind concretions along a beach in Beulah Bay.

Freedom Mine, Renner Trench, and Antelope Valley
Mile: 103.8 (2.0)

About 15 million tons of lignite, half of North Dakota’s total annual production, is mined at the Freedom Mine on a yearly basis. About half of that coal is consumed in the Antelope Creek power plant, the other half goes to the adjacent Dakota Gasification Company’s (DGC) Great Plains Synfuel Plant. The DGC plant is the only one of its kind in North America converting coal to natural gas using the Lurgi gasification process. The plant derives much if its income from the sales of byproducts such as phenols, carbolic acid, carbon dioxide, etc. The coal that is mined in this area, the Beulah-Zap bed, is about 18 feet (5.5 m) thick. The glacial meltwater that carved the Antelope Valley and Renner Trench removed approximately 600 million tons of mineable lignite (fig. 21). As a result, the Coteau Properties Company lost about 40 years of mining reserves in this area.

In 2004, North Dakota mined approximately 30 million tons of lignite. This placed us behind ten other states in coal production. While we are relatively close to five of these states (they produce less than 40 million tons), we were not close to Wyoming which led all states by mining approximately 400 million tons of subituminous coal.

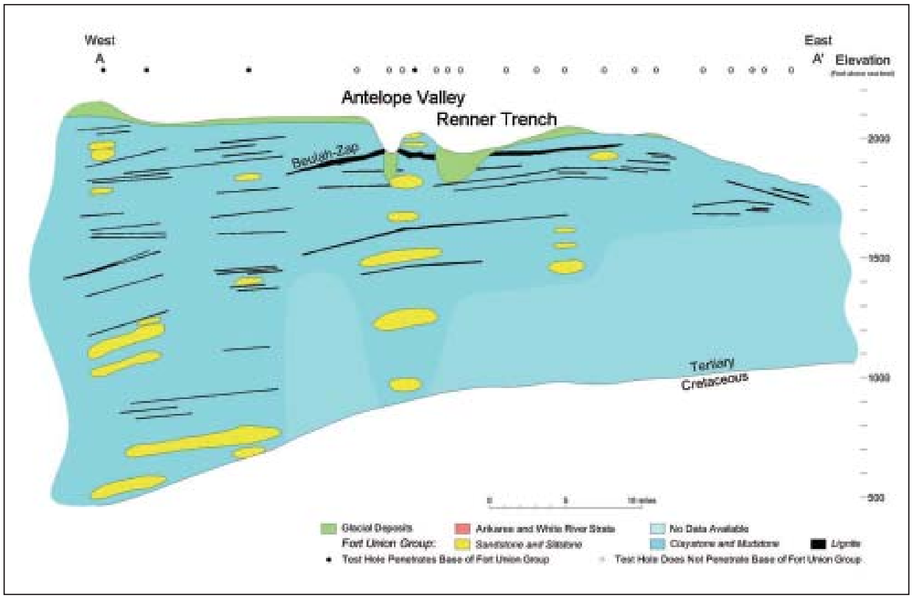


Figure 21. Glacial outwash carved two channels in this area, Antelope Valley and Renner Trench. Both channels contain more than 100 feet (30 m) of channel fill sediments; primarily till and sand and gravel. The Renner Trench was subsequently overridden by a glacial advance and has little surface expression, but there is about 100 feet (30 m) of relief along the walls of Antelope Valley.

Peace Cemetery
Mile: 104.9 (1.1)

Although there are no iron crosses in the Peace Cemetery (fig. 22), they are present in cemeteries in North Dakota, especially in Emmons, Logan and McIntosh counties. This folk art tradition migrated from Germany to the Russian Ukraine and eventually to the Great Plains of North Dakota and Canada. The iron crosses - some intricate, some simple, but no two quite the same - are found in cemeteries and in agricultural fields across the region. *"The Germans from Russia were a frugal people whose blacksmiths used wagon-wheel rims and scrap metal to fashion markers for the graves of the dead....Yet the crosses are a distinctive and beautiful art form - with unbroken hearts of metal, brightly painted stars, endless circles, banner-waving angels, exquisitely formed lilies, and rose blossoms that rust but never wilt."* (excerpt from a video documentary entitled Prairie Crosses, Prairie Voices: Iron Crosses of the Great Plains" written and narrated by T.J. Klobderdanz).

ND Highway 1806 Crosses Antelope Valley
Mile: 106.7 (1.8)

Figure 22. The Peace Cemetery northwest of Beulah is within the Freedom Mine. Mining has taken place around the cemetery, but it has been left intact.

Bison Rubbing Stone North of Highway
Mile: 112.5 (5.8)

Hummocky Topography
Mile: 116.4 (3.9) ND Highway 1806 curves to the north.

Hummocky topography is present on both sides of ND Highway 1806 in this area (fig. 23).

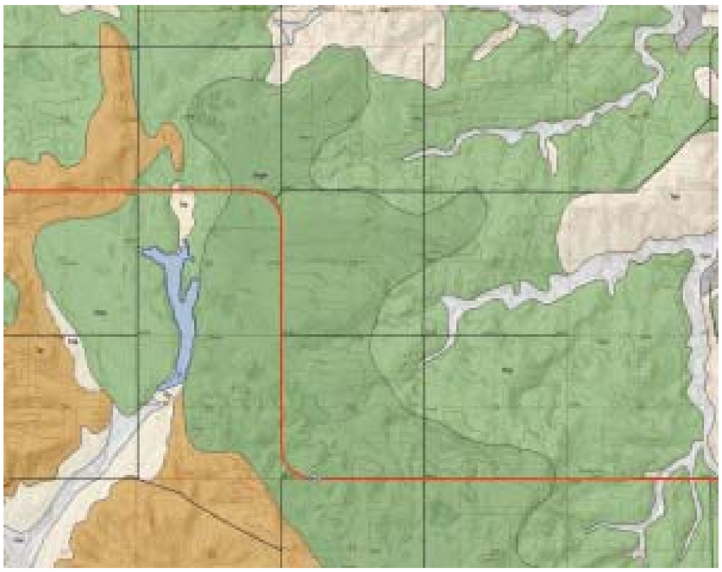


Figure 23. A portion of the geologic map of the Golden Valley NE quadrangle. Modified from Murphy (2003e).

Bear Den Member of Golden Valley Formation Exposed South of Highway
Mile: 122.5 (6.1)

The Paleocene\Eocene boundary is located between the two members of the Golden Valley Formation (Hickey, 1977). The Bear Den Member, the lower member of the Golden Valley Formation, consists of brightly colored (dazzling white, gold, and gray) kaolinitic claystones and mudstones. The upper member, the Camels Butte Member, is more somber colored and consists of alternating beds of sandstone, siltstone, claystone, mudstone, and lignite and is very similar in character and appearance to the underlying Sentinel Butte Formation. Although the Camels Butte Member is micaceous and typically has a brownish hue in contrast to the nonmicaceous nature and grayish hues of the Sentinel Butte Formation, it is often difficult to differentiate between these two units in areas of limited outcrop when the Bear Den Member is not exposed.

Goodman Creek
Mile: 124.6 (2.1)

ND Highway 1806 crosses the north-south trending valley of Goodman Creek. Three miles (4.8 km) to the south, Goodman Creek enters the valley once occupied by the Ancestral Little Missouri River and turns to the southeast.

Hans Creek
Mile: 126.4 (1.8)

ND Highway 1806 crosses the mouth of Hans Creek. Approximately one mile (1.6 km) to the south, Hans Creek enters the valley and turns to the northwest. A drainage divide occurs within the ancestral channel in this area, with one creek flowing southeast and the other northwest (figs. 15 and 24).

Figure 24. Oblique aerial photograph taken looking northwest along the channel now occupied by Hans Creek. Note in the background the ninety-degree bend in the Little Missouri River Valley now occupied by Lake Sakakawea and the change in intensity of the badland topography at dashed line.

Hans Creek (Meltwater Channel)
Mile: 129.0 (2.6)

The road bridge crosses the channel now occupied by Hans Creek in this area. This ancestral/ meltwater channel contains up to 200 feet (60 m) of Quaternary channel fill deposits.

Turn South on Highway 8 at mile 129.4. (0.4)
Turn Right (west) at Junction with Highway 200 at mile 137.6. (8.2)

Oil Field
Mile: 145.2 (7.6)

The pump jack to the south is bringing oil and gas to the surface from an oil well that was drilled in 1980 (fig. 25). Over a twenty-year-period, this well produced over 170,000 barrels of oil, 220,000 MCF of gas, and 530,000 barrels of salt water from the Red River Formation (Ordovician) at a depth of about 13,000 feet. In 2000, it was recompleted to a depth of 10,800 feet and has since produced 50,000 barrels of oil, 670 MCF of gas, and 72,000 barrels of salt water from the Duperow Formation (Devonian).

Oil was discovered in North Dakota in 1951. North Dakota produces approximately 32 million barrels of oil per year ranking it tenth in national production. Oil and gas production has so far been limited to the western half of the state. That is, most production occurs west of Bismarck and Minot.

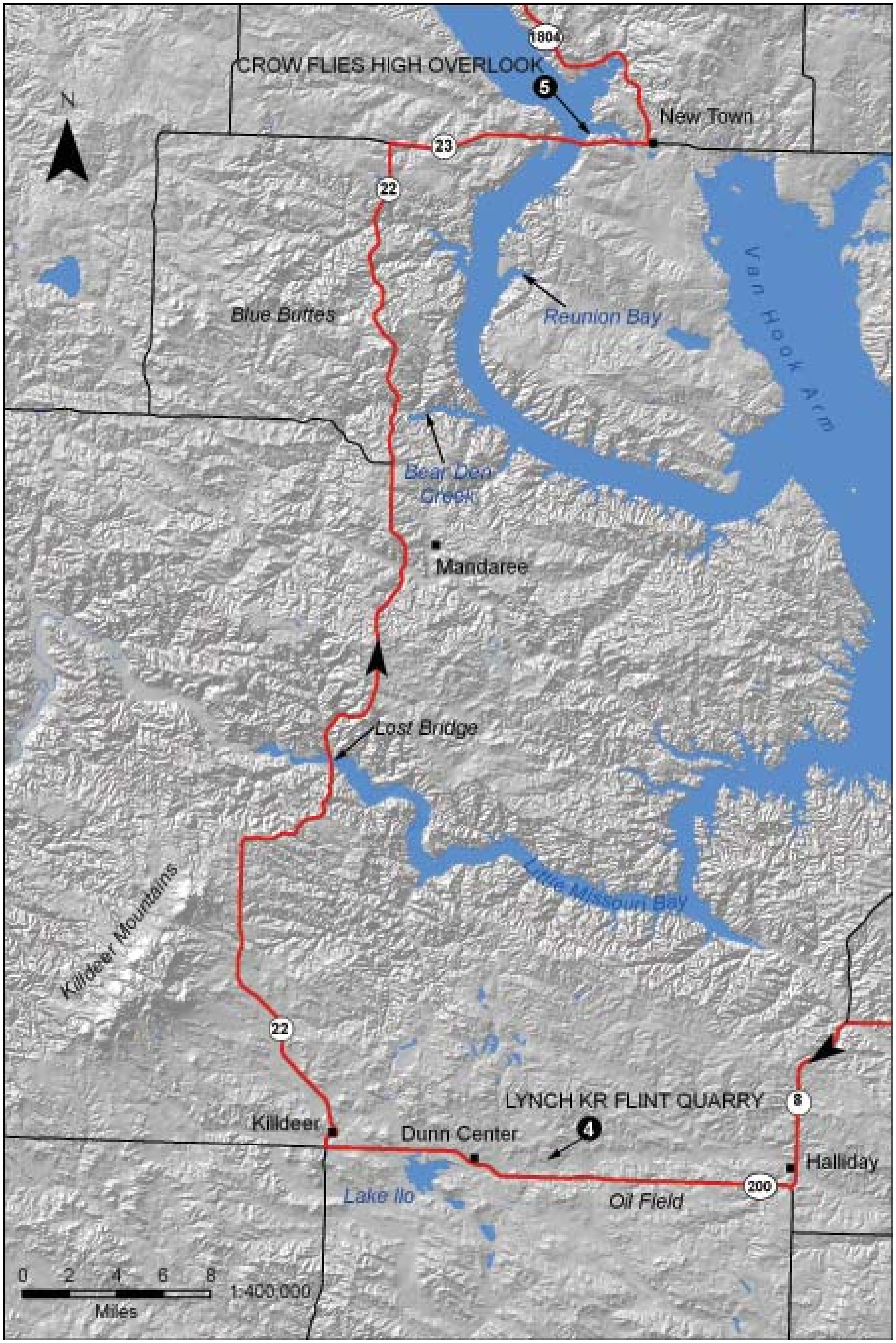


Figure 25. The fieldtrip route (in red) for day one from Halliday to New Town.

Glacial Erratics
Mile: 147.1 (1.9)

Clayton (1970) mapped the limit of glacial boulders in this area believed to be from pre-Wisconsinan and Early Wisconsinan glaciations (fig. 26). Clayton and others (1980) noted that at least two glacial advances took place in this area; the Dunn and Verone Glaciations. Post-depositional erosion has removed most of the till, often leaving only glacial boulders (erratics) at the surface (Murphy, 2001). The area covered by the Dunn Glaciation has only a few boulders per mile whereas the area of the Verone Glaciation has up to a hundred or more boulders per mile. Most of the roadlog up to this point has been within the Early Wisconsinan, Napoleon Glaciation. Lag boulders are even more abundant from the Napoleon Glaciation and till is widely preserved from this episode (Clayton et al., 1980). Clayton (1970) determined that the Dunn Glaciation was pre-Wisconsinan in age, the Verone either pre-Wisconsinan or Early Wisconsinan and the Napoleon Glaciation likely Early Wisconsinan, the latter occurring approximately 40,000 years ago.

As a result of erosion, till is generally preserved in this area only along drainage divides commonly in patches less than a few square miles in area. Till thicknesses are extremely variable in these deposits, but seldom are more than 30 feet (9 m) thick (Murphy, 2001).

Dunn Center Coal Bed
Mile: 148.0 (0.9)

The Dunn Center coal bed is exposed south of ND Highway 200 in this area. The Dunn Center coal reaches a maximum thickness of 24 feet (7 m) in this area (Murphy and Goven, 1998). There are over 900 million tons of mineable coal within the Dunn Center deposit (Murphy, 2004a). In the mid-1970s, the Gas Pipeline Company of America drilled approximately 1,800 holes in this area to determine the feasibility of establishing a coal gasification plant. Around this same time, Tenneco was evaluating the feasibility of a gasification plant at the town of Beach along the North Dakota/Montana border. Plans for both plants were abandoned when natural gas prices failed to rise to projected levels in the early 1980s.

STOP 4: THE LYNCH'S KNIFE RIVER FLINT QUARRIES
Mile: 148.8 (0.8)

Turn right (north) onto 95th Avenue at mile 148.8 and proceed one mile.

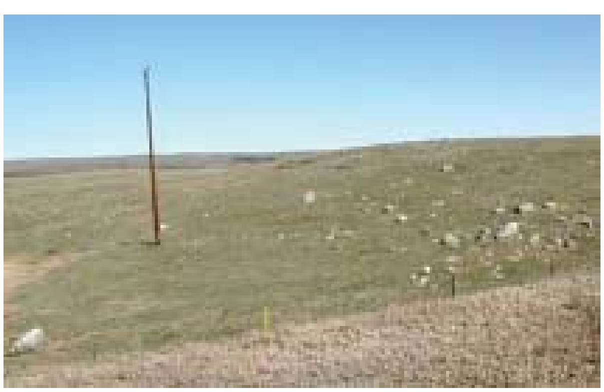


Figure 26. Glacial erratics in a field east of Dunn Center.

A Funny Story about how I Discovered Knife River Flint Quarries

Lee Clayton
Wisconsin Geological Survey, Madison, WI

During the summer of 1968, I was making a rough reconnaissance map of Dunn County geology. My 12-year-old brother Mik had asked what "field work" was, so I took him along one week (fig. 1). I tried to keep him entertained by working on interesting things, like old under-ground lignite mines. Before this, I had gone over the air photos and marked several places where the roofs of adits had failed, creating collapse pits---which are fairly common in this region. Another interesting thing was the pieces of flint littering the ground in some areas. A rain storm had made the dirt roads impassible in many places, which frustrated field work, so instead we went to look at the collapse pits. We couldn't get near the first place we tried because of the muddy road. When I was turning the car around Mik noticed flint chips in the road. Curiously, it was the same at the second place we tried and the same at the third. We thought we should look into this, so we left the car and walked to the pits. It was then pretty obvious that most of them were not collapse pits but had to be dug pits. I told him this illustrated a principle. If you notice some phenomenon only once, don't waste time on it; it's probably a fluke. Twice, keep an eye open; it could be significant. Three times, it's a trend and is probably worth looking into.

There were only a few acres of Knife River Flint quarries known before that. We added about 250 acres. Since then, archeologists have found quite a few more quarry sites and have done extensive excavating.

Figure 1. Pits within the Lynch Knife River Flint Quarry in Dunn County. Mik Clayton in the background. Photograph taken in the summer of 1968.

Knife River Flint and the Lynch Quarry

Ed Murphy
North Dakota Geological Survey, Bismarck, ND

Introduction

Knife River Flint was used extensively by Native Peoples for tools since Paleo-Indian time and is therefore of interest to archaeologists (fig. 1). Knife River Flint has only been found in secondary deposits and is therefore of interest to geologists. This flint has been found primarily within Pleistocene terraces in the valleys of Spring Creek and Knife River. Lee Clayton pointed out that the flint-bearing gravel is generally no more than several feet thick and occupies terraces cut back into the valley-side bedrock (personal communication, 4/4/06). Flint is also prevalent as lag occurring as isolated or multiple cobbles and boulders overlying strata of the Sentinel Butte Formation in the uplands of central and northern Dunn and Mercer Counties. Paleo-Indians dug numerous shallow pits into the these deposits to obtain this all important flint. In quarries such as the Lynch site, the location of the pits can often be used to define the extent of the deposit (fig. 2). For the last 10,000 and possibly 11,500 years, people came to the Knife River Flint quarries to obtain flint (Root et al., 1986). Artifacts made from Knife River Flint have been found in archaeological sites in the surrounding states and provinces dating from the Paleo-Indian, Woodland, and Plains Village Periods. These artifacts have also been found as far away as Alberta, Missouri, and Ohio (Clayton et al., 1970).

William Clark was first to provide written documentation on the presence of Knife River Flint in western North Dakota when he noted the presence of *"black flint"* at the mouth of the Little Missouri River in his journal entry of April 12, 1805. Will and Spinden (1906), while writing about Mandan culture, noted that Mandan knives were sometimes made from dark colored flints. Lehmer (1954) may well have been the first to use the term Knife River Flint in a published article. He did so while evaluating areas to be inundated by the proposed Oahe Reservoir in South Dakota. Wedel (1962) used the term "*Knife River Chalcedony*."

One of the earliest references to flint quarries in North Dakota is a letter dated February 19, 1930 from Russell Reid, Curator of the Museum and Acting Superintendent of the State Historical Society of

Figure1. Various examples of Knife River Flint. Note the well-developed patina on most of the specimens. The large specimen in the background is 3.5 x 10 inches (8.9 x 25 cm). The two specimens in the center-foreground are artifacts, possibly scrapers.

Figure 2. Aerial photograph of the Lynch Knife River Flint Quarry (numerous small depressions) located on the northern edge of the valley of Spring Creek The larger depressions along the western edge of the quarry site are underground mine collapse features or sinkholes. USDA photograph number CCP-4V-30, flown in 1958. Scale: 4.2 inches = 1 mile (6.4 cm = 1 km).

North Dakota (SHSND), to Charles Brown (Director of the Wisconsin State Historical Museum) that discusses *"Indian flint quarries on the Knife River, west of Stanton"* and notes that neither Reid nor George Will had yet "*had the opportunity to visit this locality. The only description that I have had of these quarries was given by Mr. Crawford when he visited this site last summer. As I understand it the flint obtained from this quarry is a very dark brown, almost black."*

In 1936, Lewis Crawford (SHSND) wrote that archaeologists had known for years that Native Peoples had obtained flint along the upper course of the Knife River, but it was not until the mid-1920s that a flint quarry had been identified in the area. Crawford described a newly discovered quarry about ten miles (16 km) north of the town of Dodge. This quarry covers approximately 10 acres (4 ha) and contains more than 200 pits. Crawford discovered other quarries overlooking the Knife River about 30 miles (48 km) east of Dodge. Crawford also noted that he was unaware of any oral history of either the Mandan or Sioux cultures concerning the utilization of these flint quarries.

In 1970, Clayton and others identified 24 previously unknown Knife River Flint quarries in Dunn County. Clayton relates the interesting story of how he and his younger brother discovered the first of these sites in an article in this guidebook. These discoveries were a significant addition to the database because only five quarry sites had been previously known, and those were in Mercer County. Clayton and others (1970) described the quarries as consisting of round depressions that were about 20 feet (6.1 m) in diameter, three to four feet (0.9-1.2 m) deep, and spaced about 20 feet (6.1 m) apart with a frequency of approximately 30 pits per acre (0.4 ha). The 29 known quarry sites ranged in size from 2 to 80 acres (0.8-32 ha) and had a combined extent of about 250 acres (101 ha).   They were able to disprove any suggestion that these pits had been dug by 19th Century settlers as a result of discovering relatively well-developed soil horizons at the base of the pits.

The Lynch Quarry

The Lynch Knife River Flint Quarry was initially discovered by Lee and Mik Clayton in 1968. It is the largest of the known quarries, covering an area of approximately 80 acres (32 ha). There are an additional 20 acres (8 ha) of quarries in the general vicinity. The north edge of the quarry has been under cultivation, but the majority of the quarry site is pasture and is relatively undisturbed.

The Dunn Center coal is approximately 20 feet (6 m) thick and occurs at a depth of 30 to 50 feet (9-15 m) at the Lynch farm (fig. 3). Seven to ten feet (2-3m) of this coal was mined by underground methods from 1915 to1923 in the High Grade mine (aka: Hy Grade, Hy-Grade, or Hygrade). The mine supplied coal to homes, businesses, and the school in Dunn Center via horse and wagon. In 1918, a railroad spur was laid to the mine and some coal was shipped east by rail. According to records of the North Dakota Public Service Commission, the mine “went broke” in 1923.

Typically, when all or portions of an underground mine were abandoned, miners would rob or remove coal from supporting pillars. As a result of this practice, and the inherent instability of these underground mine voids, surface collapse features are commonly found above underground coal mines throughout western North Dakota. This practice and its detrimental effects have long been known. In 1925, NDGS

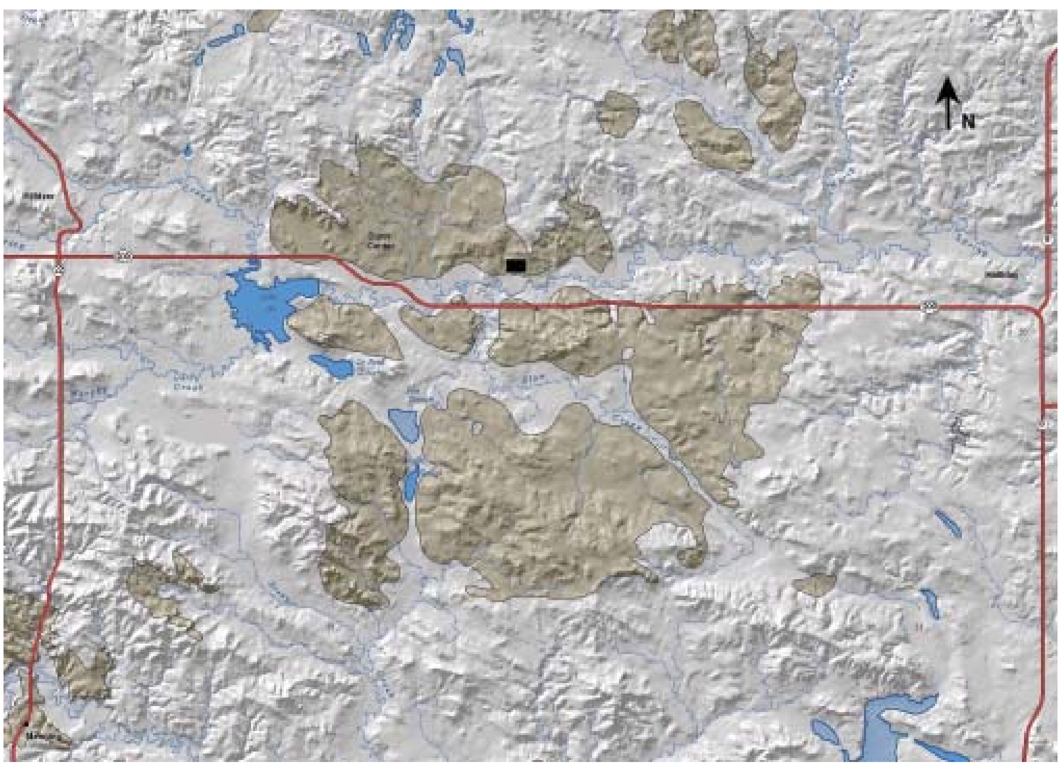


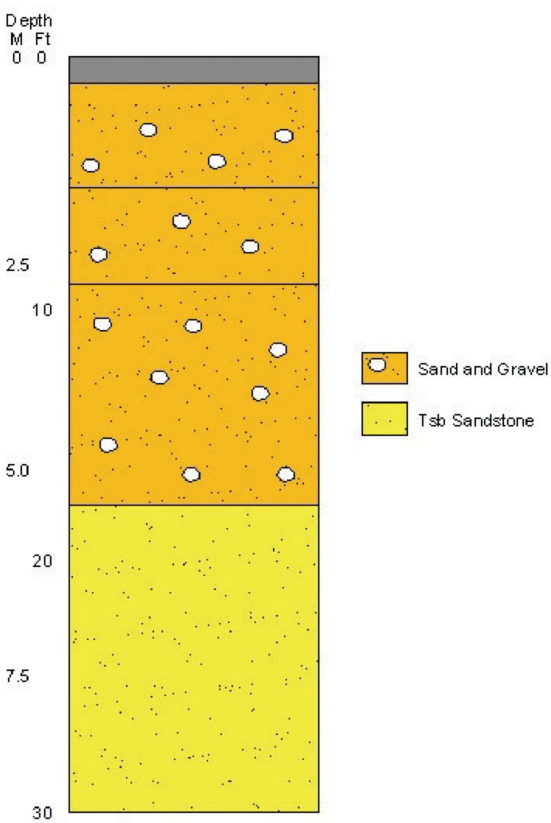
Figure 3. The Lynch Quarry (black square) is situated on economically mineable coal deposits (in brown) in the Dunn Center area. Glacial meltwater removed more than 240 million tons of mineable coal in this area (Murphy, 2004a). Scale: 0.25 in = 1 mi (0.4 cm = 1 km).

geologist L.P. Dove wrote *"From one to four feet or more of coal is left up for roof and both pillar and roof are robbed on retreat. Overlying material is invariably too weak for a roof and when roof coal is robbed, caving soon follows. Subsidence consists in straight vertical breaks of materials over rooms and the surface is pitted and rendered essentially useless for farming."* At the Lynch site, the underground workings have collapsed and surface depressions are present at several locations along the southwestern portion of the quarry. The mine collapse features can be easily differentiated from the adjacent flint pits because they are much larger and deeper (fig. 1). Exposures are nonexistent in the gentle, shallow, grass-covered slopes of the flint pits. However, the steep, poorly vegetated slopes of the mine collapse features, or sink holes, provide good exposures of the alluvial deposits to depths of about 20 feet (6.1 m).

In the 1980s, the North Dakota Geological Survey augured a 30-foot-deep (9.1 m) hole within the Lynch Quarry (fig. 4). In addition, several holes were augured in close proximity to the Benz Quarry south of ND Highway 200 (Murphy, 2001). At the Lynch site, the near-surface sediments consist of 18 feet (5.5 m) of Quaternary sand and gravel that overlie the Sentinel Butte Formation (Paleocene). Auguring ceased at a depth of 30 feet (9.1 m) when a hard object, possibly the Dunn Center coal, was encountered. This would correspond to the depth of coal listed in the mine records.

Dunn County Hole Number 105
E. Murphy
August, 1986

T145N, R93W, section 29 swnwne
Surface Elevation = 2190 feet (668 m).



Feet	Meters	
0-1	0.3	Topsoil.
1-5	0.3-1.5	Sand, medium brown, fine to medium grained, quartz and rock fragments, subrounded grains, gravel is up to 2 inches (5 cm) in diameter, predominantly Knife River Flint and bedrock concretions.
5-9	1.5-2.4	Sand, light brown, fine to medium grained, quartz and rock fragments, subangular to subrounded grains.
9-18	2.4-5.5	Sand and gravel, light brown, fine to medium grained, quartz and rock fragments, gravel ranges from small, well-rounded pebbles to 2 inch (5 cm) angular cobbles, Knife River Flint, bedrock concretions, tuffaceous carbonates from the Arikaree Formation capping the Killdeer Mountains. Highest concentration of gravel occurs between the depths of 9 to 12 feet (2.4-3.7 m).
18-30	5.5-9.1	Sandstone (Sentinel Butte Formation), very fine grained, micaceous, iron oxide lenses.
30	9.1	Drilling halted because we hit a hard object (possibly coal) and snapped the shear pins.

Figure 4. Lithology of a hole augured within the Lynch Knife River Flint Quarry.

Knife River Flint Source Rock

Geologists and archaeologists have been interested in the origin of Knife River Flint because it has only been found in secondary deposits. In the absence of an in-place flint deposit, Clayton and others (1970) established the Lynch Quarry (T145N, R93W, the north half of section 29) as the type area for Knife River Flint. They also described the physical and mineralogical characteristics of Knife River Flint, both microscopically and in hand specimen, so it could be differentiated from other flints.

Geologists have proposed various rock units as the source of Knife River Flint. These range from 50-million-year-old rocks within the Camels Butte Member of the Golden Valley Formation to 25-million-year-old rocks within the Arikaree Formation. Clayton and others (1970) suggested the HS Bed (Jepsen, 1963) as the likely source (fig. 5). The HS "hard siliceous" Bed is a 2-inch-thick (5.1 cm) flint that occurs approximately 40 feet (12 m) above the base of the Camels Butte Member of the Golden Valley Formation. Outcrops of the HS Bed are restricted to an area of about 24 square miles (62 sq km) between White Butte and Turtle Valley in the Little Badlands of Stark County. Hickey (1977) traced lag from this bed over an area of another 24 square miles.

Clayton and others (1970) noted that the HS Bed typically has a rough, nonconchoidal fracture in contrast to the smooth, conchoidal fracture of Knife River Flint (fig. 6). In addition, the HS Bed is typically grayish-brown to brown in color while Knife River Flint ranges from grayish-brown to black. Although thin sections of the HS Bed compare favorably with low quality samples of Knife River Flint, Clayton and others (1970) noted that Knife River Flint had formed from silicified lignite and such an origin was not evident in the HS Bed. They suggested that silicified lignite could have been part of the HS Bed, thereby creating Knife River Flint in parts of central Dunn County where the Golden Valley Formation has since been eroded. They also argue for a pre-Chadron source for Knife River Flint because of the presence of flint pieces in the Chalky Buttes Member of the Chadron Formation in the Chalky Buttes, Slope County. Though the HS Bed and Knife River Flint are not identical in appearance or thickness, the HS Bed does demonstrate that conditions were favorable at this stratigraphic level for flint to form. It can be argued that it is a smaller leap of faith to envision a thicker, better developed flint at the stratigraphic level of the HS Bed in an area outside of the Little Badlands, such as the Dunn Center area, than it is to envision a bed that has no stratigraphic remnant anywhere in the state.

In addition to the HS Bed, there are siliceous layers, lenses, nodules, or gravels in Fort Union, Golden Valley, White River, and Arikaree strata in North Dakota. Many of these sources of cryptocrystalline quartz were likely used for tool making to one degree or another by Native Peoples (fig. 7). The Rhame

Figure 5. The HS Bed (arrow) crops out in Turtle Valley in the Little Badlands, Stark County. The HS Bed is positioned in the lower part of the Camels Butte Member of the Golden Valley Formation.

Figure 6. A specimen of the HS Bed from Turtle Valley in the Little Badlands of Stark County (left) and a specimen of Knife River Flint from Dunn County (right). The HS sample is 1.5 x 3 inches (3.8 x 7.6 cm) and the Knife River Flint specimen is 3 x 3 inches (7.6 x 7.6 cm).

Bed in the Slope Formation (Paleocene) and the Taylor Bed in the Bear Den Member of the Golden Valley Formation are siliceous beds that have been variously termed quartzites, pseudo-quartzites, orthoquartzites and most recently silcretes (Wehrfriz, 1978). These beds are similar in appearance, that is they are typically light gray in color, contain stem molds, and are up to 3 feet (1 m) thick. The Rhame Bed has been called Tongue River Silicified Sediment (TRSS) by archaeologists (Ahler, 1977), although at least some of the lithic material identified as TRSS likely came from the Taylor Bed. In a study of the buttes of western North Dakota, Murphy and others (1993) reported cobbles and pebbles of both chert and flint in the Chalky Buttes Member of the Chadron Formation at Chalky, Square, Whetstone, and Wolf buttes; lenses of chert in the South Heart Member of the Chadron Formation at the top of Black Butte (Slope County) and Custer Lookout; chert and flint nodules overlying Chadron strata at the top of Sentinel Butte (also reported by Clayton et al., 1970); two, thin silicified peats within the Brule Formation and a layer of dendritic chert near the base of the Arikaree Formation at East Rainy Butte; as well as green and brown lenses of chert in the carbonate caprock (Arikaree Formation) of the Killdeer Mountains (fig. 7). The thin, silicified peat layers at East Rainy Butte do not appear to be of sufficient quality to be workable into knives or projectile points. A small lens (0.5 x 3 feet, 0.15 x 3 m) of petrified (silicified) peat was also reported by Ting (1972) in the lower portion of the Sentinel Butte Formation within the "petrified forest" area near Medora. Silicified and iron-cemented wood and chert are found at the surface in a few areas of eastern and north-central Slope County as gravels, stumps, and logs that are underlain by Sentinel Butte strata. Loendorf and others (1984) named this silicified wood and chert Rainy Buttes Silicified Wood. The unique appearance of this dark, reddish brown material makes it easily identifiable in field specimens and lithic tools. In addition to these sources, Paul Picha (SHSND) took a photograph of what appears to be flint, with a well developed white patina, cropping out beneath a radio tower on North Killdeer Mountain (personal communication, 3/13/2006).

The original source of Knife River Flint was likely either Golden Valley, White River, or Arikaree strata. Clayton and others (1970) pointed out that the presence of Knife River Flint gravels in the Chalky Buttes Member of the Chadron Formation indictated that the flint is no older than this stratigraphic unit. Lee Clayton followed the flint westward upstream to the Killdeer Mountains and found it as high as the Golden Valley Formation, but not above, suggesting it was the original source of the flint (personal communication, 4/4/2006). The pediments and ancient fluvial gravels around the Killdeer Mountains consist primarily of cream colored, tuffaceous-carbonate caprock of the mountains, but also contain chert and flint. The general lack of other rock fragments suggested that the carbonates, chert, and flint were being eroded at the same time (Murphy, 2001). One possible scenario is that the flint was deposited along the fringes of the playa lake system that formed the Arikaree caprock of the Killdeer Mountains. The carbonate caprock of these mesas contains abundant lenses of flint and chert (Murphy and others, 1993). Although these lenses are generally only an inch or two thick and typically occur in shades of green and

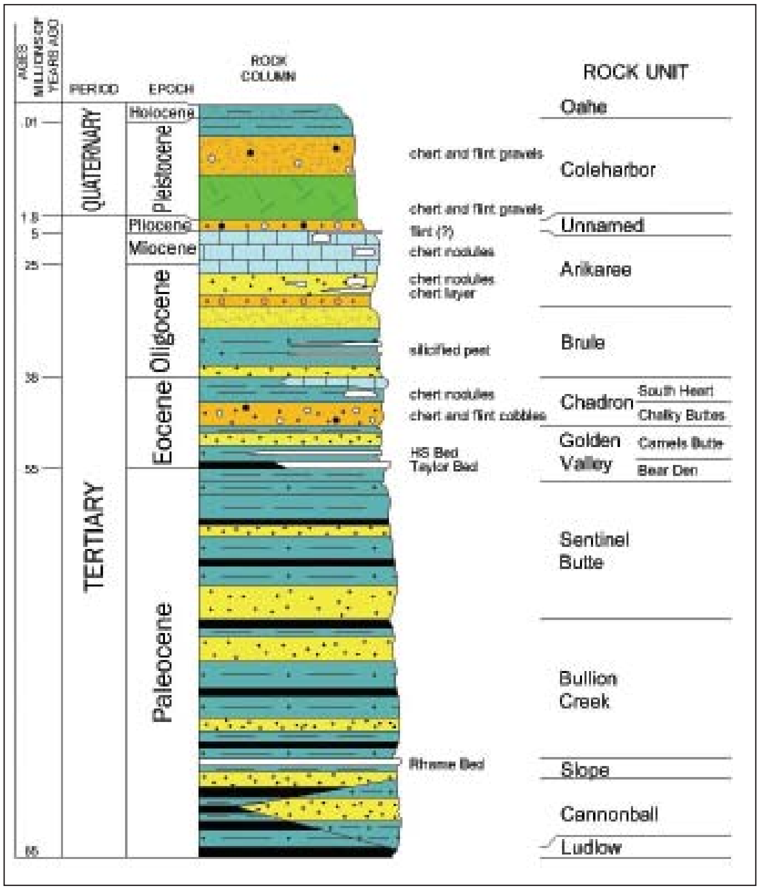


Figure 7. The stratigraphic position of siliceous beds, lenses, nodules, and cobbles (in white) in western North Dakota. The colors of the various lithologies represented in the column are: sandstone and siltstone (yellow), mudstone and claystone (green), coal (black), marlstone (light blue), sand and gravel (orange), and till (bright green).

brown (not black), their presence indicates the possibility that thicker deposits of silica accumulated adjacent to this area (fig. 8). One argument against this scenario is that Clayton and others (1970) described Knife River Flint as silicified lignite. Lignite has not been found in any rocks younger than the Camels Butte Member of the Golden Valley Formation.

In 1990, Miller and Larson reported they had discovered Knife River Flint in place at an archaeological site (32DU179) adjacent to ND Highway 22 in Dunn County. The site is located on the uplands, north of the Little Missouri River Valley (T148N, R95W, sections 13 and 24). The ridge top where Miller and Larson (1990) interpreted flint to be in place is about 80 feet (24 m) above the base of the Golden Valley Formation, at the approximate stratigraphic position of the HS Bed in Stark County. The caption from figure 36 of their report reads *"Photograph of bedded, in situ, Knife River flint encountered along the ridge top at 32DU179."* They go on to say *"Sites 32DU178 and 32DU179 are primary source areas for Knife River flint...."Primary" as used here, denotes the accepted geological usage and means in association with the primary context of deposition, in this case, in bedded facies within the Golden Valley Formation (Paleocene/Eocene)."* Murphy (2001) mapped the surface geology of this area and did not discover in-place Knife River Flint anywhere in the county. If flint was in place as Miller and Larson reported, it should have been exposed at this elevation in a ravine to the west. But, Murphy found no outcrops of flint in this draw. In addition, the photo in figure 36 suggests the flint is lag.

Large pieces of Knife River Flint (up to 3 feet (1 m) in diameter) were scattered across the surface of the uplands between Killdeer and Werner when Clayton (1970) and Murphy (2001) mapped the surface geology of Dunn County. In the late 1960s and early 1980s when this fieldwork was undertaken, rock

Figure 8. Green chert nodule within tuffaceous siltstone of the Arikaree Formation in the caprock of South Killdeer Mountain. About 8 inches (20 cm) of the handle of a Moore pick is shown for scale.

piles in this area consisted almost exclusively of large chunks of Knife River Flint. The size and frequency of these cobbles suggested the original source rock was not far away. The Sentinel Butte Formation is present at the surface in this area therefore, the flint lag could have come from any post-Paleocene strata. Although the stratigraphic unit immediately overlying the Sentinel Butte Formation (the Golden Valley Formation) is the most likely source of the flint, we know that rocks resistant to erosion can be let down stratigraphically a long distance. For example, six-foot (2m) diameter cobbles of the Rhame Bed lie on Hell Creek strata near Barren Butte in Sioux County where they have been displaced stratigraphically about 600 feet (180 m).

Scientists will likely continue to search and debate the original source of Knife River Flint long into the future. But, they may have a more difficult time documenting its distribution. For the past twenty years, the North Dakota Geological Survey has been fielding enquiries on the availability of Knife River Flint from amateur flint knappers, primarily from the Minneapolis area. In 2000, I returned to central Dunn County and found the surface almost entirely denuded of large pieces of flint. Large rock piles of flint were gone and only a few discarded granitic boulders were left in their place. Local farmers and ranchers spoke of flint being hauled away by the semi-truck load. If it has not already happened, some day people may once again be mining Knife River Flint from these deposits, albeit with a backhoe or a front-end loader instead of a bison shoulder blade and an elk horn.

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Return to ND Highway 200 via 95th Avenue and turn right (west) at mile 150.8.

The Town of Dunn Center
Mile: 153.5 (2.7)

Lake Ilo and the Killdeer-Shields Channel
Mile: 156.0 (2.5)

The surface and near-surface geology of the area south of ND Highway 200 is dominated by anastomosing channels (fig. 27). These proglacial meltwater channels developed along the margin of the Verone Glaciation and carried water that entered the state from northern Wyoming and that portion of Montana east of the Rocky Mountains (Clayton et al., 1980). The westernmost of these channels has been called the Killdeer-Glen Ullin (Clayton, 1970) or Killdeer-Shields Channel. It lies everywhere west of the Verone Glaciation indicating that it formed along the western limit of the Verone ice. The channels to the east formed either as the ice was advancing and were later overridden by the glacier, as indicated by till at the surface of the channel floors, or they may have formed on the ice margin as the glacier was retreating. As noted by Clayton (1970), the more easterly channels formed as the ice retreated. These channels are filled with up to 200 feet (60 m) of fluvial sediment and are easily identified because of their low-relief surfaces in contrast to the high to moderate relief of the surrounding bedrock topography (Klausing, 1979).

Clayton (1970) theorized that because the glacier advanced up the gradient of the regional slope in this area, the advancing ice would have dammed any valleys in the area thereby creating lakes. Clayton believed that the sudden release of water from these lakes, likely due to failure of an ice wall, caused catastrophic flooding that quickly eroded the channels. No lacustrine sediments have been found in boreholes from the ice-margin area to support this theory. However, it is possible that any silt and clay deposits were removed by subsequent upgradient catastrophic floods.

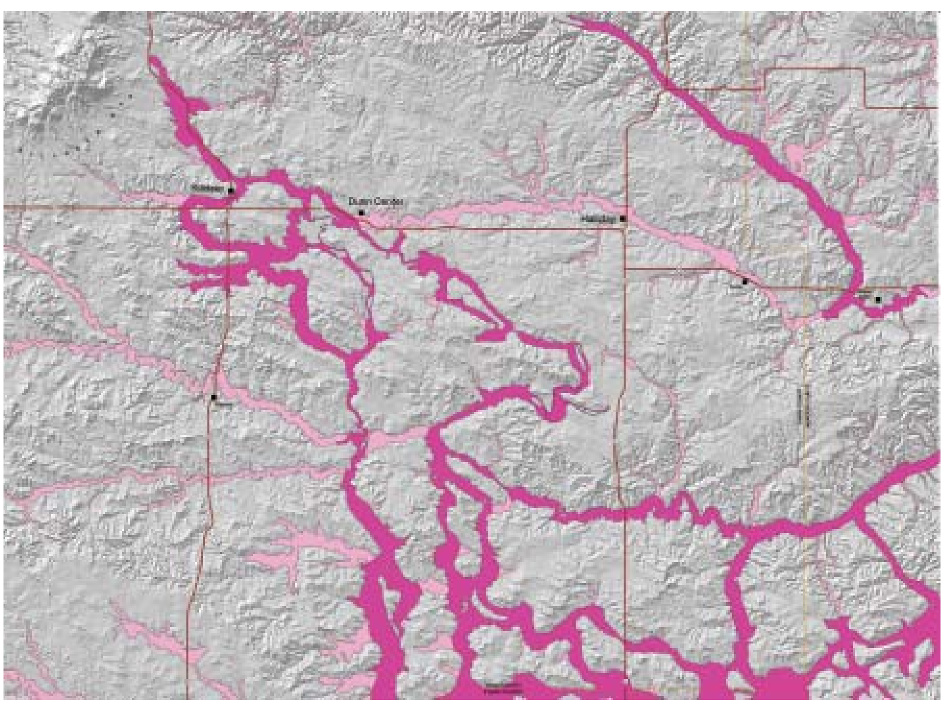

Figure 27. The northern terminus of the Killdeer-Shields Channels (dark pink) in Dunn and Mercer Counties (modified from Murphy, 2003a). Recent alluvial deposits, not underlain by these channels, are in light pink.

The position of erratics relative to the Killdeer-Shields channels may support a theory that they were formed, at least in part, by catastrophic flooding. In some areas erratics are concentrated along the sides of the glacial margin channels similar to what Kehew and Lord (1986) found near meltwater channels in Ward County (Murphy, 2001). They believed that these erratics were boulder-lags and used their frequency and position to support the hypothesis that many of the glacial meltwater channels in that area had been formed by catastrophic flooding. In addition to that evidence, several of the Killdeer-Shields channels bend sharply or abandon former channels as if done under relatively short-lived but high flow conditions (Murphy, 2001). Conversely, Clayton (1970) proposed that the relatively narrow width of these channels was evidence that they formed in a glacial climate when the ice was melting relatively slowly.

Turn North on ND Highway 22 at Killdeer at mile 160.1. (3.6)

The Town of Killdeer
Mile: 160.9 (0.8)

The route of ND Highway 22 from Killdeer to the northern edge of the Little Missouri River Valley approximates the western limit of glacial boulders as drawn by Clayton (1970). From the Little Missouri River Valley, the limit of glacial boulders trends west, paralleling that valley until it turns south near the North Unit of the Theodore Roosevelt National Park.

Killdeer Mountains
Mile: 169.1 (8.2)

The Killdeer Mountains are two large mesas that rise 600 feet (182 m) above the surrounding countryside (fig. 28). The cap rock consists primarily of 25 million year old fresh water carbonates and tuffs of the Arikaree Formation (Murphy et al., 1993). Mammalian fossils from the caprock indicate a late Arikareean age, these rocks are the youngest bedrock exposed in North Dakota (Hoganson et al., 1998). This is one of only three areas in North Dakota where Arikaree strata has been preserved.

Figure 28. Tuffaceous carbonates of the Arikaree Formation form the caprock of the Killdeer Mountains. Photo taken looking southeast from the southern edge of South Mountain.

Landslides in the Little Missouri River Valley
Mile: 179 (10)

Advancing glaciers diverted the Ancestral Little Missouri River eastward into this area approximately 600,000 years ago. The resulting steep slopes of the Sentinel Butte Formation (Paleocene) have been prone to slope failure (fig. 29). Approximately 4,000 landslides have been mapped along the Little Missouri River Valley from the mouth to a point just west of the North Unit of the Theodore Roosevelt National Park where the ancestral river was diverted (Murphy, 2003c; 2004b). Between the North and South Units of the Theodore Roosevelt National Park, the walls of the Little Missouri River Valley consist of strata of the Bullion Creek Formation (Paleocene). The Bullion Creek Formation is essentially identical to the overlying Sentinel Butte Formation in all aspects other than color. The fact that landslides are relatively rare in the Little Missouri River Valley south of the North Unit of the Park, but comprise up to 30 to 40% of the valley east of the park, suggest that downcutting and oversteepening of the slopes caused by the diversion is responsible for these slope stability problems.

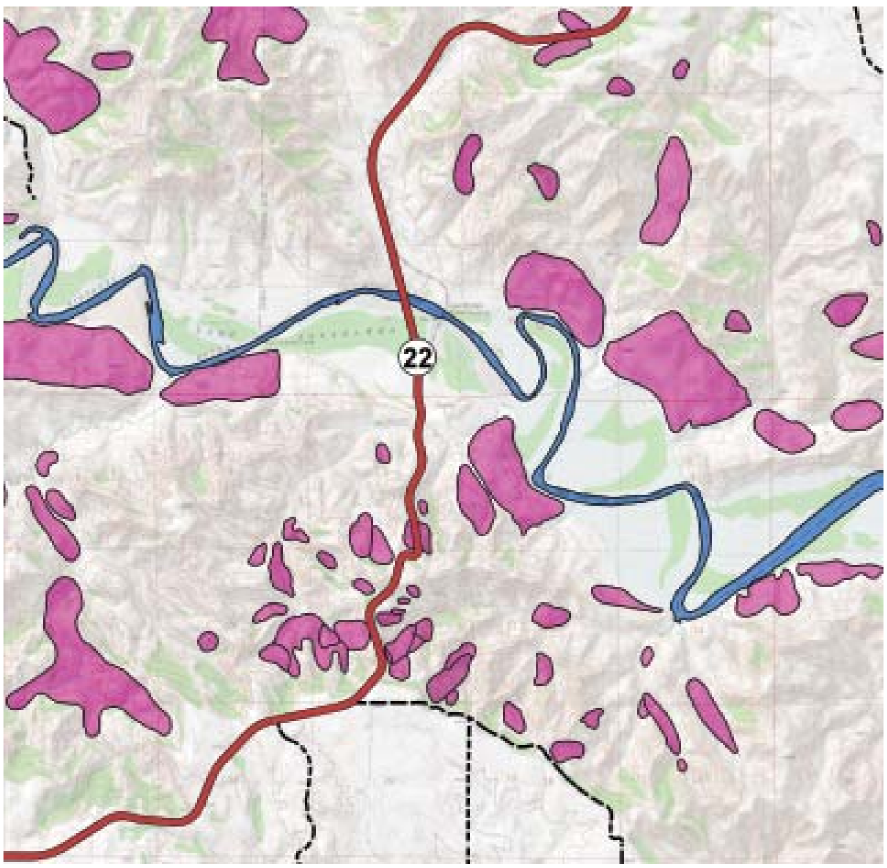

Figure 29. Landslide deposits (in pink) within the Little Missouri River Valley at Lost Bridge. Modified from Murphy (2003d).

Lost Bridge
Mile: 182 (3.0)

Erratics
Mile: 189 (7.0)

Figure 30. Lost Bridge (upper left corner of the photograph) was built across the Little Missouri River in the early 1930s. It received its name because funding was not available during the Depression and World War II to construct a road to the bridge site. As a result, it sat unconnected to a road until the 1950s. Lost Bridge was dismantled in 1994. A plaque and a piece of the old bridge remain as a memorial near the bridge site. Photograph taken in 1983, view to the northwest.

Blue Buttes
Mile: 193 (4.0)

Blue Buttes are comprised of about one dozen, low-lying buttes encompassing an area of 30 square miles (78 square kilometers) southwest of New Town. The buttes are capped by fluvial sandstone of the Camels Butte Member (Eocene) of the Golden Valley Formation (fig. 31). The buttes are visible on the horizon from more than 50 miles (80 km) away. The buttes are prominent features on the landscape from the Missouri River Valley and were visible to the Lewis and Clark Expedition for several days. For some reason, neither Clark nor Lewis mentioned them in their journals, and Clark did not plot them on his map of the area. Only Sargent Ordway noted them stating in his journal entry of April 14, 1805 *"A high mountain back of the hills S.S."* (Moulton, 1987b)

Figure 31. An outlier of Blue Buttes just west of ND Highway 22. The Bear Den Member of the Golden Valley Formation (Paleocene) is the brightly colored strata near the top of the butte. View is to the west.

Bear Den Creek
Mile: 199 (6.0)

Bear Den Creek crosses ND Highway 22 in this area. This creek was originally named Charbonneau Creek by Lewis and Clark in honor of their guide Toussaint Charbonneau and was prominently labeled on Clark's map. The delay in publishing their journals, the limited distribution of those journals, and the influx of explorers and traders into the area on the heels of the expedition resulted in virtually none of the names that Lewis and Clark applied to landforms in western North Dakota being carried forward to today.

Blue Butte
Mile: 201 (2.0)

Blue Butte on the right, to the east of the highway. Blue Butte and the adjacent butte to the east are capped by thick, fluvial sandstone of the Camels Butte Member (Eocene) of the Golden Valley Formation. A pit was opened on the southwest side of Blue Butte in the 1970s and the caprock was crushed for aggregate.

Gully Erosion
Mile: 207 (6.0)

ND Highway 22 crosses through several deep, steeply-sided gullies that have been created in this area in response to the diversion of the Missouri River into a new channel three miles west of here approximately 14,000 years ago.

Turn right (east) on ND Highway 23 and proceed towards New Town at mile 227 (20).

Oil Well on South Side of Road
Mile: 212 (5.0)

The oil well on the south side of the road is within the Antelope Field. Production comes from seven pools in rocks that range in age from Cambrian to Mississippian. The field is located on the east flank of the Nesson Anticline. The field was discovered in the mid- to late 1950s and cumulative production of oil from Antelope Field is over 41 million barrels.

Four Bears Bridge and New Town
Mile: 219 (7.0)

New Town was created in 1953 when Lake Sakakawea flooded farms, towns, and villages including Sanish, Elbowoods, Van Hook, Lucky Mound, Shell Creek, Nishu, Charging Eagle, Beaver Creek, Red

Butte and Independence. The displacement of the agrarian Native Peoples from the fertile bottomland to the less fertile upland is still being felt today.

Construction of the new Four Bears Bridge was completed in 2005. This is actually the third rendition of a Four Bears Bridge, the second at this site. The original Four Bears Bridge was built in 1934, 35 miles (56 km) southeast of here and crossed the Missouri River Valley at the town of Elbowoods. That bridge was dismantled in 1954, moved to this location, and expanded from a 1,425-foot (434 m) long bridge to a 4,483-foot (1,366 m) long bridge where it served as the center spans of the newly created Four Bears Bridge. Having been designed for traffic from the 1930s, the bridge was too narrow and after decades of complaints the bridge was replaced in 2005.

STOP 5: Crow Flies High Overlook
Mile: 220 (1.0)

The ruins of the town of Sanish can be seen on the floodplain below, just north of the Crow Flies High Overlook. The town was abandoned in the 1950s shortly before this area was inundated by Lake Sakakawea. Foundations of a variety of buildings are visible at low water levels.

This overlook is located on the southern edge of a channel that was occupied by the Ancestral Missouri River for more than 40,000 years until it was blocked by glaciers at this point approximately 14,000 years ago. The ice dam forced water to back up along the Ancestral Missouri River Valley creating Glacial Lake Crow Flies High that extended from this area west to the town of Williston. At some point, this ponded water broke past the ice dam and carved a new, relatively narrow channel (fig. 32). This channel was occupied by the Missouri River until it was dammed in 1954. The abandoned ancestral channel is referred to as the New Town Sag or the Van Hook Arm of Lake Sakakawea.

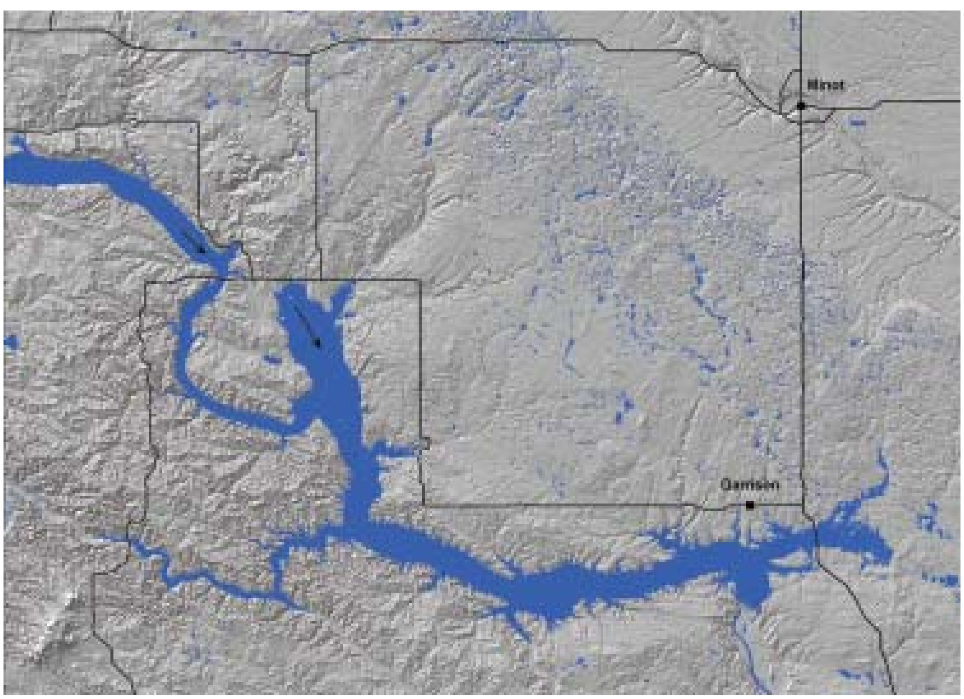

Figure 32. Shaded relief map of western North Dakota. The wide valley of the Ancestral Missouri River prior to its damming at New Town (arrows) is in sharp contrast to the narrower, younger valley carved when that ice dam was breached. The width of the younger section of the Missouri River Valley is about one mile (1.6 km) in comparison to three to four miles (4.8-6.4 km) along the older channel (Van Hook Arm).

Similar to the Little Missouri River Valley that we traveled through earlier on this trip, landslides are prevalent along the portion of the Missouri River Valley that was created by water escaping from Glacial Lake Crow Flies High. Both Lewis and Clark walked along the Missouri River Valley in this area on April 14, 1805 (fig. 33). Lewis noted the numerous landslides in the area writing in his journal *"the lard. shore on which I walked was very broken, and the hills in many places had the appearance of having sliped down in masses of several acres of land in surface*" (Moulton, 1987b).

South of here, William Clark walked outside of the river valley for the only time that we are aware of, except perhaps near Huff, while in present day North Dakota other than during the winter at Fort Mandan. Lewis wrote in his journal entry of April 15, 1805 *"I walked on shore, and Capt. Clark continued with the party it being an invariable rule with us not to be both absent from our vessels at the same time…..after breakfast Capt. Clark walked on the Std. Shore, and on his return in the evening gave me the following account of his ramble. "I assended to the high country, about 9 miles distant from the Missouri…" Clark's entry for that same day reads "I walked on shore and assended to the high countrey on the S.S. and off from the Missouri about three miles"* (Moulton, 1987b). Clark plotted his route on his map of the area (fig. 34).

The Corps of Discovery passed by the Crow Flies High Overlook on the afternoon of April 15, 1805. They named the Little Knife River "Goat Pen Creek" because the Assiniboine had built a pen along side of it to trap Pronghorn antelope which the explorers referred to as goats. On the return trip from the west coast, Clark and his party camped across from this area on August 11, 1806. Lewis and Clark had split into two parties in Montana to explore more territory. They were to reunite at the mouth of the Yellowstone River. Clark's party arrived there first, but were driven down river by mosquitoes. The party led by Lewis arrived four days later and continued down river. On August 11, 1806, Lewis was shot about 25 miles (40 km) west of this overlook in a hunting accident. The next day, both parties reunited about eight miles (13 km) south of here, near what we now call Reunion Bay.

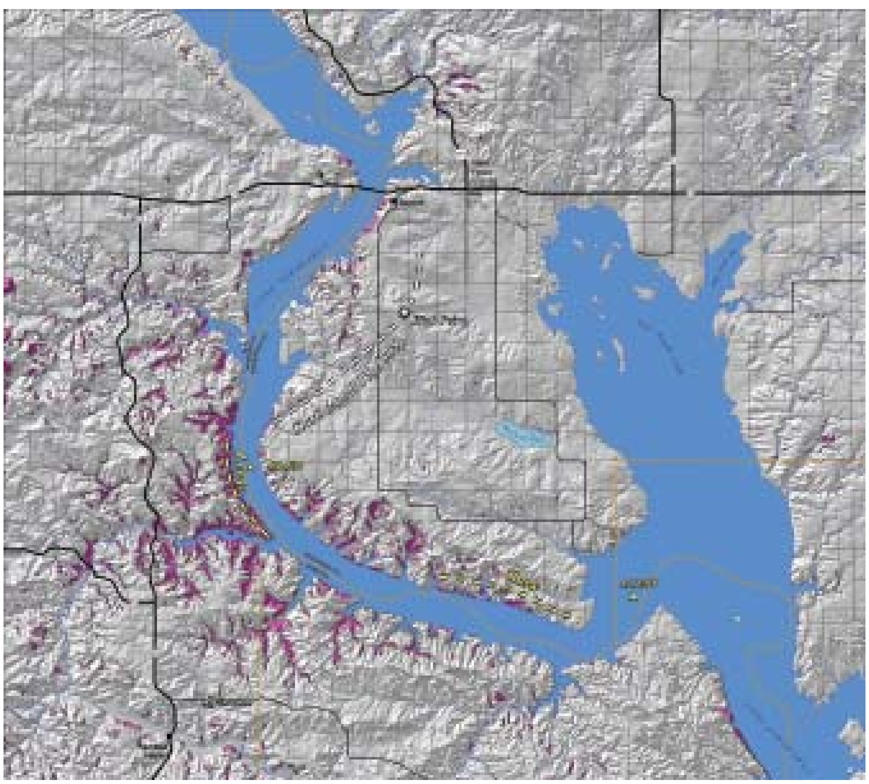

Figure 33. The routes (in yellow) walked by William Clark and Meriwether Lewis on April 14, 1805 and the route (in white) that Clark took on April 15, 1805. Landslides are in pink. On April 15, Clark appears to have followed a southwest-northeast trending ravine out of the valley and then walked along a ridge to a high point where he made his observations.

Figure 34. William Clark stood on this ridge on April 15, 1805 and proclaimed *"countrey is butifull open fertile plain the dreans take theer rise near the Clifts of the river and run from the river in a NE derection as far as I could See,"* (Moulton, 1987b). View is to the north-northeast. New Town is visible in the background.

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Late Pleistocene (Rancholabrean) Mammals of North Dakota

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Introduction

In 1987, Allen Kihm, in his review of Pleistocene and early Holocene mammals of North Dakota, lamented over the meager number of reports of Quaternary mammalian fossils in North Dakota. The same observation and concern can be made almost 20 years later because very few Pleistocene paleontology investigations have been conducted in North Dakota since Kihm's report. In one sense this is surprising because about three quarters of North Dakota is veneered with glacial deposits.

Upham (1895) was first to mention the presence of Pleistocene mammalian fossils in North Dakota, mammoth teeth and other mammoth bones from the base of the Herman beach ridge of glacial Lake Agassiz near Absaraka, Cass County. Most subsequent reports have been of isolated finds discovered during mapping of glacial deposits as a result of the North Dakota Geological Survey's county geological mapping program. These reports include remains of horse, *Equus* (Clayton, 1962; Kume and Hansen, 1965); badger, *Taxidea taxus* (Baker, 1967); and Cervidae (Baker, 1967; Bluemle, 1967) (Table 1; fig. 1). A muskrat skull, *Ondatra zibethicus*, and trace fossils (scat and gnawed wood) of the beaver, *Castor* sp.,

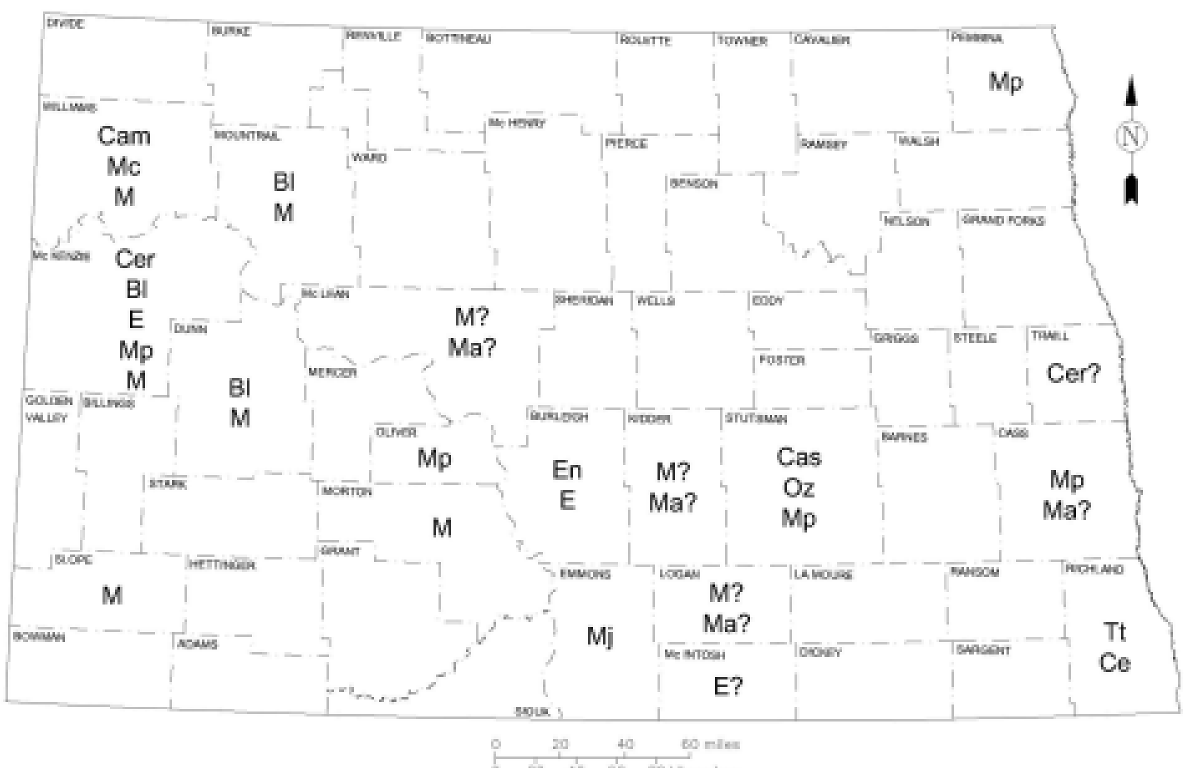

Figure 1. North Dakota counties where Pleistocene mammalian fossils have been recovered. **Tt**, *Taxidea taxus*; **Cas**, *Castor* sp.; **Oz**, *Ondatra zibethicus*; **Cam**, *Camelus* sp.; **Ce**, ?*Cervalces* sp.; **Cer**, Cervidae sp.; **Bl**, *Bison latifrons*; **En**, *Equus niobrarensis*?; **E**, *Equus* sp.; **Mc**, *Mammuthus columbi*; **Mp**, *Mammuthus primigenius*; **M**, *Mammuthus* sp.; **Ma**, *Mammut* sp.; **Mj**, *Megalonyx jeffersonii.*

were found at the 9,750 ± 140 yr B.P. Seibold Site in Stutsman County (Cvancara et al., 1971). Ashworth and Cvancara (1983) recorded mammoth teeth from Pembina and Cass counties. The tooth from Embden, Cass County was identified as woolly mammoth, *Mammuthus primigenius,* and was recovered from the Lake Agassiz Herman beach that formed about 11,500 years ago. This identification was reaffirmed by Harington and Ashworth (1986) during their study of mammoth fossils from North Dakota. In that report, they also listed *M. primigenius* remains from McKenzie, Stutsman, and Pembina counties and a tooth fragment of the steppe mammoth, *Mammuthus columbi*, from Williams County.

Since the creation of the North Dakota Geological Survey administered State Fossil Collection by legislative action in 1989, which is housed at the North Dakota Heritage Center in Bismarck, several Pleistocene fossils and fossil sites have come to my attention. These finds are summarized below and listed in Table 1.

Bison latifrons

McDonald (1981) reported the occurrence of the massive Pleistocene bison, *Bison latifrons*, in North Dakota, based on a horn fragment found near Independence, Dunn County on the Fort Berthold Reservation before the site and town were inundated by waters of Lake Sakakawea as a result of flooding by Garrison Dam. In 1998, Kent Pelton from Watford City discovered a well-preserved skull of *B. latifrons* along the shore of Lake Sakakawea on U. S. Army Corps of Engineers administered land within the boundaries of the Fort Berthold Reservation, Mountrail County (Hoganson, 2003). This skull produced an age of >47,500 years B. P. and is now on exhibit at the North Dakota Heritage Center in Bismarck (fig. 2). It was recovered from an extensive fluvial deposit of uncertain age mapped by Clayton (1980) as Quaternary or Upper Tertiary Sediment, Undivided. A few years later, *B. latifrons* remains, associated with other fossils including *Mammuthus primigenius, Equus* sp., and Cervidae indet., were discovered in the same fluvial deposit but from another site on the Fort Berthold Reservation in McKenzie County. This is called the Hoffman Site and is the first fossil site in North Dakota of Pleistocene age that is yielding a diverse assemblage of mammalian fossils. The North Dakota Geological Survey is seeking permission from the Three Affiliated Tribes to conduct investigations at this important site.

Megalonyx jeffersonii

Linda and Doug Vanurden, while strolling along the shoreline of Lake Oahe in Emmons County in 1999, discovered an ungual from a pes of the ground sloth *Megalonyx jeffersonii* completely weathered out and resting on the shore (fig. 3). They reported the find and the U. S. Army Corps of Engineers has given us permission to study the specimen (Hoganson and McDonald, in press). It is now on exhibit at the North Dakota Heritage Center in Bismarck. The ungula was not found in stratigraphic context, but it

Figure 2. *Bison latifrons* skull from Mountrail County on exhibit at the North Dakota Heritage Center in Bismarck. Horn tip to horn tip is 2.2 m. ND98-44.1.

yielded an AMS age of 11,915 ± 40 yr B. P. This fossil is the only evidence that *M. jeffersonii* inhabited North Dakota. *Megalonyx* was described by Thomas Jefferson and Casper Wistar in 1799 and was later given the specific name *M. jeffersonii* in honor of President Jefferson. It is ironic that remains of *M. jeffersonii* would be found near one of the Lewis and Clark campsites in North Dakota almost 200 years after Jefferson commissioned the Lewis and Clark Expedition.

Figure 3. *Megalonyx jeffersonii* ungual from Emmons County on exhibit at the North Dakota Heritage Center in Bismarck. Width 165 mm. ND00-10.1.

Mammuthus and *Mammut*

Several additional mammoth teeth, bones, and tusk fragments from North Dakota have been discovered since Harington and Ashworth's (1986) report on North Dakota mammoths was published. Most of these fossils are in either the State Fossil Collection or the State Historical Society of North Dakota Collection, both housed at the North Dakota Heritage Center in Bismarck (Table 1). Many of these teeth are not well preserved and can only be assigned to *Mammuthus* sp. Several also are not accompanied by temporal or stratigraphic information. Two well preserved teeth, one from Oliver County (fig. 4) and one from McKenzie County, and bones from the Hoffman Site are identified as *M. primigenius*.

A tooth identified as mastodon, *Mammut* sp., is in the museum collection at Bonanzaville, West Fargo. It is assumed that the specimen was found in Cass County, but it is not accompanied by provenance information.

Figure 4. *Mammuthus primigenius* tooth from Oliver County on exhibit at the North Dakota Heritage Center in Bismarck. Width 332 mm. SHSND1991.00158.

Equus, Camelus, and Cervidae

Equus sp. is represented mostly by isolated teeth from several localities except at the Hoffman Site in McKenzie County where other skeletal elements have been found, none of which are sufficient for species identification (fig. 5). No Pleistocene horse skeletons or skulls have been found in North Dakota. The jaw found by Clayton (1962) has been provisionally assigned to *Equus niobrarensis*? The only fossil found of *Camelus* in North Dakota is a metatarsus from Williams County. Cervid remains are equally sparse consisting of only a tooth, antler fragment, and metatarsal from three different sites.

Figure 5. *Equus* sp. phalanxes from the Hoffman Site, McKenzie County. Length 109 mm. ND03-2.

Summary

The list of Pleistocene mammalian taxa from North Dakota is short and reflects the sparsity of studies of Pleistocene faunas in this state. Most mammalian fossils that have been reported are from isolated finds often associated with glacial mapping or stratigraphic investigations. The age of most of the fossils has not been determined by radiometric dating, but all are probably Late Wisconsinan or Rancholabrean in age. Since Kihm's (1987) review of North Dakota Pleistocene and Early Holocene mammals, significant Pleistocene mammalian fossils have been discovered in North Dakota including *Bison latifrons* (Hoganson, 2003) and *Megalonyx jeffersonii* (Hoganson and McDonald, in press). Several additional *Mammuthus* and *Equus* specimens have been discovered since Kihm's review. Most of these fossils are in the North Dakota State Fossil and State Historical Society of North Dakota collections at the North Dakota Heritage Center in Bismarck and are reported here for the first time (Table 1).

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Taxon	Specimen	County	Specimen Number	Age (^{14}C yrs BP)	Reference
Mammalia					
Order Carnivora					
Family Mustelidae					
Taxidea taxus	"Bone fragments"	Richland	Unnumbered	Wisconsinan	Baker, 1967
Order Rodentia					
Family Castoridae					
Castor sp.	Trace	Stutsman	Unnumbered	9,750 ± 140	Cvancara et al. (1971)
Family Cricetidae					
Ondatra zibethicus	Skull	Stutsman	Unnumbered	9,750 ± 140	Cvancara et al. (1971)
Order Artiodactyla					
Family Camelidae					
Camelus sp.	Metatarsus	Williams	ND06-16.1	Unknown	This paper
Family Cervidae					
?*Cervalces* sp.	Tooth	Richland	Unnumbered	Wisconsinan	Baker, 1967
Cervidae indet.	Antler fragment	McKenzie	ND03-2	>47,500	This paper
?Cervidae indet.	Metatarsal	Traill	Unnumbered	Wisconsinan	Bluemle (1967)
Family Bovidae					
Bison latifrons	Horn fragment	Dunn	AMNH20074	Unknown	McDonald (1981)
Bison latifrons	Skull	Mountrail	ND98-44.1	>47,500	Hoganson (2003)
Bison latifrons	Misc. bones	McKenzie	ND03-2	>47,500	This paper
Order Perissodactyla					
Family Equidae					
Equus niobrarensis?	Lower left jaw	Burleigh	UMMP44573	Early-Wisconsinan?	Clayton (1962); Kume & Hansen (1965)
Equus sp.	Teeth; Phalanxes	McKenzie	ND03-2	>47,500	This paper
Equus sp.	Tooth	Burleigh	ND225.1	Unknown	This paper
Equus sp.	Tooth	Burleigh	ND225.2	Unknown	This paper
Equus sp.	Tooth	Burleigh	ND225.3	Unknown	This paper
Equus sp.	Tooth	Burleigh	ND225.4	Unknown	This paper
Equus sp.	Tooth	Burleigh	ND225.5	Unknown	This paper
Equus sp.	Tooth	Burleigh	ND225.6	Unknown	This paper
Equus sp.?	"Large bones"	McIntosh	UND6134	Wisconsinan	Clayton (1962)

Table 1 continued.

Taxon	Specimen	County	Specimen Number	Age (^{14}C yrs BP)	Reference
Order Proboscidea					
Family Elephantidae					
Mammuthus columbi	Tooth	Williams	UND13902	Late-Wisconsinan?	Harington and Ashworth (1986)
Mammuthus primigenius	Tooth	Cass	Unnumbered	~11,500	Ashworth and Cvancara (1983); Harington and Ashworth (1986)
Mammuthus primigenius	Tooth	McKenzie	Unnumbered	Unknown	Haraldson (1952); Harington and Ashworth (1986)
Mammuthus primigenius	Tooth	Stutsman	UND406	12,000 to 10,000	Harington and Ashworth (1986)
Mammuthus primigenius	Tooth	Pembina	UND5388	Unknown	Ashworth and Cvancara (1983); Harington and Ashworth (1986)
Mammuthus primigenius	Tooth	Oliver	SHSND1991.00158	Unknown	This paper
Mammuthus primigenius	Misc. bones	McKenzie	ND03-2	>47,000	This paper
Mammuthus primigenius	Tooth	McKenzie	ND93-62.1	Unknown	This paper
Mammuthus sp.	Tooth	McKenzie	ND93-121.1	Unknown	This paper
Mammuthus sp.	Tooth	McKenzie	ND92-62	Unknown	This paper
Mammuthus sp.	Tooth	McKenzie	SHSND05538	Unknown	This paper
Mammuthus sp.	Tooth	Morton	SHSND12487	Unknown	This paper
Mammuthus sp.	Tooth	Mountrail	SHSND15453	Unknown	This paper
Mammuthus sp.	Tooth	Dunn	SHSND1983.00264	Unknown	This paper
Mammuthus sp.	Tooth	Williams	ND01-47.1	Unknown	This paper
Mammuthus sp.	Tooth	Williams	ND93-51	Unknown	This paper
Mammuthus sp.	Tooth	Slope	ND06-15.1	Unknown	This paper
Mammuthus or *Mammut*	Tusk fragments	Logan	UND6063	Unknown	Harington and Ashworth (1986)
Mammuthus or *Mammut*	Tusk fragments	McLean?	Unnumbered	Unknown	This paper
Mammuthus or *Mammut*	Tusk fragments	Kidder	SHSND15012	Unknown	This paper
Family Mammutidae					
Mammut sp.	Tooth	Cass?	Unnumbered	Unknown	This paper
Order Xenarthra					
Family Megalonychidae					
Megalonyx jeffersonii	Ungual	Emmons	ND00-10.1	$11,915 \pm 40$	Hoganson and McDonald (in press)

Origin of the Missouri River in North Dakota

John P. Bluemle, Bismarck, ND

Before North America was first glaciated during the Ice Age about two million years ago, all of the rivers in North and South Dakota and eastern Montana drained northeastward into Canada to Hudson Bay (fig. 1). There was no “Missouri River” carrying drainage from the northern mid-continent to the Gulf of Mexico (my definition of the Missouri River requires that it flow to the Gulf of Mexico). Why is the modern situation so different than it was two million years ago?

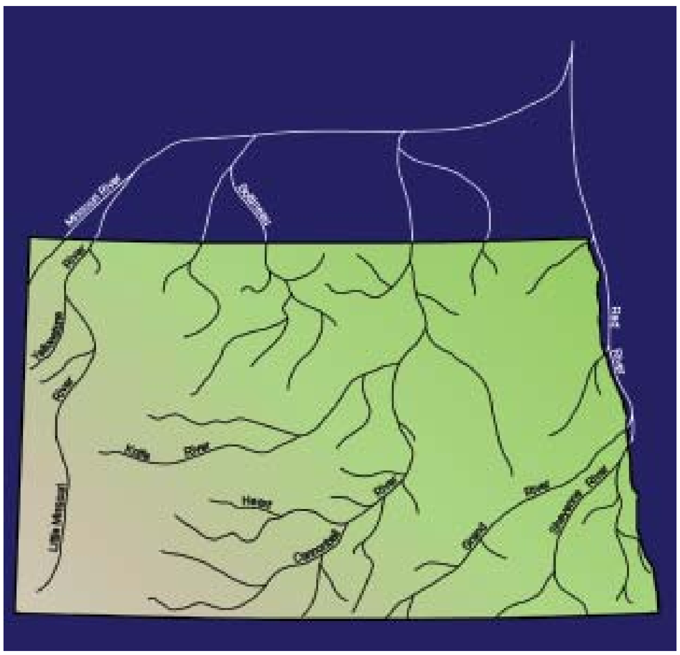

Figure 1. Map of North Dakota showing the drainage pattern prior to glaciation. All rivers flowed north or northeast into Canada. The Missouri River valley did not exist (except for short segments that correspond to portions of valleys such as the Knife and McLean River valleys — see text).

The modern Missouri River Valley in North Dakota consists of a number of “segments” of valley that are quite different from one another. Some of these valley segments are broad: six to ten miles wide from edge to edge, with gentle slopes from the adjacent upland to the valley floor. Others are narrow: less than two miles wide, with rugged valley sides. Generally, the wide segments trend west – east and the narrow segments trend north – south. There are a few exceptions. The Bismarck – Mandan area is on exception and I’ll explain why shortly.

The west-east segments of the Missouri River Valley are wide because they coincide with much older valleys, some of which had already existed for a long time prior to glaciation. Old or mature river valleys tend to be broad with gentle slopes. Younger immature valleys are usually narrower with steeper sides.

For example, the 40-mile-long segment of the Missouri Valley upstream from Garrison Dam is quite wide. This part of the valley, which is now flooded by Lake Sakakawea, was once the route of a river that flowed east to Riverdale, continued eastward past Turtle Lake and Mercer and flowed on into eastern North Dakota (fig. 2). For convenience, I’ll refer to this east-flowing river as the “McLean River.” The portion of the McLean River Valley east of U.S. Highway 83 is buried beneath thick deposits of glacial sediment. Even so, it’s still a somewhat lower area – a broad sag through eastern McLean County. A number of lakes – Turtle Lake, Lake Williams, Brush Lake, and others – are located in the sag. East of there, the McLean River Valley is so deeply buried beneath glacial deposits that it is virtually impossible to

Figure 2. Schematic map showing a portion of the route of the preglacial "McLean River," which flowed eastward through a broad valley that passed between Garrison and Riverdale, to the Turtle Lake area, and on into Sheridan County. When the McLean River valley was blocked by a glacier, a proglacial lake formed in the valley. When the lake overflowed southward from a point near Riverdale — at the site of the modern Garrison Dam — a narrow diversion trench was cut. The modern Missouri River flows through this diversion trench.

follow it without drilling test holes to determine its location. Fortunately, we have drilled hundreds of such holes in our geologic studies of the glacial deposits and we have a good idea of the route the river followed into eastern North Dakota.

Another west-east trending segment of the modern Missouri River Valley is the one between Stanton and Washburn (fig. 3). This is an eastward continuation of the modern Knife River. Prior to glaciation, the Knife River flowed east past Washburn, turning slightly northeastward there. It joined the McLean River in eastern McLean County near the town of Mercer. The Knife-McLean River continued northeastward to the Devils Lake area, then north along the east side of the Turtle Mountains into Canada.

Figure 3. Westward view of the Missouri River, 2 miles west of Washburn, North Dakota (Photo by J. Bluemle).

At Bismarck-Mandan the Missouri River Valley is only about two miles wide where Interstate Highway 94 crosses the river. However, on the south side of Bismarck the valley broadens to about six miles wide, although it retains its steep western edge (fig. 4). The reason for this widening is that, prior to glaciation, the Heart and Little Heart Rivers, which today flow into the Missouri River (the Heart River enters the Missouri River at Mandan; the Little Heart enters about ten miles south of Mandan), joined a few miles east of Bismarck (fig. 5). The old, combined Heart-Little Heart valley still exists as the broad lowland south of Bismarck – a wide spot in the Missouri River Valley.

Figure 4. View of the Missouri River, south of Bismarck (Photo by J. Bluemle).

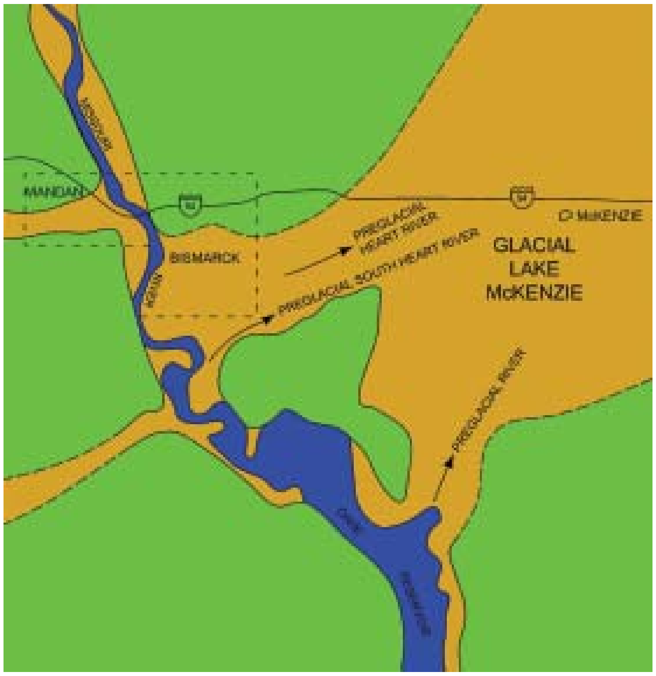

Figure 5. Schematic map showing the Missouri River Valley at Bismarck-Mandan. South of Bismarck, the valley is very wide because it corresponds to the old, northeast-trending preglacial valley of the Heart River. North of Bismarck-Mandan, the valley is narrow with quite steep sides. This portion of the valley was formed when an ice-dammed lake to the north in the preglacial Knife River valley overflowed from a point near Wilton. A similar ice-dammed lake existed in the Heart River Valley east of Bismarck — the glacial Lake McKenzie.

To summarize the situation at Bismarck-Mandan: the Missouri River Valley immediately north of the two cities is much younger (formed during a glacial event, perhaps 25,000 years ago) than is the valley several miles south of the city, where it coincides with – crosses – the old, preglacial northeast-trending Heart-Little Heart valley.

I've been discussing several of the wide, east-west segments of the Missouri River Valley. Most of the narrow, north-south segments of the valley formed in places where glaciers diverted rivers southward. North Dakota was glaciated about a dozen times during the Ice Age. Most of the glacial activity in North Dakota tended to be concentrated in the eastern and northern parts of the state. Probably every glaciation resulted in blockage of all drainage to Hudson Bay, forcing it to flow southward to the Gulf of Mexico or eastward to the St. Lawrence area.

Each time glaciers advanced southward through the Red River Valley and other parts of eastern North Dakota, they also expanded westward and southwestward, causing what had been northeasterly flowing rivers to be diverted along the western margin of the glacier. When the McLean River was blocked by a glacier in the Riverdale area midway through the Ice Age, a large, proglacial lake formed ahead (to the west) of the ice in the valley of the McLean River. This was the "original" Lake Sakakawea – an early ice-dammed lake that predated the Corps of Engineers version of Garrison Dam by a few hundred thousand years.

Eventually, the proglacial lake overflowed (there was no spillway) just about where Garrison Dam is today, and the resulting flood quickly carved a narrow trench southward to the Stanton area (fig. 6) (kind of an early Garrison Diversion Project – those glaciers moved slowly, but they got the job done!). At the same time this was happening, the Knife River Valley was also flooded, dammed by glacial ice in the Washburn-Wilton area. The lake in the Knife River Valley, in turn spilled southward into the Burnt Creek-Square Butte Creek drainage, carving a narrow trench from just south of Wilton to Bismarck-Mandan (fig. 7). It's possible these events took place quickly – kind of a domino effect, but we don't really know.

Figure 6. View over the Missouri River south of Riverdale, McLean County, North Dakota (Photo by J. Bluemle).

Figure 7. Vew looking north along the Missouri River, ten miles north of Bismarck. (Photo by J. Bluemle).

The youngest and narrowest segment of the Missouri River Valley in North Dakota is in the Newtown area between Four Bears Bridge and Van Hook Bay. As recently as 14,000 years ago, a glacier forced the river, which had been flowing trough a broad valley now known as the "Van Hook Arm," into a new position few miles farther west (fig. 8).

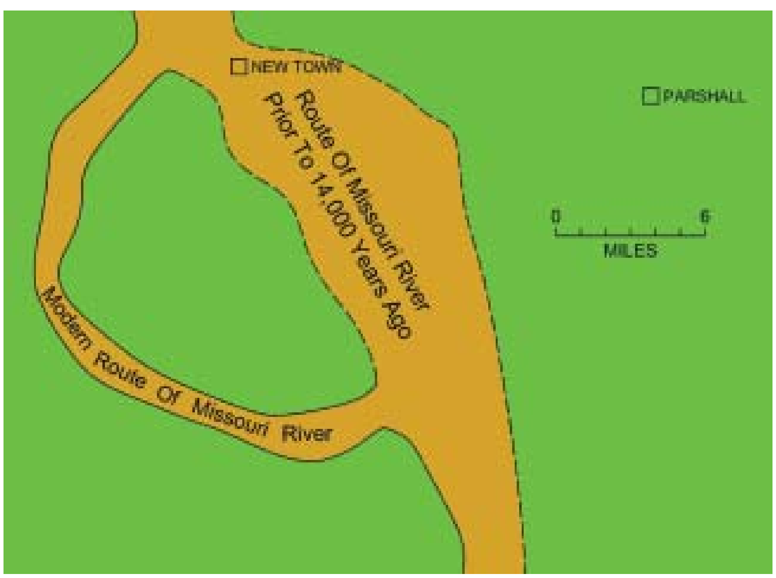

Figure 8. Schematic map showing the old route of the Missouri River at New Town (within the dashed lines) and the more recent route, formed when the glacier diverted the river farther southwest (within the solid lines). This diverted loop of the Missouri River is the youngest portion of its valley through North Dakota. It formed about 14,000 years ago.

I can't go into great detail here about the origin of the Missouri River or discuss every one of the things that contributed to the current route and configuration of the valley. The modern route of the river is only the most recent of many routes that earlier "Missouri" rivers followed through the state at various times during the Ice Age.

Day 2

Glacial Landforms of the Missouri Coteau in North Dakota

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Introduction

The Missouri Coteau is an approximately 50-kilometer-wide upland that extends for more than 1,000 kilometers through southern Saskatchewan, North Dakota and South Dakota. It forms the northeastern edge of the Missouri Plateau and is bounded on the northeast by the Missouri Escarpment, a 100 to 150-meter rise, which separates the Coteau from the lowlands to the east.

In North Dakota the Missouri Coteau is recognized as a distinct physiographic region (fig. 1). It is geomorphologically similar to the Turtle Mountains in north central North Dakota and the Prairie Coteau in the southeastern part of the state, the landforms in all three areas having been created by the same glacial processes. The common outstanding characteristic of these regions is their rugged topography. It consists of closely-spaced hummocks or knobs alternating with marshy depressions known locally as “sloughs” or “prairie potholes”. There is an almost complete absence of streams or any form of integrated drainage and the topography is almost entirely glacial in origin. The glacial sediment, which is more than 150 m thick in places, generally obscures the preglacial topography.

Figure 1. Physiographic Regions of North Dakota showing the extent and location of the Missouri Coteau.

Most of the landforms on the Missouri Coteau are the result of the collapse of sediment that covered a nearly continuous sheet of stagnant glacial ice, which melted down between about 13,000 and 9,000 years ago. Typical landforms include hummocky collapsed topography (hummocky moraine, dead-ice moraine), ice-walled-lake plains, collapsed-stream- and collapsed-lake-sediment topography, and associated disintegration ridges and trenches.

Age and Origin of the Glacial Deposits

The Pleistocene glacial deposits in North Dakota are part of the Coleharbor Group (Bluemle, 1971). This unit is distinguished from other regional late Cenozoic deposits by the presence of crystalline material derived from the Canadian Shield and the Paleozoic rocks surrounding it. It includes all sediments deposited from the first glacial advance from the northeast to the Holocene/Wisconsinan boundary, spanning a time frame of several hundred thousand years. The Coleharbor Group consists of up to 200 meters of a highly complex series of interbedded layers of mainly glaciolacustrine silt and montmorillonite clay, fluvial sand and gravel, and till. Pebbles, cobbles and boulders consist of hard granitoids, gneisses, and basalt from the Canadian Shield, dolomites and limestones from southern Manitoba and Cretaceous shales from eastern North Dakota, southern Manitoba and Saskatchewan.

The surface unit over approximately 90% of Mountrail County, including the portion of the Coteau that passes through it, was deposited by Late Wisconsinan glaciers between about 13,000 and 9,000 years ago (Clayton, 1972) during what is locally designated as the New Town advance. (The New Town ice margin forms part of a series of ice margins that extend northwest- and southeastwards across North Dakota and which, based on geomorphic and lithologic evidence, appear to mark the maximum extent of Late Wisconsinan glaciation. This boundary roughly coincides with the extent and width of the Missouri Coteau.) Evidence suggests that the New Town glacial advance was responsible for the formation of glacial Lake Crow Flies High and the diversion of the Missouri River from the New Town sag to its present position (Clayton, 1972).

Landscape Development

When south- and southwestward-moving glaciers reached the Missouri Escarpment they were forced into an uphill climb over grades as steep as 12% before advancing onto the Coteau. The resultant compressive flow and marginal thrusting within the ice, caused by deceleration as the ice flowed uphill, brought enormous quantities of sub- and englacial debris onto the surface of the glacier (fig. 2). When glacial movement finally ceased, about 13,000 years ago, sediment continued to accumulate on top of the stagnating ice, eventually forming a nearly continuous blanket of superglacial till, many tens of meters thick, over most of the Coteau. During the early stages of melting, this layer of till was spread over an almost unbroken sheet of ice, hundreds of meters thick. Its insulating effect caused the ice to melt very slowly, to the extent that much of it persisted for at least 3,000 years, until 9,000 B.P.

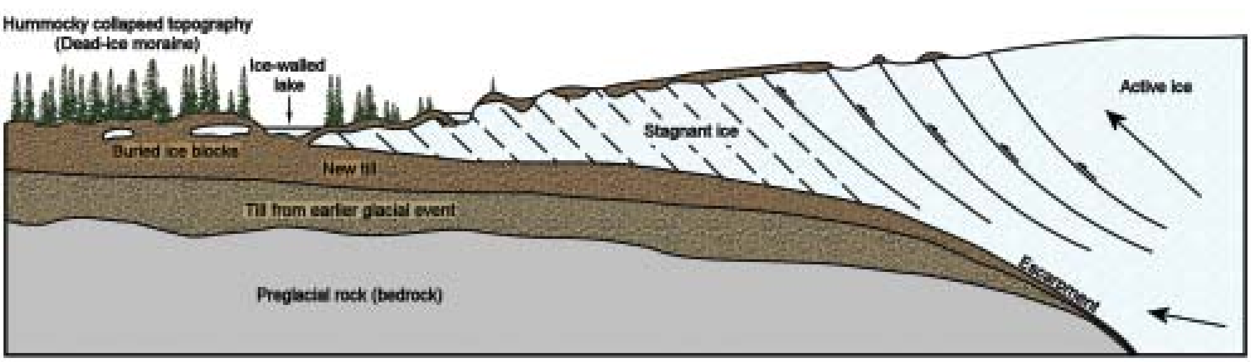

Figure 2. Schematic cross-section through the edge of a glacier (modified from Clayton, 1967). This illustration depicts a situation similar to that which developed when glaciers moved over the Missouri Escarpment and on to the Missouri Coteau. As the glacier advanced upslope the resultant compression caused shearing within the ice, which brought enormous amounts of sediment to the glacier surface. The insulating effects of this thick cover of superglacial material slowed the rate of melting of the underlying ice to the extent that plant and animal communities were able to flourish on top of the deeply buried glacier. The formation of hummocky collapse topography was the end result of this melting process.

The layer of superglacial till was unevenly distributed over the stagnant and dead ice, and consequently its rate of melting was quite variable. The superglacial topography thus became hilly and pitted with depressions as water-saturated, highly fluid till slid from high points on the ice into depressions, insulating the underlying ice in these areas and causing it to melt more slowly than the newly exposed ice higher up, resulting in continual topographic inversions. The final outcome was a landscape of closely spaced, roughly equidimensional, hills and depressions known today as hummocky collapsed topography (hummocky moraine, or dead-ice moraine).

Locally, in low-lying areas, there had been extending flow. Here there had been no marginal thrusting and little, if any, accumulation of superglacial till. The ice in these areas consequently melted faster, forming large, lake-filled depressions or superglacial valleys occupied by sediment-laden streams, which buried large areas of superglacial till under several meters of alluvium.

Within this landscape of dead-ice moraine, the unstable environment of melting ice and shifting topography gave rise to a number of unusual landforms. Disintegration ridges formed when sediment slid into cracks or crevasses in the ice (fig. 3i) or off the edge of a mass of ice (fig 3iii). They may also have formed when wet, clay-rich subglacial sediment was squeezed upwards (figs. 3ii and 3iv) by sinking ice blocks (Eyles and others, 1999) or washed into channels or crevasses by superglacial streams (figs. 3i, 3iii and 3v). Disintegration ridges may be straight or meandering, depending on whether they formed in a crevasse or stream channel. If they originated in a stream channel they may be difficult to distinguish from eskers.

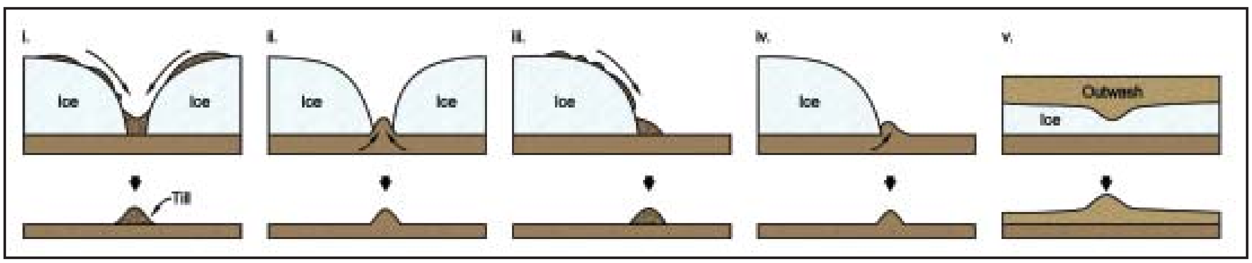

Figure 3. Formation of disintegration ridges in areas of glacial stagnation (modified from Clayton, 1967). Types i and iii involve debris sliding off the ice and piling into a ridge. Types ii and iv involve pushing by a block of glacial ice, or in some instances, squeezing of material from beneath the ice to form a ridge. Type v involves sand and gravel, deposited in a crack in the ice, and left standing as a ridge when the ice melted.

Accumulation of sediment in circular holes resulted in circular disintegration ridges called "doughnuts" (fig. 4). Gravenor (1955) proposed a mechanism consistent with differential melting for their formation: (i) sliding or flowing of superglacial debris into a sinkhole in stagnant ice, (ii) inversion of topography by insulation/exposure of ice by the shifting sediment, followed by mass movement away from the center and down the sides of the buried ice core, and (iii) eventual melting of the ice core. Bik (1967), on the other hand, proposes another origin for "doughnuts", suggesting that they are, in fact, collapsed pingos.

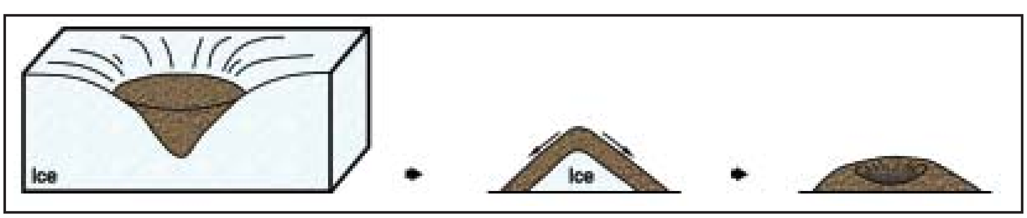

Figure 4. Three steps in the formation of a circular disintegration ridge ("doughnut"). Modified from Clayton, 1967.

“Doughnuts” are commonly breached on opposite sides of the ring and are often aligned like beads on a thread (fig. 5). These breaches are short disintegration trenches formed by the collapse of buried ice-cored crevasse fill (fig. 6). Sinkholes are frequently initiated along crevasses (Russel, 1901), and this stringing together occurs where several develop along a single crevasse. When “doughnuts” are breached in this way, they are referred to, rather whimsically, as “puckered lips”.

Figure 5. Breached circular disintegration ridges (“puckered lips”), indicated by the dashed line, near Powers Lake in Mountrail County.

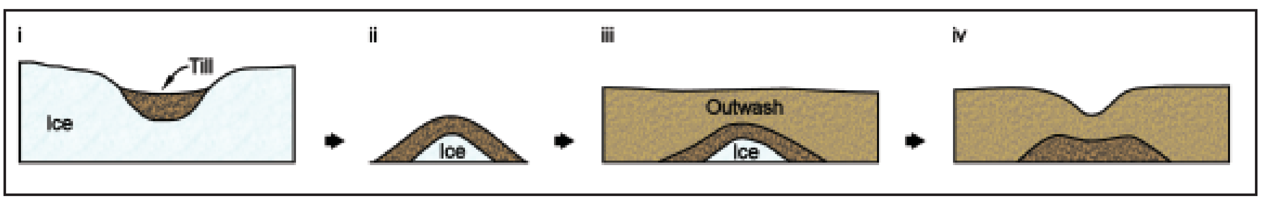

Figure 6. Four steps in the formation of disintegration trenches (modified from Clayton, 1967).

Most disintegration trenches are associated with collapsed superglacial stream sediment, and may have formed via the sequence shown in figure 6. A superglacial channel or crevasse was filled with till (i), resulting in the formation of an ice-cored esker or disintegration ridge when differential melting due to the insulating effects of the till caused topographic inversion (ii). The ridges were buried by stream sediment (iii) and the ice-cores eventually melted, leaving a shallow trench (iv).

Disintegration trenches are typically only a few meters deep, and are best observed on air photos. Most are straight and are only a few meters wide, although they may be several hundred meters in length. Straight disintegration ridges commonly show a strong preferred orientation perpendicular to the direction if ice movement.

Innumerable small lakes filled the depressions on the insulated glacial ice of the Missouri Coteau. As the ice continued to melt, sediment that had been deposited in lakes where the cover of superglacial till was thin collapsed into shallow, concave-up basins (fig. 7). Where the layer of superglacial till was thicker, the residual sediment was left as an elevated, convex-up or “perched” lake plain above the surrounding hummocky moraine (fig. 8).

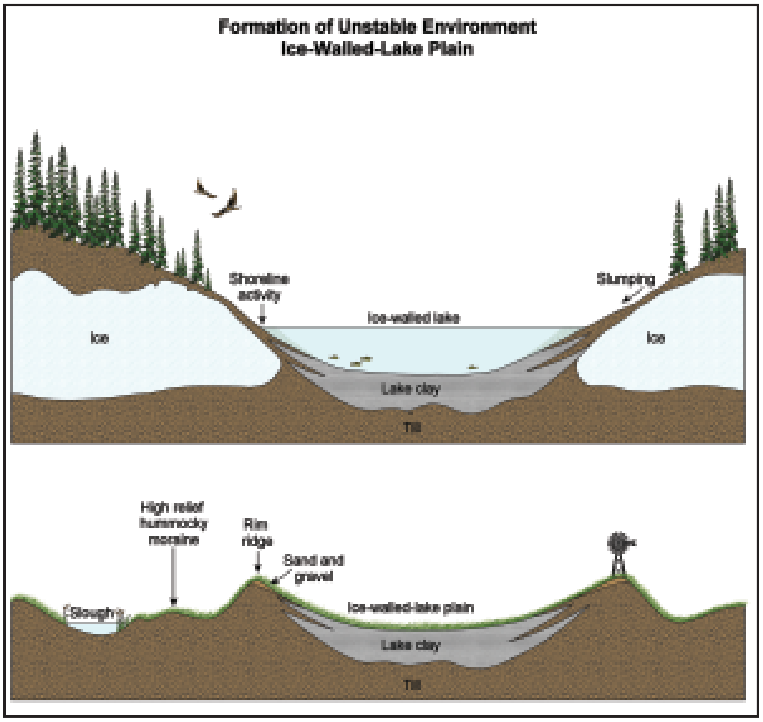

Figure 7. Formation of unstable environment ice-walled-lake plains (modified from Clayton and Cherry, 1967). Sediment is thin on the surrounding ice, causing it to melt rapidly. The large amounts of meltwater thus produced result in lakeward slumping of the confining walls and the deposition of much sediment into the lake itself.

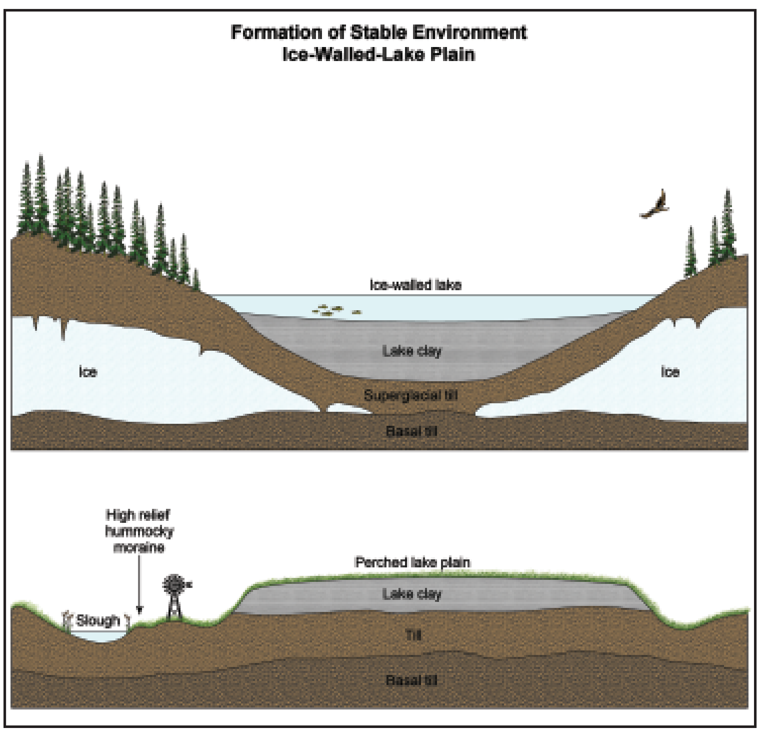

Figure 8. Formation of stable environment ice-walled-lake plains (modified from Clayton and Cherry, 1967). A thick, insulating cover of sediment on the surrounding ice slows its rate of melting resulting in a low energy, quiet water environment, dominated by fine-grained sedimentation. These lakes tend to be long-lived and show a general absence of the mass movement of water-saturated till. Stable-environment ice-walled-lake plains typically do not have rim ridges.

Ice-walled-lake plains that formed in unstable environments where the cover of superglacial sediment is relatively thin and melting is consequently more rapid (fig. 7) tend to have fairly low relief (< 20 m, 65 ft) and are often surrounded by a distinct rim ridge that divides the lake bed from the surrounding dead-ice moraine. The central part of the lake bed is typically underlain by laminated clay, silt and fine sand, which coarsens shoreward into beach sand and gravel. These shoreline and nearshore sediments are frequently interbedded with slumped material derived from debris flows of water-saturated peripheral till (Clayton and Cherry, 1967; Ham and Attig, 1997; Johnson, 2000; Syverson, 2005).

Perched, or stable-environment ice-walled-lake plains formed under conditions where a thick layer of superglacial sediment reduced the rate of melting of the confining ice (fig. 8). Slow melting meant that these types of lakes were relatively long-lived and the amount of sediment deposited in them was consequently greater than that found in unstable-environment lakes (Clayton and Cherry, 1967; Syverson, 1998). These essentially quiet water, low flow regime environments allowed for deposition of fine-grained sediments and a general absence of the mass movement of water-saturated till. For this reason stable-environment ice-walled-lake plains do not have rim ridges. They stand between about 20 and 50 m (65-160 ft) above the landscape and the meters-thick cap of lake sediment shows that they are, indeed, lacustrine remnants rather than flat-topped hills covered with a veneer of postglacial sediment (Clayton, written commun.).

On the Missouri Coteau in North Dakota, ice-walled-lake plains are easily identified both on the ground and on aerial photographs because their level, boulder-free surfaces often appear as isolated areas of cultivated land surrounded by rangeland or native prairie. Their elevated positions in the landscape and/or the presence of a well-defined rim ridge are also common indicators.

Ice-walled lake plains will be discussed further in the Day 2 roadlog.

At first the stagnating glacial environment was very active, with rapid melting of the ice, continuous redistribution of the superglacial sediment, and constant reshaping of the topography. But as the ice continued to melt and the sediment cover grew correspondingly thicker, these processes began to slow down, and the environment became more stable. The water in the lakes and streams became more temperate as runoff from local precipitation gradually replaced glacial meltwater as the predominant moisture supply. Clayton (1967) estimated that during this period of landscape development in North Dakota the amount of runoff derived from melting glacial ice was equivalent to less than 2.5 cm of precipitation a year. Average Precipitation at the time was about 110 cm a year, almost two-and-a-half times what it is today, and the mean annual temperature a few degrees cooler than the current mean of 41° F.

The superglacial ice-walled aquatic environments were well-insulated from the underlying ice by a thick blanket of till. Fish, clams, ostracodes, and other aquatic species thrived in the lakes and streams, which were surrounded by stands of spruce, tamarack, birch, and poplar. Radiocarbon dates (E. C. Grimm, written and oral communs., 2006) from wood, charcoal and spruce needles indicate that this “nonglacial” environment was well-established by about 11,000 years ago and persisted for at least another 1,500 years.

The boreal forests were inhabited by birds and a variety of mammals much greater than is found in North Dakota today. Some, like the mastodon (*Mammut americanum*) and giant ground sloth (*Megalonyx jeffersonii*) are extinct, while others, including the Arctic shrew and snowshoe hare migrated northwards as the climate warmed. A third group of mammals, a legacy of the Pleistocene Epoch, continue to inhabit the state today. Chipmunks, red squirrels, beaver, and white-tail deer are just a few examples of this group. It is also quite likely that some of North Dakota's early human inhabitants lived in these forests that were growing, at least in part, on top of stagnant glacial ice.

Eventually, all of the ice melted, and all of the superglacial sediment was let down, forming the hummocky collapsed topography that is characteristic of the Missouri Coteau today. By about 8,500 years ago most of the boreal forests had given way to grassland as the climate continued to warm and the annual precipitation moderated. Many of the lakes drained or were much reduced in size, while streams dried up and the modern non-integrated drainage pattern developed.

Today much of the Missouri Coteau is used as rangeland and the thousands of sloughs provide important nesting and feeding areas for waterfowl (the so-called North Dakota "duck factory"). In fact, the Missouri Coteau is one of the reasons why North Dakota has more national wildlife refuges (62) than any other state in the nation.

Other theories

Not all geologists subscribe to the idea that the hummocky collapse topography of the Missouri Coteau is necessarily the result of the collapse and letdown of superglacial till over stagnating ice. In studies of hummocky moraine in Alberta Stalker (1960), Eyles, Boyce and Barendregt (1999), and Boone and Eyles (2001,) proposed a subglacial origin of the modern terrain via the deformation of clay-rich till by the overburden pressure of stagnant ice. Further along this line of thought Mollard (2000) suggested that lake clay-rich hummocky moraine was the result of "pressing" beneath blocks of grounded ice following lake drainage. Others (e.g., Munro and Shaw, 1997; Munro-Stasiuk and Sjogren, 1999) believe that hummocky moraine is an erosional feature produced by meltwater in the form of regional subglacial sheetflow.

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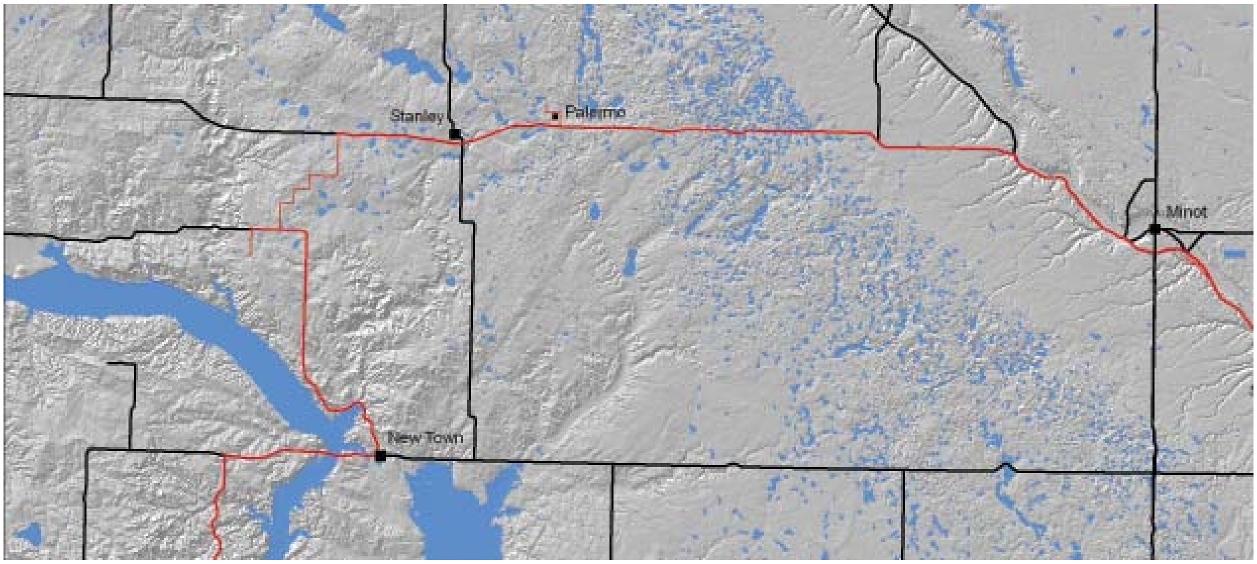
Day 2

Quaternary Geology of Northwestern and North-central North Dakota from New Town to Minot

Lorraine A. Manz, North Dakota Geological Survey, Bismarck, ND



Miles (C = Cumulative, I = interval)

C	I	
0.0	0.0	Leave Four Bears Casino from main parking lot. *Turn right (east) onto ND Highway 23*.
0.1	0.1	Cross Lake Sakakawea via Four Bears Bridge. The bridge is decorated with several emblems and medallions representing the culture and heritage of the Three Affiliated Tribes (Arikara, Hidatsa and Mandan) who live on the Fort Berthold Reservation. The bridge honors two chiefs, one Hidatsa and the other Mandan, who were both named Four Bears. Note the medicine wheel on the hillside just north of the bridge. It is a Sioux motif representing universality. The wheel was put there by Steve White Horn, an Osage Indian from Oklahoma who married into one of the local tribes, as a symbol of the Native Americans' pride in their culture.
0.9	0.8	Sentinel Butte Formation exposed in the cliffs along the eastern shore of Lake Sakakawea.
1.0	0.1	Climb out of the Missouri River Valley.

1.6	0.6	Signpost to Sanish. Residents of the original village of Sanish, which was abandoned and subsequently flooded by Lake Sakakawea, re-established their community on the uplands above the lake. The new village is also called Sanish.
2.0	0.4	Slump on south side of highway.
3.8	1.8	*Turn left (north) onto ND Highway 1804*
		Perched outhouse on south side of junction.
4.4	0.6	Wolf's Trading Post
6.0	1.6	For the next few miles the road passes through some well-developed badlands topography created by the rapid downcutting of numerous small, mostly ephemeral streams through the Sentinel Butte Formation. Since they are formed from the same material these badlands closely resemble the far more extensive and spectacular Little Missouri Badlands in the North Unit of Theodore Roosevelt National Park, about 50 miles (80 km) to the southwest.
7.5	1.5	Abundant glacial erratics on the slopes to the right (east) of the road.
8.4	0.9	Cross the Little Knife River.
9.0	0.6	View of Four Bears Bridge to the left (south) of the road.
13.0	4.0	View to the southwest across Lake Sakakawea of Blue Buttes (fig. 1). Chimney Butte and table Butte are to the right.

Figure 1. View to the southwest across Lake Sakakawea.

19.9	6.9	Brightly colored sediments of the lower (Bear Den) member of the Golden Valley Formation are exposed on the west (left) side of the road near the abandoned schoolhouse.
24.7	4.8	**Point of discussion.** Is the structure that the road cuts through here (figs. 2 and 3) an esker or the rim ridge of an ice-walled lake plain? The esker/ridge appears to emerge from the rim of a well-defined ice-walled lake plain about a mile (1.6 km) to the northeast and trends southwestwards for a distance of about 2.5 miles (4 km). Northwest of the ridge the landscape is dominated by largely uncultivated hummocky collapsed topography, while to the southeast the land is visibly more level, consisting of a mix of wetlands and cultivated areas. Glacial erratics are scattered across the surface of this feature.

Figure 2. An esker or the rim ridge of an ice-walled-lake plain?

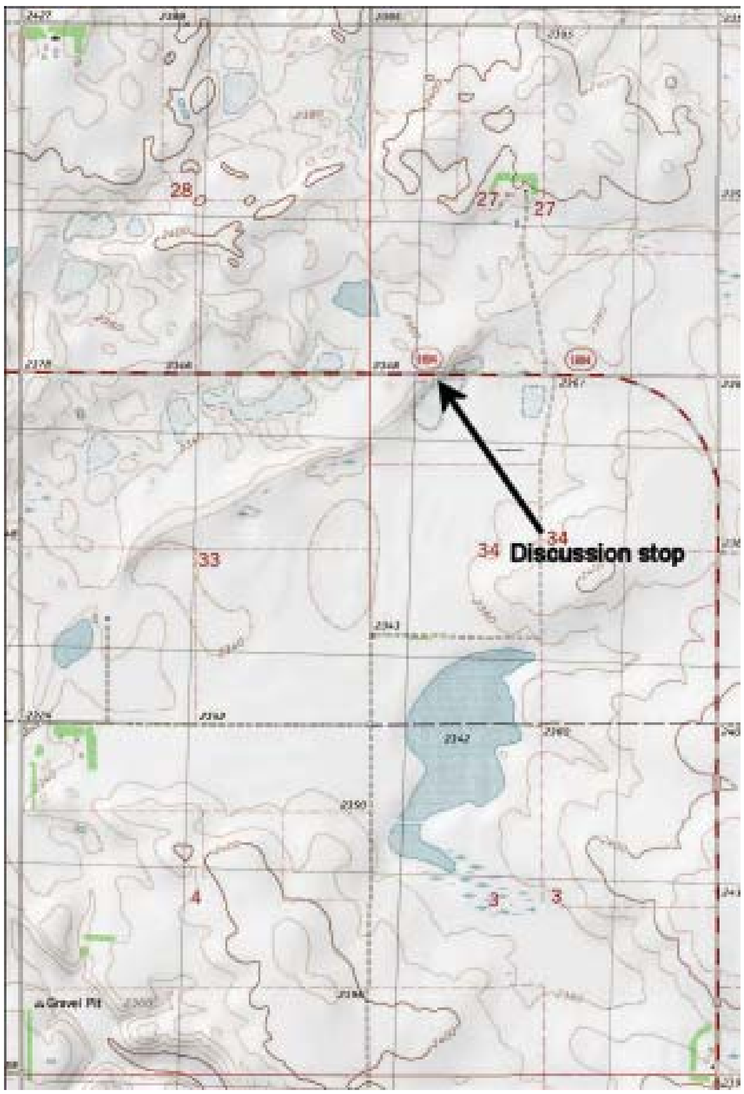


Figure 3. Topographic map with hillshading enhancement showing the location and structural relationship with the surrounding landscape of the feature shown in fig. 2. Rat Lake Quadrangle, 7.5 minute series (topographic) 1981. Scale: ~1:32,000.

27.9 3.2 *Turn left (south) onto 96th Avenue.*

29.9 2.0 STOP 1: Ice-walled-lake plain (fig. 4).

Figure 4. Topographic map with hillshading enhancement showing the location of Stop 1 – a collapsed ice-walled-lake plain located two miles south of ND Highway 1804 in T. 154 N., R. 93 W., Secs. 6 and 7 and T. 154 N., R. 94 W., Secs. 1 and 12, U.S.G.S. Rat Lake Quadrangle, 7.5 minute series (topographic) 1981. Scale as shown.

The fields in this area are newly seeded. Please be considerate and stay on the gravel road or right-of-way.

The best feature of this ice-walled-lake plain is its visibility from the air (see cover photo). As is typical of many ice-walled-lake plains in this area the boulder-free lake bed is cultivated, in contrast to the till-laden hummocky collapsed topography surrounding it. This is a classic example of a low-relief, unstable-environment ice-walled-lake plain (fig. 5). It is clearly dish-shaped, even at ground level, and the maximum relief from the center of the basin to the highest point on the rim ridge (east) is about 10 m. The basin is inclined slightly to the west where the rim ridge is absent, indicating a possible breach point.

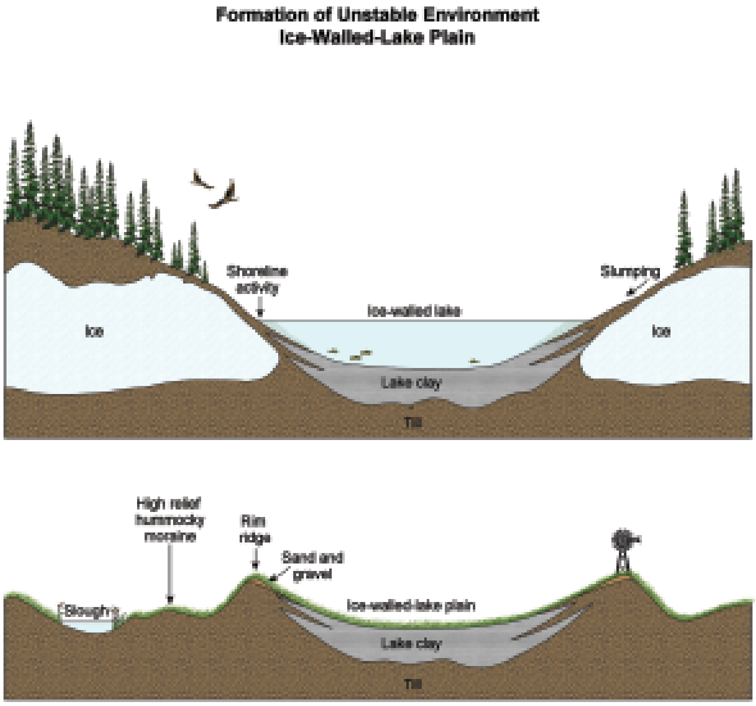


Figure 5. Formation of unstable environment ice-walled-lake plains (modified from Clayton and Cherry, 1967). Sediment is thin on the surrounding ice, causing it to melt rapidly. The large amounts of meltwater thus produced result in lakeward slumping of the confining walls and the deposition of much sediment into the lake itself.

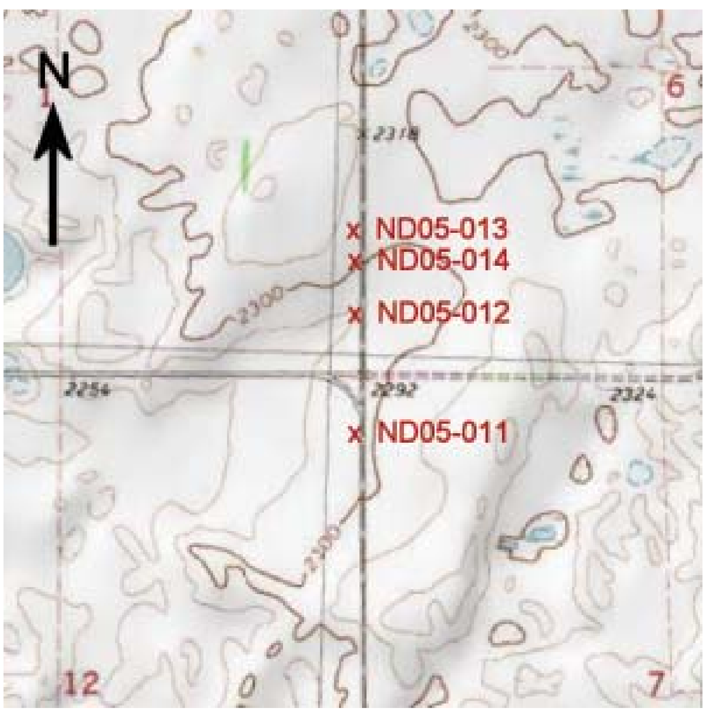


Figure 6. Topographic map with hillshading enhancement showing sampling locations at Stop 1. Rat Lake Quadrangle, 7.5 minute series (topographic) 1981. Scale as shown.

Four cores were collected along a transect from the top of the north rim ridge to the center of the lake basin (fig. 6), covering a horizontal distance of about 0.3 miles (0.5 km). Cores ND05-011 and ND05-012 revealed well-sorted dark grayish-brown (2.5Y 4/2) silty lake clay (fig. 7) to a depth of 4.1 and 3.6 m respectively overlying an olive-brown (2.5Y 4/3) clayey till (fig. 8). A very dark grayish brown (2.5Y 3/2) organic-rich (1.85%) band between 4.4 and 4.7 m in core ND05-012 was tentatively identified as a buried soil horizon (Ulmer and others, oral communs., 2005).

Figure 7. Varved lake sediments from core ND05-011. Depth: ~ 2 m. Individual varves average about 3 mm in thickness.

Figure 8. Till from core ND05-012. Depth: ~ 4 m. This material lies directly below the zone tentatively identified as a buried Ab horizon.

Figure 9. Bottom of core ND05-013. Note the abrupt color change on the extreme left of the core from light olive-brown (2.5Y 5/3) to very dark gray (2.5Y 3/1) that marks the transition to an organic-rich zone, possibly a buried soil horizon.

Upslope, core ND05-014 consisted of about 8 m of olive-brown (2.5Y 4/3) till overlying a one-meter-thick layer of interbedded till and olive-brown (2.5Y 4/4) to dark grayish-brown (2.5Y 4/4) silty lake clay. Below this was a very dark gray (2.5Y 3/1) till. A very dark grayish brown (2.5Y 3/2) organic-rich (1.13%) band between 8.7 and 9.0 m was tentatively identified as a buried soil horizon (Ulmer and others, oral communs., 2005).

Core ND05-013, collected on top of the rim ridge, comprised only till grading in color to 5.9 m from olive-brown (2.5Y 4/3) to light olive-brown (2.5Y 5/3). An abrupt color change at this depth to very dark gray (2.5Y 3/1) marked the transition to a third, organic-rich (2.2%) zone, which continued to an unknown depth (fig. 9). The core descriptions and tentative correlations between units are shown in figures 10 and 11.

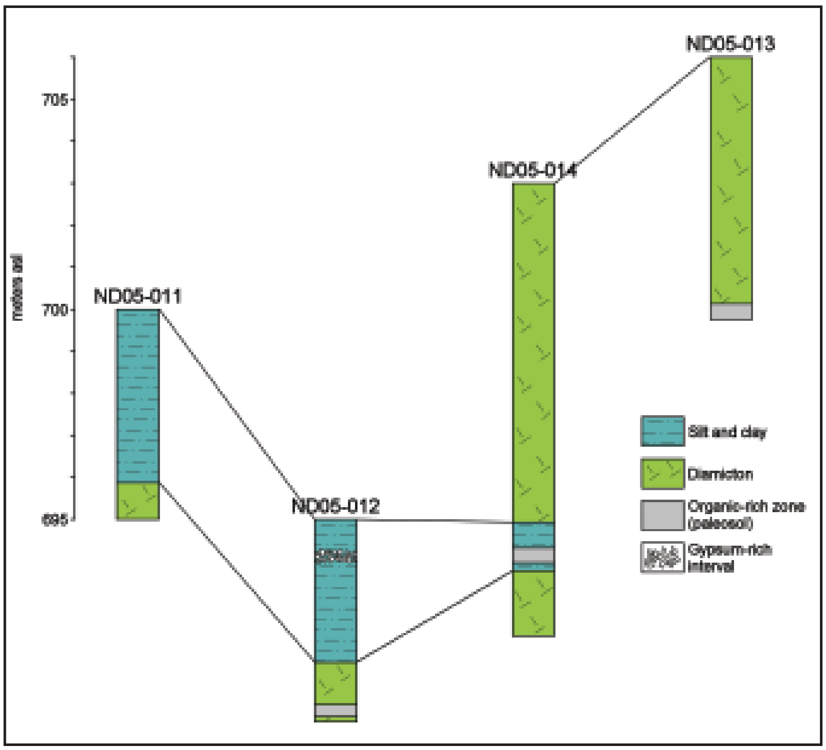


Figure 10. Fence diagram showing stratigraphic relationships between sediments in cores ND05-011 – ND05-014.

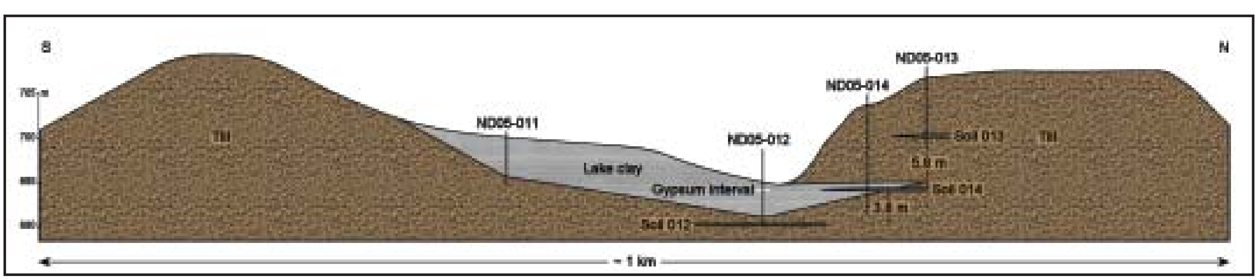


Figure 11. Proposed stratigraphy, based on cores ND05-011 – ND05-014 for the ice-walled-lake plain at Stop 1.

The vertical separation between the three paleosols (3.8 m between 012 and 014, and 5.8 m between 014 and 013) suggests that each represents a different pedogenic event. Those in ND05-012 and ND05-013, which developed in till, are most likely pedogenic in origin. The zone in ND05-014 may also be a paleosol. It is stratigraphically equivalent to an interval in core ND05-012 that is dominated by diagenetic gypsum, indicating that at some stage the lake dried up (figs. 10 and 11). This is supported by a complete absence of aquatic fossils (ostracodes) within this interval, but an increasing abundance with distance above and below it (B.B. Curry, oral commun., 2006; B.B. Curry, 2006).

Attempts to radiocarbon date these paleosols were hampered by the presence of abundant lignite and dark gray, organic-rich shale (Pierre Formation). However, based on dates obtained from other lakes in the region (E.C. Grimm, written commun., 2006) they are assumed to be late Pleistocene/early Holocene in age.

The lake sediments were well-sorted silty to fine-silty clays. Although poorly stratified for the most part well-defined varves up to 3 mm thick were visible at intervals (fig. 7). Small, oxidized iron masses and iron stains were distributed fairly evenly throughout the matrix. Sand-sized gypsum crystals were also scattered throughout the matrix, with isolated, dense accumulations observed at infrequent intervals.

All of the tills were considered to belong to the same unit. They were visually similar with between 5 and 10% coarse fragments (> gravel size) consisting mainly of granitoids and gneisses with minor carbonates and shale (fig. 9). Oxidized iron masses, small (sand-size) gypsum crystals and lignite fragments were distributed unevenly throughout a clayey matrix. Reaction with 1N hydrochloric acid was variable, but mostly within the strong to violent range.

With such limited information there are many sequences of events that could explain the stratigraphy shown in figure 11. One possible scenario is as follows:

1. Original till surface was stable long enough to allow soil 012 to develop.
2. Burial of soil 012 by mass movement or a minor glacial readvance.
3. Formation of the lake, which filled to a level somewhere above the elevation of soil 014 then receded far and long enough to enable soil 014 to develop.
4. The lake level rose again, burying soil 014.
5. Slumping of till into the northern end on the lake terminated deposition here.
6. Soil 013 developed and was subsequently buried by mass movement. Deposition continued elsewhere in the lake until it eventually drained (possibly via a breach along its western side).

This sequence of events is consistent with the concept of a dynamic and unstable environment produced by the differential rates of melting of buried versus exposed glacial ice. Nevertheless, it also raises some questions. For example, what caused the lake level to fluctuate if, indeed it did? Was it a response to a localized climate change such as those that so profoundly affect Devils Lake and other water bodies in eastern North Dakota, or was the lake fed by streams that either dried up or were forced by the shifting topography to alter course?

Return to ND Highway 1804.

31.9 2.0 *Turn right (east) onto ND Highway 1804.*

33.9 2.0 *Turn left (north) onto 94th Avenue NW.*

35.9 2.0 *Turn right (east).*

36.9 1.0 *Turn left (north).*

37.9 1.0 *Turn right (east).*

38.9 1.0 *Turn left (north).*

39.1 0.2 STOP 2: Ice-walled-lake plain (fig. 12).

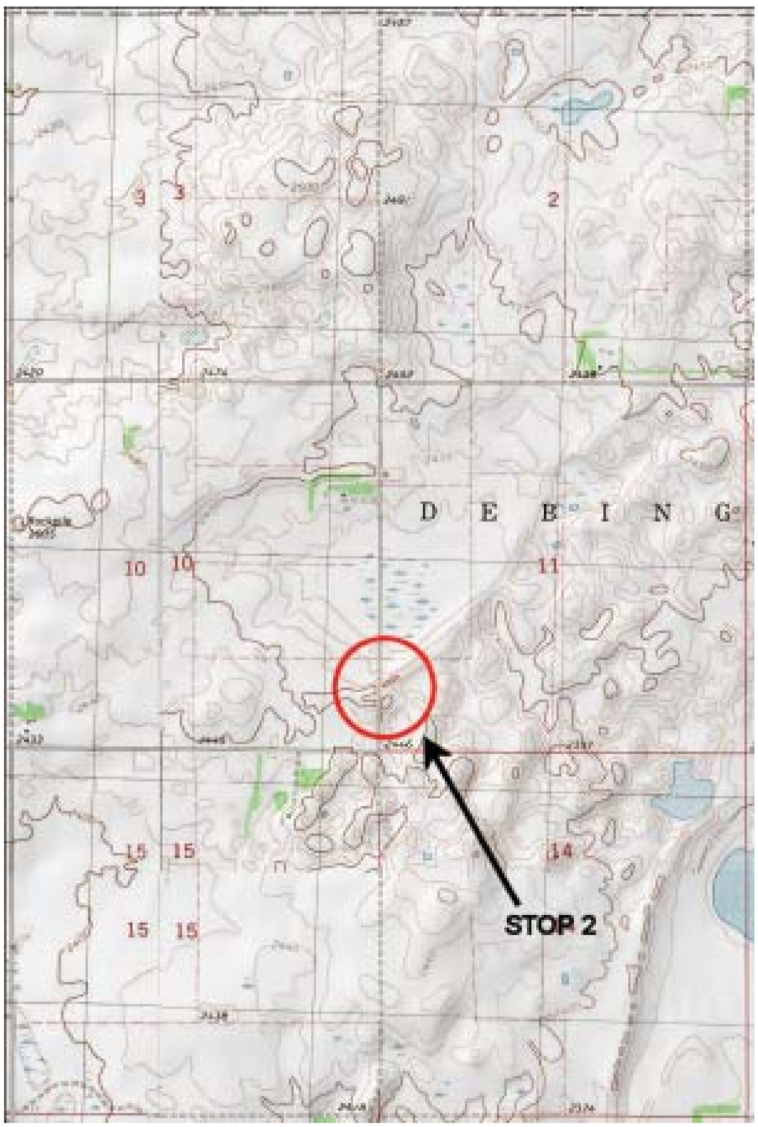


Figure 12. Topographic map with hillshading enhancement showing the location of Stop 2 – a collapsed ice-walled-lake plain located four miles southwest of Ross in T. 155 N., R. 93 W., Secs. 10 and 11, U.S.G.S. Ross Quadrangle, 7.5 minute series (topographic) 1981. Scale: ~ 1:32,000.

The road here crosses the southern rim ridge of an ice-walled-lake plain. The rim ridge can be traced almost full circle except for an area near the farm to the northeast where it becomes quite indistinct. The center of the lake basin is occupied by a seasonal wetland. The ridge consists of till interbedded with thin (~ 30 cm) moderate to well-sorted beach sand and gravel to a depth of at least 8 m. Coring also revealed two organic-rich zones, both developed in till, at 3.9-4.4 and 7.0-7.2 m. A second core, drilled just south of the fenceline consisted of a thin cover (< 1 m) of lake sediment overlying 0.5 m of moderately well-sorted silt and sand over till down to at least 4.5 m. A single shell of V*alvata tricarinata* was found at a depth of about 45 cm very close to this core site.

Pleistocene ostracodes from ice-walled-lake deposits in north-central North Dakota

B. Brandon Curry
Illinois State Geological Survey

Introduction

For the 2006 Midwest Friends of the Pleistocene field trip held out of Bismarck, North Dakota, I processed several subsamples of cores for chironomids, plant macrofossils, and ostracodes. The cores were taken along two transects across separate ice-walled-lake plains at Stops 1 and 2. I scanned twenty-five samples from six cores for fossils, and selected core 05-012 (see fig. 6, p. 102) for further analysis at 30 cm intervals starting at a depth of 1.5 m. The subsamples were dry and weighed about 50 gm apiece prior to processing by following this procedure: 1) the sample was placed in a 500 ml beaker and remoistened with tap water, 2) a pinch of baking soda was added, 3) the beaker was filled with boiling water, allowed to cool, and 4) wet-sieved with a fine shower spray on a Tyler #100 screen (with 180 ìm openings). I transferred the washed material to a Petri dish and identified the fossils under a binocular microscope.

Results

Based on the results of Clayton (1967), I had anticipated finding ostracodes, pelecypods, and plant macrofossils, both terrestrial and aquatic. What I found in nearly all the samples was ostracode valves and abundant, fine to very fine sand sized sesquioxide concretions, gypsum crystals, and lithic grains, the latter of which increased in relative abundance with depth. The gypsum crystals, in some cases doubly-terminated, are diagenetic. I identified two ostracode species: Cytherissa lacustris and Limnocythere ceriotuberosa (fig. 1; Table 1). I was disappointed to find no plant macrofossils for radiocarbon dating. Radiocarbon dating ostracode shells is feasible when the hard-water effect can be approximated (e.g., Curry, 1997), but this is not possible for Pleistocene ice-walled lake deposits

Ostracodes are aquatic microcrustaceans that are sensitive to the conditions of the host water,

Table 1. Abundance of ostracodes *Cytherissa lacustris* (CYTH) and *Limnocythere ceriotuberosa* (LCER) in core 05-012.

Depth (inches)	**Depth (cm)**	**CYTH**	**LCER**	**Notes**
60	152	26	28	Laminated silt from 60 to 132 inches
72	183	0	0	Only abundant gypsum crystals
84	213	6	24	
96	244	3	2	Secondary carbonate flakes
108	274	3	155	
120	305	5	87	
132	335	0	1	Laminated silt
144	366	0	0	Coarse, med., fine sand; no gypsum
156	396	0	0	As above, with some small gravel
168	427	0	0	As above, with gravel

Figure 1. Ostracodes from core 05-012, 60 inch depth. Top row, *Cytherissa lacustris*; second row, *Limnocythere ceriotuberosa*, males; third row, *L. ceriotuberosa*, females.

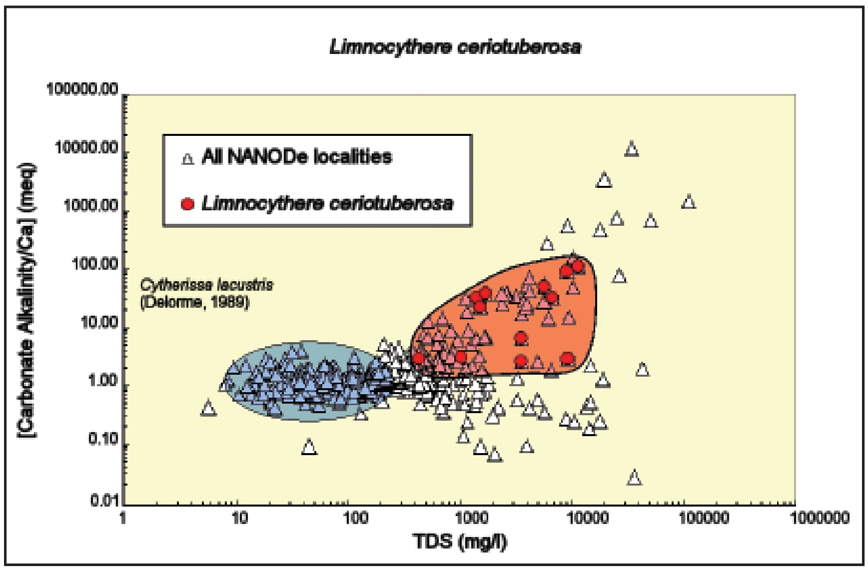


Figure 2. The “chemical space” inhabited by *Cytherissa lacustris* (blue) and *Limnocythere ceriotuberosa* (orange). The figure is modified from NANODE (Forester et al., 2006).

including water depth, temperature, currents, and solute chemistry, both in terms of concentration and composition (Smith, 1993; Curry, 2003). They are also sensitive to the variability of these parameters. Although they can inhabit a variety of aquatic habitats, the two species discussed here are benthic.

The co-occurrence of Cytherissa lacustris and Limnocythere ceriotuberosa has not been described previously in the literature either alive (Forester et al., 2006) or in the fossil record. Based on their modern distribution and hydrochemical affinities (fig. 2; Delorme, 1989), I would not expect to find them living in the same body of water. Cytherissa lacustris lives in relatively deep water with low total dissolved solids (TDS; 10-250 mg/L); in small to moderate-size lakes; the associated vegetation is boreal forest. Limnocythere ceriotuberosa, on the other hand, lives in prairie lakes with high TDS (300-10,000 mg/L) in which bicarbonate and carbonate anions are enriched relative to calcium ions (Smith, 1993; fig. 2). Modern C. lacustris-bearing lakes are associated with a positive moisture balance (i.e., precipitation exceeds evaporation), and L. ceriotuberosa-bearing lakes, a negative moisture balance.

I have found Cytherissa lacustris in glacial lake sediment deposited in ice-walled lakes, proglacial lakes, and slackwater lakes in Illinois (Curry and Yansa, in press) and Wisconsin (Maher et al., 1998).

This is the first occurrence of Limnocythere ceriotuberosa from an ice-walled lake deposit. The absence of Fabaeformiscandona rawsoni is surprising since it is very abundant in prairie lakes, including Devils Lake, North Dakota (Forester et al., 2006; Engstrom and Nelson, 1991) and in Lake Manitoba where it occurs with L. ceriotuberosa (Curry, 1997). What makes this all the more curious is that I find F. rawsoni in abundance with C. lacustris (as well as Limnocythere friabilis) in some ice-walled-lake deposits in Illinois.

Based on their current hydrochemical affinities, the ostracodes suggest that there were two sources of water within the lake. L. ceriotuberosa may have inhabited lake bottom muds saturated with upward flowing saline groundwater from long, regional flow paths (fig. 3). C. lacustris, on the other hand, inhabited shallower muds saturated with shallow low-salinity groundwater from the local melting ice and precipitation. This interpretation is consistent with the disintegration of the ice as the lake evolved, and upcore gain in abundance of Cytherissa lacustris. It is important to remember in this interpretation that these benthic ostracodes did not live in the water column, but in the mud within a few centimeters of the sediment/water interface.

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Continue north along gravel road.

39.9 0.8 *Turn right (east).*

41.9 2.0 *Turn left (north).*

44.9 3.0 *Turn right (east) onto U.S. Highway 2.*

45.8 0.9 Town of Ross.

A very well-defined rim ridge was leveled here to make way for the new eastbound carriageway of U.S. Highway 2 (figs. 13 and 14). What is left of the ridge can be seen a few yards further on where it continues to run parallel to the road for a short distance before trending away to the southeast.

Figure 13. Photograph taken ca 1970 of the southwest margin of the ice-contact side of an ice-walled-lake plain near Ross. (Photo by Lee Clayton.)

Figure 14. The same view taken in April 2006.

The First Islamic mosque in the U.S. was built near Ross by Lebanese/Syrian immigrants in 1929. Some thirty years earlier pioneer Hassen Juma, settled on 160 acres in the area and by 1902 had been joined by 20 more families from his homeland, seeking a better life. These people were denied naturalization in their new country until 1909 when the U.S. finally withdrew its ban. Thereafter the Lebanese/Syrians began claiming citizenship and many fought and died in the two world wars.

The Mosque was torn down in the 1980s but the Islamic cemetery remains, its entrance marked by an arched gateway adorned with a crescent and star. Buried there are community elders including veterans of America's foreign wars.

46.3	0.5	The road crosses the bed of an ice-walled-lake plain bordered by the rim ridge we have just seen.
47.9	1.6	Ascend out of the lake bed. Sediments (now covered) in a roadcut on the north side of the road consist of layers of poorly stratified sand and gravel, which dip away from the lake, suggesting slumping of the rim ridge.
48.1	0.2	Missile silo on the right (south) side of road. A legacy of the Cold War, this silo is one of 150 in northwestern North Dakota that remains active. These silos are under the command of the Minot Air Force Base, and while no longer on alert they continue to house Minuteman ICBMs. Between 1999 and 2001, 150 Minuteman missile silos in eastern North Dakota were demolished under the 1989 Strategic Arms Reduction Treaty I, signed by Mikhail Gorbachev, the then Soviet head of state, and President George Bush. The remaining 150 were not included in the treaty. At the height of the Cold War in the 1960s, the state of North Dakota was one of the world's largest nuclear powers, ranking third behind the United States as a whole and the Soviet Union.
52.6	4.5	Town of Stanley.
53.2	0.6	The Maranatha Assembly of God on the right (south) side of the road is built on top of a small perched lake plain.
53.8	0.6	Junction of U.S. Highway 2 with ND Highway 8.
56.6	2.8	Large glacial erratic in yard on the right (south) side of road.
61.1	4.5	*Turn left (north) towards Palermo.*
62.1	1.0	*Turn left onto Elton Avenue.*
62.9	0.8	Rest Haven cemetery.
63.1	0.2	*Turn right onto gravel road.*
63.4	0.3	Large gravel pit to the right (east) side of road (fig. 15). This is a very old pit, one of many in the area, which were quarried into collapsed, superglacial channel sediments. Deposits consist of flat-bedded well-sorted sand and gravel that in places show marked evidence of deformation in the form of folded and faulted bedding. The partially quarried structure to the west (fig. 16) may be the remnants of a kame. Local resident Kenneth Lystad commented that this pit was also a water stop for trains using the Burlington Northern railroad, which skirts its southernmost end. Remnants of railroad tracks can also still be found within the pit itself.

Figure 15. Large gravel pit near Palermo. View is to the south.

Figure 16. Partially quarried kame(?) near Palermo. This structure lies a few tens of meters west of the gravel pit shown in fig. 15.

Return to U.S. Highway 2.

65.6 2.2 *Turn left (east) on State Highway 2.*

67.5 1.9 Playa lake about 1 mile north of the road (fig. 17).

Many of the lakes in northwestern North Dakota contain brine throughout much of the year. Sulfate concentrations exceed 100,000 milligrams per liter (mg/l) in many of these lakes. The salt content of these lakes typically is lowest in the spring and increases throughout the year until it reaches a point in the late summer and fall when evaporation and cooling water temperatures cause Glauber salt (sodium sulfate decahydrate, $Na_2SO_4 \cdot 10H_2O$) to be precipitated. In fact, like the one visible to the north, many of these are playa lakes; that is, they routinely go completely dry in the late summer and fall. Due to the high salinity of the water, most of these lakes contain little or no aquatic life, with the exception of brine shrimp.

Figure 17. Playa lake about 3 kilometers east of Palermo. There is no ice in this picture. The white material on the lake surface is Glauber salt (sodium sulfate decahydrate).

Scientists believe that sodium sulfate crystals (as mirabilite) began forming in some of the shallow lake bottoms in the northwest portion of the state shortly after the end of glaciation approximately 12,000 years ago. Many of the lakes in this area contain layers of sodium sulfate crystals that are from a few centimeters to over 6 m (20 ft) thick. It is estimated that 46 million tons of Glauber salt lie beneath just fifteen lakes in northwestern North Dakota.

Historically, the main use for Glauber salt has been in the production of Kraft paper. It is also used as filler in powdered laundry detergents and as a raw material in the manufacture of ammonium sulfate.

74.4 6.9 Signpost to Blaisdell

75.9 1.5 Abandoned gravel pit on the right (south) side of road.

81.6 5.7 Ward County line.

At about this point the road begins a gentle descent off the Missouri Escarpment, which separates the rugged, hummocky collapsed moraine of the Missouri Coteau from the more subdued topography of the Glaciated Plains. The Missouri Escarpment is also considered to mark the boundary between two major U.S. physiographic provinces: the Central lowlands to the east and the Great Plains to the west.

86.1 4.5 Road crosses Burlington Northern railroad.

88.6 2.5 Missile silo on the right (south) side of road.

89.3 0.7 Cross Burlington Northern railroad.

90.1 0.8 Town of Berthold.

96.3 6.2 Cross Lonetree Coulee.

99.0 2.7 Begin descent into Des Lacs River Valley.

The Des Lacs River joins the Souris (Mouse) River at Burlington, a few kilometers east of here. Both river valleys are spillways, formed by the catastrophic draining of meltwater from glacial Lake Regina in Saskatchewan into glacial Lake Souris, which occupied most of northern McHenry County (fig. 18).

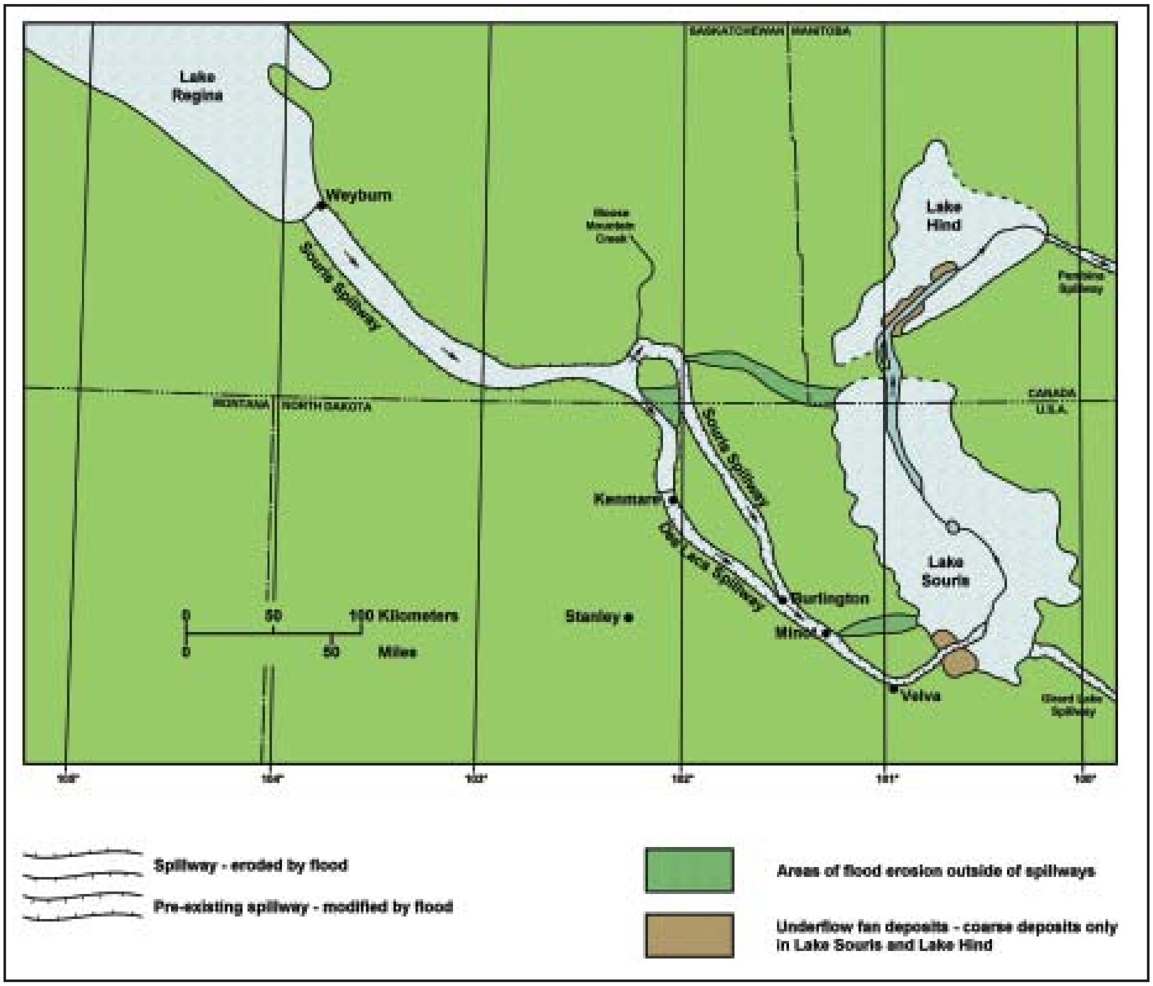

Figure 18. Map showing the routes of the Souris and Des Lacs spillways, now active river valleys, which were formed as a result of the catastrophic draining of glacial Lake Regina into glacial Lake Souris.

The Souris spillway begins as a broad, shallow 8-kilometer (5-mile) wide channel that merges upvalley with the floor of glacial Lake Regina near Weyburn, Saskatchewan. Immediately downvalley from this outlet, the spillway consists of an inner trench that is about 0.8 km (0.5 mi) wide and as much as 45 m (150 ft) deep. Both sides of the inner trench are flanked by erosional, terrace-like surfaces that are up to six kilometers (four miles) wide. These upper surfaces, which are continuous upvalley with the floor of the Lake Regina outlet, contain conspicuous longitudinal grooves parallel to the inner channel. The grooves have been modified in some places by Holocene erosion and they now comprise segments of intermittent tributaries to the inner channel of the spillway. The lower part of the upper erosional surface is mantled by a discontinuous lag deposit of coarse sand and gravel.

The inner channel generally maintains a regular channel shape along its course, with nearly constant width and depth. In places, the inner channel bifurcates into two parallel trenches separated by a narrow ridge. About midway between the Lake Regina outlet and the international border, the inner channel becomes broad and shallow for a short distance. In this area, glacial sediment is thin, and the inner channel is cut entirely into the Paleocene bedrock. Drill holes on the floor of the inner channel near Minot indicate a thickness of 41 to 50 m (135 to 165 ft) of mostly fine-grained, dark-colored, fossiliferous alluvium, colluvium, and lacustrine sediment. Coarse sand and gravel at the bottom of the Holocene valley fill, which could have been deposited by the glacial spillway flood, is either thin or totally lacking in some places. The original erosional depth of the inner channel, prior to deposition of Holocene sediment, was as much as 105 m (350 ft).

In the vicinity of the international border, the spillway splits into two branches. One branch consists of a continuation of the broad upper surface across a low drainage divide to the south. For several kilometers, no inner channel exists in the broad, grooved surface; however, over a distance of about 40 km (25 mi), an inner channel 1.6 km (1 mi) wide and 41 m (135 ft) deep develops. This spillway, the Des Lacs spillway, rejoins the Souris spillway north of Minot. The Des Lacs spillway has two topographically different segments. The valley sides of the lower segment are much more deeply dissected by gully erosion than those in the upper segment. In addition, the lower segment has no scoured upper surface. Non-eroded, hummocky topography extends to the edge of the spillway. Therefore, it is apparent that floodwater from the Lake Regina discharge was channeled into a pre-existing drainageway and that bankfull flow in the lower Des Lacs spillway was never achieved.

Downstream from the point where the Souris spillway bifurcates at the international border, the main branch of the spillway makes several relatively tight meanders and then trends southeastward to the point where it is rejoined by the Des Lacs spillway near Minot. This segment of the spillway consists of a trench 1.6 to 3 km (1 to 2 mi) wide and 45 m (150 ft) deep and, like the Des Lacs spillway, it has an upper level. Because both the lower reaches of the Souris and Des Lacs spillways lack erosional surfaces and are larger than the inner channel near Lake Regina, it is likely that the lower segments of both spillways were pre-existing drainageways that were scoured and deepened by discharge from glacial Lake Regina.

Along the path of the Souris spillway downvalley from the main bifurcation, water spilled out of the channel and flowed eastward in several locations. The most spectacular example of such overflow can be seen downvalley from the point where the Souris and Des Lacs spillways join. Just west of Minot, the spillway makes a sharp bend to the east, and then, east of Minot, it makes another sharp bend to the southeast. At this second bend a large part of the flow from the main channel breached the east wall of the channel and continued eastward along a more direct path to the glacial Lake Souris basin. While flowing out of the channel, the water eroded the channel wall to about a third of its normal height in that area. Just beyond the breakout point on the channel, the water eroded a plexus of anastomosing channels in the glacial sediment adjacent to the spillway. Streamlined fluvial erosional forms are present in this area, but the anastomosing channels contain no fluvial channel deposits near their heads. Farther along the flood path, the channels diverge around obstacles that must have been higher than the flood-water surface. Channel deposits consisting of coarse gravel in point-bar positions in channel meanders are more common with increasing distance from the Souris spillway. The water continued to flow eastward to the glacial Lake Souris basin.

Depositional features of the massive discharge from glacial Lake Regina and associated spillway erosion include huge point bars located at the inside of each spillway meander. The flat to gently undulating upper surfaces of the bars are mantled with boulders up to 3 m (10 ft) in diameter. The boulders are probably a lag deposit that formed as discharge and velocity dropped, causing their deposition. The bars project as much as 25 m (80 ft) above the present valley floor. Test-hole lithologic logs indicate that coarse sand and gravel extend into the subsurface along the valley wall. One of the largest bars in either spillway occurs just west of Minot, but is not visible from Highway 2. This bar, which has been extensively quarried for sand and gravel, consists of an upper level of moderately well-sorted and cross-bedded sand and gravel that looks much like most normal outwash deposits in the area. The lower section of the bar, however, is composed of poorly sorted, nonbedded gravel containing very large boulders. Some of the boulders are nonresistant lithologic types such as glacial till and Paleocene sandstone, shale, and lignite, which must have been deposited quite near their source. One chunk of lignite weighing two tons was removed from this deposit and burned for fuel. This lower part of the bar suggests a rapid decrease in current velocity, resulting in dumping of material eroded just upstream. Such deposition could be the result of a flood terminating with a rapid drop in discharge soon after peak discharge had been achieved.

100.7 1.7 Large slump on the right (south) side of the road next to the U.S Highway 52 overpass (fig. 19).

Figure 19. Slumping along U.S. Highway 2 near the junction with U.S. Highway 52.

Landslides have occurred along the valley sides of the Des Lacs and Souris rivers, especially where the bedrock-glacial contact is close to the surface. Most of the landslides occurred during or soon after the catastrophic flooding and scouring of the valleys as the bedrock materials were subjected to a loss of lateral support. Because the geologic history of the Fort Union Group sediments has resulted in a condition known as overconsolidation, exposure during erosion or excavation causes rebound or volume expansion of the sediments with accompanying loss of strength. Other factors, such as bedding composed of alternating coarse- and fine-grained sediments and aspects of groundwater flow, influence the stability of slopes in the Fort Union Group. In the western part of the Des Lacs valley, the bedrock-till contact occurs well above the present valley floor. Abundant landslides and slumps, ranging from old to presently active, characterize the valley and tributary slopes.

The landslides typically consist of parallel slump ridges and slump blocks. Material within the slump blocks remained mostly intact and relatively undisturbed. With several exceptions, such as the one here, landslides in the area appear to be inactive.

More roadside slumps become visible as we progress along the valley bottom, such as those at mile 101.8 and 102.0

101.1 0.4 Large gravel pit on the left (north) side of road.

103.8 2.7 Large gravel pit on the left (north) side of road.

104.9 1.1 Town of Burlington.

Road turns southeastward.

106.8 1.9 Abandoned coal mine on the right (southwest) side of road.

Lignite coal was mined throughout Ward County between about 1900 and 1986. Most of the mining was along the Souris and Des Lacs Rivers where underground mines were opened into the valley walls.

The coal mined in the Des Lacs and Souris river valleys came from the stratigraphically lowest of three major lignite seams, the Burlington bed, that occur in Ward County. This bed outcrops at an elevation of about 490 m (1,620 ft) along the river valleys and was mined extensively in the vicinity of the town of Burlington. Lignite in the Burlington bed may be as much as 3 m (11 ft) thick. Testhole data indicate that the bed is overlain by as much as 60 m (200 ft) of glacial deposits and Tertiary sedimentary rocks. Original reserves in the Burlington bed were estimated at over 725 million short tons.

110.7 3.9 City of Minot.

112.9 2.2 Old Minot Landfill and Superfund Site on the left (northeast) side of road.

The open area set back a few hundred yards to the left of the highway is the site of the Old Minot Landfill. Originally about 0.2 km^2 (45 acres) in extent, the site operated as a landfill between 1945 and 1971, receiving both industrial and municipal wastes. Beginning in 1985 the North Dakota Health Department and the EPA identified an alarming number of toxic chemicals, including benzene and several of its derivatives, PCBs, arsenic, and lead, in the soils, sediments, surface and groundwater in and around the site. Gases generated by decomposing material in the landfill were found to contain about 20% methane, bubbles were observed in standing water and the place stank.

The EPA designated the Old Minot Landfill a Superfund Site in 1989. Cleanup involved the installation of drains to collect leachate for transfer to the City of Minot waste-water treatment plant; and a clay cap over the top of the landfill through which the landfill gases could be safely vented. Installation of a ground water monitoring system and the implementation of regulations to control land use in and around the landfill completed the cleanup process and the Final Remediation Action Completion Report was approved in 1996. The facility was officially removed from the National Priorities List (NPL) in 1997.

According to the first five-year review, which was released by the EPA in 2001, the site remains under control. Good news for the owners of the properties that are slowly encroaching upon this piece of prime real estate.

114.7 1.8 Junction of U.S. Highways 2 and 83.

Reference

Curry, B.B., 2006, Pleistocene ostracodes from ice-walled-lake deposits in north-central North Dakota, *in* Quaternary geology of the Missouri River valley and adjacent areas in northwest-central North Dakota – guidebook and miscellaneous short papers prepared for the 52nd annual field conference of the Midwest Friends of the Pleistocene in northwest-central North Dakota, 2 to 4 June 2006: North Dakota Geological Survey Geologic Investigations No. 24, 163 p.

Day 2

Quaternary Geology of Northwestern and North-central North Dakota from Minot to Bismarck via Velva, the Hogback Ridge and Anamoose

Fred J. Anderson, North Dakota Geological Survey, Bismarck, ND
John P. Bluemle, Bismarck, North Dakota

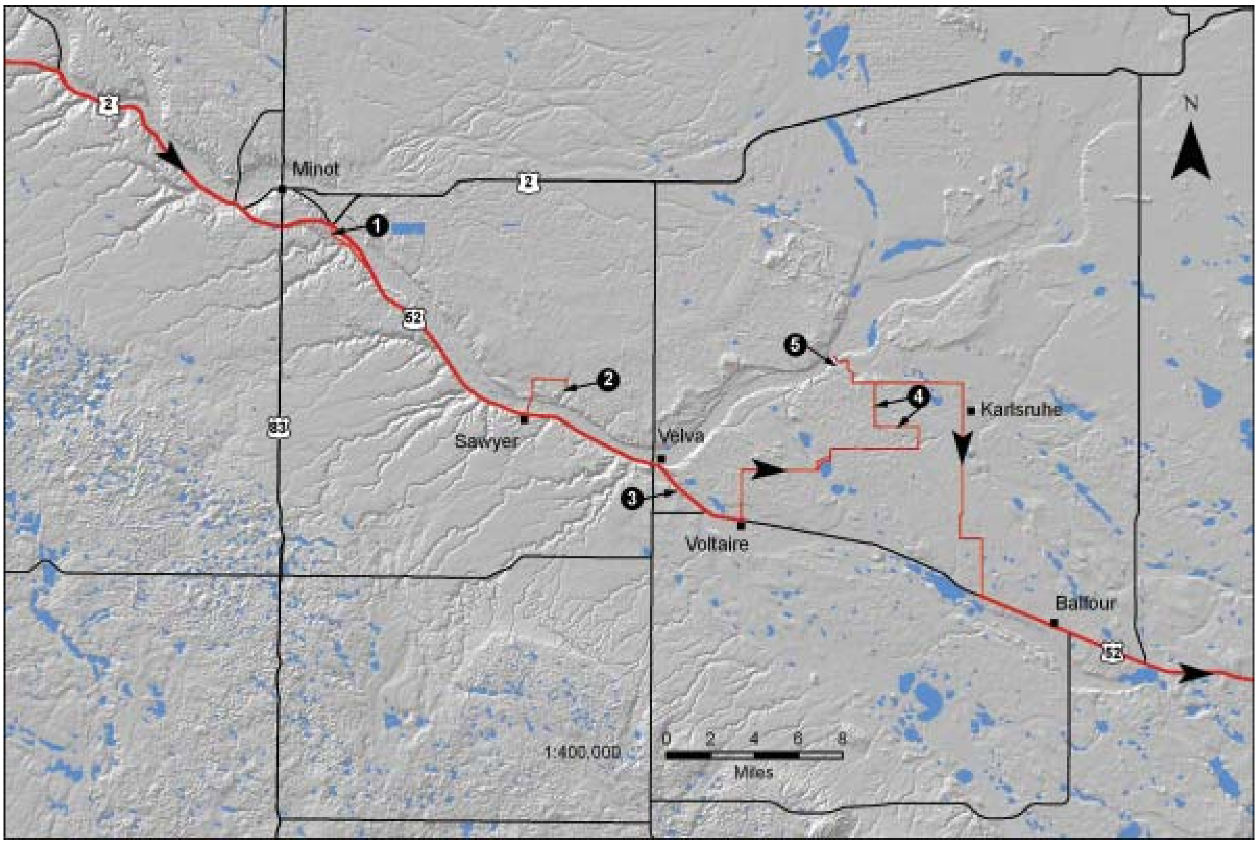

Figure 1. The fieldtrip route for Day 2, Minot to Anamoose.

Miles (C = Cumulative, I = interval)

C	I	
0.0	0.0	*Begin in Minot at junction of U.S. Highway 83 and U.S. Highway 2 and 52 bypass (fig.1). Proceed east on U.S. Highway 2 and 52 bypass.*

Turn right onto off-ramp. Take next immediate right (21st Avenue SE) and proceed off the ramp along frontage road.

Turn left on County Road 19 and proceed around the southwestern edge of river terrace and Souris River gravel pit.

STOP 1: Souris River Terrace and Gravel Pit (fig. 2)

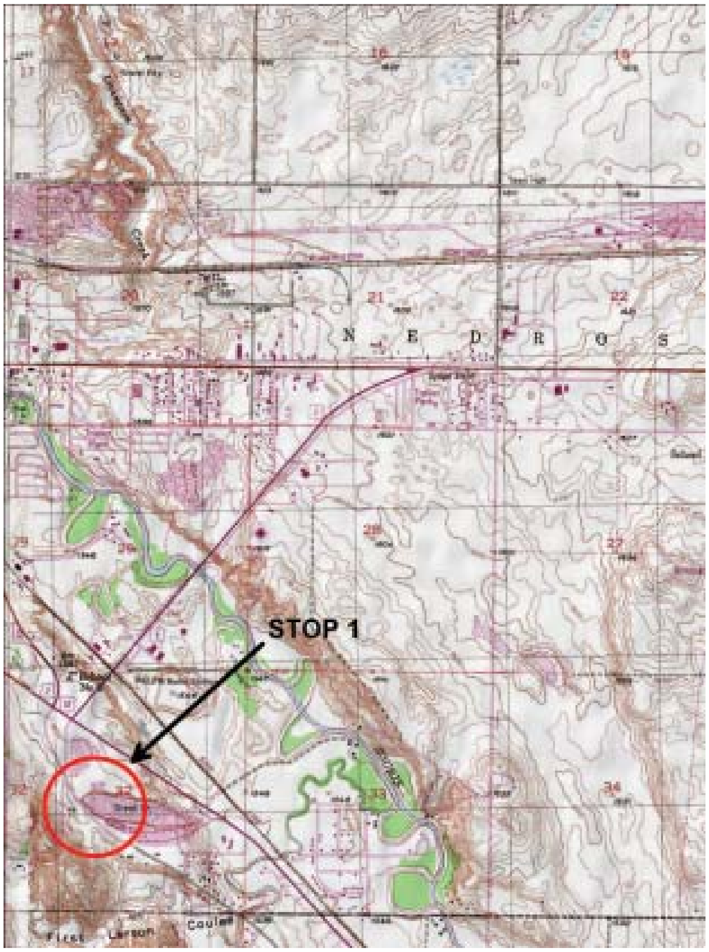

Figure 2. Topographic map with hillshading enhancement showing the location of Stop 1 – Souris River Terrace and Gravel Pit, located 2 miles southeast of the city of Minot, ND in T. 155 N., R. 82 W., Sec. 32, U.S.G.S. Surrey Quadrangle, 7.5 minute series (topographic) 1989.

This stop is located along one of the many river terraces formed within the Souris River Valley southeast of Minot and has been the location for many years of a sand and gravel extraction operation (fig. 2). This location provides a view of what remains of the fluvial terrace created during Pleistocene channel flow around the southern margin of the Souris Lobe, across the Souris River Valley floodplain, out upon the discharge plain that eroded into glacial till sediments when glacial meltwaters spilled out from within the Souris River Valley onto the till plain. The eroding of an anastomosing set of shallow channels permitted high flow of glacial outburst floodwaters northeast into glacial Lake Souris (Kehew, 1979).

The deposits found within these terraces generally consist of planar-bedded, poorly sorted, very coarse grained gravels that contain boulders with diameters in excess of 2.5 m (8 ft) (fig. 3). Typically these boulders contain resistant lithologies like Precambrian-age glacial erratics as well as boulders of less resistant glacial till or lignite. The presence of large boulders within these terrace sediments, in addition to coarse overall grain sizes and presence of bedding is suggestive of high flow velocities providing rather short, rapid transport and deposition (Kehew, 1983).

Figure 3. Selected boulders obtained from the sand and gravel operation located within the gravel terrace deposits southeast of Minot, North Dakota. Size of boulders and lithology are suggestive of rapid sediment transport and deposition in a high flow velocity setting, interpreted to be outburst flows associated with the drainage of glacial Lake Regina (Kehew, 1983).

Continue on County Road 19 to 37th Avenue SE.

Turn left on 37th Avenue SE and continue towards intersection of U.S. Highway 52.

Turn right and proceed southeast towards Velva on U.S. Highway 52.

5.7	5.7	Bell School.
6.0	0.3	Ascend out of the Souris River Valley onto terrace sands and gravels.
8.2	2.2	North access road into Logan.
9.2	1.0	South access road into Logan.
9.4	0.2	Descend back into the floodplain floor of the Souris River Valley.
11.3	1.9	Goheen’s Ranch on the left.
14.7	3.4	Approaching the City of Sawyer, northeast (left) of the highway.
14.9	0.2	View to the northeast of Black Butte across the floodplain of the Souris River Valley.
16.3	1.4	Overlook to the northeast of Black Butte across the floodplain of the Souris River Valley and the City of Sawyer.
16.5	0.2	Southeast access road to the City of Sawyer, *turn left and follow into town.*
17.5	1.0	City of Sawyer, heart of the downtown area. *Turn right onto Main and proceed north across railroad tracks towards and across the Souris River.*
17.9	0.4	Crossing the Souris River, *continue on gravel road to Sawyer Cemetery ahead.*
19.0	1.1	T-Intersection at Sawyer Cemetery. *Turn right on gravel road.* Traveling over typical ground moraine of the Souris Lobe.

20.5 1.5 STOP 2: Black Butte (fig. 4)

Figure 4. Topographic map with hillshading enhancement showing the locations of Stop 2 – Black Butte, a glacial kame, located 1.5 miles northeast of the city of Sawyer, ND in T. 153 N., R. 81 W., Sec. 1, SE ¼, U.S.G.S. Sawyer Quadrangle, 7.5 minute series (topographic) 1981.

Second stop at Black Butte (fig. 4). At first glance it appears odd that this glacial landform has been named Black Butte as it is neither black nor a butte in the traditional vernacular of North Dakota geomorphology. The feature is a glacial kame, first commented on extensively by R.W. Lemke, in 1960. Black Butte is located adjacent to the Souris River Valley just northeast of Sawyer and is surrounded by glacial till (clay matrix supported diamicton-type sediments) and diversion channel sands and gravels that lie adjacent to the Souris River (fig. 5).

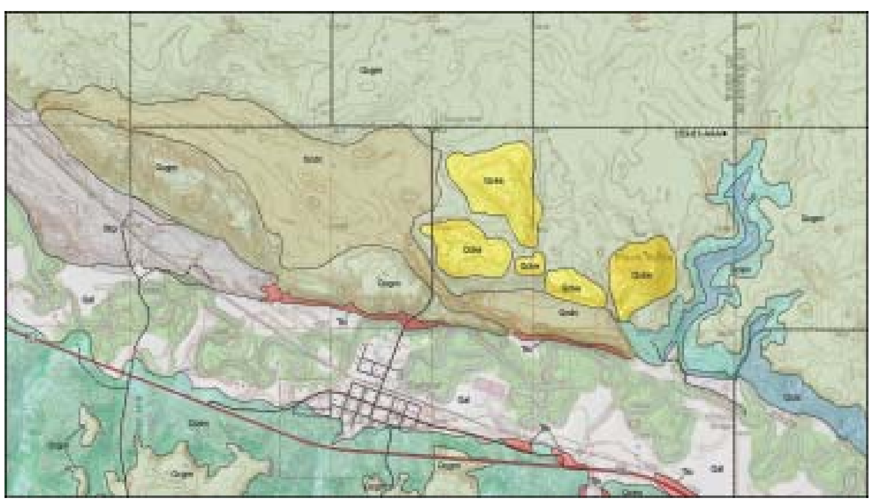

Figure 5. Surface geology of the Souris River Valley within the vicinity of the city of Sawyer (modified from Lemke, 1960). Black Butte, a glacial kame, is located approximately 1.5 miles northeast of the city in Section 1 of T. 153 N., R. 83 W., in southeastern Ward County. Surficial units mapped in this area consist of Quaternary-age fluvial and glacial sediments of the Coleharbor Group and Tertiary sandstone of the Fort Union Group (Cannonball Formation). Cannonball Formation sediments (Tfc) outcrop along the valley walls of the Souris River Valley and are overlain by younger glacial and fluvial sediments consisting of ground moraine (Qcgm), slope-washed till (Qcsw), ice-contact deposits (Qcic), diversion channel sands and gravels (Qcdc), kames and eskers (Qcke), terrace gravels (Qtg), and alluvium (Qal) within the Souris River Valley.

The areas immediately surrounding the kame are generally of low relief, particularly to the north. A conspicuous drainageway, related to the variability of glacial meltwater flow traveling down the Souris River Valley, is located next to the kame on its eastern side. The drainageway empties directly into the Souris River and consists of slope-washed tills and ice-contact sands and gravels. The kame itself is approximately 35 m (115 ft) high and has several small sinuous ridges that tail away from its base (fig. 6).

Figure 6. Aerial oblique view from the northeast across Black Butte near Sawyer, North Dakota. Note the eskerform ridges tailing away from the kame proper towards the west.

Lemke originally interpreted Black Butte to be a moulin kame, a conical shaped hill consisting of glaciofluvial material formed within a large circular depression in glacial ice. The kame consists dominantly of coarse sand and fine gravel with lesser amounts of cobbles and boulders (fig. 7) several of which are granitic and are scattered along the top and sides. Some of these boulders are up to 1.5 m (5 ft) in length and provide evidence for the requirement of a considerable volume of meltwater flow to have been present in order to transport this coarse sediment load. Till balls and intercalated till lenses have also been reported from within the sediments (Lemke, 1960).

Figure 7. Aerial oblique view across Black Butte from the northeast showing the exposed faces of the kame on the northern side created by borrow pit excavation. Several large boulders can be seen scattered across the feature.

Textural analysis of the dominant coarse sand and fine gravel fraction indicates a coarsely skewed, very poorly sorted, sand with a mean grain size (M_z) of 0.6 Ö (fig. 8). A large undrained depression is present on top of the kame that may provide evidence suggesting that little or no erosion has occurred since deposition (fig. 7).

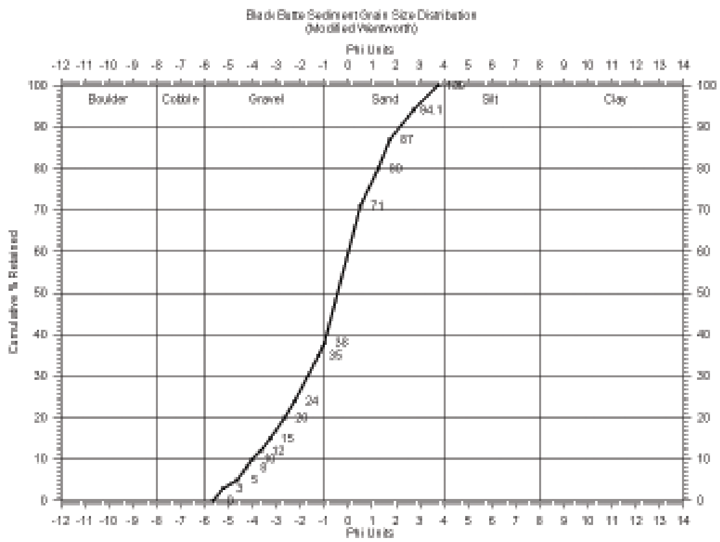

Figure 8. Grain size distribution curve for the dominant sediment fraction for a single sample collected from Black Butte.

A good portion of the kame (the northeastern two-thirds) is currently owned by the State of North Dakota, reserved for use as a future sand and gravel resource. The kame was the subject of detailed sand and gravel exploration and characterization studies conducted by the North Dakota Department of Transportation in the early 1960s, and has also been commented on by Bluemle (1989). Several borrow pits that have been excavated on the northern side of the kame reveal the gross lithologic character of the landform. Recent pebble counts indicate a high percentage of crystalline lithologies with lesser amounts of carbonate and shale (fig. 9) which is suggested here to be more related to transport than provenance.

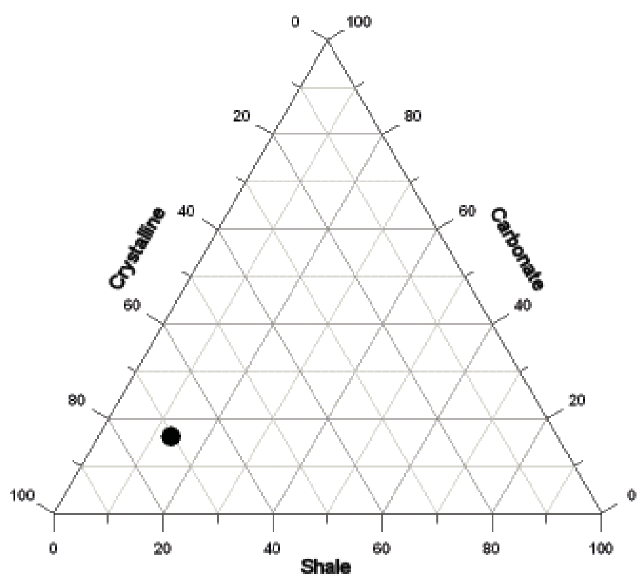

Figure 9. Ternary diagram of pebble count mineralogy illustrating the amounts of shale, carbonate, and crystalline gravel clasts from the Black Butte kame. Counts plotted are from one individual sample.

One hypothesis for the formation of Black Butte was put forth by Lemke (1960) when it was suggested that glacial meltwater originating on the wasting ice sheet transported and deposited the sands and gravel in a depression in the glacial ice and potentially along some outlets at the bottom of the moulin. Deposition likely occurred until filling of the moulin was complete or glacial meltwater was diverted away. As the ice that formed the moulin melted away, the deposit collapsed further (as indicated by deformed bedding throughout the deposit) with the occurrence of additional faulting and folding. This feature may be one of the largest single kames of its kind in the upper Great Plains (fig. 10).

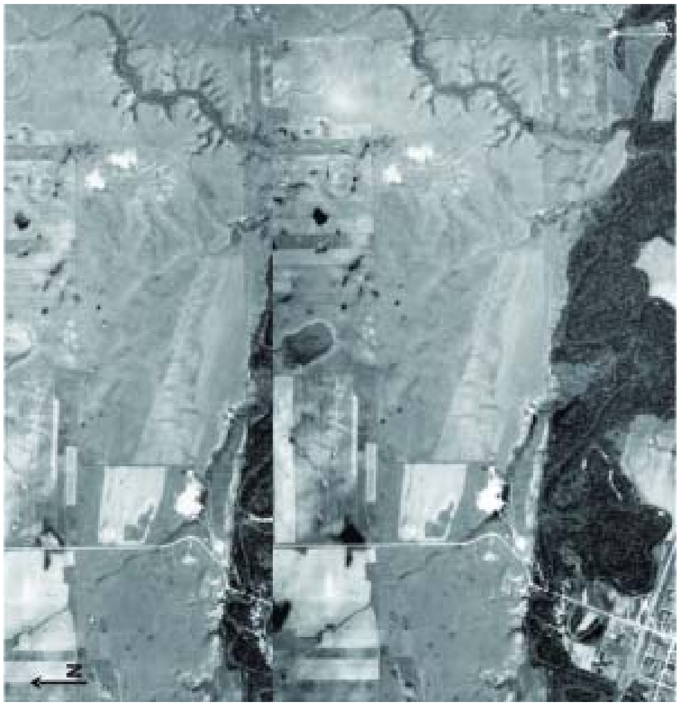

Figure 10. Aerial stereopair created from 1950s vintage aerial photography showing the area adjacent to the floodplain of the Souris River just northeast of the City of Sawyer. The city of Sawyer can be seen in the lower right portion of the stereopair. Black Butte can be viewed in the upper left corner portion of the stereopair.

Depart Stop 2. *Proceed west from entrance gate back towards the Sawyer Cemetery.* Traveling back over typical ground moraine of the Souris Lobe.

21.9	1.4	T-Intersection at Sawyer Cemetery (on the right).
23.0	1.1	Crossing the Souris River proceeding back into the city of Sawyer.
23.3	0.3	Railroad crossing
23.4	0.1	City of Sawyer, back into the heart of the downtown area, *turn left (southwest) along U.S. HWY 52 access road and return to the highway.*
24.4	1.0	U.S. Highway 52 South. *Turn left at intersection and proceed SE along the* highway.
24.7	0.3	Descending back onto the Souris River floodplain.
25.3	0.6	McHenry County line.
26.0	0.7	Continuing down the highway. Glacial thrust feature comes into view directly ahead and south of the town of Velva.
29.7	3.7	Town of Velva (Proceed to Town Park for Facilities Break). Junction of the start (NW end) of the Velva Diversion Channel and Souris River Valley is directly ahead.

Town of Velva. *Turn left (north) at the junction of U.S. Highway 52 with State Highway 41. Turn left. Drive through the Soo Line (Minneapolis-St. Paul & Sault Ste. Marie - now Canadian Pacific Railroad) underpass, then turn right toward Karlsruhe.* [The name Sault Ste. Marie" is a French translation of an Iroquois word, meaning "rapids of the St. Mary" - the term "sault" (pronounced "Soo") means "jump" or, in this case, "cascade" or rapids"].

Continue to the east out of Velva, across the Souris River floodplain.

Velva was originally called “Mouse River.” The town was renamed “Velva” by Soo Line railroad officials, who noted the velvet-like appearance of the Souris River (“Souris” is French for “Mouse”) Valley in this area.

The river flows into North Dakota from Saskatchewan, flowing as far south as Velva, then turning north and flowing back into Manitoba. It has always been referred to by most people as the “Souris River,” but North Dakota has recently “officially” decided that it is the <u>Mouse</u> River (at least that part of the river in North Dakota – in Canada, it is still the Souris River). “Souris River,” Glacial Lake Souris,” etc. are preferable terms, to most geologists at least, (“Glacial Lake Mouse” has the wrong resonance).

30.0 0.3 Ascend out of the Velva diversion channel on U.S. Highway 52.

31.5 1.5 STOP 3: Velva Diversion Channel (fig. 11)

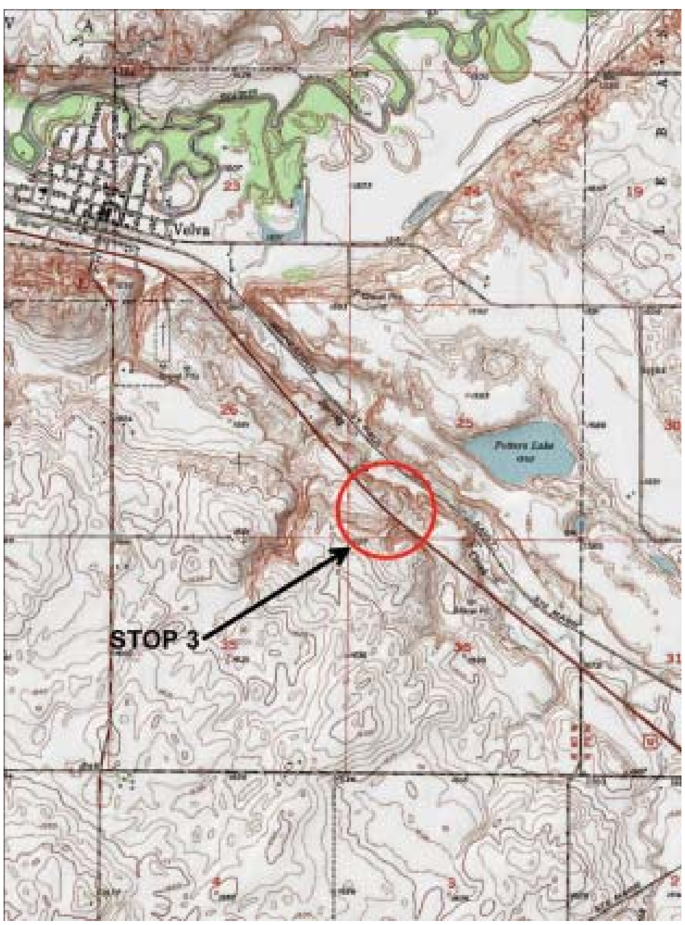

Figure 11. Topographic map with hillshading enhancement showing the location of Stop 3 – Velva Diversion Channel, a glacial meltwater flowpath located directly southeast of the town of Velva on the southeastern side of the Souris River Valley in T. 153 N., R. 80 W., Sec 5., SW1/4, U.S.G.S. Velva Quadrangle, 7.5 minute series (topographic) 1959.

The rerouting of the Souris River Valley drainage was caused by the recession of glacial ice and facilitated the emplacement of several diversionary outwash channels in the area southeast of Velva. Three of these channels, the Velva, the Lake Hester, and the Verendrye, will be traversed multiple times on this trip. This stop provides a northward view of the southernmost of these three channels, the Velva diversion channel (fig. 12) and provides a glimpse of the Pleistocene hydrologic processes that helped sculpt the subtle landscape of this area.

Figure 12. Low-angle aerial oblique view from the east of the town of Velva and the confluence of the Souris River Valley and start of the Velva Diversion Channel. Direction of flow within the diversion channel is to the east/southeast (towards the viewer) and is marked by abundant sand and gravel deposits within the channel in the foreground.

These diversionary outwash channels were formed as the flow of glacial meltwater was diverted out of the Souris River Valley when the downstream portion was blocked by glacial ice and flow was subsequently rerouted towards the southeast. Each channel marks the successive positions of the glacial ice margin during retreat of the Souris River ice lobe. The Velva diversion channel was created first, followed by the Lake Hester and the Verendrye diversion channels as receding ice and water levels sought out lower outwash flow elevations within the Souris River valley. Eventually the northernmost Verendrye channel was abandoned as water was permitted to flow directly down the Souris River Valley and into Glacial Lake Souris roughly seven miles northeast of the Verendrye channel.

Most of the diversion channels in this area are around 0.8 to 3 km (0.5-2 mi) wide with corresponding depths ranging from 4.5 to 9 m (15 to 30 ft) and are generally flat-floored (Lemke, 1958) and Kehew (1983). Numerous localized slumping and pitting of loosely consolidated outwash sands and gravels that can be observed directly at this stop give one a clue to the origin and character of the sediments.

Continue along southeastward on U.S. Highway 52.

32.8	1.3	ADM Processing Plant.
33.5	0.7	Crossing Railroad Spur.
34.6	1.1	Town of Voltaire
34.9	0.3	Begin gravel road

36.2	1.3	Kravel Charlois Ranch
36.9	0.7	Hardball to Stop #4
40.5	3.6	Oleo Acres Ranch. Lake Hester is on the right; Stink Lake about a mile to the northwest.
		This area is covered by sand deposited in another spillway where water flowed southeastward from the area of the Souris River. Many long, linear, drumlin-like ridges occur in this spillway area. The sand-filled, 1.2 km- (0.75 mi) wide spillway, which we cross at this point, is about 6 to 7.5 m (20 to 25 ft) deep.
40.9	0.4	Crossing Stink Creek between Stink Lake (towards the northwest) on the left and Lake Hester (towards the southeast) on the right.
41.7	0.8	Turning east towards Karlsruhe area. Till plain again.
		Bethel Cemetery on the right.
		Snowdak Warming Hut (abandoned school). The rough topography just to the northeast is an esker. This esker follows Hogback Ridge (see below) for much of its length.
		Cross esker ridge
45.4	3.7	Crossing over Hogback Ridge. This is the largest of several streamlined ridges in this area. It extends about 19 km (12 mi) to the southeast from here, and 6 km (4 mi) to the northwest. Several trenches were excavated in the Hogback Ridge in June, 1987, one at this location. We will cross the ridge several times as we drive to Verendrye from here on gravel roads. Keep in mind, as we make our way northwest, that we are repeatedly crossing the same 25-kilometer-(16-mile) long ridge. We will discuss the ridge at our next stop.
		Proceed across ridge to first intersection.
45.7	0.3	Road intersection, *turn left (north) and proceed along 4th Ave. North for one mile.*
		Cross a small valley that cuts through Hogback Ridge about a half-mile west of here. It appears to head at a point where it grades into the esker (the one pointed out earlier), suggesting that both the valley and the esker are slightly younger than Hogback Ridge.
46.7	1.0	Road intersection, *turn left (west) and proceed west back towards the hogback.* Notice the level, unbroken profile of Hogback Ridge, ahead. The ridge is broken only where it is truncated (to the south) by the valley just mentioned.

Relationship Between Exceptionally Long Drumlins and Ice-thrust Topography

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Note: This synopsis is taken from *"Large-scale glacial thrusting and related processes in North Dakota"* published in 1984 in the journal Boreas. Authors are John P. Bluemle and Lee Clayton. Reprints of the complete paper are available.

Glacial thrust forms

Three main types of thrust masses have been identified in North Dakota: (1) *hill-depression forms* are roughly equidimensional hills located down-glacier from a source depression of similar size and shape (fig. 1); (2) *transverse-ridge forms* occur above overturned folds or at the ends of imbricate thrust slabs (fig. 2); and (3) *irregular forms* contain elements of the other two forms. All three types of thrust masses are widespread from Alberta to North Dakota.

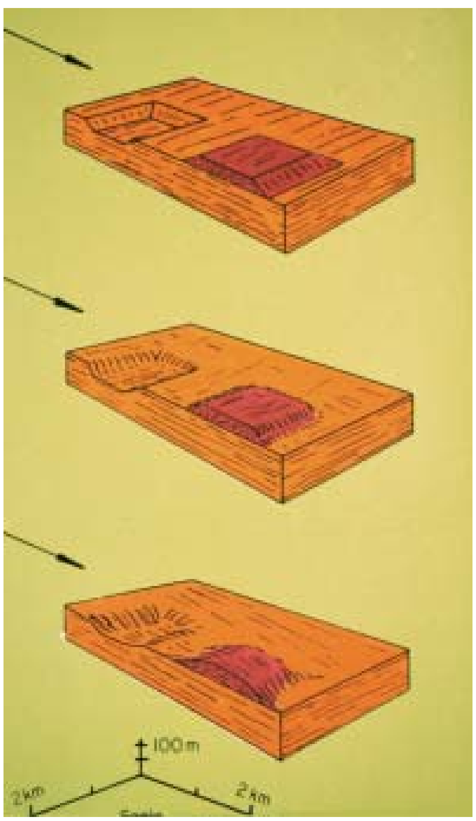

Figure 1. Schematic diagrams illustrating progressively more rounded and molded character of a hill-depression form as the glacier advances over it. The freshest thrust topography (top diagram) occurs near the margin of the glacier; streamlined forms occur farther back under the thawed (sliding) bed of the glacier as it advances.

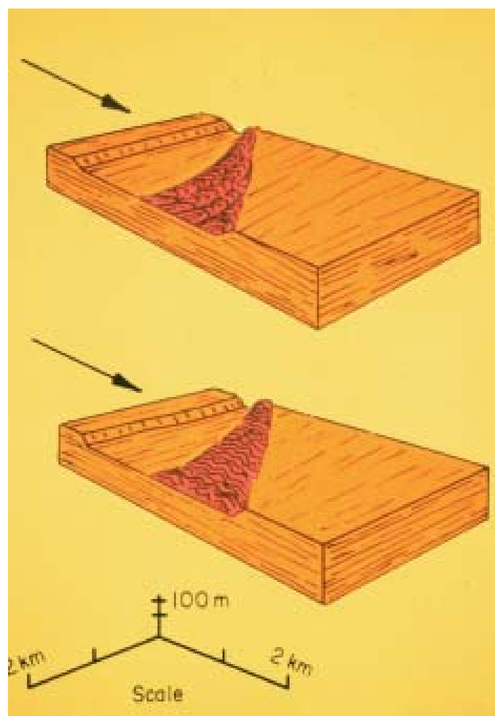

Figure 2. Two alternative interpretations of transverse-ridge forms. Imbricate thrusting is shown on the upper diagram, folding on the lower diagram.

Drumlin formation and thrusting

In places, ice-thrust topography is closely associated with streamlined features (fig. 3). The zonal relationship between ice-thrust features at or near the terminal position of the glacier, with associated streamlined features located at a greater distance behind (upglacier from) the zone of thrusting, is strikingly illustrated in north-central North Dakota. Ice-thrust masses are concentrated near (mainly immediately behind) the Martin ice-margin position. In addition, a spectacular array of drumlins, including the remarkable Hogback Ridge, lies behind the ice-thrust zone.

Commonly, the sediment in the upglacier depression behind a thrust mass has been fluted and, in places, the thrust mass itself is fluted. The flutings within the depressions may be the result of large-scale slickensides that formed during the thrusting episode; if so, the flutings would actually continue beneath the ice-thrust mass, but verification of this would be difficult. The possibility exists that the flutings in the depressions formed after the thrusting episode; in this case they would continue over the top of the thrust mass. This has not been observed in North Dakota.

Other ice-thrust features are apparently unrelated to existing streamlined features. In such places, the streamlined features, if they once existed, were destroyed by later glacial action such as a shift in flow direction or a slight readvance that, however, left the more prominent ice-thrust features intact. A low, subtle, streamlined ridge would be much more easily destroyed than a relatively higher ice-thrust hill.

In the Martin area of North Dakota, a large number of hill-depression forms occur (fig. 4). Most of the drumlins upglacier of these forms have upglacier heads that consist of small, molded, ice-thrust blocks (fig. 3). The drumlins were initiated by obstructions at their heads. The ice-thrust block was pushed up into the glacier, causing a low-pressure zone in the ice, or even a tunnel down-glacier from it; water-saturated material flowed in the tunnel and was molded by squeezing, thrusting, shearing, flowing, or folding.

Figure 3. Map of a part of central North Dakota showing zonal relationship of the ice-margin position, thrust features, and drumlins. Although similar situations can be recognized in other places in parts of North Dakota, Alberta, and Saskatchewan, it is difficult to find a place where the position of the ice-margin can be verified as well as here. This map shows known areas of thrusting; more may exist that were not recognized.

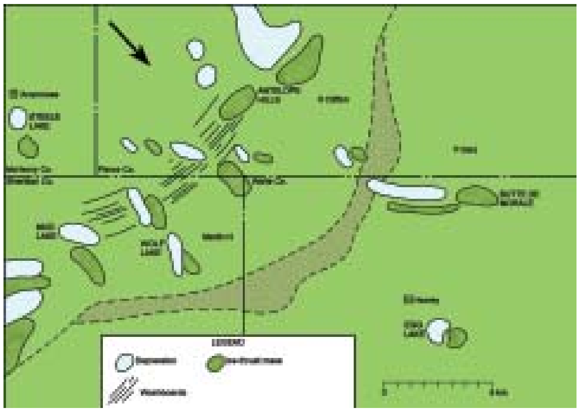

Figure 4. Area of intense ice-thrusting with numerous hill-depression forms in a 1,000-square-kilometer area of central North Dakota (transverse-ridge forms and irregular forms are not shown here, although many do occur within the area). Most of the hill-depression thrust masses are located behind the Martin moraine, which marks the outer extent of a glacial advance. Mottled green areas represent ice-thrust masses; light blue areas are depressions from which masses were thrust.

Summary

Although the ice-thrusting process has been recognized in the North American midcontinent area for some time, the actual extent and magnitude of the process as an eroding and land-forming process and the regional factors that interacted to bring about the process had not been adequately explored or understood until recently. Ice thrusting was the single most important eroding force in certain areas of exceptionally thick glacial sediment, such as along the face of the Missouri Coteau Escarpment and in other areas where appropriate hydrologic situations developed. The modification of the preglacial surface, which was appreciable in places, needs to be taken into careful account when attempts are made to determine the preglacial drainage pattern, glacial history, and glacial stratigraphy.

Many features that were once identified as ‘end moraine’ are, in reality, long, linear areas of ice-thrust materials. In fact, few classic end moraines can be verified in North Dakota; many ridge-shaped features previously considered to be end moraines can be shown to be the result of thrusting. Recognition of the presence of broad areas of landforms that are the result of glacial thrusting may lead to markedly different interpretations of the sequence of events that shaped glaciated landscapes.

The ice-thrust structures of North Dakota have been studied in sufficient detail to establish their relationship to underlying aquifers. Because regional drainage flow patterns prior to glaciation were northeastward, many of the glaciers advanced into areas of ice-dammed proglacial lakes and blocked aquifer systems, which extended beneath the advancing glaciers. This situation led to the development of elevated pore-water pressure in many places, a condition that often facilitated thrusting.

Although it is not always possible to determine the precise relationship of an isolated thrust mass to an aquifer or to presumed groundwater conditions at the time of thrusting, in many places a clear relationship can be shown. Almost all of the transverse ridge forms and the irregular thrust forms observed in North Dakota can be shown to be closely associated with aquifers. Conversely, thrust masses are seldom located in areas where aquifers are absent. Even the few supposed exceptions (thrust masses not located over apparent aquifers) are located in areas of discontinuous sand or gravel lenses that may locally serve as more permeable zones.

Most hill-depression thrust forms occur over aquifers in buried meltwater trenches, and most transverse-ridge forms occur over aquifers in buried outwash plains or over broad, preglacial or interglacial alluvial valleys. Consequently, the hill-depression forms are typically a kilometer or less across because meltwater trenches are typically a kilometer or less wide, and the transverse-ridge forms are typically more than a kilometer across because outwash plains or broad preglacial drainages are typically more than a kilometer wide.

Exceptionally Long, Narrow Drumlins - The “Hogback” Ridge

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Note: This synopsis is taken from *“Exceptionally long, narrow, drumlins formed in subglacial cavities, North Dakota,”* published in 1993 in the journal Boreas. Authors are John P. Bluemle, Mark L. Lord, and Nathan T. Hunke. Reprints of the complete paper are available.

The geologic setting of the Interior Plains of North Dakota, southern Saskatchewan, and eastern Alberta is characterized by flat-lying or nearly flat-lying Cretaceous and Paleocene shale and sandstone beds with broad areas overlain by as much as 100 to 200 m of glacial sediment. The near-surface formations are nearly flat-lying with preglacial tectonic structures having dips of no more than 2^{o} or 3^{o}.

The area in north-central North Dakota, where the long, narrow drumlins occur (fig. 1), is covered by glacial sediment that ranges from 3 to 25 m thick, but averages about 10 m. The Paleocene Cannonball Formation immediately underlies the glacial sediment throughout the area. It consists mainly of poorly indurated to slightly lithified, micaceous, marine sandstone interbedded with carbonaceous and lignitic sandstone and shale (Bluemle, 1982).

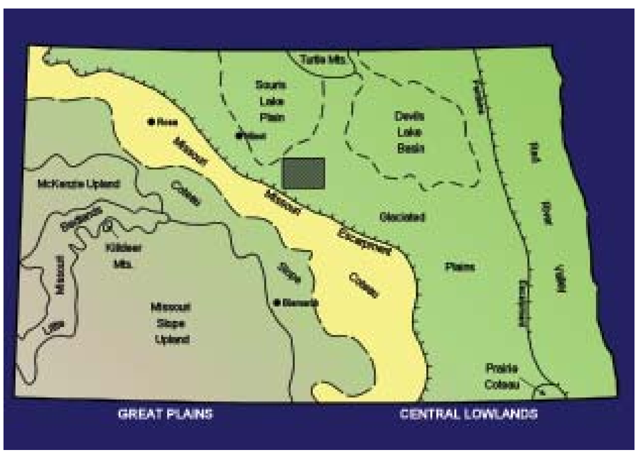

Figure 1. Physiographic map showing the area in north-central North Dakota, where the long, narrow drumlins occur.

The most obvious physical characteristic of the drumlins is their extreme length-to-width ratios. Typical drumlin ridges in the area are about 2 to 3 km long and length-to-width ratios range between 30:1 and 50:1; however, the largest and longest of the drumlin ridges, a feature known as ‘Hogback Ridge,’ is 27 km long, 60 m to 120 m wide at the base, and about 8 m high through most of its length. It has a length-to-width ratio of about 240:1. Hogback Ridge trends S40^{o}E with negligible variation along its course (the ridge curves very slightly to the east down-glacier). All of the drumlin ridges in the area are exceptionally straight (figs. 2 and 3), so straight, in fact, that they might at first be mistaken for artificial features. Hogback Ridge resembles a large railroad or highway grade, and in fact, a segment of it was once utilized as a road. At the southeast end of Hogback Ridge, and slightly offset from it, is a second ridge, which continues for another 6 km. Some of the drumlin ridges, including Hogback Ridge, are bordered on one or both sides by long, narrow, pond-filled depressions, most of which are 1 to 2 m deep, 0.1 to 0.2 km wide, and at least 2 km long.

Figure 2. A. Air photograph of the Hogback Ridge in its upglacial portion, beginning about 5 km from the northwest end and extending for a distance of 6 km (north is to the top of the photo). Area shown is about 23 km^2. B. Topographic map of the same area shown on the air photograph. Contour interval is 10 ft. (~ 3 m). Notice the long depression along and parallel to the southwest side of the ridge and the shorter depression on the northeast side.

Hogback Ridge, along with other long drumlins nearby, occurs within a zone situated 5 to 10 km up-glacier from a band of ice-thrust topography (fig. 3). The drumlins splay or radiate parallel to the direction that the glacier was flowing when it emplaced the thrust features in the area to the east and southeast. The long drumlins occur in an area in which a thin layer of silty to sandy diamicton overlies bedded silt and sand that were deposited in a proglacial lake.

Figure 3. Map of a part of central North Dakota showing zonal relationships of the ice-margin position, ice-thrust features, and long drumlins. The drumlins are positioned about 5 to 10 km behind the area of thrusting.

Detailed studies of the glacial sedimentary stratigraphy in the area where the long, narrow drumlins occur aroused our interest in the problem of how such features could form (Bluemle 1982; Lord 1998). We were especially intrigued by the apparent close genetic relationship between the drumlins and the array of nearby thrust features. Excavations in some of the shorter ridges commonly penetrate a thin (less than 1-m thick) layer of diamicton overlying a core of well sorted, fine, massive sand (Bluemle 1982). Borrow pits in several of these short (less than 3 km long) ridges also reveal sand. However, none of the longer drumlins had ever been systematically excavated. For this reason, during June of 1987 we used a backhoe to dig trenches in Hogback Ridge. The descriptions of these excavations are available in the complete *Boreas* paper, referenced above.

The glacier that formed the long drumlins had an extremely low surface profile near its margin. We estimated that the thickness of the glacier in the vicinity of the Hogback Ridge, at a distance of 125 km up-glacier from the Martin ice marginal position was no more than 240 m. We estimated that the thickness of the ice was from 158 m to 86 m for the upglacier and down-glacier edges of the drumlin field, respectively. Minimum estimated ice thickness ranged from 70 m at the upglacier end to 38 m at the down glacier end of the drumlin field. A transverse profile of Hogback Ridge, with maximum and minimum ice thicknesses, drawn with no vertical exaggeration, is shown in fig. 4.

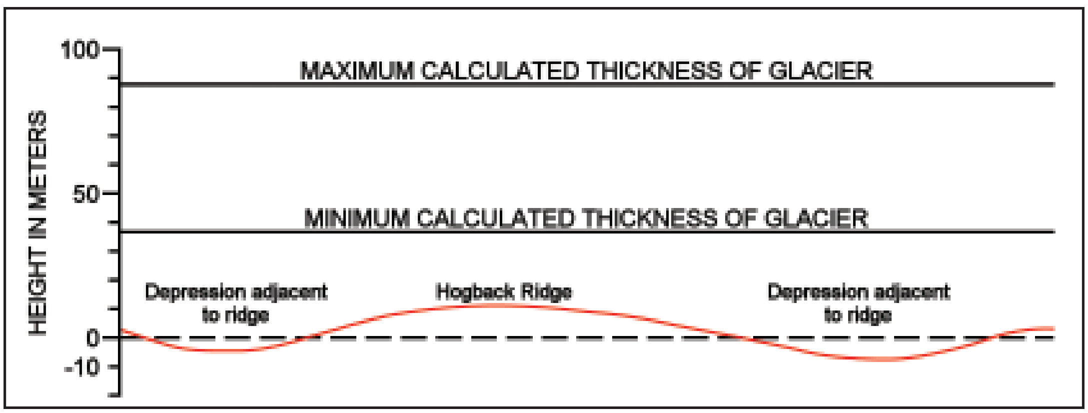

Figure 4. Cross-section drawn to scale through the Hogback Ridge approximately at the mid-point of its length. Maximum and minimum calculated glacier thicknesses are shown.

Conclusions

We believe that Hogback Ridge, and the other long drumlins in this area, were formed by the glacier as constructional features, with glacial and hydraulic transport from the sides, inward, under conditions of high subglacial pore-water pressure conditions. These materials were forced – squeezed, shoved, and injected – into the ridge from the source depressions along the sides of the drumlins; that is, most of the materials in the drumlins were derived from the adjacent depressions. Intact blocks of material with intricate, essentially undisturbed bedding suggest that at least some of the sediments in the ridge may have been frozen at the time they were emplaced, although it is possible for soft sediment deformation to occur resulting in rip-up clasts or other blocks that survived deformation during plastic flow. Highly deformed sediments in places clearly indicate transport while in a semi-fluid state. Bluemle (1982) theorized that the glacier that formed the drumlins and the ice-thrust masses advanced over the proglacial lake floor, possibly while the lake still existed. The proglacial lake reformed when the glacier melted again, but when it did so it flooded a more restricted area than it had prior to the last glacial advance and the area in which the drumlins occur was not flooded again.

Hogback Ridge was probably initiated in a subglacial cavity formed as the glacier overrode either a previously ice-thrusted block or at essentially the same time the block was being thrust into place. The cavity that resulted at the base of the glacier as it flowed over the block became a zone of low pressure, with adjacent higher pressure glacial ice surrounding the cavity. As a result of the pressure differential, the adjacent glacial ice converged, producing elevated pore-water pressures in the immediate subglacial area. Subsequent shear-strength reduction induced sediment transport into the basal cavity as the moving glacier continued to equalize the pressure differential produced by the subglacial obstruction. This formed the long, narrow depressions along the sides of the drumlin. Pore-water dissipation and over-consolidation of sediments increased the shear strength of the deformed material above the shear stress applied by the ice, forming an obstruction. The cavity in the thin, surging glacier remained open long enough for the long, narrow drumlin to form. Had the glacier been thicker, the cavity would quickly have been filled in with ice. In instances when the cavity did fill in, the formation of a drumlin was terminated. As the bedded sediments were transported into the cavity, they fell inward, resulting in vertical and near-vertical bedding. Gravity faults resulted as the sediment settled and also when the supporting sides of the glacier finally melted.

The presence of the esker that extends southeastward, near the western side of Hogback Ridge, is consistent with the ice-thrusting process (Bluemle & Clayton, 1984). When thrusting takes place, large volumes of ground water escape from beds beneath the glacier and flow beneath the ice toward its margin. Many ice-thrust masses in the area have associated eskers that begin near the thrust mass and extend to the position of the glacier margin when thrusting occurred.

In summary, our study of the long, narrow drumlins in North Dakota leads us to the conclusion that a close and consistent relationship exists between the ice-thrusting process and the formation of such drumlins. Conditions necessary for ice thrusting also tended to favor the formation of long, narrow drumlins in the area.

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Development of Linear Glacial Ridges near Karlsruhe, North Dakota

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Many of the landforms we will observe over the course of this Friends of the Pleistocene Meeting provide clues to subglacial conditions that existed during the times of glaciation. As part of a geologic mapping effort in the Karlsruhe, ND, region in the late 1990s through the early 2000s, an attempt was made to understand the subglacial shear stress conditions associated with the development of many of the northwest–southeast elongated ridges in the region. Field evidence, together with laboratory reconstructions of subglacial conditions, resulted in the conclusions presented here.

A trench excavation, made with assistance from the North Dakota Geological Survey, revealed the internal structure of Hogback Ridge, the largest of the linear ridges in the region. At the excavation, the ridge was characterized by two main stratigraphic units beneath the soil. The upper unit is comprised of collapsed diamicton deposited as the last glacier ice in this area melted. Beneath this is a unit comprised of three distinct textural groups: 1) a massive sand, 2) a diamicton, and 3) a sand, silt, and gravel. The sediments of the lower unit are highly disturbed, with lenses of the massive sand, as well as the sand, silt, and gravel within the diamicton. In places, the contacts between the three groups are gradational, and in places the sand, silt, and gravel unit is stratified. The massive sand is well sorted, but has been deformed by normal faulting. The cross-sectional stratigraphy and texture of the ridge reveal that flute formation is the result of both deformation and fluvial processes.

A former ice surface was approximated for when the ice extended southward to the Martin Moraine in north-central North Dakota, using methodology similar to that used by Mathews (1974), to facilitate the calculation of basal shear stress at the time of ridge development. It was concluded that the ice sheet was very thin in the area south of Karlsruhe where many of the ridges are located. Shear stress values based on ice thickness were low, generally less than 2 kPa.

Any theory proposed to account for the formation of these ridges must explain how simultaneous sediment deformation and fluvial processes can occur under the reconstructed subglacial conditions. Ice-thrust blocks at the heads of flutes presumably initiated tunnels that became at least partially filled with highly pressurized water, draining from regions of higher hydraulic head. The volume of water flowing through subglacial conduits may have been sufficient to keep them open during deglaciation, even when the ice thinned and flow velocity decreased (Cutler, 1998). Because of the high porewater pressures and deformable sediment at the base of the glacier in this region, some sediment would have been squeezed into these subglacial tunnels (Bluemle, Lord & Hunke, 1993). The amount of sediment in the tunnels depended on the ability of the water to erode and transport sediment compared to the rate of tunnel infilling with deforming sediment.

As the ice thinned, glacier flow diminished and less water was available to keep the subglacial tunnels open. Eventually, lower water pressures resulted in deposition of sediment in the tunnel, creating the observed stratification. At a later stage, the tunnels collapsed and sediment on top of and within the ice settled onto the fluvial deposits. Sediments along the tunnel walls collapsed, resulting in deformation of the sand and creation of the structures observed in cross-section.

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47.7 1.0 STOP 4: The Hogback Ridge (fig. 13)

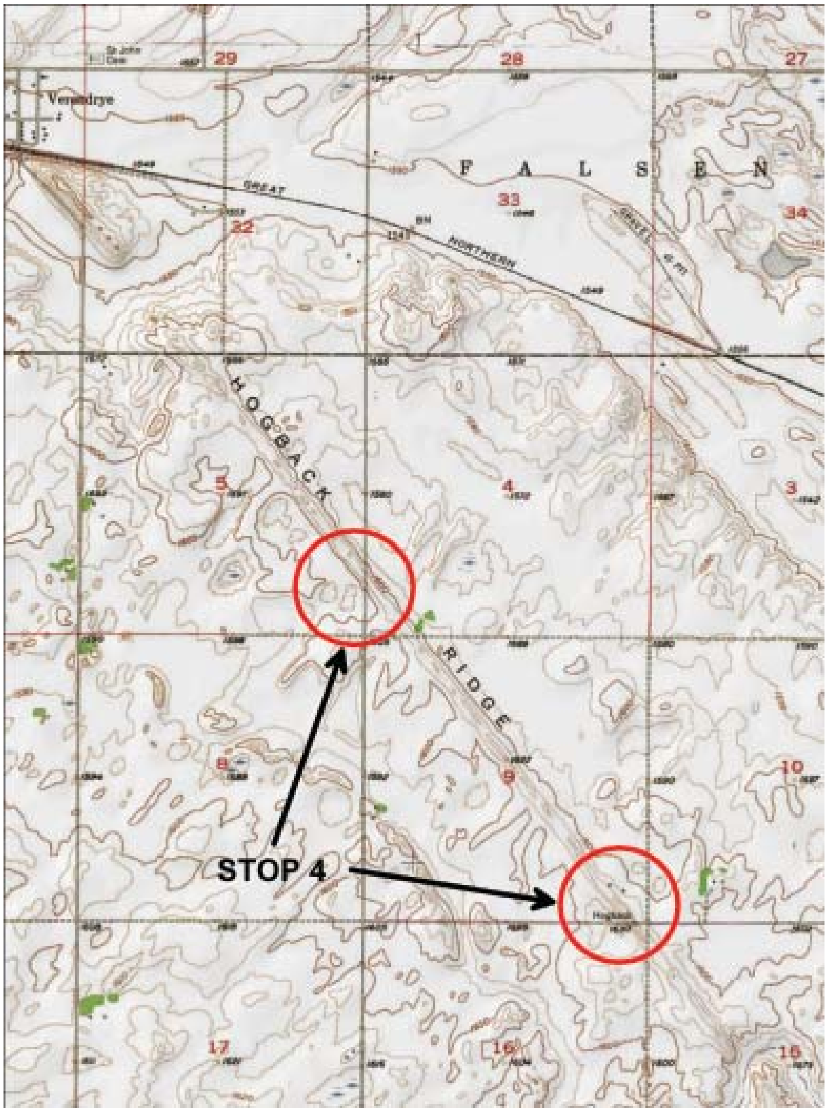

Figure 13. Topographic map with hillshading enhancement showing the locations of Stop 4 – Hogback Ridge, an elongate drumlinoid subglacial ridge, located 19 km (12 mi) east of the city of Velva (location of stops in the NW ¼ of T. 153 N., R. 78 W., U.S.G.S. Bergen Quadrangle, 7.5 minute series (topographic) 1957.

Hogback Ridge at this point is about 12 m (40 ft) high and 120 m (400 ft) wide at the base. The ridge is remarkably straight, 6 to 9 m (20 to 30 ft) high through most of its length, and 60 to 120 m (200 to 400 ft) wide. In many places, the ridge has slough-filled depressions on either side or on one side (fig. 13). This part of McHenry County has a spectacular array of similar ridges all oriented northwest to southeast (fig. 14).

In 1987, the NDGS rented a backhoe and excavated two trenches across Hogback Ridge, 3 to 4.5 m (10 to15 ft) deep, 30 to 38 m (100 to 125 ft) long. The internal stratigraphy of the ridge is extremely complex with folded, faulted, contorted beds of sand and silt, and inclusions of glacial till, lake sediment and Paleocene Cannonball Formation sandstone. We concluded that the internal structures were generally the result of lateral pressure

Figure 14. Aerial oblique view toward the northwest along the long axis of Hogback Ridge in McHenry County, North Dakota. Linear pond and slough type depressions formed adjacent to the ridge are well defined at this location.

toward the center of the ridge, probably mainly from one side or the other (not necessarily both at the same time), with a down glacier component, but shifting sides from place to place. These resulted in the transfer of subglacial material in a moving void beneath the glacier. Most of the materials in the ridge were apparently transported in semi-fluid condition, probably by groundwater that was being subjected to pressure. This tentative conclusion is part of a more inclusive theory that is included in our explanation of the formation of the drumlins and ice-thrust blocks in this area (Bluemle, Lord & Hunke, 1993, Exceptionally long, narrow drumlins formed in subglacial cavities, North Dakota: *in* Boreas, vol. 22, p. 15-24, Oslo).

The origin of the features (linear features and thrust blocks) is a result of associated hydrologic conditions. The array of linear features occurs in a zone just behind (up glacier of) a zone in which the most prominent landforms are ice-thrust blocks. It seems logical (conceivable at least) to conclude that the conditions which led to the one kind of glaciotectonic features (ridges) also operated to form the other (the thrusts). We hypothesize that a thin, rapidly advancing glacier, moving over an area (which coincided at least in part with the pro-glacial Lake Souris), of saturated sediments that consisted of alternating beds of permeable and impermeable materials so that it was possible for high porewater pressures to develop in the impermeable beds. It is also likely that the impermeability of some of the beds may have been due to permafrost – a permanently frozen surface layer – which the glacier rapidly overrode. When the glacier flowed over this frozen layer, the layer melted, soon after the glacier had covered it with its insulating bulk. Thrusting was most likely to occur in the frozen-bed zone – streamlining (and ridges) in the zone where the permafrost had melted.

All of these features we will see today: streamlined features, thrusts, associated eskers – speak of abundant, high-pressure groundwater moving toward the edge of the glacier, through the materials beneath the ice. A long and persistent esker, which we have seen in several places, roughly parallels Hogback Ridge for a considerable part of its length and this is a typical relationship. Eskers also commonly emanate from the depressions associated with ice-thrust blocks, and are transformed to outwash plains or meltwater valleys where they leave the near vicinity of the ice margin. In places, it appears that the pressurized groundwater simply “blew out,” forming sand volcanoes of various sizes, as it flowed rapidly to the surface out of the over-pressured aquifer beneath the glacier.

Figure 15. Aerial oblique view to the north just northeast of Hogback Ridge of a set of long linear subglacial features trending from the northwest to the southeast parallel to the trend of Hogback Ridge.

Continue west off of the hogback and proceed to 1st gravel road intersection.

48.4	0.7	Crossing over eskers here. Both crests are part of the same, sinuous, very irregularly-crested esker. Notice the small gravel pit on top of the westernmost ridge. The gravel is dirty, poorly sorted
48.6	0.2	Road intersection, *turn right (north) and proceed along 6th Ave. North.*
49.9	1.3	Crossing over Hogback Ridge. Open road cut along the east side of the road. *Continue north across hogback towards 1st road intersection.*
50.6	0.7	Road intersection. Turn left and proceed west on 48th St. North.
51.3	0.7	Crossing over the northwestern end of Hogback Ridge. Continue west to 1st road intersection.
51.7	0.4	Road intersection. *Turn right and proceed north on 7th Ave.* North.
52.3	0.6	Excavation in ridge/ice-thrust mound. This excavation is in a hill that occurs at the head of Hogback Ridge (fig. 16). Although the hill lines up with the ridge, it is separated from the rest of the ridge by a gap of several hundred yards; it is not considered to actually be a part of Hogback Ridge. Rather, this hill is probably an ice-thrust block (see discussion of glaciotectonic geology commencing in the Anamoose area, below). The hill was thrust into its present position by glacier ice moving southeastward. Following emplacement of the ice-thrust hill, the glacier continued to move southeastward. As it flowed over the hill, a cavity formed in the base of the glacier and, as the glacier continued to flow southeastward, Hogback Ridge was shaped into this cavity.
52.5	0.2	Crossing over BNSF Railroad Crossing. About all that was left of the village of Verendrye burned in May of 1986. Verendrye is situated on the edge of an extensive plain of outwash gravel – material that was deposited at the edge of the early glacial Lake Souris.

Figure 16. Low-angle aerial oblique view from the south of the hill that occurs at the head of Hogback Ridge just south of Verendrye.

52.6 0.1 Verendrye. *Proceed through the town to the T junction with 49th St. NW.* Notice the remains of the original school still present today. Verendrye (originally called "Falsen ") is named for Pierre Gaultier de Varranes la Verendrye, the French explorer who in 1738 led the first party of white men into what is now North Dakota.

52.7 0.1 T Junction with 49th St. NW. *Turn left and proceed west along 49th street towards the David Thompson Memorial.* Access road is just off on the left (White Bicentennial Sign).

53.0 0.3 STOP 5: David Thompson Memorial (figs. 17 and 18)

Entrance to the David Thompson Memorial.

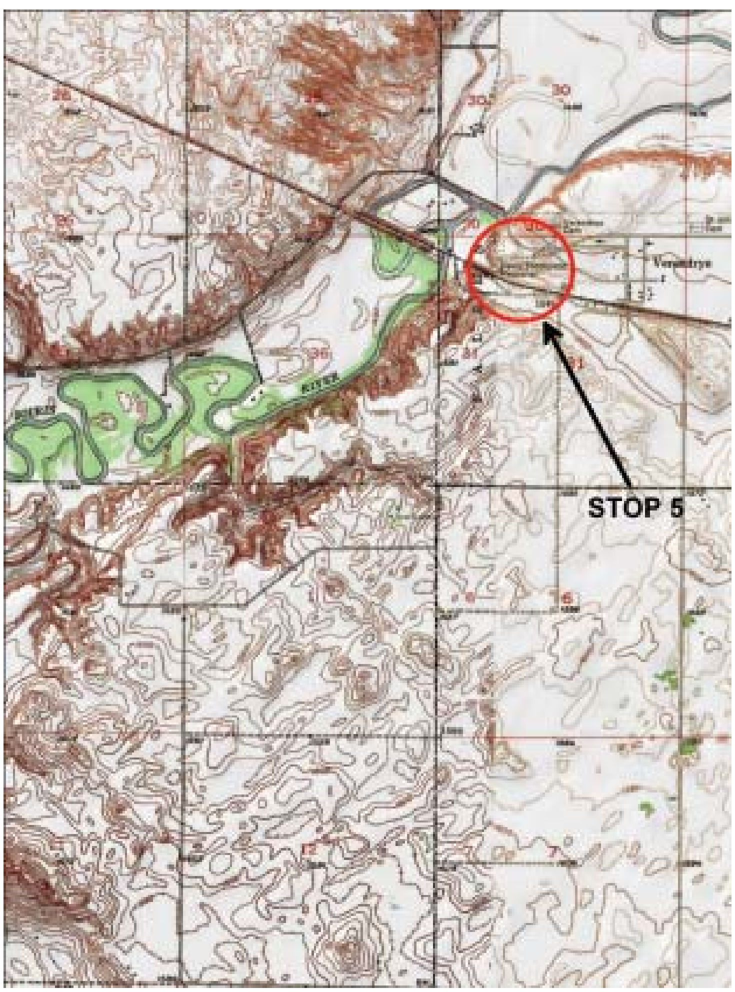

Figure 17. Topographic map with hillshading enhancement showing the location of Stop 5 – David Thompson Memorial, located just west of Verendrye in T. 154 N., R. 78 W., Sec 31., NW 1/4, U.S.G.S. Bergen Quadrangle, 7.5 minute series (topographic) 1957.

Figure 18. David Thompson State Historic Site and memorial just west of Verendrye. David Thompson was a geographer and scientist and the first to explore this country. The pedestal for the granite ball is inscribed as follows: 1770 DAVID THOMPSON 1857, GEOGRAPHER AND ASTRONOMER - Passed near here in 1797 and 1798 on a scientific and trading expedition. He made the first map of the country which is now North Dakota and achieved many noteworthy discoveries in the northwest. Local tradition (a tradition of over 40 years) requires that geology students visiting this site be photographed astride the memorial globe!

Thompson was born in London, England and died February 10, 1857, at Longeuil, near Montreal. He was 14 when he came to Hudson Bay from London and spent the next 28 years in the fur trade. Although only self-taught in astronomy and cartography, over the next three decades he carefully mapped the location of all of the most important routes in the Canadian plains and Rockies. By the time he retired to Montreal in 1812, Thompson had traveled by foot and canoe over most of the western British America (to become Canada) from Hudson Bay to the Pacific, covering a total of 90,000 km (56,000 mi) and making scientific surveys of nearly five million square kilometers (two million square miles) of wilderness. After returning to civilization, he drew and published the standard comprehensive map of the Canadian West. Although Thompson emerged from the woods at 52 as a reasonably affluent man, a series of domestic and business misfortunes ruined his later years. By the time he died at age 87, he was bankrupt and largely forgotten, though the great British Fur corporations and countless settlers continued to rely on his meticulous maps and surveys.

Thompson came to this spot in North Dakota during an expedition in 1797-1798 to the Mandan Villages. He left his headquarters in Canada on November 28, 1797, with a small party to discover the location of the Mandan Villages in this area. The Mandan lived in permanent agricultural settlements and because they possessed cultivated crops and trade goods from St. Louis, they were a commercial focal point for the nomadic plains and mountain tribes from further west. Thompson found their village from the north and stayed with the Mandan until January 10, 1798, but was unable to win their allegiance away from the French-speaking American traders who came upriver from St. Louis. He returned home after a brutal winter trip on February 3, 1798.

Thompson's achievements are staggering. He explored vast areas that later became part of Western Canada and the northwestern United States. In 1796 he blazed a new route to Lake Athabaska for the Hudson Bay Company, traveling from York Factory by way of the Nelson, Burntwood, and Churchill rivers and Reindeer Lake to Fond du Lac. After he joined the Northwest Company in 1797, Thompson surveyed (1797-98) the Mississippi's headwaters (this was done during his trip through North Dakota), in 1807 crossed the

Rockies by the Howse Pass to the source of the Columbia, from 1808 to 1810 explored the present states of Washington, Idaho, and Montana, and in 1811 became the first white person to travel the Columbia's entire length.

At the age of 30, Thompson married Charlotte Small, a half-blood, and lived with her for 57 years, until he died. Following his retirement in 1812, Thompson completed a map that became the basis for all subsequent maps of Western Canada. From 1816 to 1826 he surveyed the Canadian-United States boundary between the St. Lawrence River and Lake of the Woods for the International Boundary Commission.

After the amalgamation of the Hudson's Bay Company and the Northwest Company in 1821, David Thompson's 'Great Map' eventually surfaced in London at the Hudson's Bay Company Headquarters. The map itself could fill one wall of a room. One of the major disservices done to Thompson occurred when Thompson's maps and notebooks were handed by the Hudson's Bay Company to Aaron Arrowsmith, a London cartographer. Commissioned by the Hudsons's Bay Company, Arrowsmith incorporated Thompson's maps into his own maps of North America to which the Hudson's Bay Company was given credit, claiming proprietary ownership. Ironically, Thompson's original maps published in 1795 of North America while in the employ of the Northwest Company, gave no credit or mention of Thompson.

It was not until the early part of the 20th century that J.B. Tyrell discovered Thompson's notes, journals, and narrative. They included 39 journals, 11 books of field notes, and a large yellowing map of the western half of North America between the 45th and 60th parallels.

In the valley to the northwest just below the Thompson Memorial, the Paleocene Cannonball Formation is exposed and is overlain by glacial, glaciolacustrine and glaciofluvial deposits. Marine Cannonball sands are well exposed here and sporadically upstream from this location to the Sawyer area, about 24 km (15 mi) upstream.

Turn around and continue east on 49th Street NW back towards Verendrye.

54.3 1.0 *Turn left (east).*

54.6 0.3 Hogback Ridge. The area to the east for about two miles is covered by thin, sandy till that overlies sandy lake sediment.

56.2 1.6 Drive off the till plain onto outwash. The glacier ice that deposited this gravel flowed southeastward.

56.6 0.4 BNSF Railroad tracks and gravel pits. The large metamorphic gneiss erratic on the left (north) has a flat, ice-worn and striated upper surface. A large amount of gravel has been removed from these pits.

57.0 0.4 *Continue eastward over gravel,* which becomes finer and grades into glaciolacustrine sands of glacial Lake Souris. This is a deltaic area that was later reworked by shore processes, although no discrete beach ridges are obvious. The small hills in this area were islands or shoals of till in the lake.

58.8	1.8	*Turn right (south) on paved road toward Karlsruhe.* At this point, you are traveling over near-shore deposits of Glacial Lake Souris. For about the next three miles, you will be traveling over near shore lake sands and fluvial gravel deposits.
61.3	2.5	Village of Karlsruhe on the left (east). Karlsruhe ("Charles rest" in German) is named for the city of Karlsruhe, Baden, Germany, from where many of the settlers emigrated about 1900. While I (JPB) was at the Thompson Memorial last August, working out the route for this trip, a couple from Karlsruhe, Germany stopped by. They were making it a project to visit every town called "Karlsruhe" in the United States and Canada.
62.9	1.6	Drive onto a fluted till plain. Numerous drumlin-ridges that occur in this area, all trending northwest to southeast, range in length from one-and-a-half to three kilometers (one to two miles) in length (except the much-longer Hogback Ridge). Notice the more conventional drumlin-shaped feature on the left (radio tower on top).
65.9	3.0	Crossing over the southeastern portion of Hogback Ridge.
		Cross Hogback Ridge as the highway jogs to the right at the township-correction line. The hills in the far distance, about 15 – 20 km (10 – 12 mi) away, are the face of the Missouri Escarpment.
70.6	4.7	*Turn left (southeast) on U.S. Highway 52 and continue on towards Anamoose.*
		Drive over till plain for the next 17 miles. In places the till surface is strongly streamlined with small ridges, typically 5 to 8 km (3 to 5 mi) long (all of the ridges are parallel to Hogback Ridge). These are not apparent from the ground but they are striking from the air. At the town of Balfour, the highway crosses the much-reduced, southeasternmost extremity of the Hogback Ridge.
74.3	3.7	Town of Balfour (fig. 19). The Hogback Ridge terminates about 3 km (2 mi) southeast of Balfour; it has lost most of its surface expression in this area, although it is still obvious on air photos. Balfour is named for a British railroad official.
78.6	4.3	Crossing over the Wintering River.
80.9	2.3	Railroad Crossing.
82.3	1.4	Town of Drake. The town is named for a local homesteader.
		In November, 1973, the Drake, North Dakota, school board condemned, as obscene, Kurt Vonnegut's book *Slaughterhouse Five.* The novel – a story based on Vonnegut's own World War II experience as a captured GI in Dresden when the city was firebombed – was torched in the high school furnace by the school janitor. Reactions to the Drake book burning evoked memories of the 1933 "bibliocaust." The Drake furnace consumed 36 paperback editions of *Slaughterhouse Five.* The *New York Times* exclaimed, "Book burning! Shades of Adolf Hitler and *Fahrenheit 451!"* The *Bismarck Tribune* reminded its readers that dictators had burned books as "terrifying object lessons" to would-be dissenters. Vonnegut wrote to the chairman of the Drake School Board: "Books are

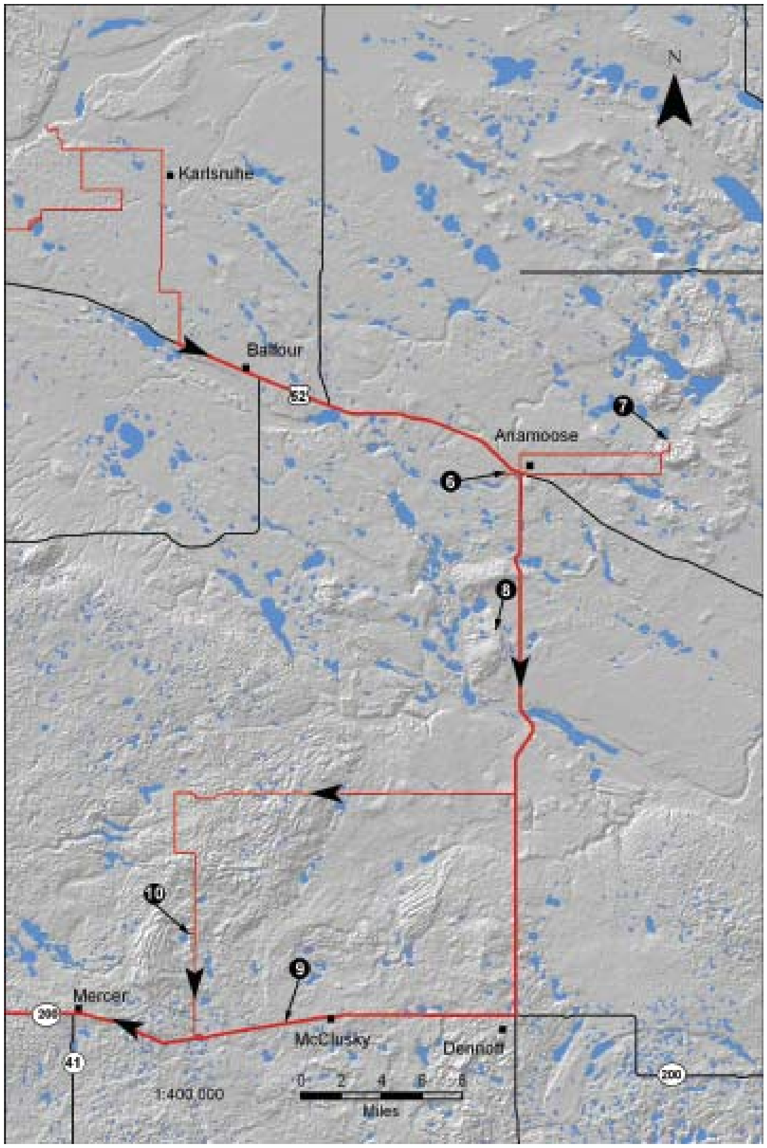

Figure 19. The fieldtrip route for Day 2, Anamoose to Bismarck.

sacred to free men for very good reasons. . . . Wars have been fought against nations which hate books and burn them."

88.9 6.6 Approaching the village of Anamoose. Anamoose was founded by Romanian settlers from Saskatchewan. The name is a corruption of a Chippewa word, *uhnemoosh* meaning female dog. In 1969, when JPB first began to understand the origin of ice-thrusts like the one here, he thought "Anamoose" would be an appropriate name for the features. However, he decided that the name presented problems with the plural.

Turn right (south) off of U.S. Highway 52 onto gravel road, following it through the slough on gravel road just west of Steele Lake and proceed around bend towards the south and west up the hill to the pull off area on the left.

89.4 0.5 STOP 6: Anamoose Ice Thrust (fig.20)

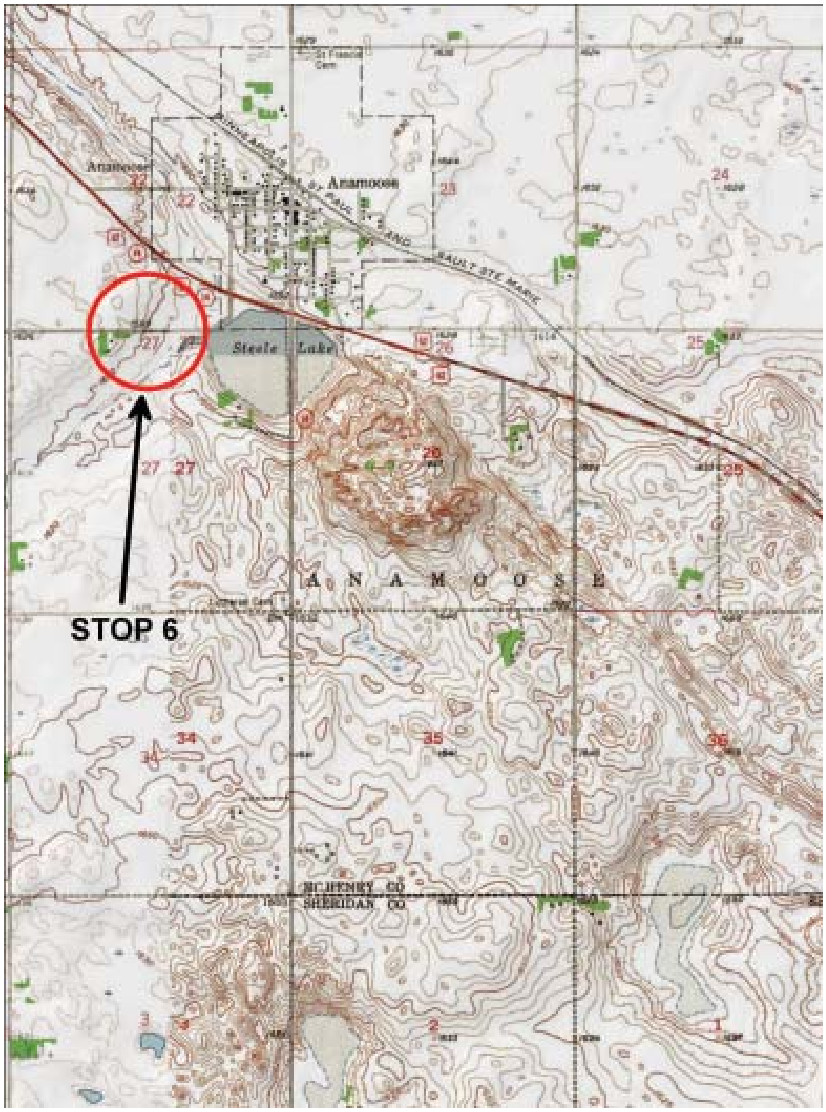

Figure 20. Topographic map with hillshading enhancement showing the location of Stop 6 – Anamoose Ice Thrust, a glaciotectonic thrust feature located in north-central North Dakota located directly south of Anamoose in T. 151 N., R. 75 W., Sec 26., U.S.G.S. Anamoose SW Quadrangle, 7.5 minute series topographic.

The hill and lake at Anamoose (fig. 21) are a classic example of a hill-depression type of ice-thrust. Basically, the material in the hill was derived from the area now flooded by the lake. A look at an air photo of the area, or of a topographic map, will show that the hill and depression are about the same size and shape and that the hill is located down glacier from the depression.

Large numbers of similar hill-depression combinations occur in this area. In some instances, the hill is composed of glacial sediment, either till, gravel, or lake silt, or, in other instances, preglacial materials. The materials in the ice-thrust hill may be a simple homogeneous mass or they may show internal structures; sometimes the hills look like a pile of stacked dominoes that have been knocked over. The hill-depression combination, like this one, is the simplest case; often the depression has been nearly or completely filled by later glacial or fluvial deposition and is no longer apparent.

Figure 21. Aerial oblique view of the Anamoose Ice Thrust obtained during the Fall of 2005. This view of the Anamoose Ice Thrust from the southeast is along the long axis of the landform and is somewhat parallel to the direction (from the northwest) of glacial-tectonic ice-thrusting.

A more complete explanation of ice-thrust features in North Dakota is given in Bluemle and Clayton, 1984, Large-scale glacial thrusting and related processes in North Dakota in Boreas, vol. 13, p. 2749 – 299, Oslo.

Return to Anamoose, turn right (south) on ND Highway 14

Side route (separate roadlog)

0.5 0.5 *Cross U.S. Highway 52 at Anamoose and head east from town on a gravel road.*

7.5 7.0 *Turn north on gravel road.*

8.8 1.8 *Continue right (east) across top of hill towards the Koble Ranch. Road curves to the right (east) after a mile and then back to the north, crossing the northwest part of a large ice-thrust mass. Continue driving as far as the railroad viaduct. Walk northwest, following the railroad track (BNSF Railroad) for 0.5 mile to a railroad cut exposing faulted and contorted beds of Cretaceous Fox Hills bedrock (likely Colgate Member).*

STOP 7: Clifton Cut (fig. 22)

The railroad cut near Clifton is currently the best-available exposure through a portion of an ice-thrust feature exposing glaciotectonic structures. Unfortunately, we cannot take the Friends of the Pleistocene group to this location due to dangerous rail traffic conditions; trains traveling over 60 mph pass by the location approximately hourly, although more than one train may pass by here within an hour. It would not be possible to assure the safety of tour participants.

The northwest end of a large thrust block is exposed in the railroad cut. The thrust block covers approximately 5 km^2 (2 mi^2) and rises 70 m (230 ft) above the surrounding area. It is composed largely of stacks of bedrock, initially interpreted to be the Colgate Member of the Cretaceous Fox Hills Formation. However, Ed Murphy notes that the lithologies and carbonaceous nature (plant fragments) are more indicative of the Hell Creek Formation (Murphy, 2006). Ed says that it appears to be a highly weathered Hell Creek channel sandstone that contains kaolinite, which is not normally seen in the Colgate (fig. 23).

Figure 22. Topographic map with hillshading enhancement showing the location of Stop 7 – Clifton railroad cut, a glaciotectonic thrust feature located in north-central North Dakota located northeast of Anamoose in T. 181 N., R. 74 W., Sec 13., U.S.G.S. Clifton Quadrangle, 7.5 minute series topographic.

The bedrock portion of the thrust block is covered by a discontinuous layer of glacial deposits. The thrust mass was emplaced by glacial ice moving southeastward. Although a poorly defined depression is located to the immediate northwest of the thrust mass, the depression has itself been partially filled by a smaller thrust mass that was apparently emplaced immediately after the larger one.

Two photos of the north side of the railroad cut (figs. 23 and 24) show the stratigraphic and structural effects of the movement of materials by the glacial ice, from left to right (northwest to southeast). Bedding that was [presumably] originally flat-lying, has been shoved by the glacier, forward and upward, to the southeast, into an anticlinal structure. Numerous thrust planes can be seen in places on the right sides of the photos.

Figure 23. View to the north within the railroad cut near Clifton exposing glacial thrust mass.

Figure 24. North side exposure of the Clifton railroad cut showing the stratigraphic and structural effects of ice-thrusting.

Figure 25. South side exposure of the Clifton railroad cut depicting the relationship between flat-lying and thrusted sediments.

The photo of the south side of the cut (fig. 25) shows thrust planes extending from lower right to upper left (northwest to southeast).

All three of the photos illustrate badlands topography typical of the Colgate Member, which has formed in less than a century, since 1912 when the Sueey Cutoff part of the Great Northern Railroad (now the Burlington Northern Santa Fe Railroad) was constructed through this area.

Although this area, and the land to the north for several miles, all of which are commonly referred to as the Antelope Hills, is notable for the density of occurrence of large ice-thrust masses, reasonably fresh and accessible exposures in which the stratigraphic and structural relationships may be observed, are rare. Most of the known ones are isolated and would require hours of hiking to reach.

The Antelope Hills are the result of an unusual situation that was marked by the advance of two glacial ice lobes, one moving toward the east and the other toward the west. The ice-flow directions were somewhat governed by the Turtle Mountains, an upland located about 120 km (75 mi) to the north of here. The Turtle Mountain upland split the ice flow into two parts, known as the Souris Lobe (the western lobe) and the Leeds Lobe (the eastern lobe) and as these glacial lobes continued their southward advance, they "collided" in a zone that extends to the north from here for about 100 km (60 mi) toward the Turtle Mountains.

The collision of the two ice lobes resulted in extensive thrusting. Some of the resulting thrust masses are large, up to 105 m (350 ft) high and cover areas up to sixteen square kilometers (six square miles), with adjoining source depressions. Most of the source areas are partially flooded by lakes, some of which cover several square kilometers. The washed shores of the lakes typically expose beds of the Cretaceous Fox Hills and Hell Creek Formations, which appear to be in place.

All of the ice-thrust masses in this immediate area (~ two townships) were emplaced by glacial ice moving southeastward (the Souris glacial lobe). However, to the north, equally large thrust masses exist that were emplaced by glacial ice moving mainly westward (the Leeds lobe).

This area is one of several in central North Dakota in which nearly all of the landforms are due to ice-thrusting processes and fluvial processes relating to ice thrusting. Some of these areas of thrusting cover several townships and some of the individual thrusts may cover twenty-five square kilometers (ten square miles). Materials incorporated in thrusts in central Sheridan County have been quarried from depths over 275 m (900 ft).

Retrace route back to Anamoose.

End of side route (round trip distance: 17.6 miles.)

Turn left (south) on ND Highway 14

Resume roadlog on page 148.

90.2	0.8	Crossing Steele Lake.
90.4	0.2	Crossing the northwest end of the Steele ice-thrust hill.
91.0	0.6	St. Martin Lutheran Cemetery on the right. The route in this area is passing over a gently undulating glacial surface ("ground moraine").
92.0	1.0	McHenry/Sheridan County line. Note the energy-efficient house, half buried in the hill, on the east side of the road.
94.4	2.4	The highway curves to the right (west) around Mud Lake (on the east). Mud Lake is a source depression for a rather non-descript thrust. However, a few miles to the east, two notable thrust blocks border the east sides of Chase and Wolf Lakes. The hill on the horizon to the south is an eight-kilometer- (five-mile) long ice-thrust. Thrusting was from northwest to southeast.
95.6	1.2	The route is once again over a gently undulating till surface. As we continue southward over the nearly level plain, notice the prominent bluff on the southwestern horizon. This is the leading edge of a large and complex ice-thrust mass (the "Germantown Thrust," named for the township in which it occurs). The thrust is arctuate, convex toward the east, with about 60 m (200 ft) of local relief. It was derived from a broad, lowland area to the west in which are numerous lakes and a myriad of ice-contact fluvial deposits. If road conditions permit, we may drive to the crest of the Germantown Thrust for an overview of the area and a further discussion of glacial thrusting in this area.
99.8	4.2	*Turn right (west) on gravel road.*
100.2	0.4	Depression. Cretaceous Hell Creek sandstone is at the surface in this area. The embankment along the slough was fresh in 1970 when JPB mapped the geology of Sheridan County; it has grown over with grass.
100.5	0.3	Begin ascent onto the front of the ice thrust.
		STOP 8: Germantown Ice-thrust Mass (fig.26)
101.0	0.5	Top of hill. Stop briefly for a further discussion of thrusting. This location is the outer edge of the Germantown ice-thrust mass. The glacier was moving from west to east. The thrust mass is between 75 and 90 m (250 and 300 ft) thick and consists of layers of Cretaceous Fox Hills beds, possibly with some Cretaceous Hell Creek Formation sandstone interbedded with layers of glacial till and fluvial sediment. The thrusting has lifted the Fox Hills sandstone beds here about 85 m (280 ft) above their original position. The thrust mass, which includes numerous en-echelon ridges, covers about six square miles. A broad, low area to the west was quarried to provide the materials in the Germantown thrust; it appears that repeated thrusting occurred here even after the main block was

Figure 26. Topographic map with hillshading enhancement showing the location of Stop 8 - The Germantown Thrust, a glaciotectonic ice-thrust mass located in north-central North Dakota located 9 miles south of Anamoose in T.150 N., R. 75 W., Sec. 33, U.S.G.S. Drake SE Quadrangle, 7.5 minute series topographic.

moved. The quarried area, which extends over about 40 square kilometers (15 square miles), itself includes numerous small thrust blocks, some up to several square kilometers in area and with 45 m (150 ft) of local relief. Cretaceous Fox Hills bedrock is exposed in many places in the quarried area, particularly along the lake shores.

Following, or perhaps coincident with the emplacement of the Germantown Thrust, a large number of intricate esker deposits containing gravel and sand were deposited in the glacial ice that remained in the quarried area.

The broad lowland area to the west of the Germantown Thrust coincides with the preglacial (?) route of the combined Cannonball and Knife rivers through this area. Glacial and glaciofluvial deposits in the lowland are over 275 m (900 ft) thick in some places.

102.2 1.2 *Return to Highway 14 and turn south.*

105.7 3.5 Begin a curve to the left (east) onto the Lonetree Dam. This dam was built in the early 1980’s as a part of the Garrison Diversion Unit. Had the dam been flooded, it would have held back a reservoir that would have extended west (upstream along the Sheyenne River) from the dam, flooding much of the lowland area west of the Germantown Thrust.

The Pick-Sloan Plan

The Garrison Diversion Unit is part of the Pick-Sloan Missouri River Basin program, authorized by the federal Flood Control Act of 1944. The Pick-Sloan plan provided for construction of a series of dams on the Missouri River to control flooding, provide power generation, and maintain a dependable water supply for irrigation, municipalities, industry, recreation, wildlife habitat, and navigation.

One feature of the Pick-Sloan plan was the Missouri-Souris Unit, which was the forerunner of the Garrison Diversion Unit. Water was to be diverted below the Fort Peck Dam in Montana and transported by canal for irrigating 5,200 square kilometers (1,275,000 acres); supplying municipalities in North Dakota, South Dakota, and Minnesota; restoring Devils Lake; conserving wildlife; and augmenting the Red River. However, the building of Garrison Dam changed the diversion point of the Missouri-Souris Unit from Fort Peck Dam to Garrison Reservoir (Lake Sakakawea). After considerable study and review of the Missouri-Souris Unit, Congress reauthorized the project as the initial stage, Garrison Diversion Unit, in August 1965.

Garrison Diversion Unit/Lone Tree Reservoir

The first detailed investigations of the Garrison Diversion Unit involved a proposed development of 4,075 square kilometers (1,007,000 acres). The original plan called for the construction of major supply works to transfer water from the Missouri River to the Souris, James, and Sheyenne Rivers and to the Devils Lake Basin (Devils Lake at that time had been experiencing a series of years during which it had been very low – however, the lake is currently at an all-time historic high level).

The Garrison Diversion plan would also provide water to 14 cities and it provided water for several recreation areas, as well as for a 593-square kilometer (146,530-acre) wildlife plan to mitigate wildlife habitat losses resulting from project construction and to enhance other wetland and waterfowl production areas.

The Snake Creek Pumping Plant, which has been built, lifts Missouri River water from Lake Sakakawea into Lake Audubon, an impoundment adjacent to Lake Sakakawea. Were the project completed, water could flow by gravity from Lake Audubon through the 118.5-kilometer (73.6-mi) McClusky Canal into Lonetree Reservoir, situated on the headwaters of the Sheyenne River. The Lonetree Reservoir was to be created by construction of Lonetree Dam on the upper Sheyenne River, Wintering Dam on the headwaters of the Wintering River, and the James River dikes on the headwaters of the James River. Lonetree Reservoir would be situated so that water could be diverted by gravity into the Souris, Red, and James River Basins and into the Devils Lake Basin.

A number of concerns have slowed or halted construction on the Garrison Diversion Project in recent years. They include:

- Canadian concerns that the Garrison Diversion Unit would allow transfer of foreign species of fish and other biota to the detriment of Canadian waters in violation of the Boundary Waters Treaty of 1909.

- Numerous problems concerning wildlife mitigation and enhancement lands.
- Legal suits brought by various groups, such as the National Audubon Society, seeking to halt construction of the Garrison Diversion Unit by claiming the project violates the National Environmental Policy Act and to enforce a stipulation between the United States and the Audubon Society to suspend construction until Congress reauthorizes the Garrison Diversion Unit.

Since 1966, about $625 million dollars has been spent on various aspects of Garrison Diversion. Among the projects originally envisioned, several were constructed or partially constructed. No attempt will be made to provide any amount of detail about these, but some of the things we will see along our field trip route are worth mentioning. We drive along the crest of Lonetree Dam, which is located in northeastern Sheridan County, about 19 kilometers (12 mi) south of Anamoose. Although the dam has been constructed, Lonetree Reservoir has not been completed. Water to flood the Lonetree Reservoir, which would extend westward from the dam, would require that water be pumped through the McClusky Canal (a portion of which we will see).

Assorted Facts, Problems, Concerns, etc.

- The Lake Audubon impoundment and the Snake Creek Pumping station have both been constructed, along with Garrison Dam.
- The McClusky Canal, New Rockford Canal, and other early construction projects built, have never been used, and are now deteriorating.
- Construction of Fort Peck and Garrison Dams accomplished flood control. Among other things, this made it possible to build on the flood plain in what is now south Bismarck. Prior to construction of the dam, that part of Bismarck south of the railroad regularly flooded during the spring.
- A prolonged drought has been ongoing west of [approximately] the 100^{th} meridian (Bismarck is at 100^{o} 50' west longitude). This drought, coupled with controversial management by the U.S. Corps of Engineers, has resulted in a drastic drop in the level of Lake Sakakawea. Management of the Missouri River has included (and currently includes) providing sufficient river flow to float barge traffic between Sioux City and New Orleans. This has been a point of contention with upstream states, which contend that recreational usage, maintenance of the fishery in the upstream reservoirs, etc., suffer at the expense of maintaining the barge traffic.
- East of the 100^{th} meridian, North Dakota has seen excess precipitation, causing high surface and ground water levels and flooding on Devils Lake and elsewhere. Plans are currently underway to build a pipeline to the Red River Valley to provide a reliable water source for Fargo, Moorhead, Grand Forks, and East Grand Forks.
- The flooding of Lake Sakakawea displaced the Native American tribes who lived on farms and villages in the now-flooded area. Few of the promises made to the Native American tribes at the time the Pick-Sloan Plan and Garrison Diversion were proposed have been honored. About a dozen towns and 627 square kilometers (155,000 acres) of agricultural land that belonged to the Arikara, Mandan, and Hidatsa tribes is now submerged beneath Lake Sakakawea. New Town is so-named because it was built to replace several now-flooded towns (Sanish, Van Hook, Elbowoods, and others).

- About half of North Dakota's original woodlands were flooded by Lake Sakakawea and no longer exist.

105.9 0.2 We will drive along the crest of the dam. The bridge at the midpoint of the dam allows the Sheyenne River to flow through. To the east are Sheyenne Lake and Coal Mine Lake (the Sheyenne River flows through both lakes). See the accompanying sidebar for a discussion of the Garrison Diversion Unit.

113.2 7.3 Begin a gradual ascent onto the Missouri Coteau. The topography grades to increasingly rugged collapsed glacial topography. Notice the occasional exposures of glacial till or gravel.

121.2 8.0 Junction of ND Highways 14 and 200. This junction marks the center of a relatively level elevated lake plain that covers an area of about 2 square kilometers (3/4 of a square mile).

Turn west on ND Highway 200 and continue traveling through high-relief collapsed glacial topography.

122.8 1.6 Area of collapsed outwash gravel.

123.3 0.5 Drive back onto a hilly till surface.

129.9 6.6 Town of McClusky. McClusky has always billed itself as the "Center of North Dakota." Several years ago, when we got our first GPS receiver at the ND Geological Survey, we calculated the "exact" coordinates of the true center of the state and then walked to the location using the new receiver. We found it to be in a pothole about 2.8 miles southwest of McClusky, close enough to vindicate McClusky's claim.

For years, a sign at the edge of McClusky proclaimed: *"McClusky – Geographical and Economical Center of North Dakota."*

STOP 9: McClusky Canal (fig 27)

132.8 2.9 McClusky Canal. Stop briefly for discussion. The canal is another major component of the Garrison Diversion Unit. Actual construction on the McClusky Canal started on May 1st, 1970 and continued until 1976. It stretches 119 kilometers (74) miles, beginning on the east shore of Lake Audubon, and ends abruptly near the Sheyenne River in northeastern Sheridan County. To prevent additional deterioration, the McClusky Canal is kept partially flooded with water that has been pumped into it from Lake Audubon.

Figure 27. Topographic map with hillshading enhancement showing the location of Stop 9 - The McClusky Canal, a civil-works structure located in north-central North Dakota locted 3 miles west of McClusky in T. 150 N., R. 77 W., Sec.11, U.S.G.S. McClusky Quadrangle, 7.5 minute series topographic.

Some slumps can be seen in the canal walls (fig. 28). Since the McClusky Canal was constructed 30 years ago, the slopes have been maintained by a permanent crew of about 20 employees, Annual maintenance costs are about $3.5 million, half of which is used to maintain and operate the canals themselves and half for upkeep of associated features, including 400 kilometers (250 miles) of roads and rights of way.

Environmental critics consider the Garrison Diversion to be “the granddaddy of wasteful water projects.” It depends upon your point of view.

Continue to the west through collapsed glacial topography.

Figure 28. View to the northeast of the northern end of the McClusky Canal just north of ND Highway 200 approximately five kilometers (three miles) west of the town of McClusky.

137.2 4.4 Pickardville.

141.9 4.7 McLean County line. The southern end of the Prophets Mountains, another large ice-thrust mass, can be seen on the horizon to the north-northeast.

STOP 10: Prophets Mountains (fig. 29)

Figure 29. Topographic map with hillshading enhancement showing the location of Stop 10 - Prophets Mountains, a large glaciotectonic ice-thrust feature located in north-central North Dakota located five miles northeast of Mercer in T. 147 N., R. 78 W., Sec. 22, NE 1/4, U.S.G.S. Pickardville Quadrangle, 7.5 minute series topographic.

Note: The following synopsis is taken from *"Large-scale glacial thrusting and related processes in North Dakota"* published in1984 in the journal Boreas. Authors are John P. Bluemle and Lee Clayton. Reprints of the complete paper are available.

One of the most graphic examples of a large, imbricate thrust and folded feature in North Dakota is the Prophets Mountains (figs. 30 and 31). The Prophets Mountains cover an area of about 20 square kilometers (8 square miles) in western Sheridan County in central North Dakota. They have local relief exceeding 100 m (325 ft), strong north-south linearity indicating imbricate thrusting from the east, and associated ice-contact fluvial deposits along their western edge. Much of the thrust feature is composed of Pleistocene material, but a road cut on the south end of the Prophets Mountains exposes folded and contorted Cretaceous and Paleocene shale, sandstone, and coal beds (fig. 31). (Note: the road cut was fresh in 1969; it is now grassed over.) About 15 m (50 ft) of Cretaceous shale and sandstone were measured in the road cut. The elevation of the exposure is about 600 m (1,970 ft), whereas the subsurface contact between these two normally flat-lying formations is found in nearby test holes at an elevation of about 500 m (1,640 ft). The preglacial materials in the exposure are therefore interpreted as having been lifted, as a result of glacial thrusting, about 100 m (330 ft) above their original in-place position.

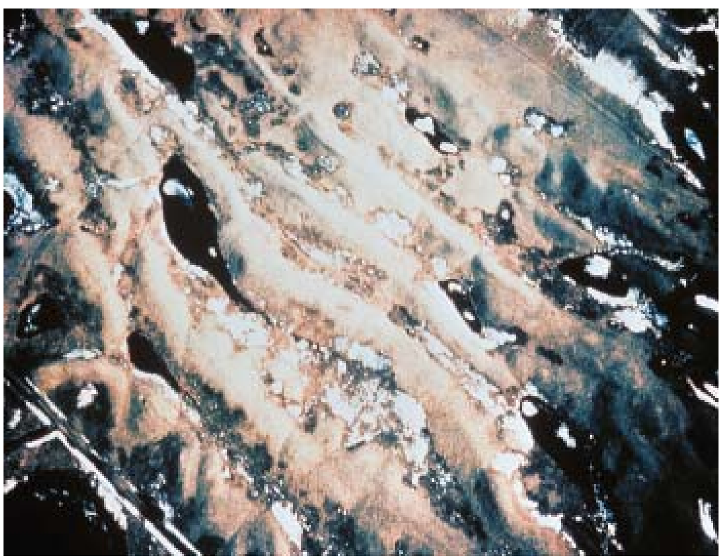

Figure 30. A vertical air-view of the Prophets Mountains in central North Dakota. The area shown is about 4 km (2.5 mi) wide with north oriented towards the top of the page. Slabs of Cretaceous material have been quarried from as deep as 180 m (600 ft) here and stacked up by glacier action, in an en-echelon fashion, to form a ridged landscape. This is an aerial view showing the edges of a series of slabs, stacked on each other. Glacier movement in this area was from upper right to lower left. A few miles from here, sandstone and shale slabs have been found that were excavated by the glacier from about 275 m (900 ft) deep. In both the Prophets Mountains and Lincoln Valley area, these slabs now occur at elevations ranging from about 100 to 300 m (330 to 1000 ft) higher than their original positions, before glacial thrusting took place.

Figure 31. Road cut through a slab in the Prophets Mountains. This is a road cut through one of the slabs depicted in the previous figure. The beds here are Cretaceous and Paleocene sandstone and shale that have been thrust upward about 100 m (330 ft) from their original (preglacial) position. The total thickness of the individual ice-thrust slabs here is about 25 to 30 m (80 to 100 ft).

The Prophets Mountains are situated over a large, complex aquifer (the Lake Nettie Aquifer), which is developed partly in Cretaceous sandstone and partly in a broad, largely buried, easterly trending valley that served as an interglacial route for an early, ancestral route of the Missouri River (fig. 32).

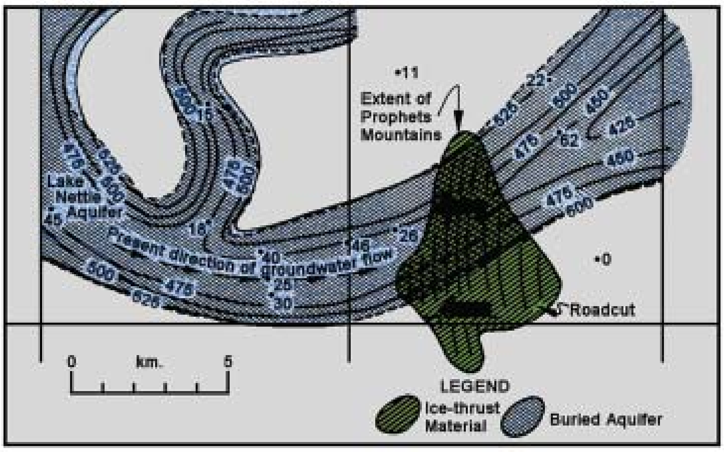

Figure 32. Relationship between Prophets Mountains and the underlying Lake Nettie Aquifer. The Prophets Mountains are an example of a large ice-thrust mass that overlies an aquifer, in this case a major buried river channel. A large proportion of the ice-thrust features in North Dakota are closely associated with buried aquifers. Probably 90 percent of the ice-thrust features that have been identified in North Dakota are closely associated with specific glacial or pre-glacial aquifers. The ice-thrust features tend to occur over buried aquifers, and it has been theorized that this is because the thrusting occurs in places where high pore-water pressures are more likely to build up within alternating layers of permeable and impermeable materials.

The north-south trending transverse ridges on the Prophets Mountains are slightly convex westward because the slightly lobate glacier that emplaced them flowed nearly straight west. The position of the collapsed, supraglacial, fluvial gravel on the west face of the Prophets Mountains indicates that, at the time the hills were emplaced, the area immediately to the west of the feature was covered by stagnant glacial ice that was approximately 30 m (100 ft) thick.

At the time the thrusting of the Prophets Mountains occurred, the groundwater in the aquifer beneath the area was confined by the sides and base of the interglacial (possibly preglacial) valley and on top by a layer of permanently frozen ground. The aquifer extends westward beneath the position of the former ice margin, seemingly providing an under-drain that would have prevented the buildup of groundwater pressures great enough to facilitate thrusting; the aquifer west of the Prophets Mountains therefore must have been sealed by permafrost. The pre-Pleistocene material at the south end of the Prophets Mountains was thrust over a Cretaceous aquifer connected to the glacial aquifer where the interglacial valley cuts through the Cretaceous materials east of the Prophets Mountains. During the thrusting event, the groundwater flow direction was reversed because the glacier to the east provided a much higher hydrostatic head gradient; groundwater could not flow eastward beneath the advancing glacier.

143.7 1.8 Town of Mercer. *Turn south on ND Highway 41.*

We are still driving over collapsed glacial topography of the Missouri Coteau. The glacial materials and topography here date to the Late Wisconsinan, but we will shortly pass onto much-less-rugged topography as we leave the Late Wisconsinan glacial deposits and drive onto deposits of Early Wisconsinan age.

144.8 1.1 Curve around lake. Area of collapsed gravel deposits.

148.9 4.1 The broad, relatively level area in the distance ahead is subdued topography of Early Wisconsinan age.

150.4 1.5 Pass from Late to Early Wisconsinan deposits and topography. To the south (the remaining portion of this trip) the surface is covered in most places by a veneer of Early Wisconsinan (?) glacial deposits. The exception is where thicker deposits exist in buried valleys.

151.6 1.2 McClusky Canal.

157.5 5.9 Road to Washburn. The broad valley to the south (ahead) which we will cross over the next four miles, is the preglacial (?) route of the Knife River (the modern Knife River flows eastward and ends where it flows into the Missouri River).

This valley is partly buried by pre-Late Wisconsinan glacial deposits, which in this area are piled against the south wall, within the valley. Prior to its diversion and burial, the Knife River flowed to the east and northeast from this area, joining the Cannonball River, and eventually making its way northward to Hudson Bay.

158.7 1.2 Bridge over Painted Woods Creek. Painted Woods Creek flows westward into the Missouri River, through the old Knife River Valley, in the opposite direction that the Knife River flowed.

165.1 6.4 McLean County line. The highway curves toward the west. The hills to the south on the periphery of the town of Wilton, are spoils of the old Truax-Traer lignite mine, dating to the mid-1940s. The Truax-Traer Mine was a surface mine, but underground coal mining in this area dates to 1901. By 1907, the Wilton underground mine was billed as the largest underground lignite mine in the world. Many of the early miners were Ukrainians, Austrians, and Hungarians who brought with them their talents, customs and religion. At times the mine had more than 900 men on the payroll, which was as much as $90,000 a month.
Because of the lignite mine, Wilton had electric lights before any other small town in North Dakota. The lignite mined in this area is from the Paleocene Bullion Creek Formation (Fort Union Group).

167.7 2.6 Junction with U.S. Highway 83. *Turn south.*

168.4 0.7 Town of Wilton.

170.5 2.1 FPL Energy windfarm to the east.

181.6 11.1 Highway curves slightly to the left, down into a broad valley. The Paleocene Bullion Creek Formation forms semi-badlands topography and small buttes.

184.4 2.8 Leave valley.

188.9 4.5 Bismarck.

192.4 3.5 Heritage Center.

End of Day 2
End of trip

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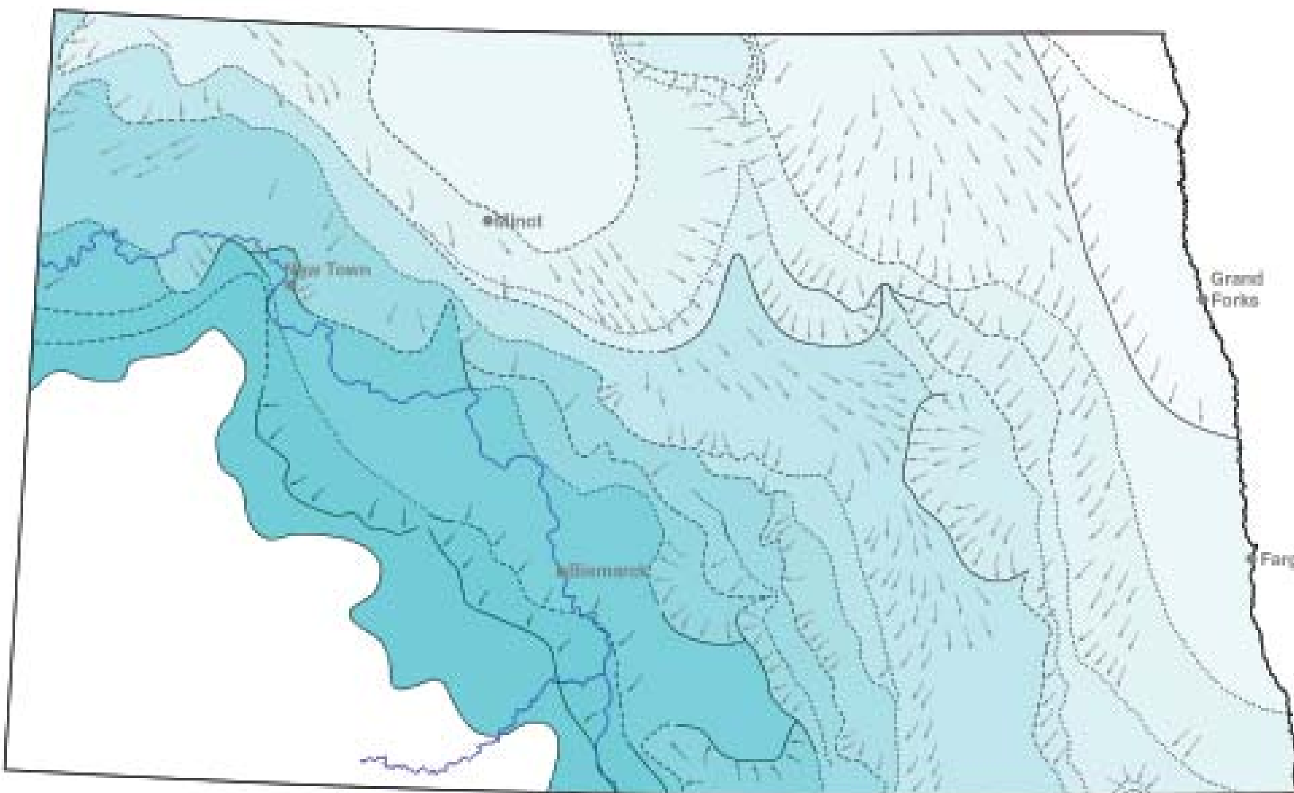

0 20 40 60 miles
0 20 40 60 80 kilometers
N

Limits of Pleistocene glaciation in North Dakota

Direction of ice movement

Adapted from L. Clayton, S.R. Moran, and J.P. Bluemle, 1980, Explanatory text to accompany the geologic map of North Dakota: North Dakota Geological Survey Report of Investigations RI-69, 93 p.

Approximate ages of ice margin positions (years B.P.)

< 11,900
11,900
?
12,000
12,100
12,200
?
?
12,400
12,700
12,900
15,000
> 40,000?
> 40,000?