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Origin and stratigraphy of Holocene sediments, Souris and Des Lacs glacial-lake spillways, north-central North Dakota

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ORIGIN AND STRATIGRAPHY OF HOLOCENE SEDIMENTS,
SOURIS AND DES LACS GLACIAL-LAKE SPILLWAYS,
NORTH-CENTRAL NORTH DAKOTA

by

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This thesis submitted by William M. Boettger in partial fulfillment of the requirements for the degree of Masters of Arts from the University of North Dakota has been read by the Faculty Advising Committee under whom the work has been done, and is hereby approved.

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

A. William Johnson 7/17/86
Dean of the Graduate School

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Signature William M. Boettger

Date July 16, 1986

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ABSTRACT

In the past few years, a new interpretation of the formation of the Souris and Des Lacs glacial-lake spillways has been proposed. Now, based on geomorphological evidence, it is concluded that the Souris and Des Lacs Valleys were formed by massive glacial-lake outburst floods at the end of the late Wisconsinan deglaciation. Five phases of drainage have been recognized with the first forming the Des Lacs Valley and the other four associated with drainage in the Souris Valley from different proglacial lakes in Canada. The last of these floods down the Souris Valley was the most erosive.

This study is concerned with Holocene sediments that have filled the Souris and Des Lacs Valleys in Ward and Renville Counties. Most of the discussion is focused on the Souris Valley. Twelve cross sections were constructed from data gathered in the field, from the U.S. Army Corps of Engineers, and the North Dakota State Water Commission. These data include: texture, structure, fossils, and amount of organic material. Study of these data allows reconstruction of the depositional environment of the Holocene sediments and of the history of the valleys.

While the Souris Valley was being eroded during the last glacial-lake outburst, a headward-migrating knickpoint developed in the Souris Valley. This was caused by downcutting of the valley bottom while the flood was

discharging into Glacial Lake Souris. After the flood subsided, an aggrading, meandering Souris River occupied the valley. Initially, the sides of both the Souris and Des Lacs Valleys were steep, and slumping occurred. Numerous intermittent streams entered the valleys from the sides and deposited coarse material close to the valley walls. The centers of the valleys contain silt with sand and clay lenses typical of fluvial systems dominated by meandering streams. The center of the Souris Valley, between its confluence with the Des Lacs River and the position of the Soo Line R.R. to the north, is characterized by a completely different stratigraphic sequence that includes a central clay plug. Differences in the types of organic materials and fossil assemblages in this section suggest a swampy to shallow-pond environment. This pond may have been dammed by an alluvial fan deposited by the higher-gradient Des Lacs River.

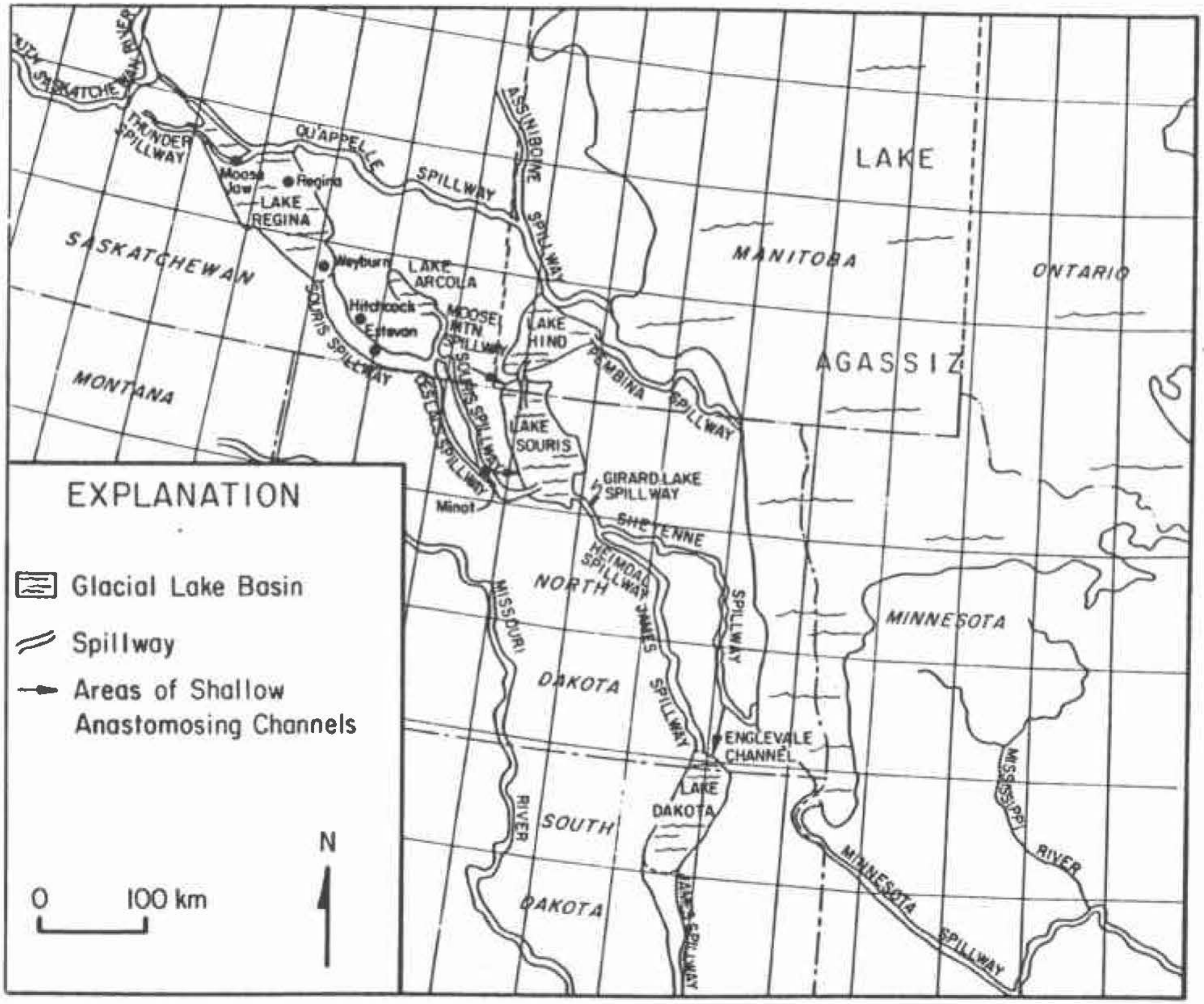
Three organic horizons were recognized and are interpreted to represent cool, moist, climatic conditions that enabled vegetation to stabilize the steep valley sides. The lower horizon has been correlated with the Aggie Brown Member of the Oahe Formation of early Holocene age by C-14 dating. The other two horizons are not dated but may be correlative with the late Holocene Riverdale Member of the Oahe Formation. A warm and drier climate during the middle Holocene was characterized by greater slope erosion and more deposition in the valleys.

INTRODUCTION

General Statement

Over the past ten years a new interpretation of the origin of the Souris and Des Lacs glacial-lake spillways has been proposed. It is now believed that the spillways were incised by a sudden catastrophic drainage of Glacial Lake Regina in southwestern Saskatchewan (Kehew, 1982; Kehew and Clayton, 1983; Kehew and Lord, 1986). The Souris spillway, which begins at the southern outlet of Glacial Lake Regina, terminates at the Glacial Lake Souris basin in north-central North Dakota. The Des Lacs spillway begins north of Bowbells, North Dakota and intersects the Souris spillway near Burlington, North Dakota (Fig. 1). Because the flood originated from a standing body of water, the initial sediment load was low and the floodwater was highly erosive. According to this hypothesis, coarse-grained channel deposits from a catastrophic flood of this nature should be thin and discontinuous on the spillway bottom. Lord (1984) and Kehew (1982) described geomorphic features that indicate a flood of enormous discharge occurred in the Souris and Des Lacs spillways. This evidence includes: bars composed of boulder gravel, channel bifurcation, streamlined landforms, and scabland topography near Minot, North Dakota. Work on the gravel deposits by Lord (1984) indicates that the deposits consist of coarse, poorly sorted, massive gravel. The overlying valley-fill deposits

Figure 1. Map showing the location of the Souris and Des Lacs glacial-lake spillways in north-central North Dakota (Kehew and Lord, 1986).



SOUTH SASKATCHEWAN RIVER
THUNDER SPILLWAY
QU'APPELLE SPILLWAY
Moose Jaw
Regina
LAKE REGINA
SASKATCHEWAN
Weyburn
LAKE ARCOLA
Hitchcock
Estevan
MOOSE MTN SPILLWAY
SOURIS SPILLWAY
ASSINIBOINE SPILLWAY
LAKE HIND
PEMBINA SPILLWAY
LAKE SOURIS
MONTANA
MANITOBA
LAKE
AGASSIZ
ONTARIO
GIRARD LAKE SPILLWAY
SHEYENNE
HEIMDAL SPILLWAY
Minot
NORTH
DAKOTA
MISSOURI
JAMES SPILLWAY
SPILLWAY
MINNESOTA
ENGLEVALE CHANNEL
LAKE DAKOTA
RIVER
SOUTH
DAKOTA
JAMES SPILLWAY
MISSISSIPPI RIVER
MINNESOTA SPILLWAY
EXPLANATION
Glacial Lake Basin
Spillway
Areas of Shallow Anastomosing Channels
0 100 km
N

have been described by Lemke (1960) as fine-grained, organic sediments of fluvial and lacustrine origin.

Purpose and Objectives

The purpose of this study is to investigate the spillway-bottom deposits and overlying Holocene deposits in the Souris and Des Lacs Valleys in order to determine their origin and environments of deposition. The primary objectives of the study are:

1.) To determine the stratigraphy and sedimentological characteristics of the Holocene section.

2.) To determine through C-14 dating the age of the Holocene deposits.

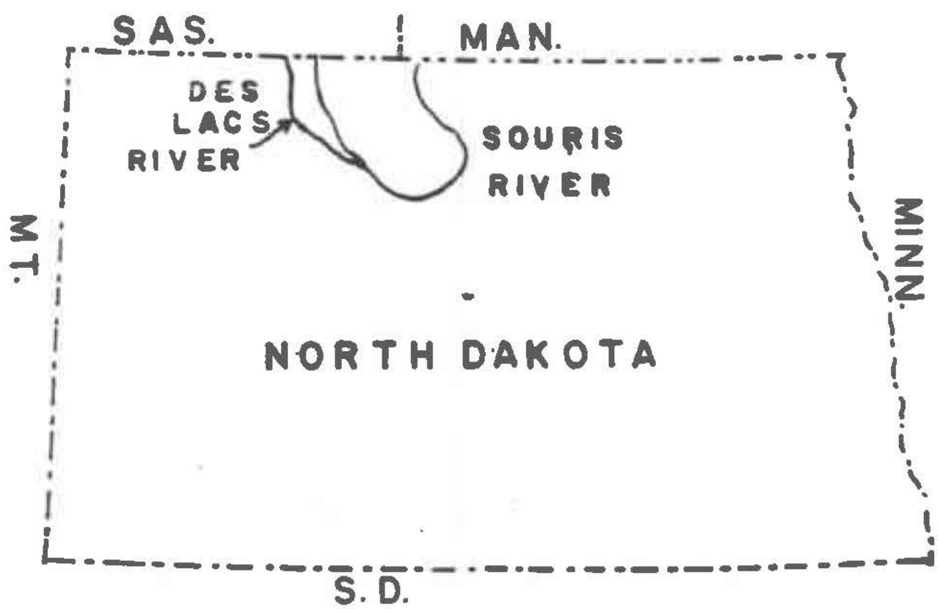
3.) To develop an understanding of the environmental setting using fossils and organic material.

4.) To determine if it is possible by looking at drill cores if the base of the spillways reveal discontinuous coarse-grained Pleistocene deposits.

Study Area

The Souris and Des Lacs Valleys are located in Ward and Renville Counties in north-central North Dakota (Fig. 2). The Souris Valley trends north-northwest from Velva, North Dakota to the United States-Canadian border. The Des Lacs Valley also trends northwest from its intersection with the Souris Valley north of Burlington to the international border.

Figure 2. Map showing the Souris and Des Lacs Rivers in Ward and Renville Counties, North Dakota.


SAS.
MAN.
DES
LACS
RIVER
SOURIS
RIVER
MT.
MINN.
NORTH DAKOTA
S.D.

Regional Geological Setting

The bedrock immediately underlying the study area is the Fort Union Group of Paleocene age. Bedrock exposures occur along the lower slopes of the Souris and Des Lacs Valleys and their major tributaries (Lemke, 1960; Kehew, 1983). Clayton et al. (1980) stated that the bedrock may belong primarily to the Bullion Creek Formation, which consists of alternating beds of poorly lithified claystone, siltstone, sandstone, and lignite. These sediments were laid down in fluvial and lacustrine environments during the Paleocene. When the Rocky Mountains started to form, the area was uplifted and erosion occurred. By Pleistocene time, most of the Tertiary sediment deposited above the Fort Union Group was removed (Bluemle, 1960, 1980; Kehew, 1983).

The surficial deposits are Pleistocene and Holocene in age. These deposits are assigned to the Coleharbor Group and Oahe Formation and probably date from late Wisconsinan through Holocene time (Lemke, 1960; Clayton et al., 1980; Kehew, 1983). During retreat of the Laurentide Ice Sheet, ice stagnation occurred. Thick deposits of superglacial sediment accumulated on top of the stagnating ice sheet in many areas. Differential melting caused by variable thickness of the superglacial sediment led to the development of hummocky collapse topography. Topographic inversion resulted in some areas where the ice melted more quickly than in other areas, allowing material to slump into the depressions and eventually form ridges or mounds when the ice completely melted (Clayton and Moran, 1974). The area is also characterized by various types of valleys that were buried by successive glacial advances (Kehew, 1983).

The youngest sediment present is Holocene in age and is assigned to the Oahe Formation. These deposits of alluvial and lacustrine sediment are composed of beds of silt, clay, sand, and organics (Lemke, 1960; Clayton et al., 1980).

PREVIOUS WORK

Late Glacial Chronology

The chronology adopted here is that of Clayton and Moran (1982). The reasons for using their chronology are twofold. First, their work is the most up-to-date version of glacial chronology for this area, and second, their dates are based on radiocarbon dating of wood, excluding shells and peat, which are subject to carbon contamination.

About 14,000 BP a major glacial readvance occurred into northeastern North Dakota and west-central Minnesota, terminating near Des Moines, Iowa (Fig. 3). Clayton and Moran (1982) referred to the extent of this advance as margin F in North Dakota. Margin F is correlated with the Bemis moraine in Iowa and the Altamont moraine in South Dakota and Minnesota. Two minor readvances (G and H) occurred before 12,300 BP (Clayton and Moran, 1982), following retreat from margin F.

At about 12,300 BP, the ice retreated, then readvanced to margin I (Fig. 4). Also, the Des Moines Lobe readvanced from central Minnesota into northern Iowa (Clayton and Moran, 1982).

After 500 years of stagnation, a significant readvance of the ice occurred into North Dakota from the northeast at about 11,800 years BP (Fig. 5). The marginal features of this readvance are referred to as phases J, K, and L by Clayton and Moran (1982), and the Mankato substage by Lemke (1960). Phase J advanced over the northeastern half of

Figure 3. Map showing margin F, G, and H (Modified from
Clayton and Moran, 1982).


MANITOBA
ONTARIO
MINN
NORTH
DAKOTA
F
G
H
Des
Moines
Lobe
James
Lobe
WISC
SOUTH
DAKOTA
NEBRASKA
IOWA

Figure 4. Map showing margin I (Modified from Clayton and Moran, 1982).

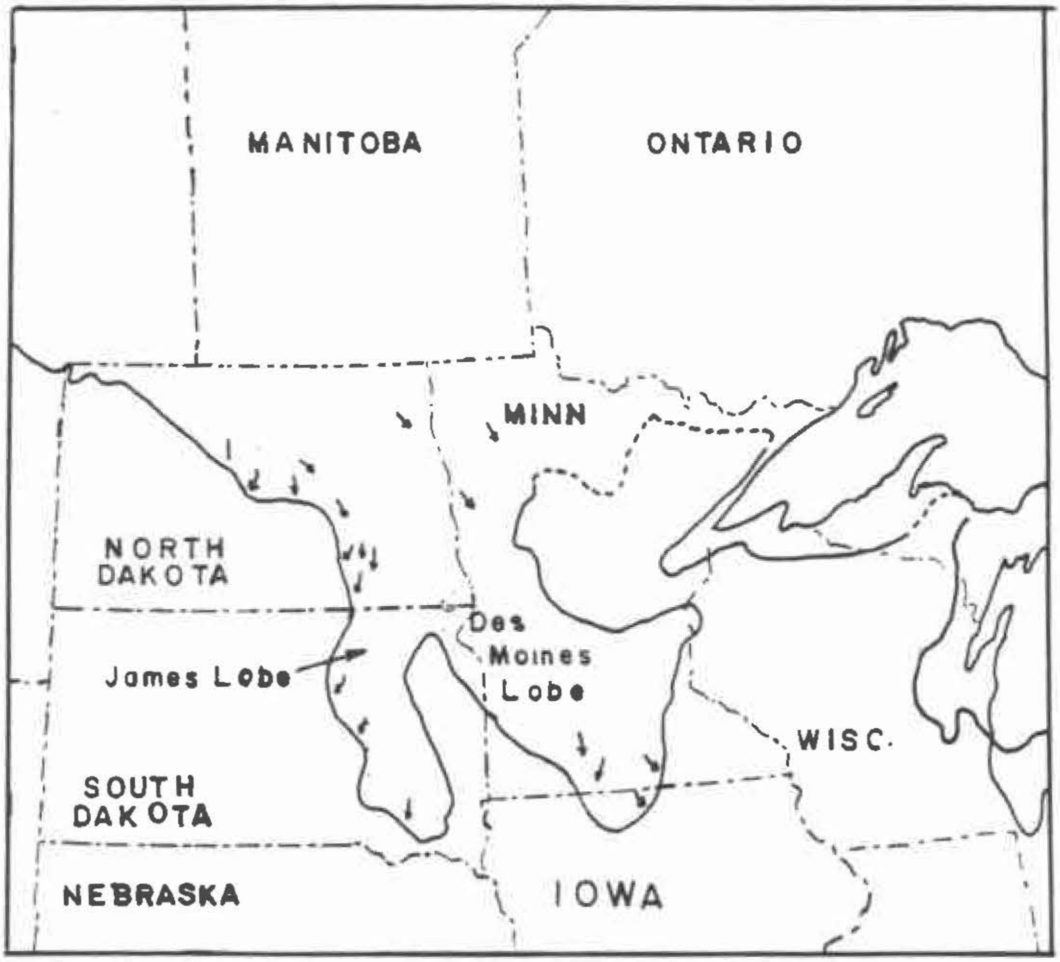
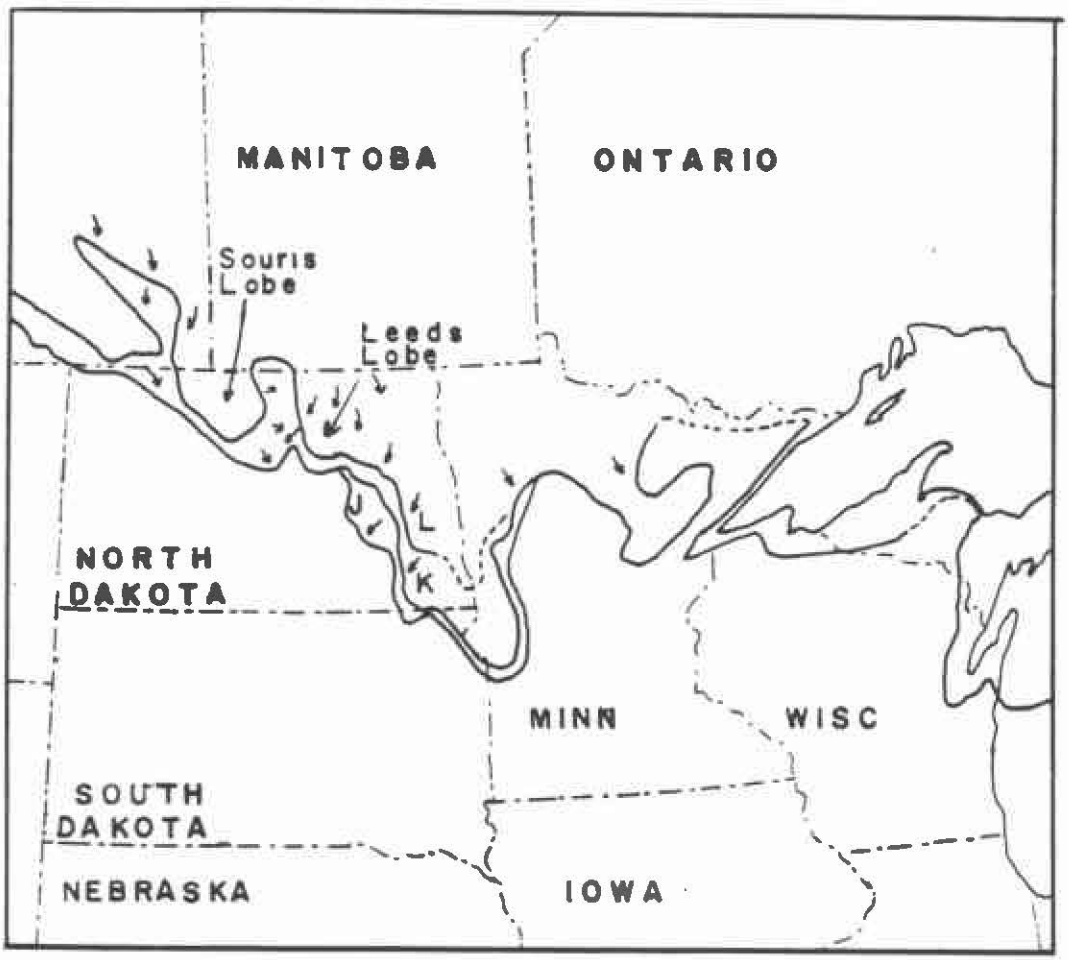

MANITOBA
ONTARIO
MINN
NORTH
DAKOTA
Des
Moines
Lobe
James Lobe
WISC.
SOUTH
DAKOTA
NEBRASKA
IOWA

Figure 5. Map showing margins J, K, and L (Modified from Clayton and Moran, 1982).


MANITOBA
ONTARIO
Souris Lobe
Leeds Lobe
J
L
K
NORTH DAKOTA
MINN
WISC
SOUTH DAKOTA
NEBRASKA
IOWA

North Dakota, across the northern edge of South Dakota, and into west-central Minnesota. After minor wastage, the ice readvanced to margin K. Lemke (1960) identified this phase as the early Mankato substage. The ice advanced to the Missouri Coteau and proceeded to override it. Because the ice advanced over the Missouri Coteau, it must have been thick enough to cover the Turtle Mountains. This advance produced the Max moraine. During wastage of the ice, superglacial and englacial material was deposited to form hummocky topography by differential melting.

After the ice wasted from margin K, a significant readvance of the ice occurred to margin L in northwestern and northeastern North Dakota (Clayton and Moran, 1982). Lemke (1960) defined this advance as the late Mankato advance. The ice was apparently thin enough to be deflected by topographic obstacles and it split into two lobes around the Turtle Mountains. To the east of the Turtle Mountains, the Leeds Lobe formed, while to the west, the Souris Lobe developed.

The Souris Lobe advanced as far as the Martin moraine, referred to as margin 11 by Clayton et al. (1980), before stagnating. The Leeds Lobe advanced eastward, then turned and advanced towards the west. This interpretation is based on probable interlobate deposits interbedded with deposits of the Souris Lobe in north-central North Dakota (Lemke, 1960).

As the Souris Lobe stagnated, a belt of ice lying against and parallel to the Missouri Coteau extended as far north as the Des Lacs and Souris spillways (Lemke, 1960). As the southwestern side of the Souris Lobe melted, meltwater flowed down the Des Lacs Valley first, along with meltwater from the stagnating ice on the Coteau (Lemke, 1960), because the Souris Lobe was still blocking the northern half of the Souris Valley. As the Souris Lobe continued to waste, Glacial Lake Souris formed as a series of small lakes between the ice and the Turtle Mountains to the east (Clayton et al., 1980).

Eventually, the meltwater flowed into Glacial Lake Souris. Glacial Lake Souris by this time had expanded to a continuous lake stretching as far as the Turtle Mountains to the north, and Verendrye to the west (Lemke, 1960; Clayton et al., 1980).

There is evidence that the Souris Lobe either halted or readvanced slightly before 12,000 years BP. Till analysis by Kehew (1984) suggests that there probably was a minor readvance.

At first, Glacial Lake Souris was dammed to the northeast by the Souris Lobe. As the Souris Lobe retreated, Lake Souris drained down the Pembina trench to Glacial Lake Agassiz (Fig. 1) (Lemke, 1960; Clayton et al., 1980).

The area has experienced isostatic rebound since the ice retreated. Rebound may be as much as 60 m as judged by tilted strand and beach lines formed by Glacial Lake Agassiz (Clayton et al., 1980).

Origin of Spillway and Gravel Deposits

Until recently, the origin of the Souris and Des Lacs Valleys was assumed to be the result of normal meltwater flow as the glaciers melted and retreated. In the last few years, a new hypothesis has been offered concerning the origin of these spillways.

It is now recognized, mainly on the basis of geomorphic relationships, that one or more catastrophic floods are responsible for the origin of the Des Lacs and Souris spillways (Kehew, 1982; Kehew and Clayton, 1983: Lord, 1984; Kehew and Lord, 1986). The evidence includes scabland topography near Minot, North Dakota, probably caused by water breaching the side of the spillway. Other topographic evidence for a flood of large magnitude includes channel bifurcation, divide crossings, streamlined erosional features, and terraces that may be remnants of point-bar deposits from the flood.

Kehew and Clayton (1983) and Kehew (1982) have proposed that the flood was caused by a sudden discharge of water from Glacial Lake Regina in southeastern Saskatchewan. The arrival of the flood water at a downstream proglacial lake from an event of this type would cause the lake to rapidly enlarge its outlet spillway and drain into the next proglacial lake.

The major piece of evidence cited to support this hypothesis is the lack of large channels crossing the lake basins, indicating the presence of a standing body of meltwater at the time of flood inflow. The presence of large channels that enter and leave the proglacial lake basins (Kehew and Clayton, 1983), indicates that huge discharges both entered and left the basins.

The Glacial Lake Regina outburst floods discharged down the Souris for 150 km and then bifurcated, following both the Des Lacs and Souris Valleys until they rejoined northwest of Minot. From there, the flood water flowed southward past what is now Velva and into Glacial Lake Souris. The sudden influx of water caused the lake to erode its northern outlet and flow north into Glacial Lake Hind. This inflow triggered a sudden drainage of Glacial Lake Hind toward the east through the Pembina spillway into Glacial Lake Agassiz (Kehew and Clayton, 1983). Using the Manning equation, Kehew (1982) calculated the discharge from Glacial Lake Regina to be on the order of $1 \times 10^5\ m^3/s$.

Lord (1984) indicated that there may have been as many as four episodes of massive outburst dicharges along the Souris and Des Lacs spillways with the last being the largest and most erosive. Lord (1984) proposed that the Des Lacs spillway was formed during the first discharge or phase from a supraglacial lake near Bowbells, North Dakota. The Souris spillway was partially eroded during the second drainage phase by glacial meltwater from the Moose Mountains area. The drainage of Glacial Lake Arcola during phase 3 eroded the Souris spillway and also caused landslides along the spillway sides. Phase four was also a discharge from Glacial Lake Arcola that deposited gravel over much of the Souris spillway. Phase five was the catastrophic flood from Glacial Lake Regina that incised and widened the Souris and Des Lacs Valleys. This flood is proposed to have truncated deposits of gravel from phases three and four.

Valley-fill Deposits

The alluvium deposited in the Souris and Des Lacs Valleys consists mostly of clay, silt, sand, and gravel deposited during the last 10,000 years. Lemke (1960) determined that the Souris Valley deposits contain a higher percentage of clay than the Des Lacs Valley deposits. The alluvium covers the entire length of the valleys in a zone about 1.6 km wide. The deposits have a moderately flat surface with occasional abandoned meanders. The alluvium is derived from erosion of tributary valleys by ephemeral streams that flow into the main valleys (Lemke, 1960).

The thickness of the alluvium varies along the valley bottoms. In 1964, the U.S. Bureau of Reclamation drilled five holes across the Des Lacs Valley 2.6 km northeast of Kenmare. Holes penetrated bedded clay, silt, and sand, ranging in thickness from 7.3 m to 16.5 m (Lemke, 1960).

Near Minot, numerous holes were drilled for water supply along the Souris Valley, and thicknesses of 28 m to

86.5 m of alluvium were encountered (Lemke, 1960). A hole drilled near Sawyer penetrated about 50 m of material before reaching bedrock. Outwash deposits may be present near the base of this test hole. Also, a dark layer of humified soil was identified (Lemke, 1960).

Lemke (1960) also reported that most of the alluvium is moderately to well sorted, and in some places bedding is present, especially in the fine sands. He also found several immature A horizons with B and C horizons present in some places. These paleosols range from a few centimeters to 0.3 m in thickness.

In the early 1970's, the U.S. Army Corps of Engineers (1978) drilled four cross sections along the Souris Valley near the cities of Minot, Sawyer, and Velva as part of a flood-control study. They presented their data as stratigraphic cross-sections with lithological descriptions. Their results indicate sand and gravel deposits along the valley sides, whereas the center of the valley is underlain mainly by silt and clay.

A more recent study of spillway sediment was made by Klassen (1972) in the Assiniboine and Qu'Appelle Valleys in Saskatchewan and Manitoba, Canada. These valleys are cut into the underlying bedrock and contain 30 to 40 m of valley-fill sediment. The fill consists of silt, clay, fine sand, and gravel. Organic material and fossil shells are scattered throughout. The alluvium is interpreted as overbank silt or sheetwash. The valley floors are characterized by meander scars and scrolls.

The occurrence of lacustrine ostracodes in the Assiniboine and Qu'Appelle sediment indicates that lakes formed on the flood plains over the course of time. The origin of the lakes is not indicated, but it is likely that alluvial fan deposits were sufficient to dam the river. Alternatively, water may have remained ponded on the flood plain after a flooding event for a sufficient amount of time to allow aquatic life to exist.

Klassen (1972) also concluded that most of this alluvium was deposited before the Late Wisconsinan glaciation, probably during the Mid-Wisconsinan. The upper 9 to 12 m of sediment were deposited after Late Wisconsinan time.

METHODS OF STUDY

Preliminary Work

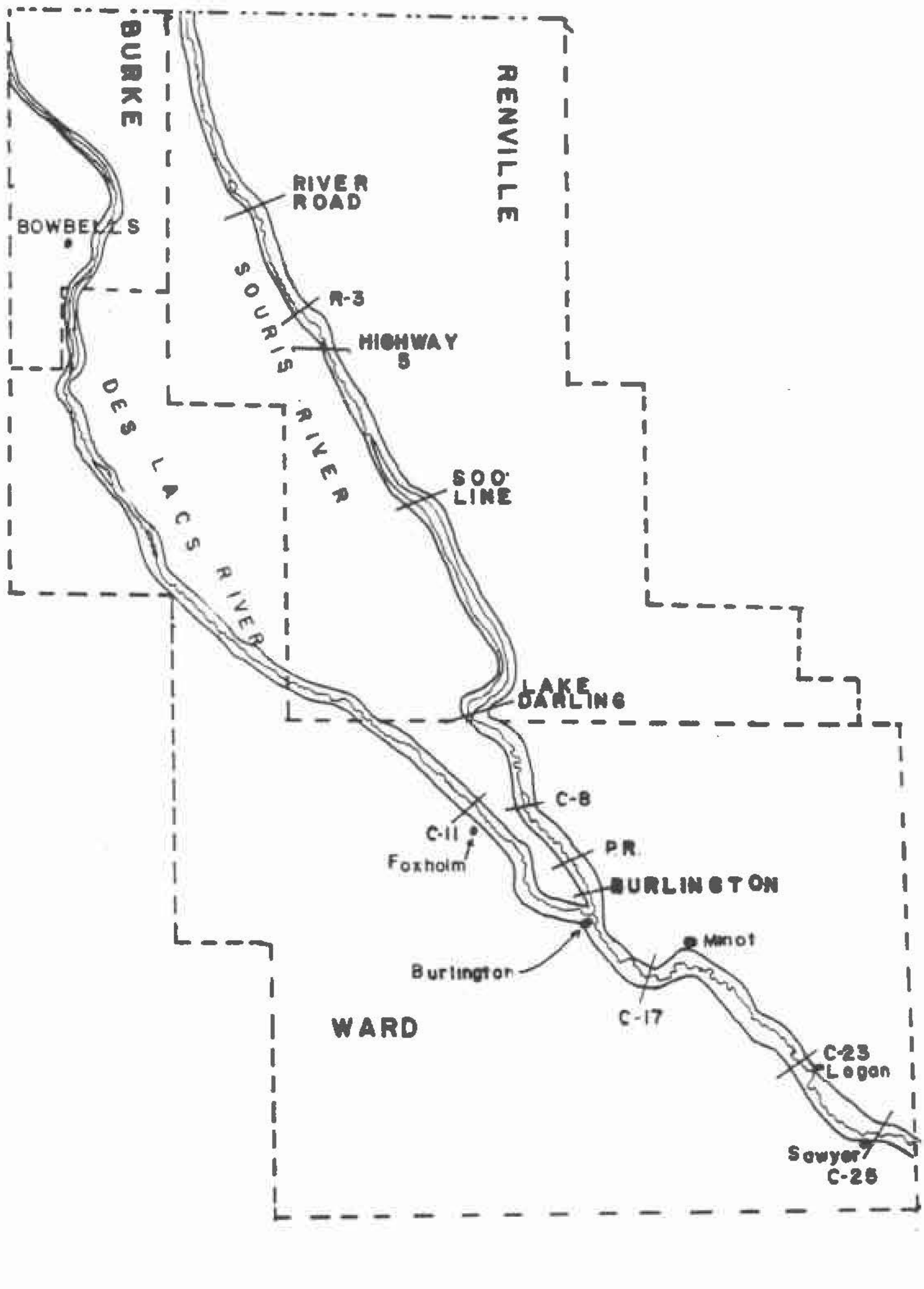
At the beginning of the 1984 summer, I traversed the Souris and Des Lacs Valleys to locate suitable roads that crossed the valleys and were accessible to the North Dakota Geological Survey (N.D.G.S.) drill rig. Before going out, prospective sites were selected using United States Geological Survey (U.S.G.S.) topographic maps and county highway maps of Ward and Renville Counties. Eight acceptable sites were chosen along both county and private roads that traversed the Souris and Des Lacs Valleys. Sites along six roads in Ward County were chosen and included: County Roads 25, 23, 17, 8, 11, and a privately-owned road about 4.8 km north of Burlington (Fig. 6). Two roads were chosen in northern Renville County, including County Road 3 and the River Road (Fig. 6).

Conditions that made these sites acceptable included gently dipping ditches for easy accessibility, county and private landowner permission, and lack of overhead obstacles to obstruct the drill-rig tower.

Field Work

Between three and four holes were drilled along each cross section during a three-week period in July, 1984. The distance between the holes was estimated to be 152 to 304 m. Generally, one hole was drilled close to each valley side, with two holes in the middle of the

Figure 6. Location of cross sections along the Souris and Des Lacs Valleys.



BURKE
RENVILLE
BOWBELLS
RIVER ROAD
SOURIS RIVER
R-3
HIGHWAY 5
SOO LINE
DES LACS RIVER
LAKE DARLING
C-8
C-11
Foxholm
P.R.
BURLINGTON
Burlington
Minot
C-17
WARD
C-23
Logan
Sawyer
C-26

valley. In cross sections C-25 and the Private Drive, only three holes were drilled.

Shelby-tube samples were taken through the entire section until sample recovery was no longer possible. The samples were extracted at the site and sealed in appropriately labeled coreboxes. Once the water table was encountered, core recovery became impossible in most places. The sediment was highly fluid and flowed out of the tube before reaching the surface. Also, when water reached a certain level in the hole, the Shelby-tube mechanism would not lock into place, and the hole had to be abandoned. Only two holes were cored to the maximum depth that the rig was capable of drilling; these locations were C-8 and P.D. in the Souris Valley.

Field descriptions were recorded for each sample extracted. Because of the friable nature of the silt and sand samples, noting bedding features was important before the samples dried or were disturbed during transportation. Most of these features were destroyed by the time they reached the lab. Also noted in the field descriptions were location, texture, color, fossils, organic content, and identification of the core box. Topographic features were also described at each drill site, such as the presence of intermittent streams and abandoned meanders.

During the winter of 1984, samples collected by the U. S. Army Corps of Engineers (Corps) along four traverses of the Souris Valley were obtained from the St. Paul, Minnesota regional warehouse. These samples were collected along Highway 5, Soo Line railroad bridge, the Lake Darling Dam in Renville County, and the proposed Burlington Dam site 2 km up the Souris Valley from Burlington in Ward County (Fig. 6). These samples were collected by penetration techniques throughout the entire valley-fill section to the spillway bottom, and stored in Mason jars. The Corps also supplied stratigraphic data, maps, and cross sections.

Laboratory Methods

The cores from each cross-section were studied in the Quaternary Lab in Leonard Hall at the University of North Dakota. The cores were re-examined for texture, bedding, fossils, organics, and color. The color was determined using the Munsell Soil Color Chart. These descriptions are included in Appendix A. Both dry and wet colors were noted for each major lithological unit.

In order to determine the texture of each lithology, textural analysis was done. The material was split to between 50 g and 60 g, and, when necessary, wet-sieved to remove abundant clay. The coarse fraction was dried and sieved by Ro-Tap for 15 minutes with sieves at 1/2 ϕ intervals ranging from -3 ϕ to 4 ϕ (Folk, 1980; Carter, 1978). The sample in each sieve interval was then weighed and stored in envelopes. The raw cumulative weight was recorded.

The fine (silt/clay) fraction was analyzed using the Micromeritics 5000E SediGraph. A graph was created by plotting the cumulative mass percent versus equivalent spherical diameter. By knowing which size diameter corresponded to its equivalent size, the percentage of sample could be determined for each 0 interval, along with the cumulative percent. The interval chosen was also 1/2 ∅, ranging from 4 ∅ to 13 ∅.

The distribution of the sand and silt/clay fraction for each sample were combined, normalized to 100%, and individual ∅ intervals for the entire sample were calculated. The data were then entered into a computer program to determine the median, mean, sorting, skewness, and kurtosis in both moments and graphics (LeFever, R., personal communication). In addition to these statistical modes other printouts included frequency and cumulative percent curves. These grain size distributions enabled accurate lithologic correlations to be made for stratigraphic analysis. Graphics analysis was used for descriptive work.

Some core samples contained abundant horizons of fossil gastropods and mussels. When present, the depth was noted and fossils collected. Once removed, these fossils were examined visually. It was determined that a comprehensive identification of the fossils was beyond the scope of this thesis. However, where easily recognized, species identification was made. The occurrence and distribution of these fossils provides important information on the depositional environment and age of the sediments.

All highly organic layers were noted, and where possible, organic material was removed and stored in envelopes. In two instances, enough organic material was available for C-14 dating. The organic layers consisted of woody stems, oxidized rootlets/stems, and peaty material. The samples were sent to Beta Analytic Inc., in Coral Gables, Florida for C-14 dating.

RESULTS

General Statement

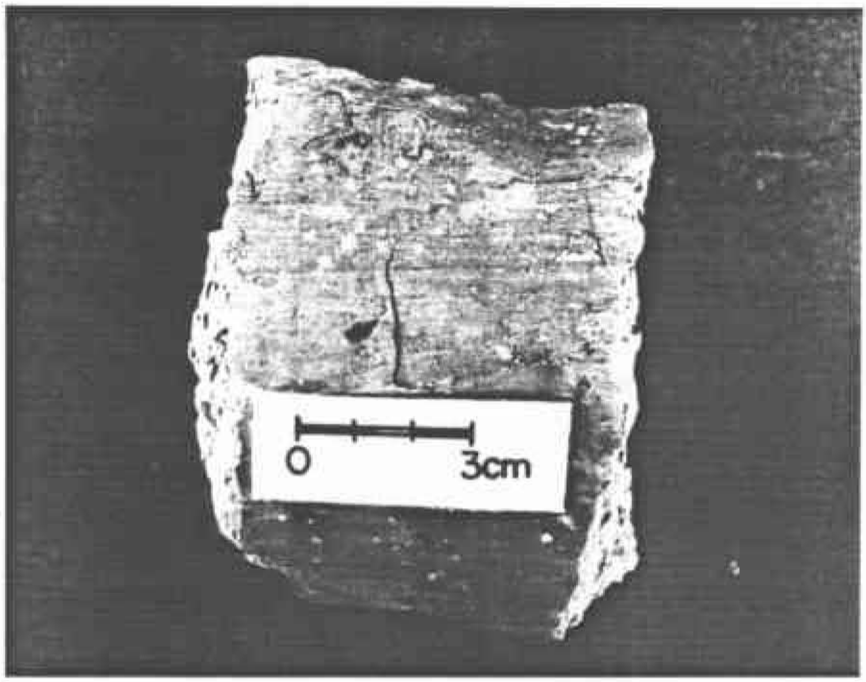
Textural results are presented in Appendix B. This information was used to correlate lithologies across each valley cross section. What is generally present is coarse-grained material near the valley sides, and silt/clay in the middle. Figures 7, 8, 9, 10, and 11 are typical examples of the sediment recovered from the Souris and Des Lacs Valleys. The textural analysis indicated the texture and degree of sorting for each lithology.

There does seem to be a correlation of the organic horizons across the valleys. Three horizons are recognized, especially in the Burlington cross section. Two C-14 dates from the lower horizon indicate that the sediment is Holocene and belongs to the Oahe Formation (Clayton et al., 1976). The fossil shells, in most instances, are associated with these organic layers. It is believed that these fossil assemblages indicate a fluvial/lacustrine environment (Cvancara, 1983).

Because of the number of cross sections made, each will be discussed separately, including location, number of cores taken, depth, and significant characteristics and general environmental conditions of each. The discussion will begin at the southernmost location (C-25) and progress north to the River Road (R.R.), with C-11 across the Des Lacs Valley discussed last (Fig. 6).

Figure 7. Typical example of clay from the valley centers of the Souris and Des Lacs spillways.

Figure 8. Typical example of silt from the Souris and Des Lacs Valley centers.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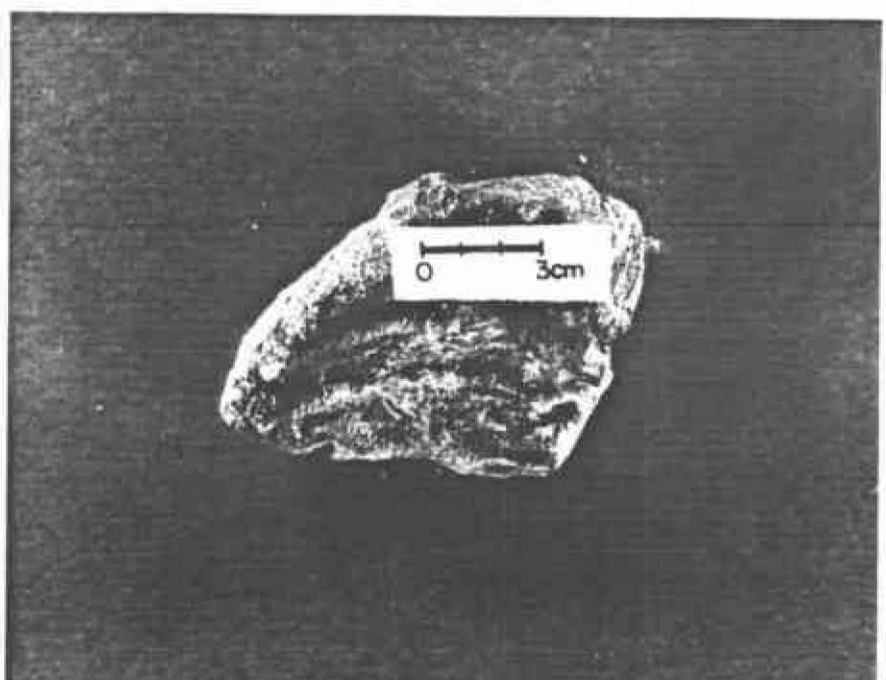
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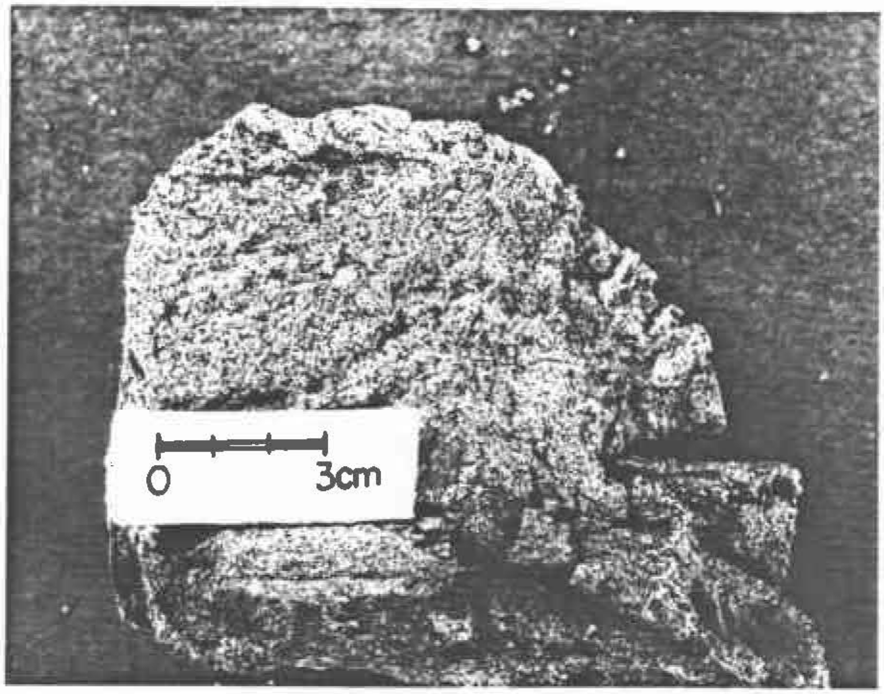
3cm

Figure 9. Typical example of sand in the Souris and Des Lacs Valleys.

Figure 10. Typical example of pebbly sand found along the sides of the Souris and Des Lacs Valleys.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3cm

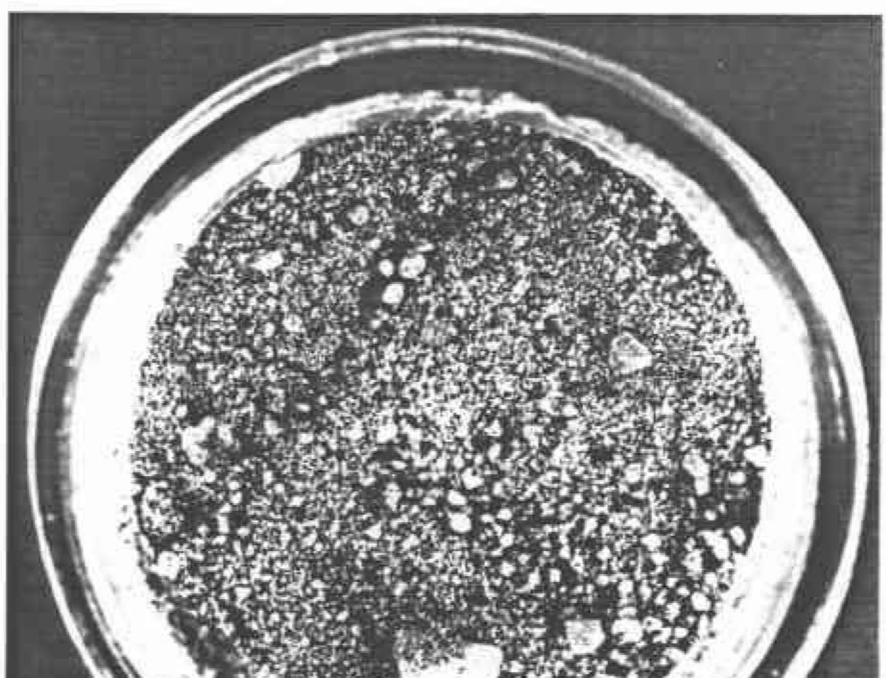
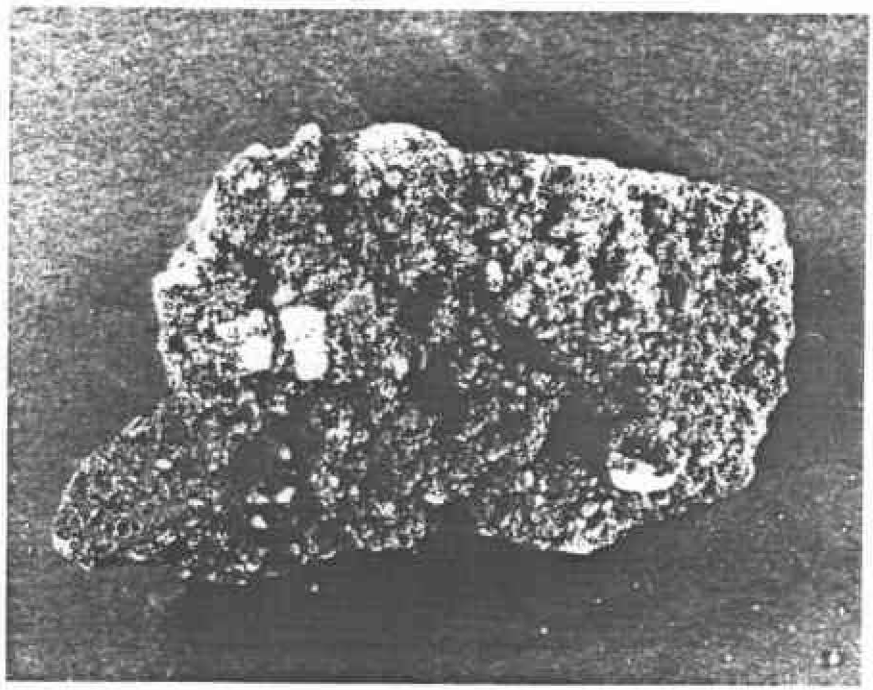


Figure 11. Typical example of gravel found along the sides of the Souris and Des Lacs Valleys.



C-25

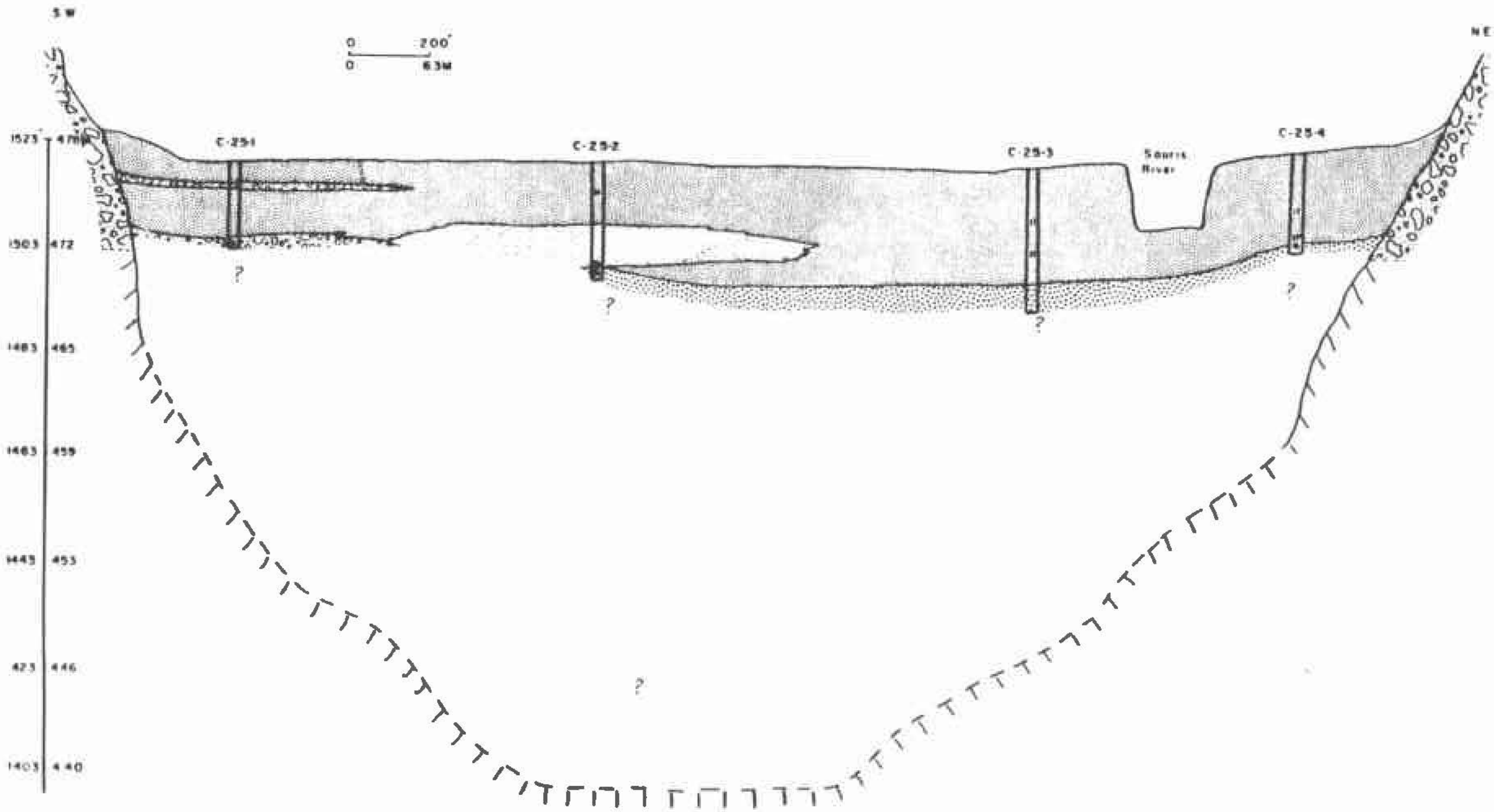
The C-25 cross section is 2.7 km southeast of Sawyer, along Ward County Road 25 (Fig. 6). The cross section follows the section line that separates Section 7, T153N, R80W and Section 12, T153N, R81W, Sawyer 7.5' Quadrangle. The valley floor is gently undulating with an abandoned meander scar on the north side. Four cores were taken to an average depth of 6.3 m and are 304 m apart (Fig. 12).

Core 25-1 was drilled to 5 m and is composed of medium to coarse, very poorly sorted silt with stringers of pebbles. The basal unit is coarse sand with subangular pebbles. A zone of oxidized organic material was encountered at 4.6 m, but an insufficent amount was recovered for C-14 dating.

Core 25-2, drilled to a depth of 6.7 m, consists of silt and moderately sorted fine sand in the upper unit, with clay lenses containing rootlets and parallel laminations at 2.4 m. This is underlain by clay, with an organic layer containing scattered plant stems at 5.47 m. The base is very poorly sorted sand with parallel laminations. A strong organic smell was observed for this unit.

Hole 25-3 was drilled to 8.2 m and contains very poorly sorted silt with poorly sorted sand at the top and base. For the most part, the silt contains parallel bedding. Weak organic layers are present at 3.6 and 5.1 m.

Figure 12. Cross section of C-25. The legend applies to all the cross sections.



SW
NE
0 200'
0 63M
C-25-1
C-25-2
C-25-3
C-25-4
Souris River
1523' 478
1503 472
1483 465
1463 459
1443 453
423 446
1403 440
?

Core 25-4 was drilled to 5.5 m and consists of very poorly sorted silt with moderately well-sorted medium sand at the base. At 3 m, cross-bedding with scattered shell fragments and organics were found and at 4.5 m, woody stems were recovered. The sand at the base contained several gastropods and numerous pill clam fragments.

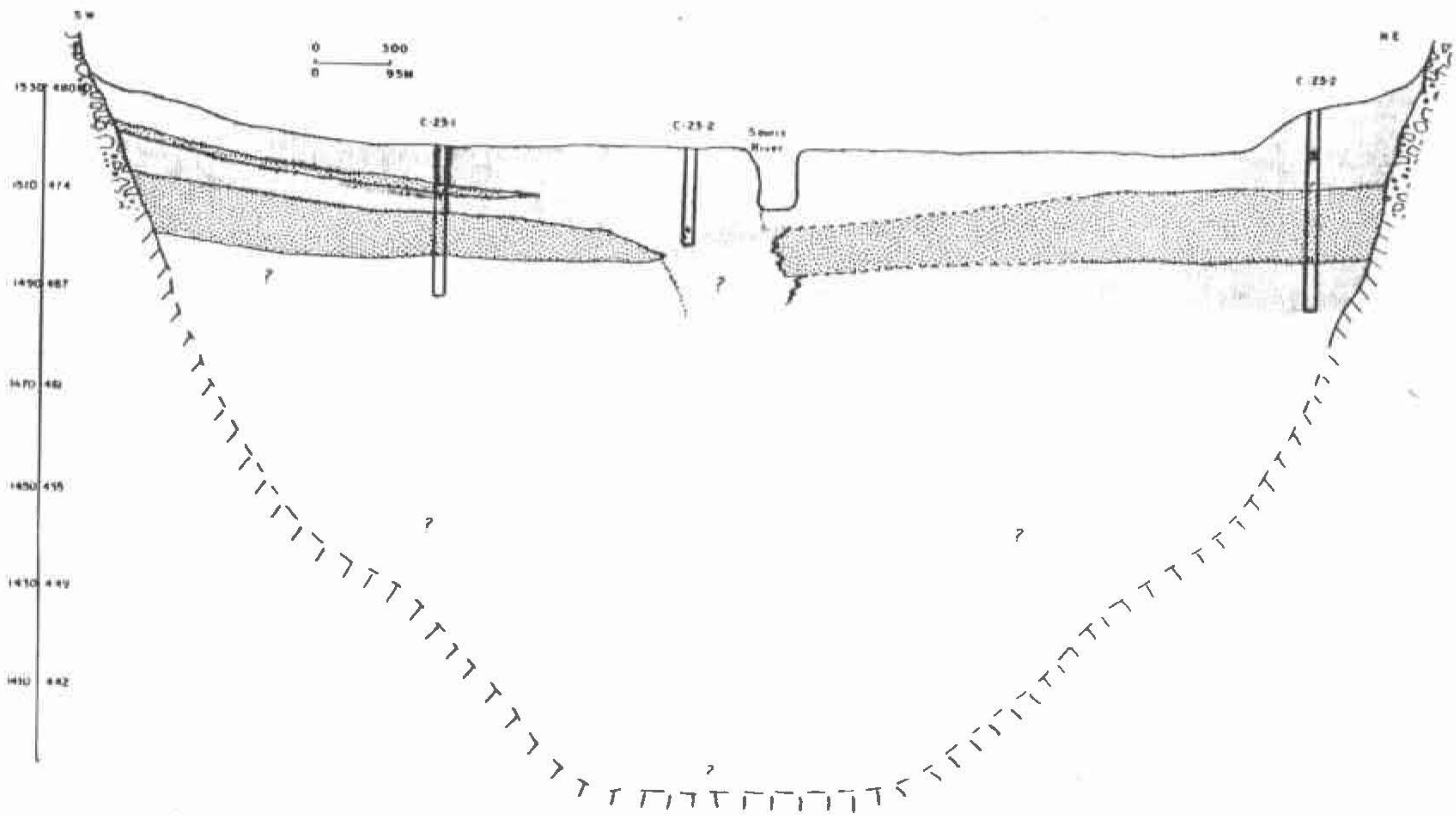
Two organic horizons, which consist mostly of fossil shells and stems, can be correlated most of the way across the valley (Fig 12). Core 25-1 is opposite an ephemeral stream which deposited coarse alluvium that thins across the valley floor. The valley floor probably is underlain by flood-plain deposits and alluvial material reworked by wind. Core 25-4 deposits, because of cross bedding and shell fragments, may represent a beach or point bar.

C-23

Cross section C-23 is located along Ward County Road 23 about 0.3 km north of Logan (Fig. 6). The road trends east-west along the line between sections 13 and 24, T154N, R82W of the Surrey 7.5' Quadrangle. The valley floor generally is flat with an abandoned meander in the center and an oxbow lake near the east valley wall. Three cores were drilled to an average depth of 8.2 m and spaced about 300 m apart (Fig. 13).

Core 23-1 was drilled to 9.1 m and consists of poorly sorted silt underlain by very poorly sorted medium to fine sand. At 5.2 m, rootlets and oxide staining is present.

Figure 13. Cross section of C-23 (see Fig. 6 for location).



SW
NE
0 300
0 95M
C-23-1
C-23-2
Souris River
1530 480
1510 474
1490 467
1470 461
1450 455
1430 449
1410 442

The bottom of the core is composed of massive clay with probable organics at the base.

Hole 23-2 was drilled on the east slope of the Souris Valley to 12.8 m. The core is characterized by very poorly sorted silt and sand with stringers of coarser material scattered throughout. At about 9.1 m, the very fine sand is underlain by a black, organic-rich clay with silt at the base. At 3 m and 4 m, scattered rootlets were present with cross-bedding evident.

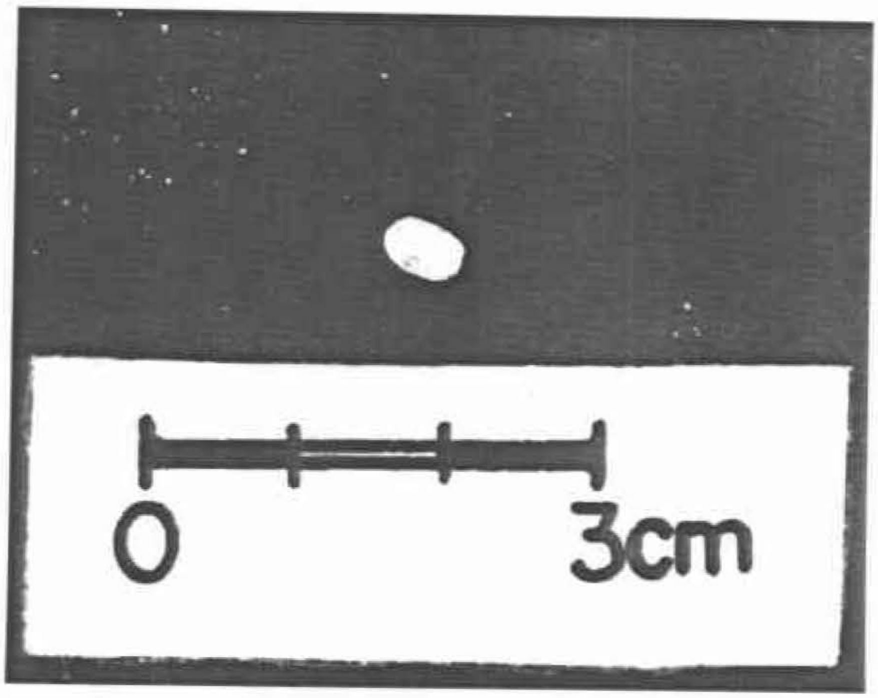
Hole 23-3 was drilled in the center of the valley to 5.5 m. It penetrated poorly sorted, medium to coarse silt. Fossil fragments were scattered throughout with two organic layers present. The base of the core contained numerous pill clam fragments and a cap-shaped gastropod, *Ferrissa rivalaris* (Fig. 14).

The cross section shows probable organic horizon correlation between all three cores, especially the top organic layer. Core 23-2 is on the east slope and the lithologies may reflect sheetwash and ephemeral stream deposition. Core 23-3 probably represents a point bar or beach because of the shell fragments and cross-bedding.

C-17

Cross section C-17 is located along Ward County Road 17 about 5 km west of Minot (Fig. 6) and trends northeast-southwest on the line separating sections 20 and 17, T155N, R83W, Minot 7.5' Quadrangle. Four holes were drilled to an average depth of 5.2 m and spaced an average

Figure 14. Gastropod, Ferrissa rivalaris from hole C-23-2.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3cm

of 300 m apart. The valley floor is gently undulating with a large ephemeral stream entering the valley on the northwest side (Fig. 15).

Hole 17-1 was drilled to 6 m with only partial core recovery due to high moisture content. The top of the core contained silt with scattered rootlets underlain by poorly sorted coarse sand. Poorly sorted, very fine to coarse sand and silt was present below the missing middle section. The samples were massive and contained no organics or fossils.

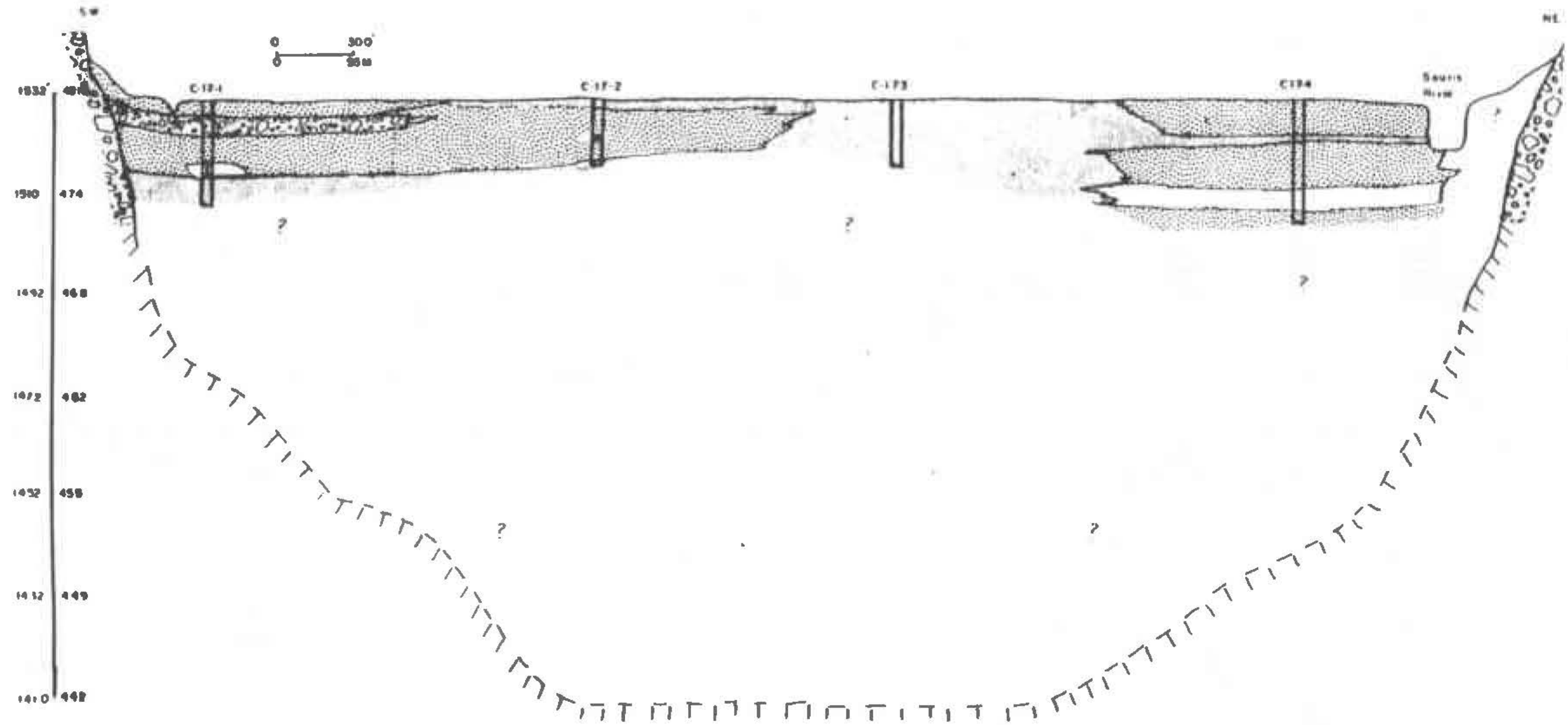
Hole 17-2 was drilled to 3.6 m and the core consists of poorly sorted fine and coarse sand with silt at the top. The interval between 2.1 and 2.4 m was not recovered. Traces of organic-rich silt were recovered at the base.

Core 17-3, drilled to 3.3 m consists of poorly sorted silt with no organics or shells. The base of the section does show indications of parallel bedding.

Core 17-4 is on the northwest side of the Souris Valley and reached a depth of 7 m. The first metre is silt, with rootlets underlain by moderately sorted, very fine sand to a depth of 2 m. From 2 to 5 m, moderately well-sorted sand is present with a weak organic zone. This is underlain by clay with poorly sorted medium sand at the base containing a pill clam.

Cross section C-17 is difficult to correlate across the valley. It should be noted that the south side of the valley is coarse, with a fining to the northwest where clay with fossils was recovered. This indicates that ephemeral

Figure 15. Cross section of C-17.



SW
0 300'
C-17-2
C-17-3
Souris
NE

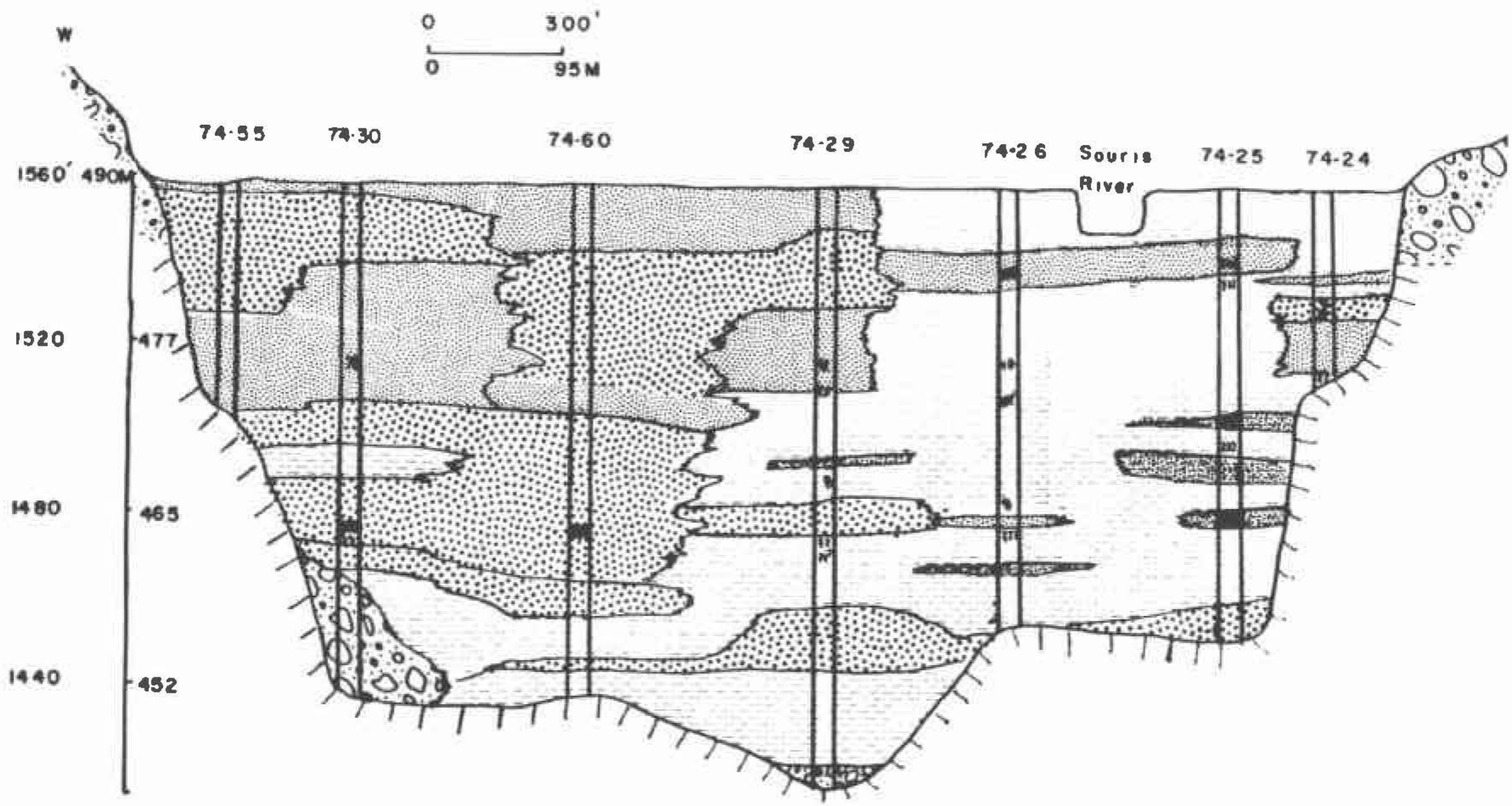
streams were sufficiently active to deposit alluvium across the valley floor. Also, at this location, the river meanders to the base of the northeast wall. The amount of alluvium may be sufficent to force the Souris River to flow around it.

Burlington

The Corps drilled seven holes across the Souris Valley about 1.5 km north of Burlington at the proposed Burlington Dam site (Fig. 6). The cross section trends east-west through parts of sections 35 and 36, T156N, R84W, Burlington 7.5' Quadrangle. The holes were drilled to bedrock, which was encountered at a maximum depth of 39 m at the center of the valley (Fig. 16). This is the most detailed section because of the number of holes drilled and the depth involved. Samples collected were stored in Mason jars and some of them were used for engineering tests and therefore destroyed. Where samples are missing, lithologic descriptions from the Corps published report (1978) were utilized for correlations.

The west side of the Souris Valley contains coarser sediment than the eastern side. Cores 74-24, 25, 27, and 73-29, on the eastern side, consist of a high amount of clay extending to the base of the spillway, interbedded with lenses of fine silt to fine sand in the center and fine to medium sand near the east valley wall. Figure 17 shows a typical example of the clay. Cores 74-60, 30, and 55 contain fine to coarse sand with some stringers of

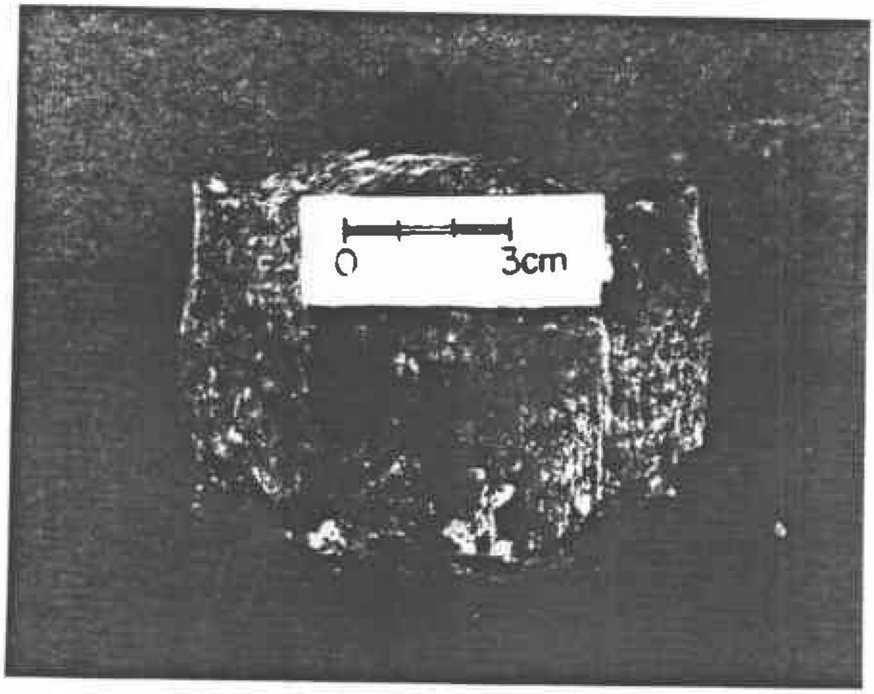
Figure 16. The Burlington cross section.



W
0
300'
0
95M
74-55
74-30
74-60
74-29
74-26
Souris
River
74-25
74-24
1560' 490M
1520
477
1480
465
1440
452

Figure 17. Clay from center of the Burlington cross section.

Figure 18. The gravel in a clay/silt matrix from base of the Burlington cross section.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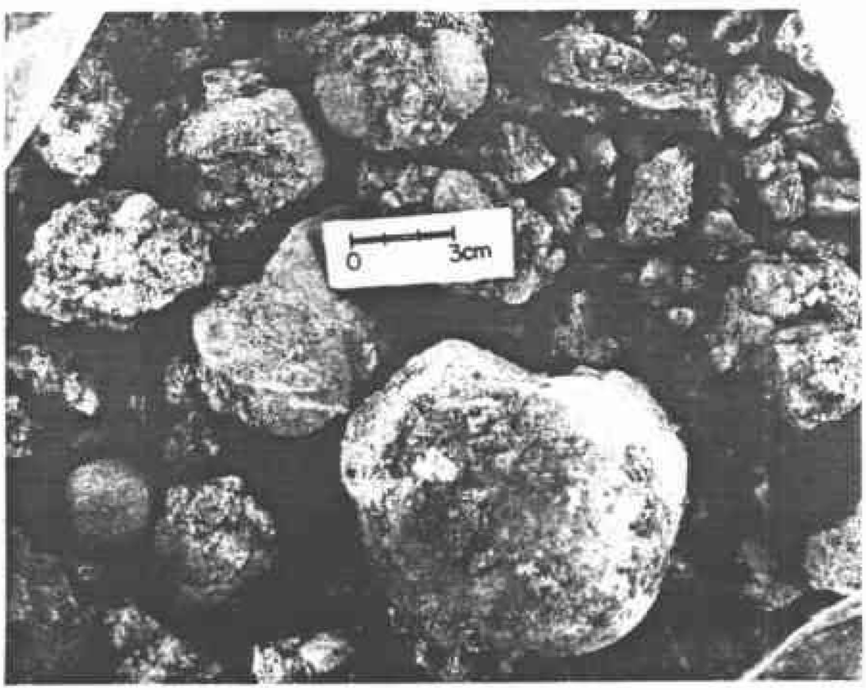
3cm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3cm

clay/silt. Core 73-29 is the deepest core, and at the base of the spillway gravel is present in a clay matrix. Although no dates can be obtained from the gravel, it is possible that this coarse sediment was derived from slumping of the valley walls after the last flood (Fig. 18).

Three organic horizons have been identified in the cross section. These horizons consist of rootlets, peaty material, and woody stems (Fig. 19, 20, 21 and 22). Associated with these organic horizons in a few instances are fossil gastropods.

A C-14 date of 9440 ± 100 years BP was determined for the lower organic horizon in core 74-24 at a depth of 23 m. This correlates with the Upper Aggie Brown Member of the Oahe Formation of early Holocene age in North Dakota (Clayton et al., 1976).

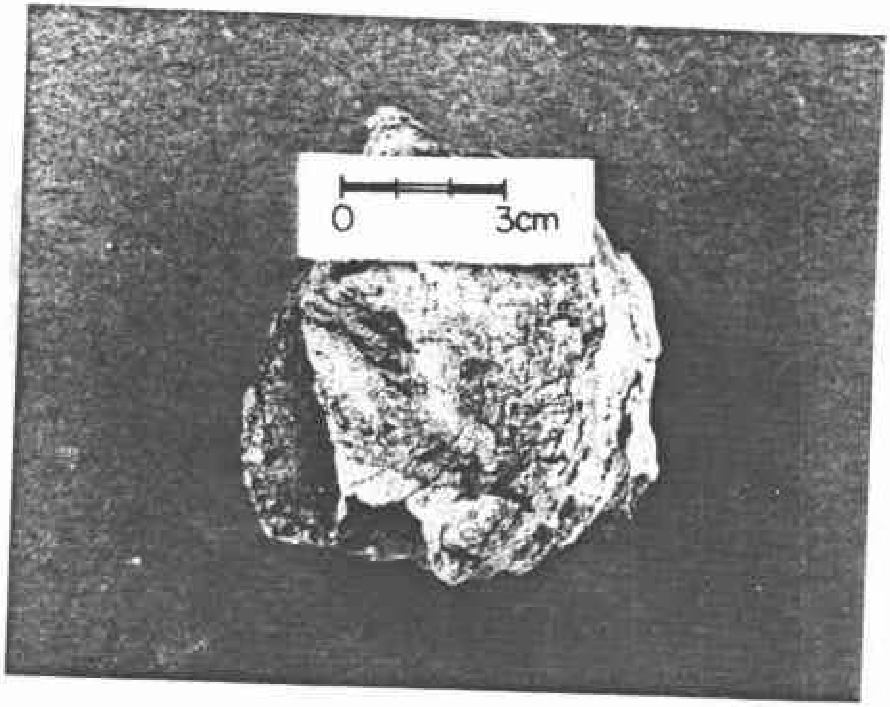
The west side of the valley may be dominated by alluvial sediment from the valley wall that has been deposited by intermittent streams or sheetwash. The clay in the middle is highly organic and may represent lacustrine conditions and the organic horizons may indicate moist periods during which valley slopes were stable and aquatic life and vegetation were abundant.

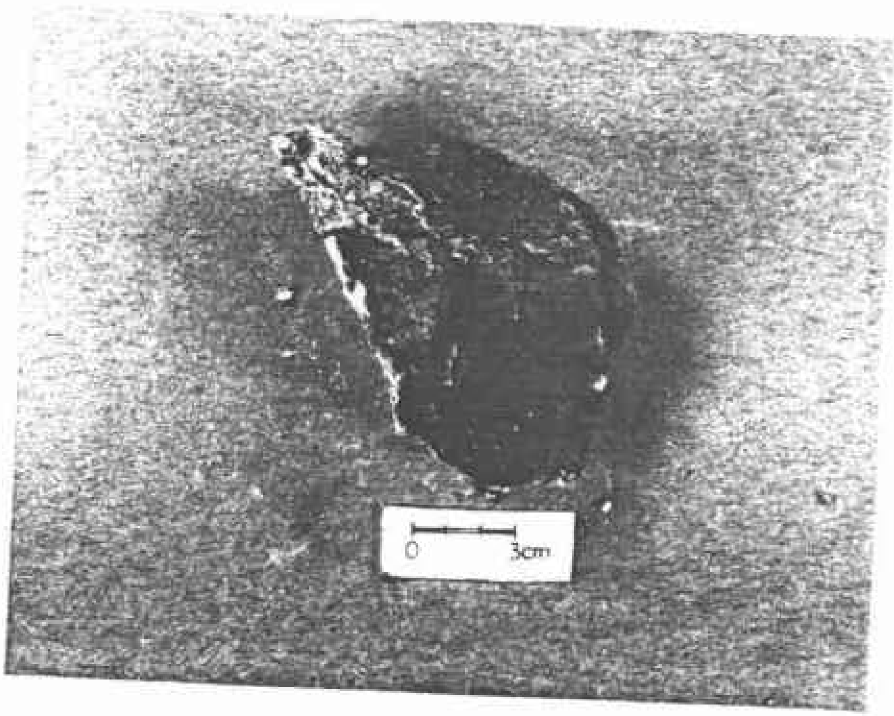
P.D.

The P.D. cross-section was drilled along a private road in Ward County (Fig. 6). This cross section trends east-west on the line separating section 15 and 10,

Figure 19. Example of organic material from upper horizon.

Figure 20. Example of organic material from middle horizon.


0
3cm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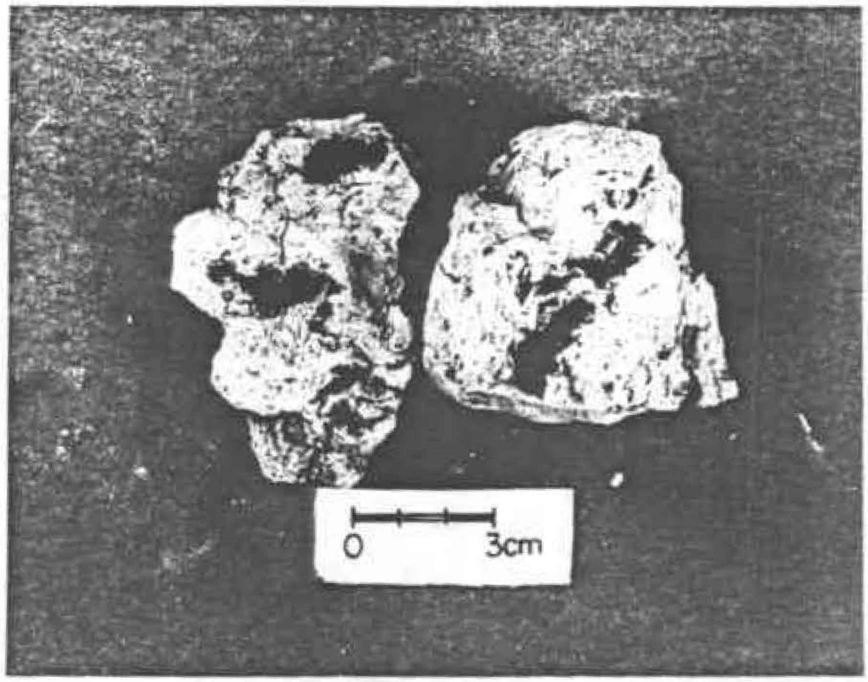
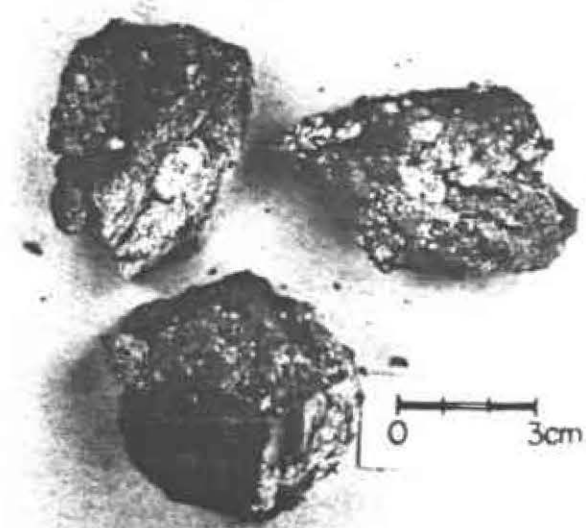
3cm

Figure 21. Peat from the second organic horizon.

Figure 22. Peat with fossils from the lower organic horizon.


0
3cm


0
3cm

T156N, R84W, located on the Burlington 7.5' Quadrangle. The average depth of the cores is 9 m, with the deepest being 15.5 m in the center of the valley (Fig. 23). The cores are about 300 m apart.

Hole P.D.-1 was drilled to a depth of 7.6 m. Coarse sand and gravel are present to 3 m. A clay lens between 1.5 and 2 m, contains abundant gastropods. This is underlain by moderately sorted medium sand to 5.4 m, characterized by oxide staining between 3.6 and 4.2 m. Fossils and scattered organics are present near the base. The remaining core interval is composed of poorly sorted fine silt with wood fragments, mussel and gastropod shells.

Hole P.D.-2 was drilled in the center of the valley to a depth of 15.5 m. The core consists predominantly of clay (Fig. 24) with lenses of silt. The clay contains abundant gastropods and occasional mussel shell fragments (Fig. 25). A highly organic layer at 4.5 to 6 m is characterized by oxidized stems and rootlets (Fig. 26 and 27). A fossiliferous, organic horizon was also identified at 8 m (Fig. 28).

Core P.D.-3 was drilled to a depth of 4 m. The uppermost sediment is clay underlain by poorly sorted fine silt to 2.4 m. The remainder of the core is poorly sorted medium sand.

This cross section is interpreted as coarse alluvial-fan sediment near the valley sides with a clay plug in the middle. The clay, with abundant fossils, indicates a

Figure 23. Cross section along P.D.

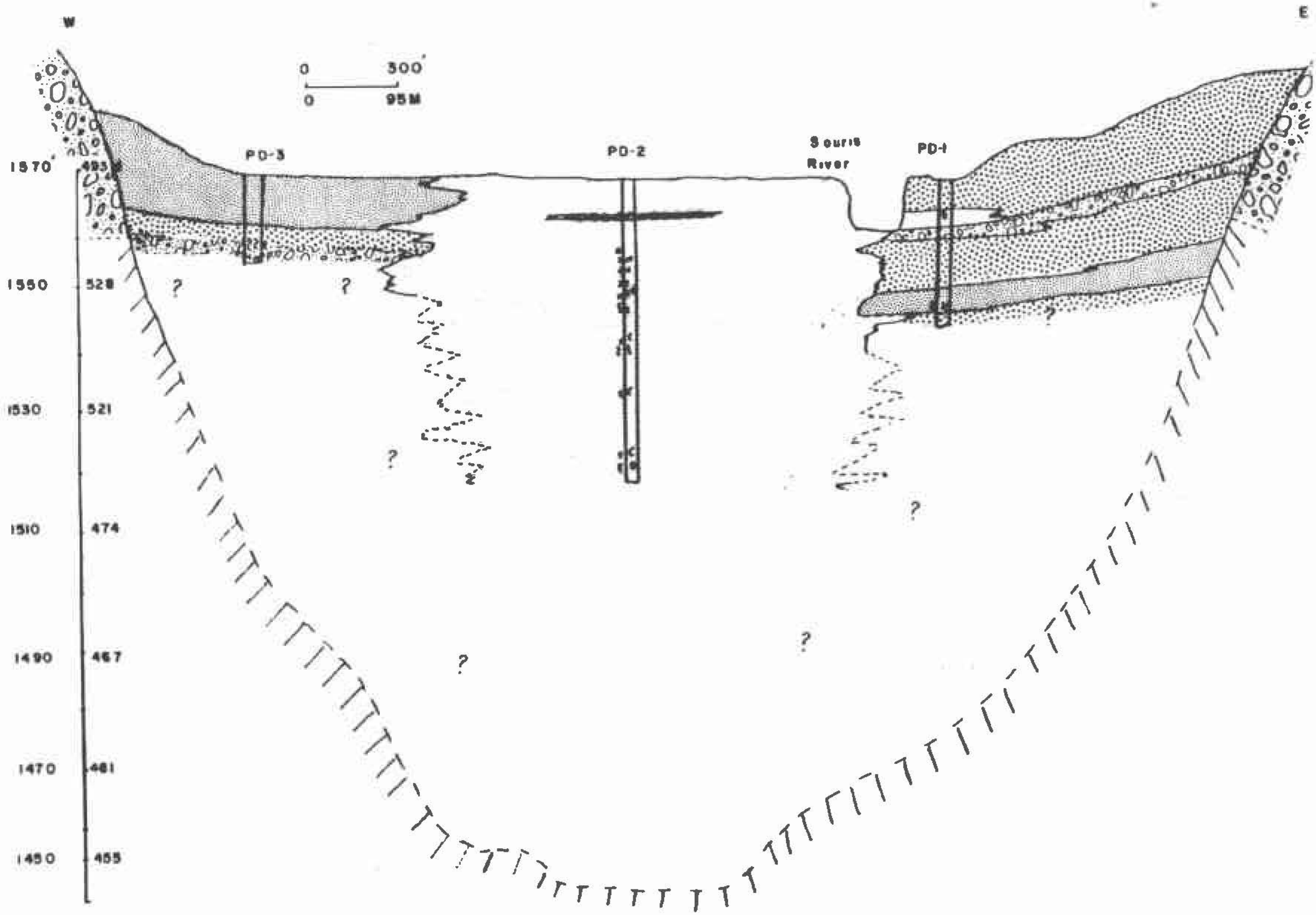
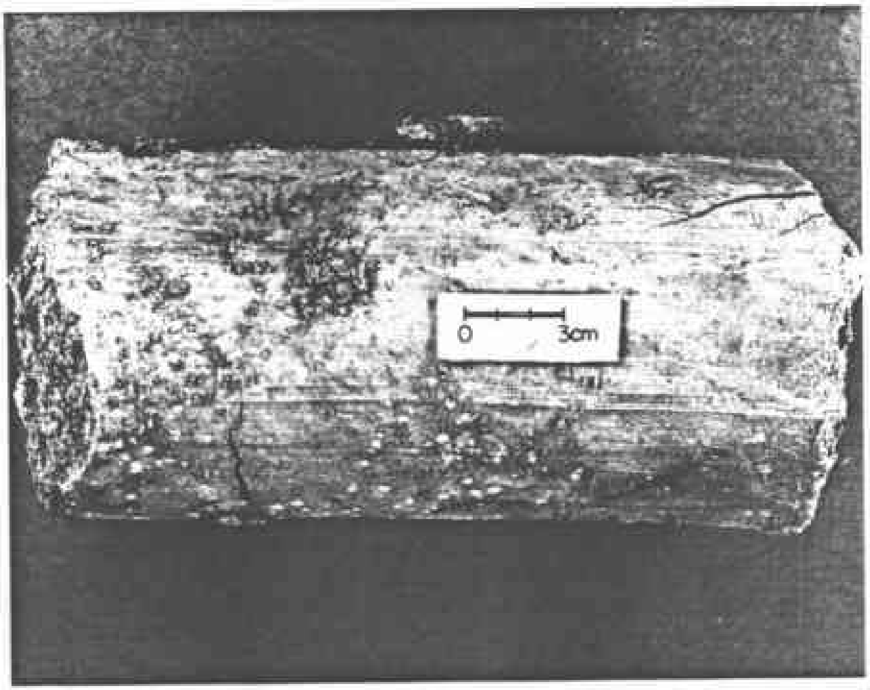

W
E
0 300'
0 95M
PD-3
PD-2
Souris River
PD-1
1570' 493
1550 528
1530 521
1510 474
1490 467
1470 461
1450 455

Figure 24. Example of clay from P.D. cross section.

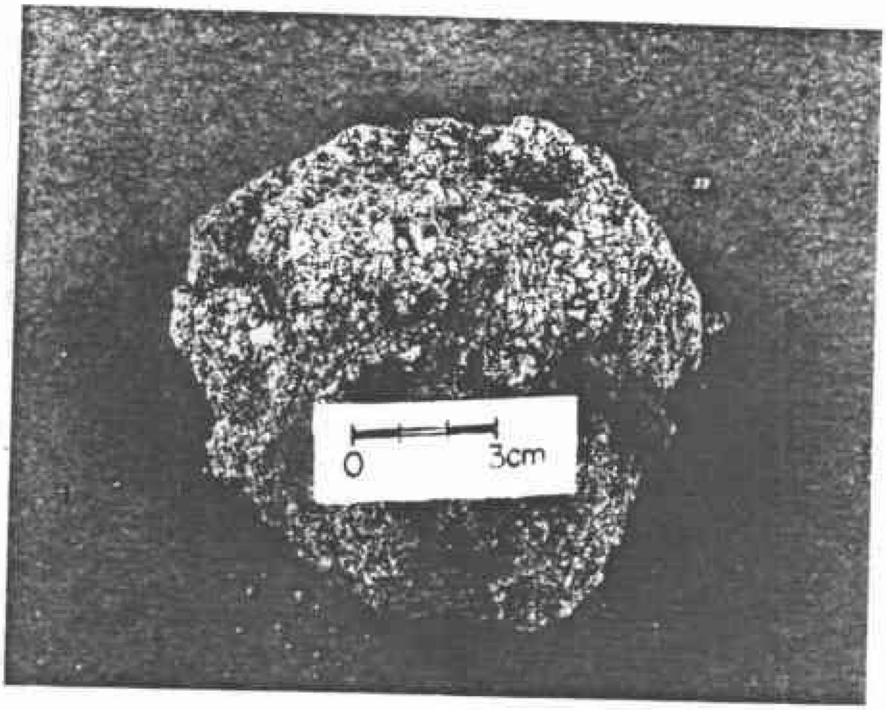
Figure 25. Example of gastropod assemblage at P.D. cross section.


0 3cm


0 3cm

Figure 26. Oxidized rootlets from upper organic horizon.

Figure 27. Wood from the base of the upper organic horizon.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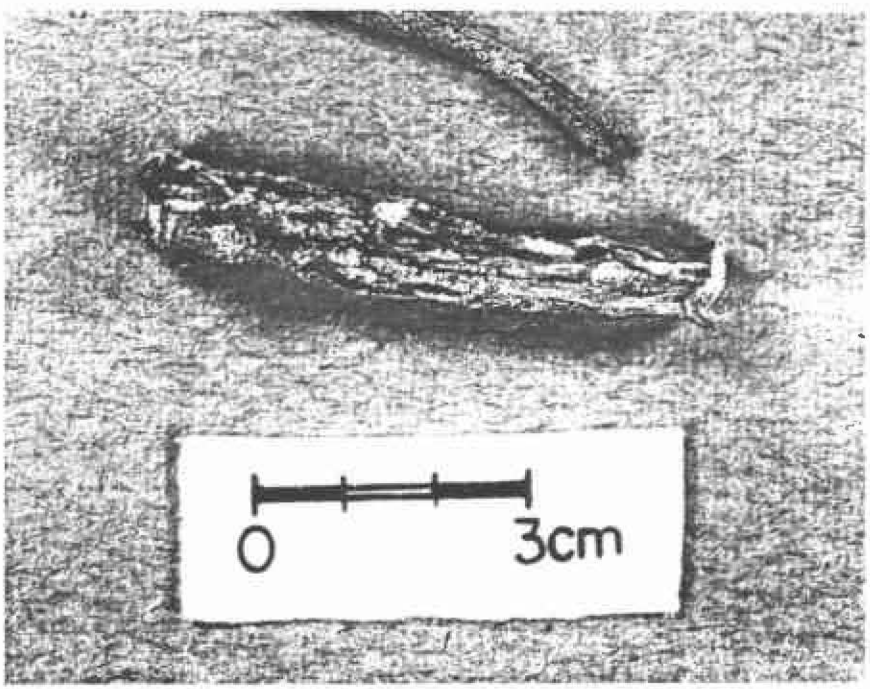
3cm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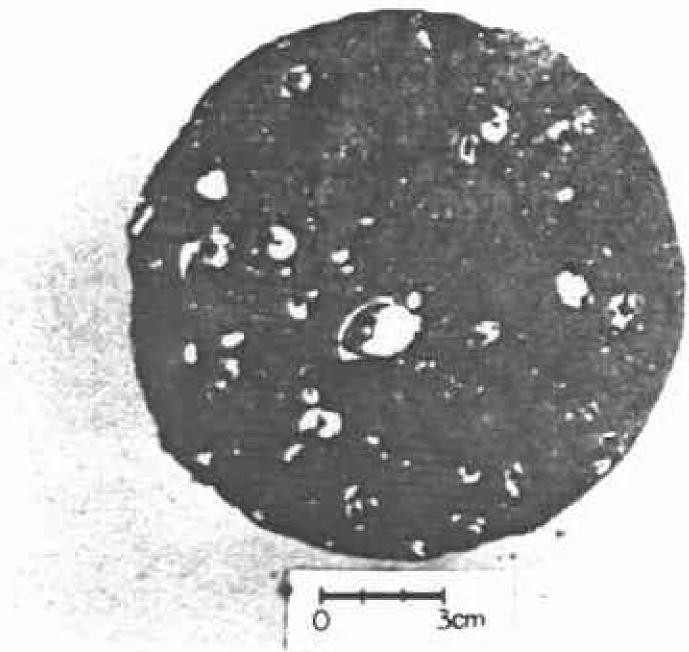
3cm

Figure 28. Peaty material with associated gastropods from second organic horizone.


0
3cm

backwater or lacustrine environment both before and after a period of marsh or swamp conditions.

C-8

Cross section C-8 is located along Ward County 8 on the southern border of the Souris Wildlife Refuge (Fig. 6). The road trends east-west along the boundary between section 5, T156N, R84W, and section 34, T157N, R84W, located on the Des Lacs 7.5' Quadrangle. Four holes were drilled about 300 m apart to an average depth of 9.4 m, with the deepest being 24.3 m in the center of the valley (Fig. 29). Hole C-8-1 was drilled on the east side of the valley to a depth of 4 m. Silt was encountered at the top and underlain by poorly sorted, apparently structureless medium and fine sand. There are no organics present.

Hole C-8-2 was drilled in the middle of the valley to 24 m. The core consists wholly of clay except for some lenses of very fine silt. Fossil gastropods and mussel shell fragments are scattered throughout. Three organic layers are present, consisting of peaty material (Fig. 30, 31, and 32). The middle to bottom of the core has alternating light and dark banding. The light bands are silt 1 to 2 mm thick. The dark layers are clay about 12 cm thick.

Hole C-8-3 also lies in the central part of the valley; a depth of 5.5 m was reached. The upper 3 m is composed of massive clay with rootlets at the top. Poorly sorted, very fine silt containing gastropods and organics

Figure 29. Cross section along C-8.

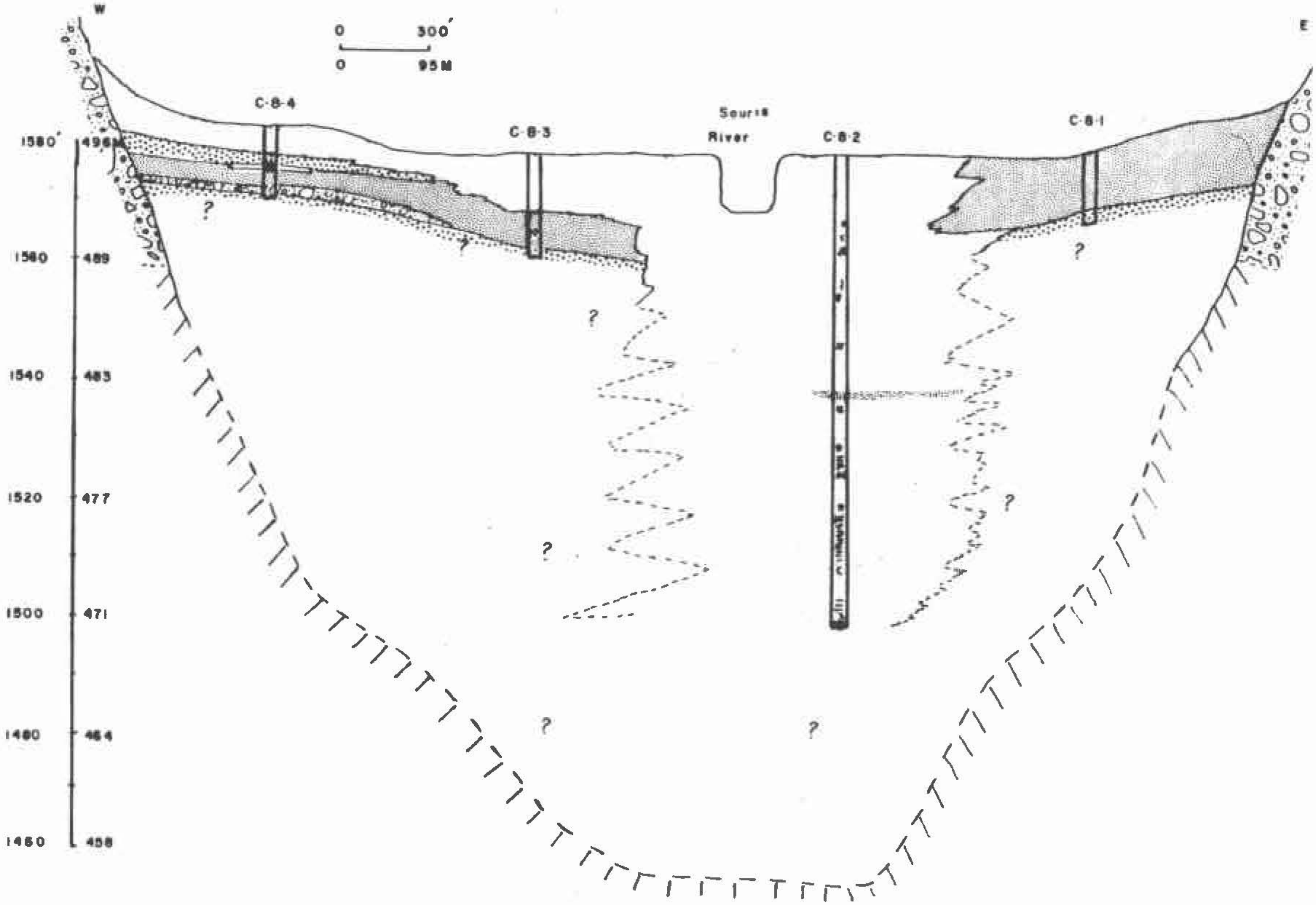
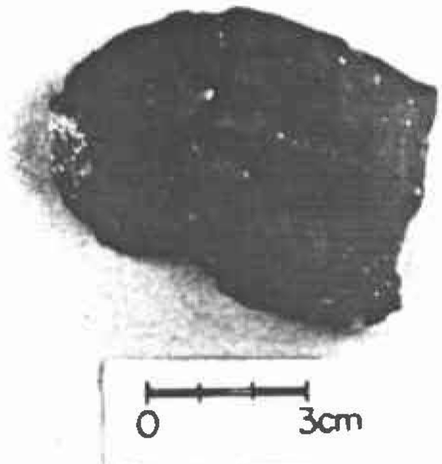

W
E
0
300'
0
95M
C-8-4
C-8-3
Souris
River
C-8-2
C-8-1
1580'
1560
1540
1520
1500
1480
1460
496M
489
483
477
471
464
458
?

Figure 30. Organic material from the upper horizon (peat).

Figure 31. Highly organic material with fossil fragments from the middle organic horizon at C-8.


0
3cm

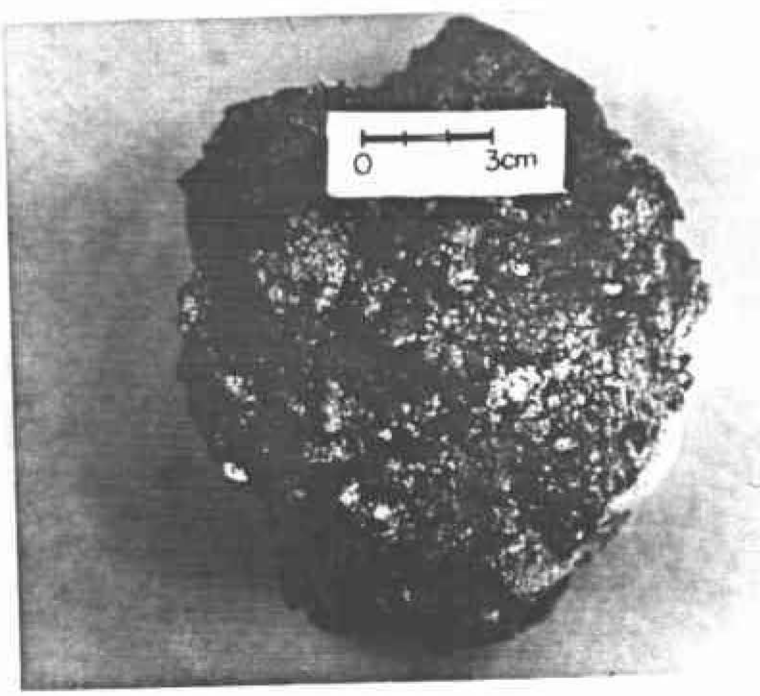
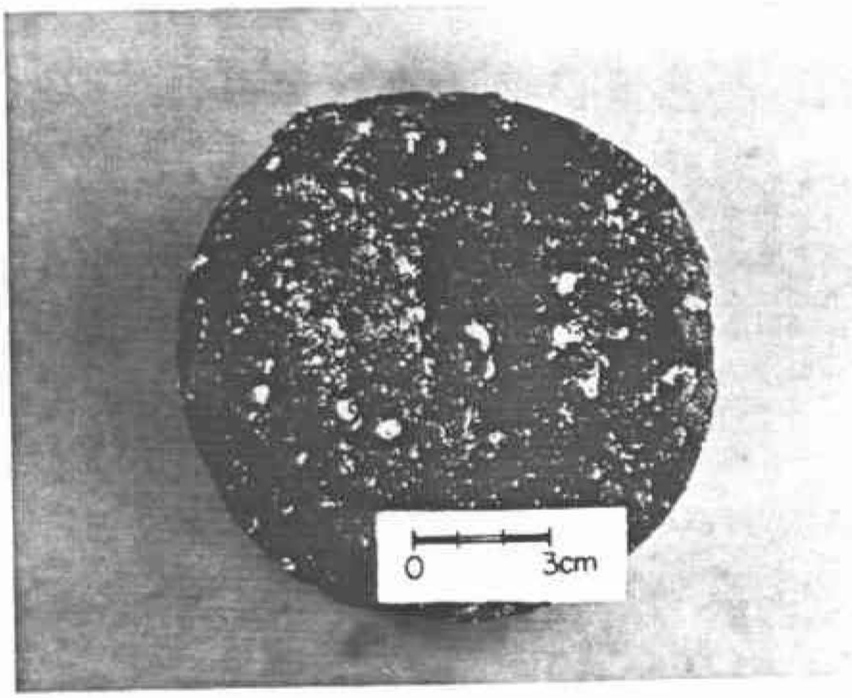

0
3cm

Figure 32. Fossiliferous peat from the lower organic horizon at C-8.


0
3cm

underlies the clay. The lower part of the core is poorly sorted medium silt with poorly sorted medium sand at the base.

Hole C-8-4 was drilled to a depth of 4 m on the west side of the Souris Valley. Clay at the top grades down to fine and coarse silt at the base. No structures or organics were evident.

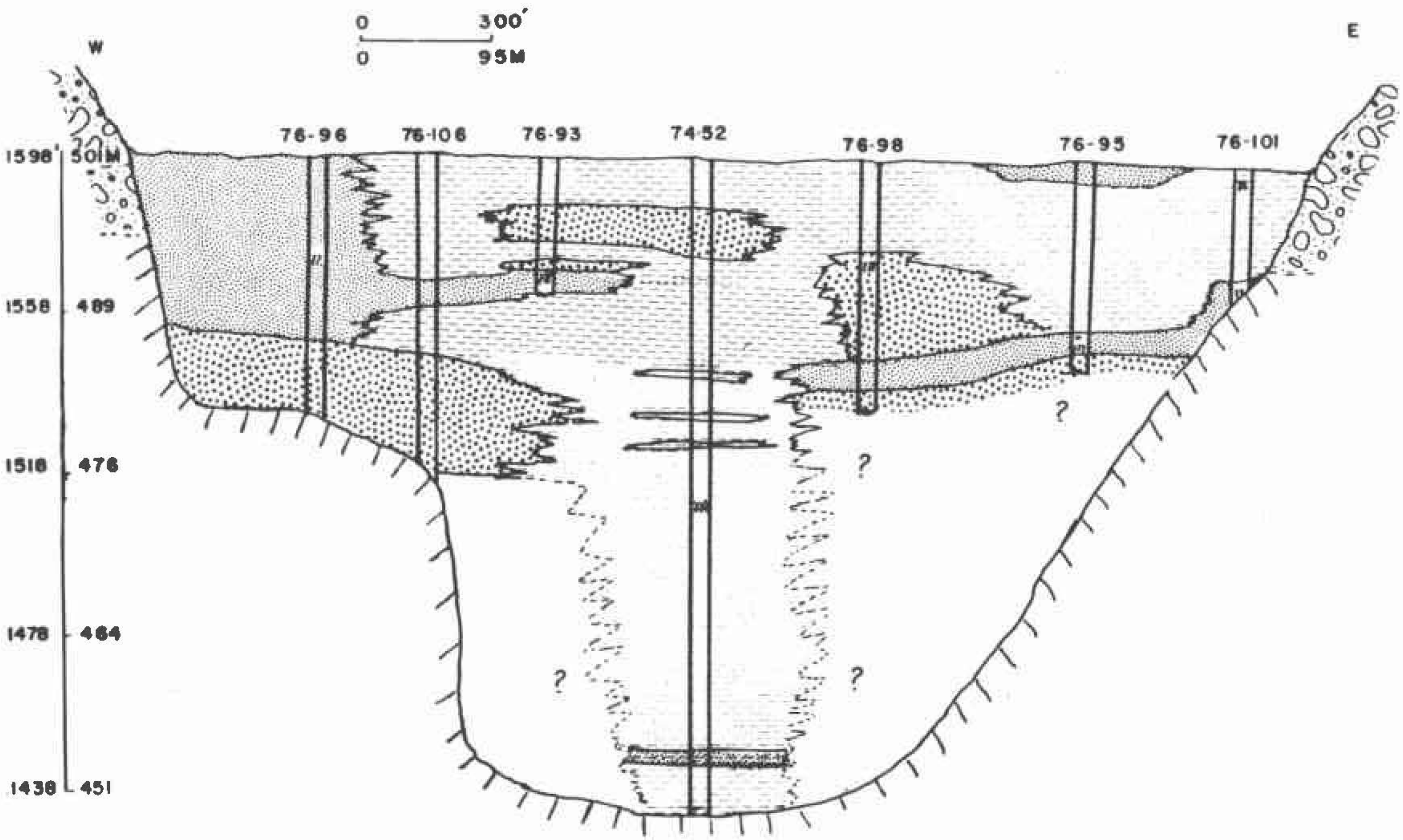
The cross section, like the Burlington and P.D. sections, is characterized by coarse alluvial-fan sediment on the valley sides with a highly fossiliferous organic clay plug in the valley center. These relationships indicate the presence of lacustrine conditions in this part of the Souris Valley throughout much of Holocene time.

Lake Darling

Lake Darling cores were collected by the Corps. The cross section is at the Lake Darling dam on the border of Ward and Renville Counties, mostly in section 6, T157N, R84W, and section 1, T157N, R84W, on the Carpio NE 7.5' Quadrangle (Fig. 6). Figure 33 shows the cross section to bedrock. Only three of the cores were made available for this project: they include 76-106, 98, and 95. The stratigraphy of the remaining test holes was interpreted from stratigraphic columns provided by the Corps (1978).

The section shows horizons of mostly silt and sand along the eastern valley side, grading into alternating clay/silt near the valley center. The west side of the valley is underlain mostly by clay. Between depths of 9

Figure 33. The Lake Darling cross section.



0 300'
0 95M
W
E
76-96
76-106
76-93
74-52
76-98
76-95
76-101
1598' 501M
1558 489
1518 476
1478 464
1438 451
?
?
?
?
?

and 12 m across the valley an organic horizon occurs, characterized by peaty material and wood at core 76-93. Between 3 and 4.5 m, another weak organic horizon is present, which includes oxide staining and stems in core 76-101. Gastropod fossils are present at this horizon and at the deeper horizon in core 76-95. The Corps (1978) data note a lower organic horizon at 25 m consisting of woody fibers.

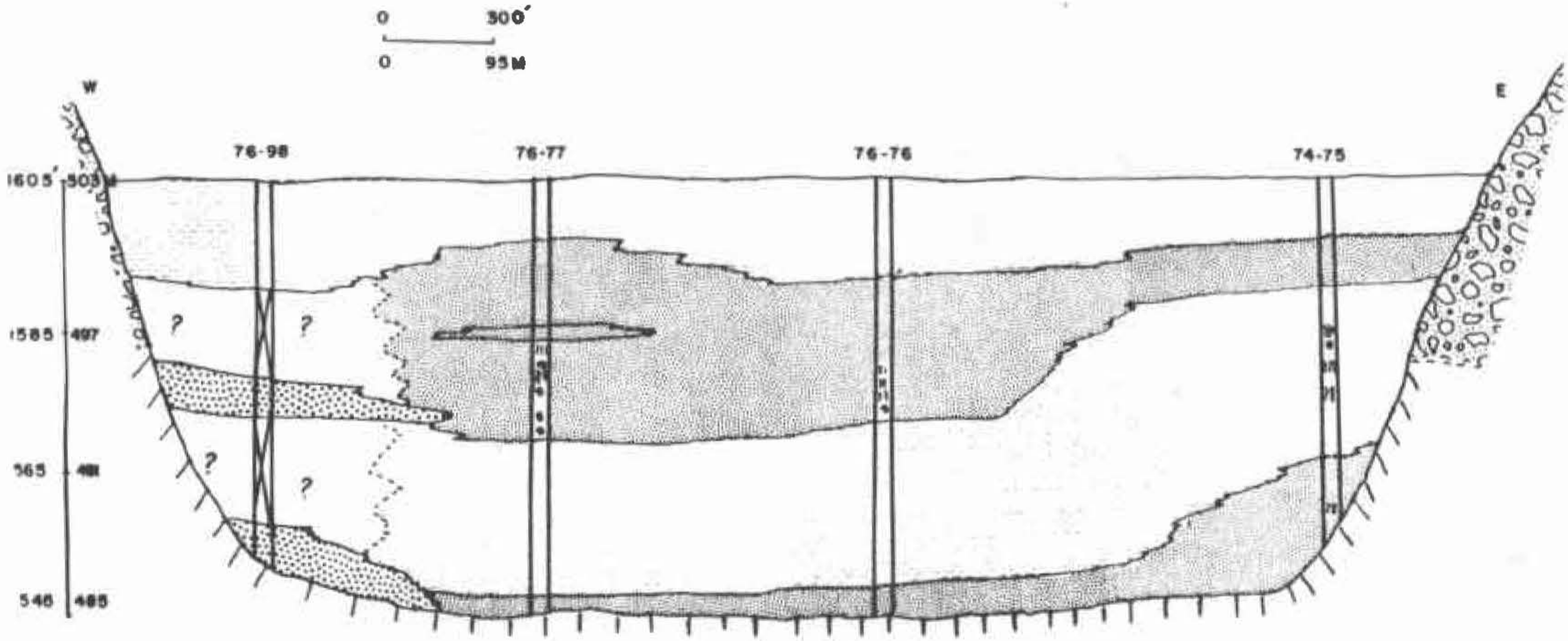
On the west bank of the Souris Valley, two large intermittent streams enter the valley and could account for the large amounts of sand. The organic layers presumably indicate a time of stability, with vegetation anchoring the material in place.

Soo Line

The Soo Line cross section was drilled at the point where the Soo Line Railroad crosses Lake Darling in Renville County (Fig. 6). These holes were drilled by the Corps to bedrock, which is 18 m at this point in the spillway. Five cores were obtained with two adjacent to each other (76-95 and 76-75). The columns at this site are incomplete because most of the samples were destroyed. Therefore, the stratigraphic columns provided by the Corps were used to fill in some of the gaps (Fig. 34).

The stratigraphy of the cross sections consists of coarse sediment on both valley sides and clay at the center. Between 6 and 7.9 m, a thick organic horizon exists consisting of rootlets and woody stems (Fig. 35).

Figure 34. The Soo Line cross section.



0 300′
0 95M
W
E
76-98
76-77
76-76
74-75
1605′
503M
1585
497
565
546
485
?

Figure 35. Woody material from organic horizon at Soo Line cross section.


0
3cm

At core 76-76, organics were reported by the Corps (1978). Shell fragments are also associated with the organics. Near the base of the section, a weak organic zone occurs, characterized by rootlets and gastropods.

Highway 5

The Highway 5 cross section was drilled along U. S. Highway 5 west of Mohall, North Dakota, in Renville County by the Corps (Fig. 6). Six holes were drilled, but samples from only two were acquired for this project, including 74-44 and 74-50, both from the center of the Souris Valley. Only generalized information from the other holes could be obtained from Corps (1978) stratigraphic columns (Fig. 36).

Most of the valley-fill section consists of fine silt to clay with thick beds of fine to medium sand. Core 74-44 shows a thick layer of gravel at the base (Fig. 37). Between 9 and 12 m, fossil gastropods are present and an oxide color is associated with the fossils in 74-50. Also, in 74-50, oxidized rootlets are present at 15.5 m.

Because of the lack of information, correlating an organic horizon across the valley is difficult, but, fossil gastropods do occur in the same horizon across the valley, indicating some continuity. The gravel at the base may be sediment deposited by slumping of the valley sides after the last glacial lake outburst flood, based on a high clay/silt matrix.

Figure 36. The Highway 5 cross section.

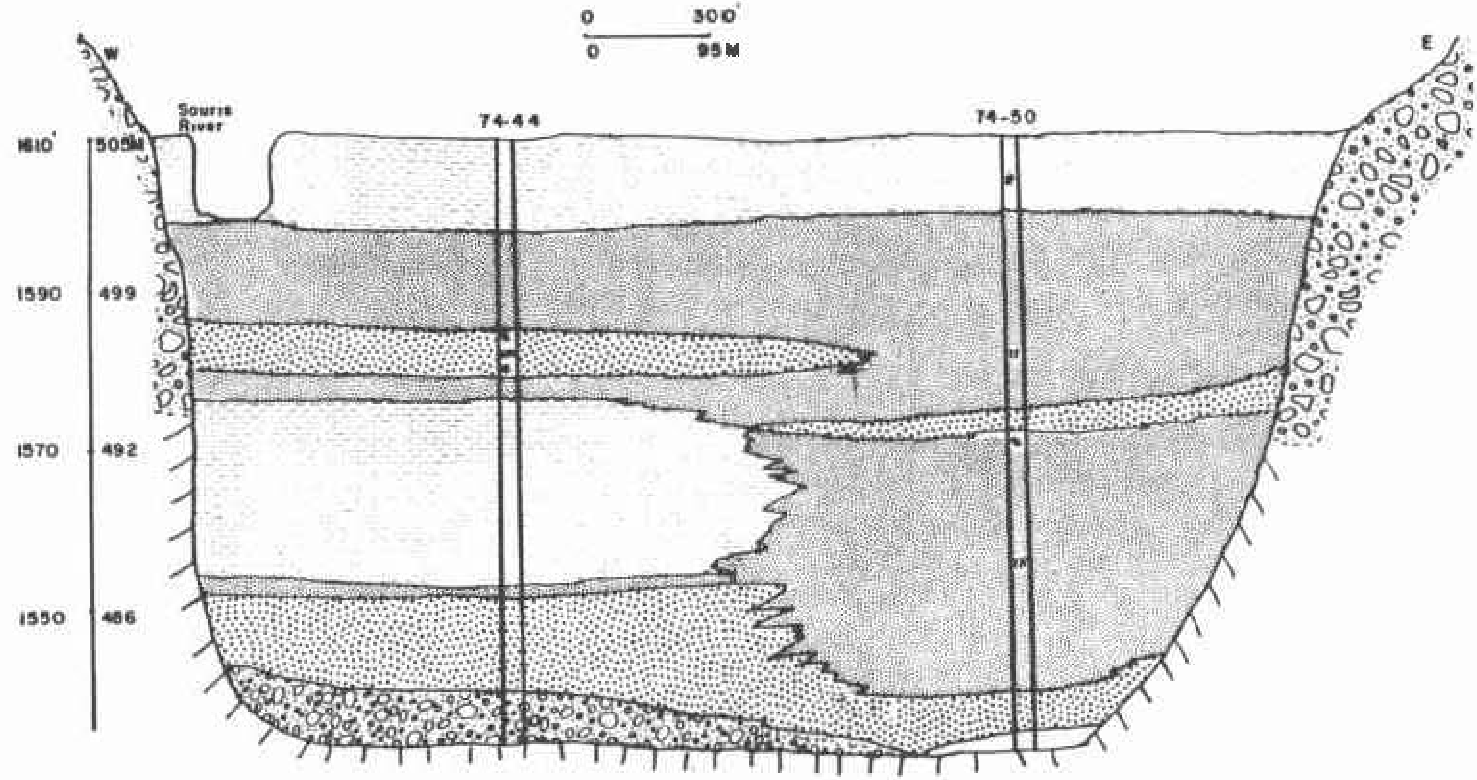
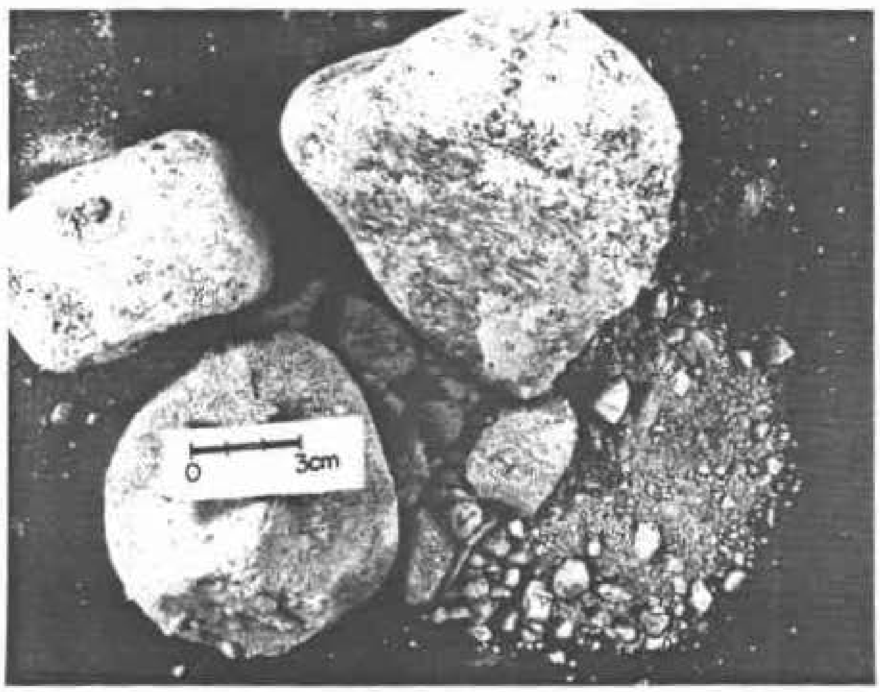

0 300'
0 95 M
W
E
Souris River
74-44
74-50
1610'
505M
1590
499
1570
492
1550
486

Figure 37. Coarse material at base of Highway 5 cross section in clay/silt matrix.


0
3cm

R-3

Cross section R-3 was drilled about 3.5 km northwest of Mouse River Park along the Souris River (Fig. 6) in Renville County (Sec. 4 T156N, R84W, and Sec. 34, T156N, R84W, Mouse River Park 15' Quadrangle). Four holes were drilled to an average depth of 5.5 m and spaced about 300 m apart (Fig. 38).

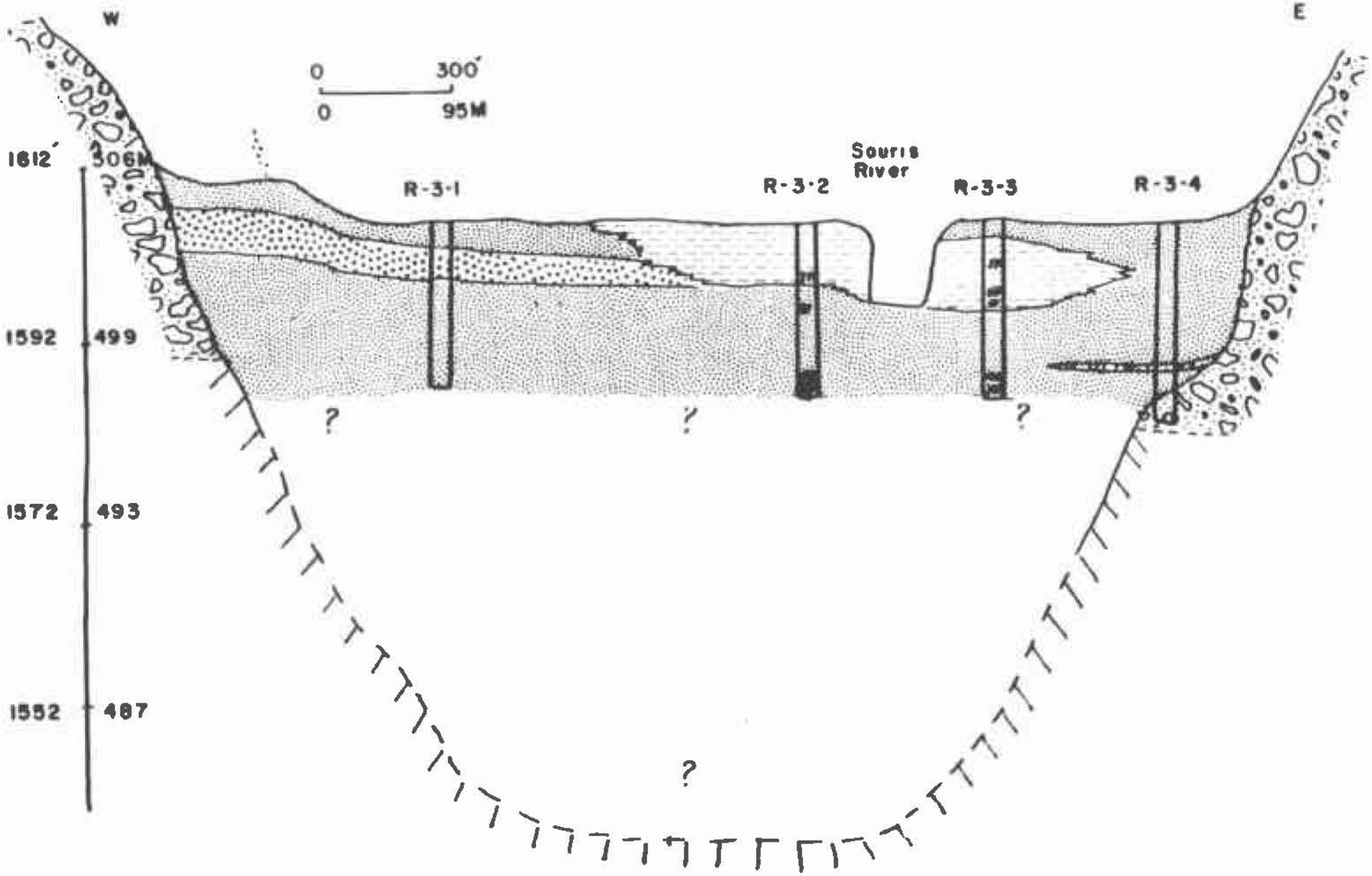
Hole R-3-1 was drilled on the west side of the valley to a depth of 3.6 m and the sediment consists mostly of massive, very poorly sorted, coarse to fine sand that contains lenses of pebbles.

Hole R-3-2 was drilled to a depth of 5.5 m and the swediment consists of very poorly sorted silt with clay between 0.6 and 2 m. Fossil fragments are present in the fine silt and woody stems were recovered at the base. Oxide stains and some organic material is present in the poorly sorted silt between 2.4 and 3.6 m.

Core R-3-3 was drilled to a depth of 5.5 m and consists of poorly sorted fine and medium silt with clay between 1.5 and 3 m. Rootlets and scattered fossil shells were present at the base. The fine silt at the base of the column contained a few stems and shell fragments.

Hole 4 was drilled along the northeast side of the valley to a depth of 7 m; the stratigraphy consists mostly of poorly sorted medium silt with a gravel lens at 5 m. The section from 5.4 m to the base has been interpreted as a till slump by the Corps (1978).

Figure 38. Cross section of R-3.


W
E
0
300'
0
95M
1612'
306M
1592
499
1572
493
1552
487
R-3-1
R-3-2
Souris
River
R-3-3
R-3-4
?
?
?
?

In cores R-3-2 and R-3-3, an organic layer of stems and fossil fragments and can be correlated. This lithology probably indicates a backwater deposit because of the lack of clay that would indicate a lacustrine deposit.

River Road

The River Road cross-section was drilled in Renville County (Fig. 6) along the River Road (Sec. 7, T162N,R84W, and Sec. 8, T162N, R86W, Mouse River Park N.E., 7.5' Quadrangle). The average depth of the cores is 8.5 m and the holes are spaced about 300 m apart (Fig. 39).

Core R.R.-1, which was drilled on the west side of the valley to a depth of 6.7 m, consisted of poorly sorted medium to very fine silt. Fossil gastropods and oxide staining were present at 2.4 m and at the base.

Hole R.R.-2 is in the center of the Souris Valley and reaches a depth of 8.5 m. The sediment also consists of poorly sorted medium to coarse silt (Fig. 40). This core yielded woody stems, gastropods, pill clams, and mussels at a depth of 5.1 to 6.7 m (Fig. 41, 42, and 43). The shell fragments continue to the base of the core. A C-14 date of 8840 ± 100 years BP was obtained for this layer.

Hole R.R.-3 was drilled on the east side of the Souris River to a depth of 6 m with poorly sorted silt occurring within the upper 1.5 m. The silt is underlain by clay containing scattered shell fragments. The rest of the core is poorly sorted coarse sand with poorly sorted silt at the base.

Figure 39. Cross section along the River Road.

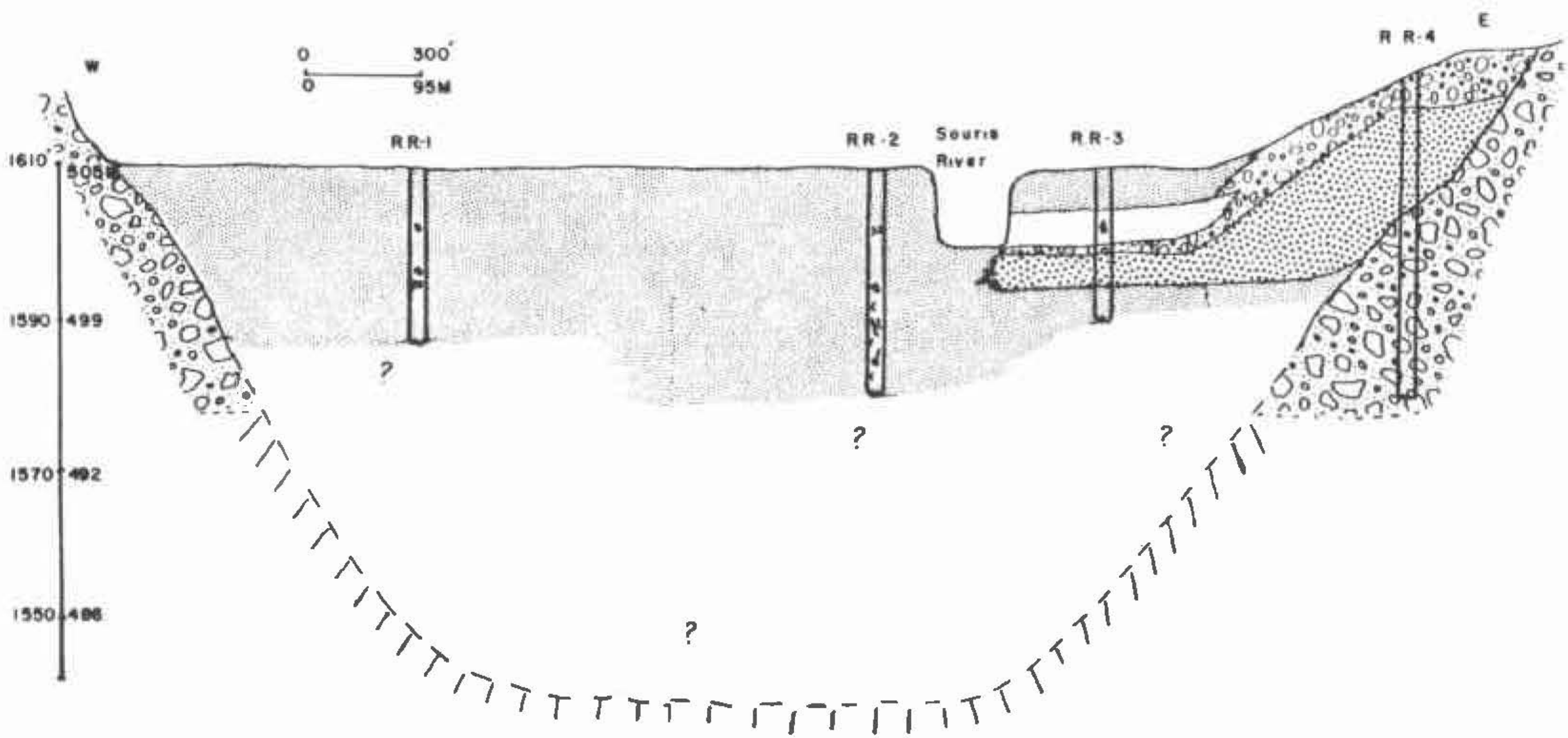

W
E
0
300'
0
95M
RR-1
RR-2
Souris
River
RR-3
R R-4
1610'
505M
1590
499
1570
492
1550
486
?
?
?
?

Figure 40. Woody stems collected from R.-R.-2.

Figure 41. Mussel shell collected from R.-R.-2.


0 3cm

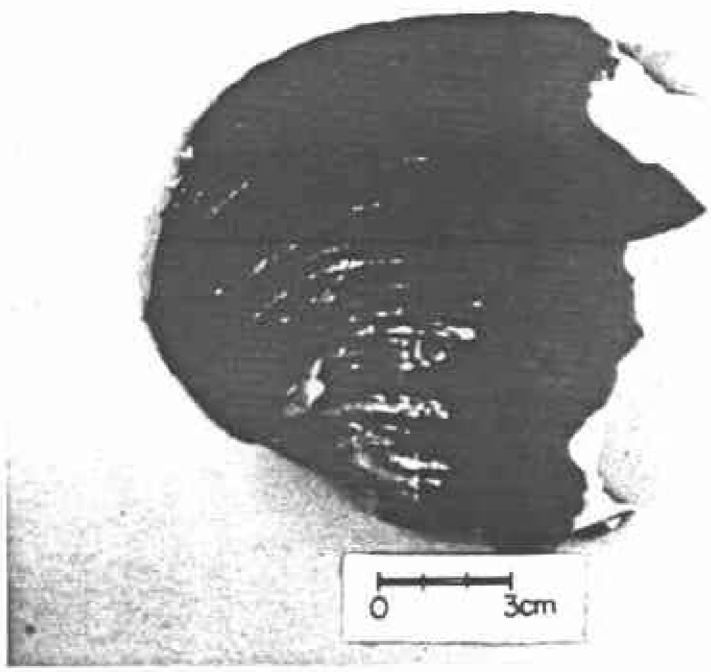
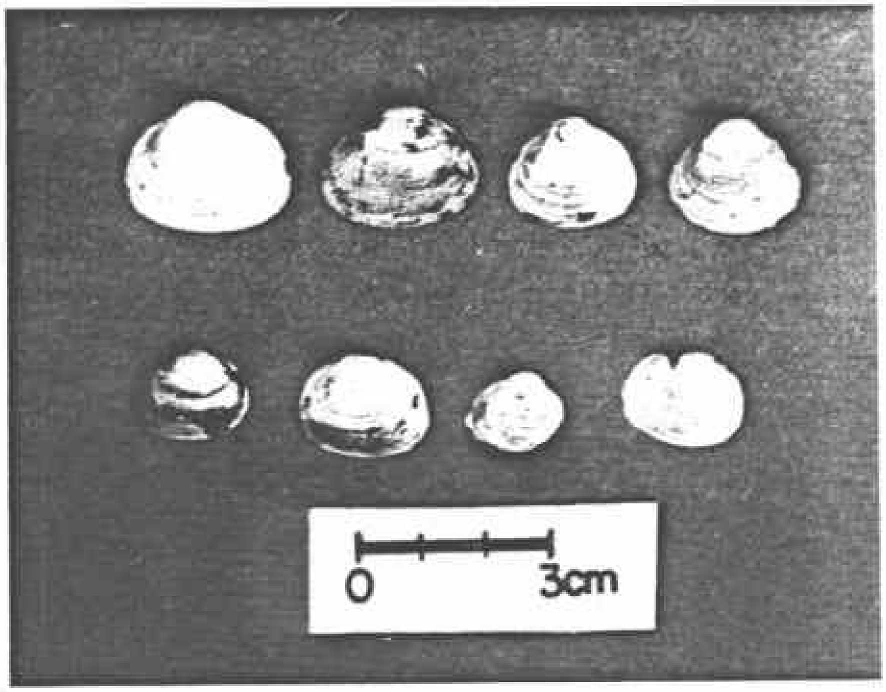
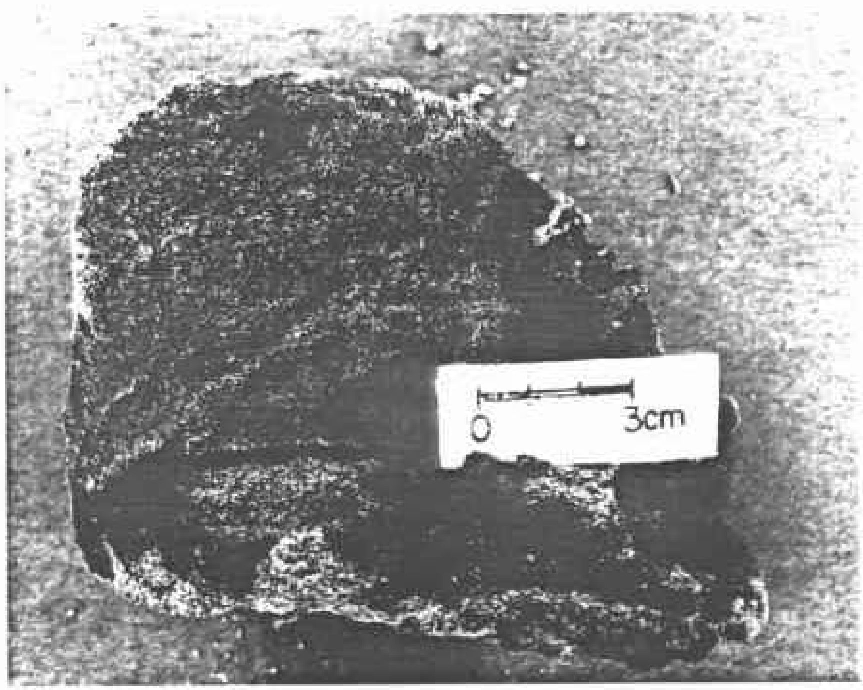

0 3cm

Figure 42. Numerous pill clams collected at R.-R.-2.

Figure 43. Typical example of silt in the Souris Valley center at R.-R. cross section.


0
3cm


0
3cm

Hole R.R.-4 was drilled along the east side of the Souris Valley to a depth of 12.7 m. The upper 4.5 m consist of poorly sorted medium silt to fine sand with gravel at the surface. The rest of the column consists of poorly sorted, pebbly, sandy silt/clay that I interpret to be till.

The most notable feature of this cross-section is the highly fossiliferous organic layer in core R.R.-2. This may represent a backwater deposit with abundant aquatic life. An upper organic horizon is poorly preserved, but does contain rootlets and scattered shell fragments.

C-11

C-11 was drilled along Ward County Road 11 about 1 km northwest of Foxholm, North Dakota along U.S. Highway 52 (Fig. 6). It trends north-south across the Des Lacs Valley and follows the line that divides section 36, T156N, R85W, and section 31, T157N, R84W, Carpio N.E. 7.5' Quadrangle. Four holes were drilled across the Des Lacs Valley to an average depth of 6 m, and spaced about 300 m apart (Fig. 44).

Core C-11-1 was drilled to a depth of 5.5 m and consists of poorly sorted very fine to coarse silt with poorly sorted medium sand at the base. At the base, shell fragments and wood were recovered (Fig. 45).

Core C-11-2 was drilled to a depth of 5.5 m and contained poorly sorted fine to medium sand with woody

Figure 44. Cross section along C-11.

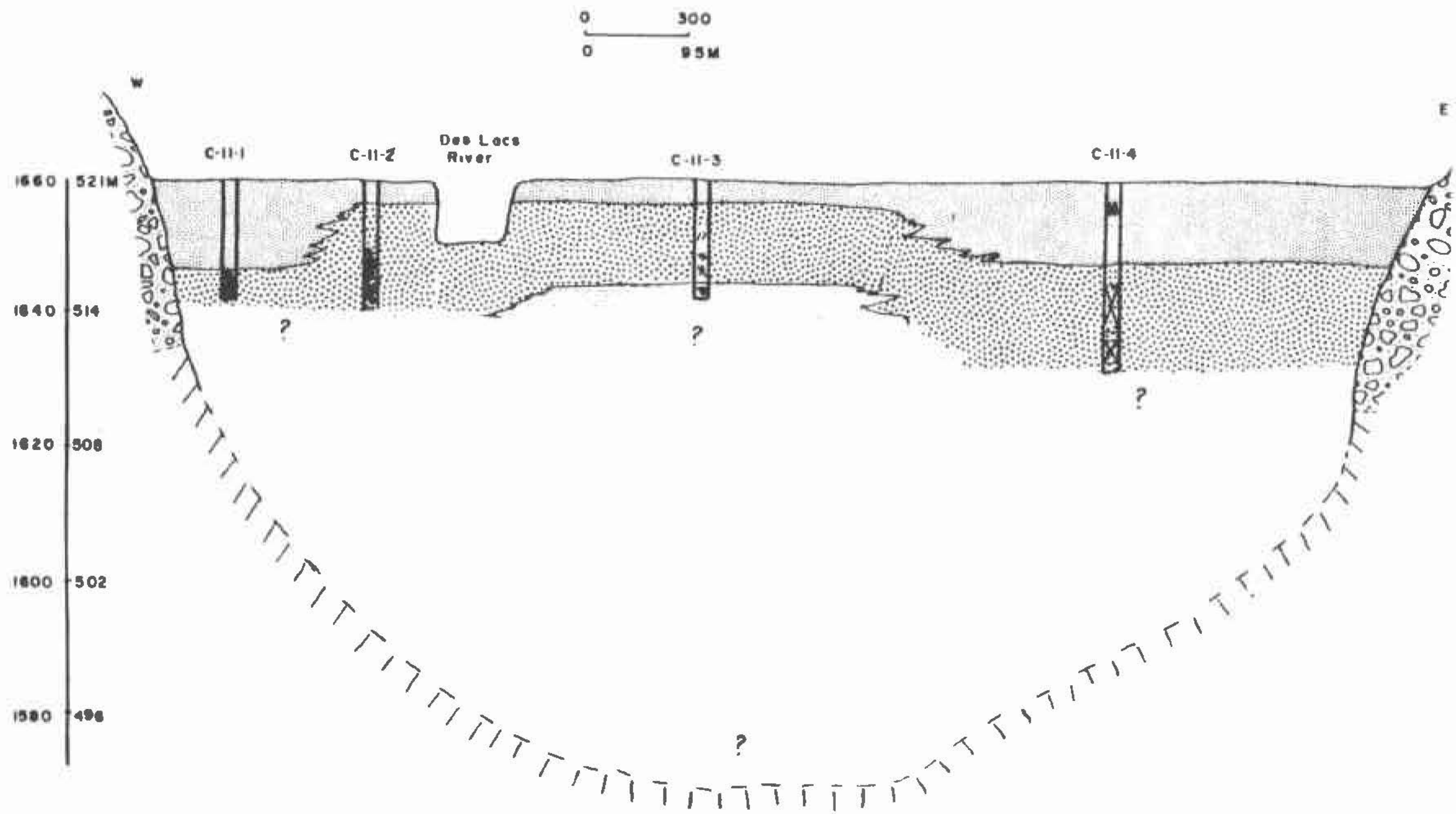
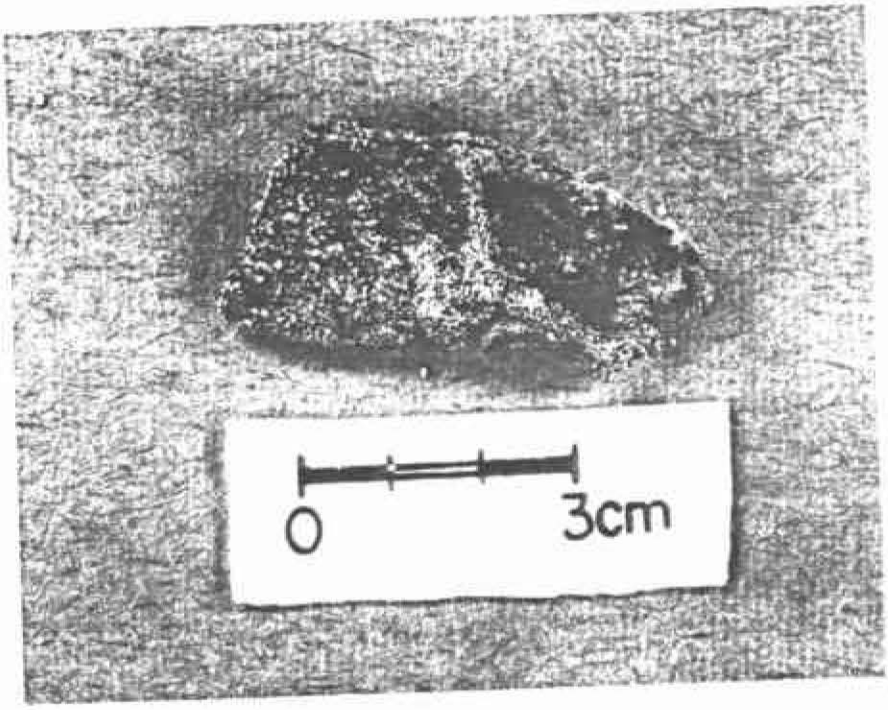

0 300
0 95M
W
E
C-11-1
C-11-2
Des Lacs River
C-11-3
C-11-4
1660 521M
1640 514
1620 508
1600 502
1580 496
?

Figure 45. Woody material from lower organic horizon at C-11 cross section.


0
3cm

stems and gastropod fragments from 4.5 m to the base. Most of the basal material was not recovered due to water saturation.

Core C-11-3 was drilled to 5 m and consists of poorly sorted very fine sand with clay at the base. Rootlets and shell fragments were scattered throughout.

Core C-11-4 was drilled to 8.5 m with most of the material below 5.2 m not recovered. The section consists of poorly sorted coarse to fine silt with scattered pebbles, with the base being poorly sorted medium sand.

The bases of cores C-11-1 and 2 correlate because of the presence of wood at the same depth. Unfortunately, most of the material in core 4 was not recovered. The fine-grained material may indicate fluvial deposits and reworked sheetwash.

DISCUSSION

General Statement

Because all the cores collected for this study did not reach bedrock, the valley profiles could not be precisely determined. The drilling by the Corps (1978) and the North Dakota State Water Commission (NDSWC) (1971) did reach bedrock in the Souris and Des Lacs Valleys. Using their data, I interpreted the valley profiles prior to the deposition of the valley-fill sediment. Combining the Burlington and Lake Darling cross-section depths with the NDSWC data, the depth to bedrock in the Souris Valley between C-25 and Lake Darling was assumed to be about 36 to 42 m in the valley center. The depths of the R.R. and R.-3 cross sections were inferred using the Soo Line and Highway 5 sections. These data indicate that the Souris Valley deepens significantly as it proceeds south to the Glacial Lake Souris basin. In the Des Lacs Valley, the depth to bedrock at the C-11 cross section is inferred to be at 20 m based on data from the NDSWC (1971).

The results of all data collected for this study indicate that coarse sediment along the valley sides interfingers with fine-grained sediment in the valley centers. Both the Corps data and my work suggest coarse-grained sediment is commonly present along the sides of the valleys. The middle of the Souris Valley commonly has fine-grained alluvial or lacustrine sediment at the center of the valley with stringers of coarse-grained sediment extending to the valley sides. These relationships suggest interfingering of valley-side deposits with the fine-grained valley-center deposits. Only one shallow cross section was drilled along the Des Lacs Valley (C-11). There, the sediment is apparently of the same origin as the Souris Valley fill. These similarities are expected because of the similar Pleistocene and Holocene origins of the two valleys.

A random sample of the two different valley center lithologies and the valley-side alluvium was plotted on a standard U. S. Department of Agriculture textural classification triangle to demonstrate the major differences in sediment in the Souris Valley (Fig. 46). The percentages of sand-silt-clay are listed in Appendix C. The material from the Souris Valley, between the confluence with the Des Lacs River and Lake Darling cross section (Fig. 6), plots dominantly as clay. The material in the rest of the Souris Valley center generally plots as sandy clay to silty clay loam. The alluvial sediment on the valley sides generally plots on the sandy side of the diagram. This shows that three types of deposition occurred in the Souris Valley. This is particularly evident with the valley center sediments, which indicate two distinct environments.

Major Features of the Souris Valley

A longitudinal cross section has been constructed for the entire length of the Souris Valley (Fig. 47). This

Figure 46. U.S. Department of Agriculture textural classification triangle with randomly selected analyses plotted

●: Souris Valley center texture between confluence with the Des Lacs and the Lake Darling cross section.

■: Souris and Des Lacs Valleys center texture outside of confluence with the Des Lacs and Lake Darling cross section.

▲: Valley side texture.

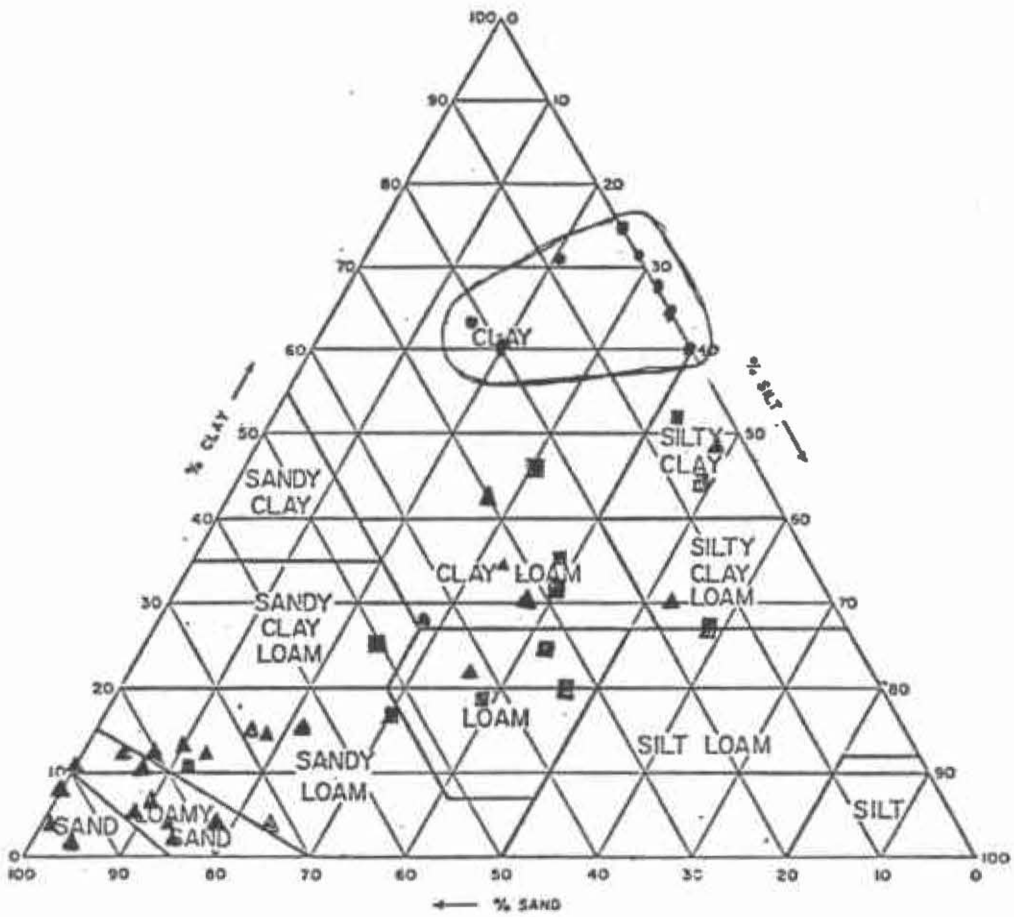
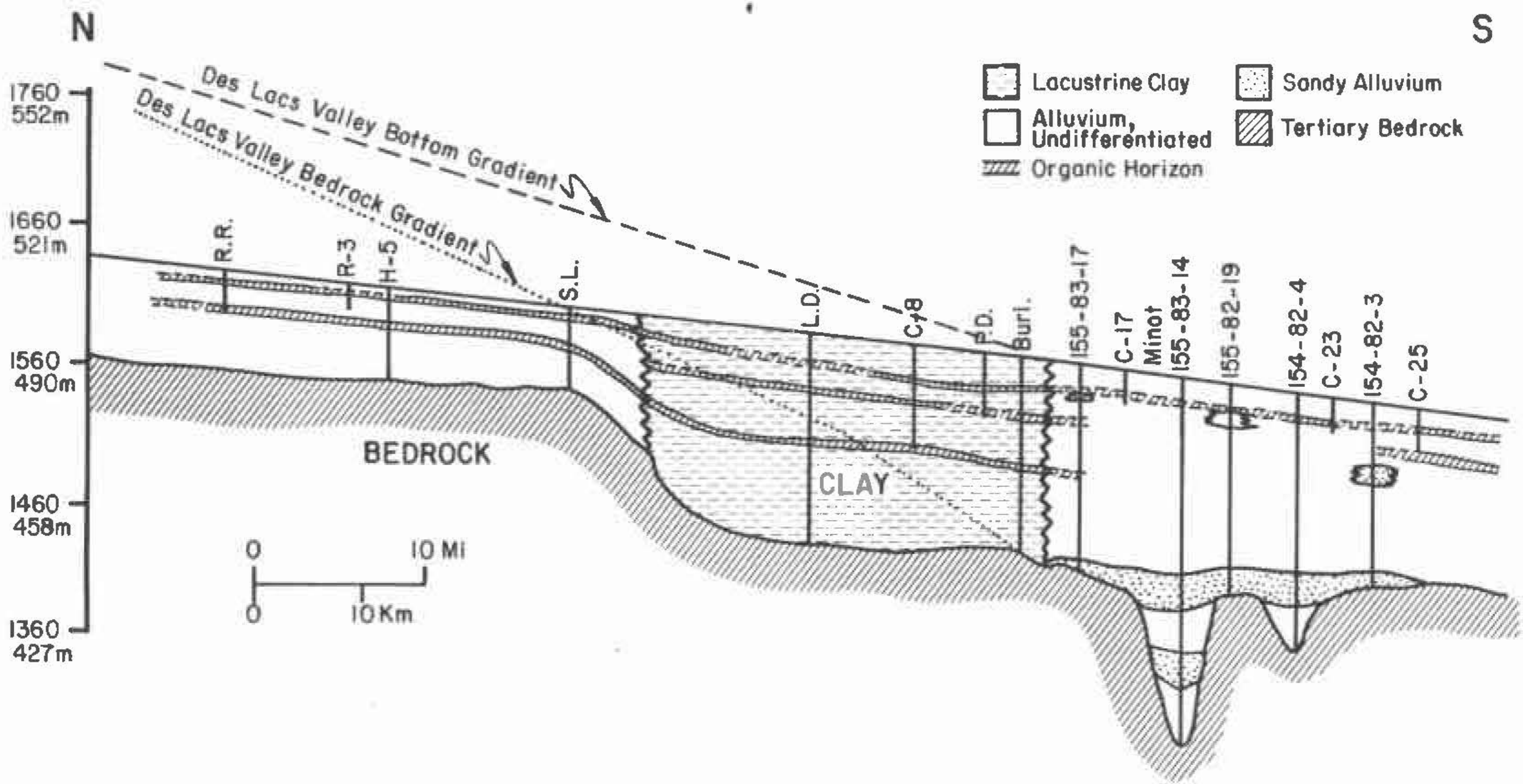


Figure 47. Longitudinal profile down the center of the Souris Valley.



N
S
1760 552m
1660 521m
1560 490m
1460 458m
1360 427m
Des Lacs Valley Bottom Gradient
Des Lacs Valley Bedrock Gradient
Lacustrine Clay
Alluvium, Undifferentiated
Organic Horizon
Sandy Alluvium
Tertiary Bedrock
R.R.
R-3
H-5
S.L.
L.D.
C+8
P.D.
Burl.
155-83-17
C-17
Minot
155-83-14
155-82-19
154-82-4
C-23
154-82-3
C-25
BEDROCK
CLAY
0
10 Mi
0
10 Km

cross section, which shows several features, runs north from the Canadian-United States border to the south of the C-25 cross section (Fig. 6). Data from the NDSWC (1971) were used to determine bedrock depths in the southern part of the Souris Valley.

Depth to Bedrock

The first important feature is the difference in depth to bedrock along the course of the Souris Valley. In the northern part of the valley, from the Soo Line to the R.R. cross section, the depth to bedrock is about 20 m. South of the Soo Line cross section, the depth to bedrock is about 40 m. Therefore, there is a significant difference in bedrock elevation between the two valley sections. This feature may be a remnant from the last glacial-lake outburst flood down the Souris Valley. As the flood drained into Glacial Lake Souris, a headward migrating nickpoint may have formed and moved-up valley until the flood subsided and downcutting no longer occurred. Nickpoints or cataracts similar to this are present in the scablands of Washington State (Baker, 1973).

Lithology Change

A second notable feature is the lithological contrast at the valley center along the Souris Valley. The lithology between the Burlington and Lake Darling cross sections is characterized by high amounts of clay, abundant gastropods, one species of which prefers a pond/lake environment. The organic material present, for the most part, is peat, especially within the lower horizon.

From the Soo Line north to the R.R. cross section and from the C-17 cross section south to the C-25 cross section, the Souris Valley lithology is characterized by sand/silt with occasional lenses of clay and sand. The Des Lacs valley, based on the C-11 cross section, is similar. The fossil assemblage in these reaches includes mostly pill clams and mussels. The organic material is mostly wood stems with some rootlets present.

There is a significant difference in fossil assemblages, organic material, and lithology between the two valley-fill types, indicating that two types of environments existed in the Souris Valley during most of the Holocene. Based on this evidence, the clay plug is interpreted as a pond or lake deposit caused by partial damming of the Souris River below the Burlington cross section.

A longitudinal profile comparing the modern valley-floor gradient and bedrock gradient of the Des Lacs Valley is compared to the Souris Valley modern valley-floor and bedrock gradient on Figure 47. The modern valley floor gradient for both valleys was plotted with elevations from U.S.G.S. topographic maps, and the bedrock gradient for the Des Lacs was obtained by plotting bedrock elevations from three cross sections drawn by the NDSWC (1971). Comparison of the gradients indicates that the Des Lacs River gradient is steeper; therefore, its alluvial-fan deposits accumulated during dry periods of the Holocene, and should have been sufficient to partially dam the Souris River to form a lake upstream from the confluence of the two spillways. After the Lake Regina outburst flood subsided, the Souris Valley was deeper than the Des Lacs Valley. As the higher gradient Des Lacs River entered the Souris Valley, deposition occurred and an alluvial-fan composed of a tonque of coarser material spread across the Souris Valley. It should also be noted that the Des Lacs Valley gradient should be higher because the last and most erosive outburst flood was confined mostly to the Souris Valley. The Des Lacs Valley was, therefore, not eroded as deeply. A modern example of this proposed mechanism is present in western Wisconsin where the Chippewa River meets the Mississippi River. Because the Chippewa River has a steeper gradient, alluvium is deposited across the Mississippi River Valley, causing a lake to form (Attig, J., 1986, verbal communication). This alluvial-fan dam is illustrated on the U.S.G.S. Wabasha North 7.5' Quadrangle of Minnesota and Wisconsin.

Organic Horizons

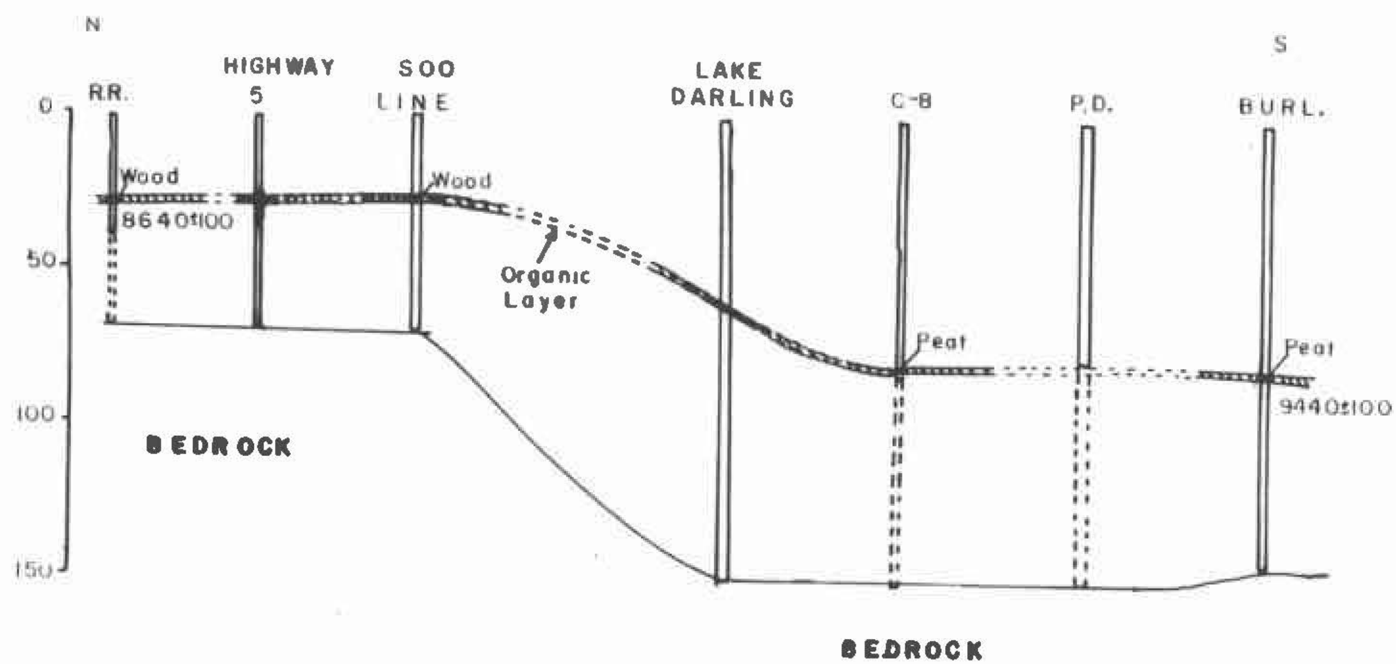
The third major aspect of the Souris Valley stratigraphy is the character and correlation of organic horizons (Fig. 47). Three organic horizons were identified in the lacustrine lithotype between the Burlington and Lake Darling cross sections. The lowest horizon was at 25 m, a middle horizon at about 12 m, and an upper horizon at 4 to

6 m. The organic material is mostly peat with the upper horizon containing abundant rootlets, especially at the P.D. cross section.

Two organic horizons were identified between the Soo Line and the R.R cross sections, with the lowest at 8 to 9 m, consisting of woody stems. The upper zone is poorly developed and consists of rootlets with some oxide staining. From the C-17 to C-25 and C-11 cross sections, two thin upper organic horizons were also noted with rootlets and some woody stems.

Figure 48 is a longitudinal cross section down the Souris Valley north to south showing a correlation of the lower organic horizon. Dates were obtained for this layer at the Burlington (9440±100 years B.P.) and at R.R. cross sections (8840±100 years B.P.). Other criteria were used for correlation in addition to the dates. First, between the Highway 5 and Soo Line cross sections, an organic horizon consists of woody stems similar to those at the R.R. cross section and occurs at the same depth. Second, organics at the Lake Darling and C-8 cross sections consist of peat similar to that found at the Burlington cross section and occur at the same depth. Third, the organic horizon is present at about the same relative position in the section, taking the difference in bedrock elevation and Holocene section thickness into account. Fourth, with two types of environments present, one would expect two types of organic horizons to form.

Figure 48. Longitudinal cross section of the center of the Souris Valley showing correlation of the lower organic horizon.



N
S
R.R.
HIGHWAY 5
SOO LINE
LAKE DARLING
C-B
P.D.
BURL.
0
50
100
150
Wood
8640±100
Wood
Organic Layer
Peat
Peat
9440±100
BEDROCK
BEDROCK

The C-14 dates place the age of the lower organic horizon within the Aggie Brown Member of the Oahe Formation, whose type section is at Riverdale in McLean County, North Dakota (Clayton et al., 1976). Figure 49 is a stratigraphic column showing the position of the two C-14 dates from the lower organic horizon. Also, this column correlates changes in temperature, precipitation, erosion, deposition, and periods of soil formation during the Holocene in western North Dakota.

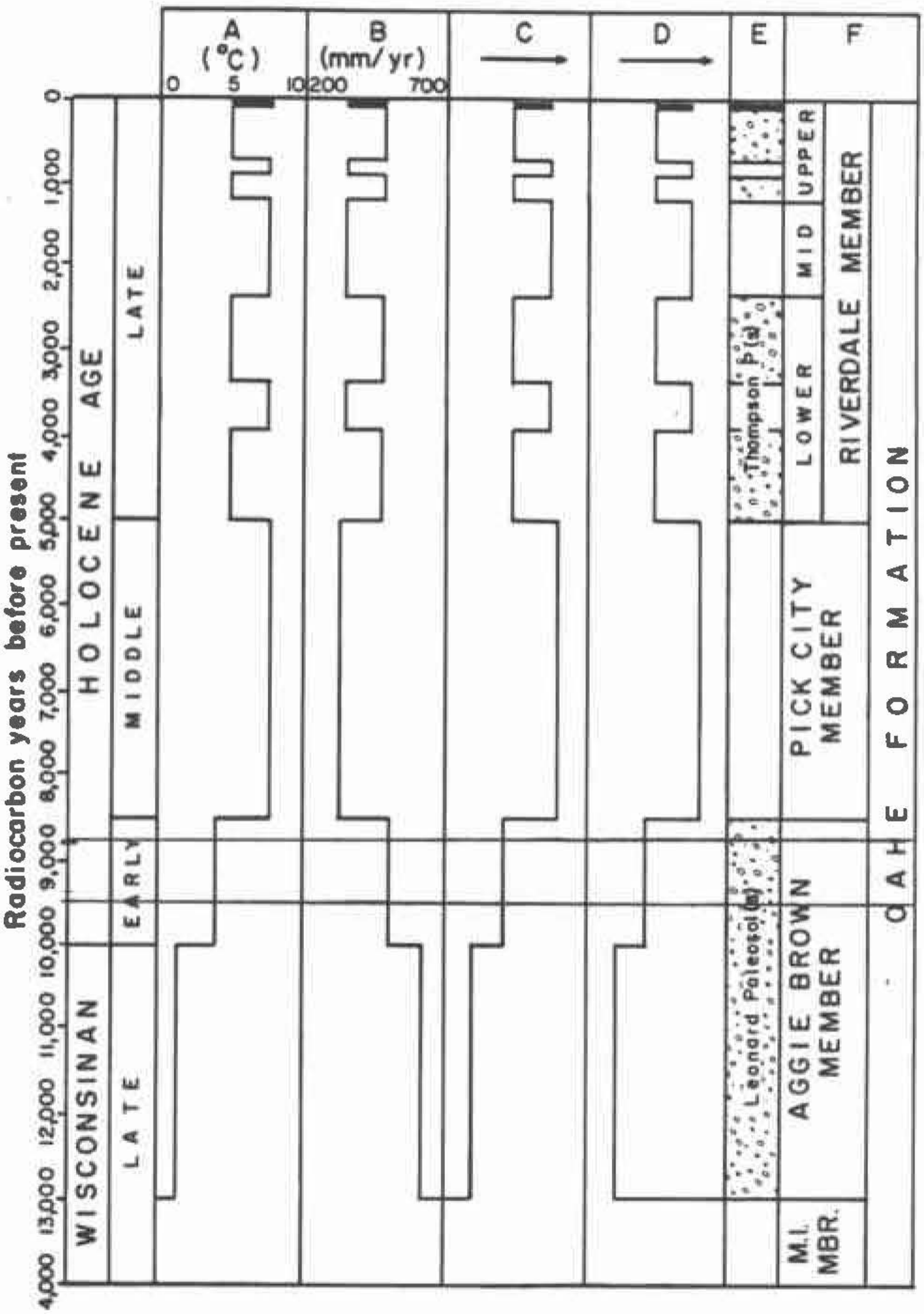
Origin of Coarse Gravel

After the final glacial-lake outburst flood, the Souris Valley was eroded into bedrock as a steep-sided, narrow trench (Kehew, 1982). When the discharge subsided, both the Souris and Des Lacs Rivers occupied their respective valleys. Both rivers are now typical of meandering fluvial systems. Because of the steepness of the entrenched valley slopes, slumping of till blocks was probably common along the valley sides (Klassen, 1972). Both the Burlington and Highway 5 cross sections (Figs. 16, and 36) show till slumps at the base of the Souris Valley sides and bottom.

Origin of Alluvial Material

Study of topographic maps of both the Souris and Des Lacs Valleys show numerous ephemeral streams that enter the sides of the valleys (Figs. 50 and 51). Topographic relief defines fan-shaped deposits from some of these ephemeral

Figure 49. Holocene stratigraphic column of North Dakota showing position of the two C-14 dates (after Clayton et al., 1976).

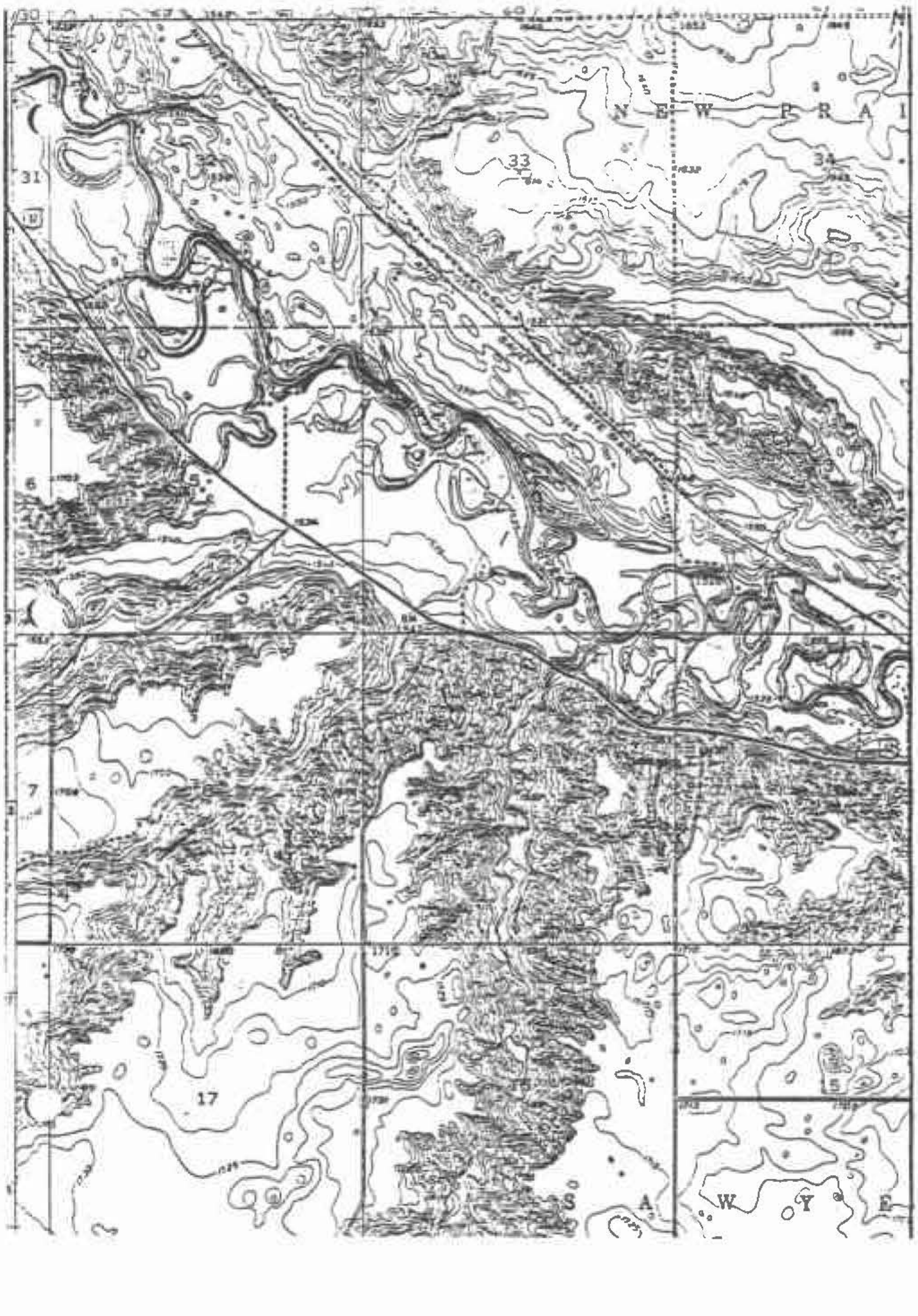


Postglacial (A) mean annual temperature, (B) precipitation, (C) slopewash erosion on steep slopes, (D) eolian deposition on gentle slopes, (E) periods of conspicuous soil formation, and (F) suggested correlations with the subdivisions of the Oahe Formation. Values are extremely approximate. Many small fluctuations have been omitted.

streams on the valley floors. This is evident at the C-17 cross section (Fig. 15) where a large ephemeral stream enters the Souris Valley on the southwest side. During a spring thaw or heavy rain, these streams would become active. The high discharge would carry large amounts of sediment (Friedman and Sanders, 1978, p. 203). Alluvial fans form when water confined by a narrow valley enters a broad valley. Deposition occurs as the result of a sharp decrease in transport efficiency as the stream emerges from the narrow valley out onto the major valley floor. The sediment deposited becomes finer with distance from the valley mouth (Rust and Koster, 1984). The source of the material is till or bedrock from the tributary valleys. Igneous and metamorphic rock fragments and dolostone pebbles are common in the till of the Minot region (Kehew, 1983). As the sediments enter the valley and transport efficiency decreases, the channel becomes braided in a fan-like pattern as it deposits the material (Friedman and Sanders, 1978, p. 203-205). So, gravel and coarser sand will be deposited at the apex of the fan with silt near the distal margin. This depositional pattern is evident in the subsurface stratigraphy of the valleys. Near the valley walls, gravel and coarse sand are common and the material becomes finer with distance across the valley floor.

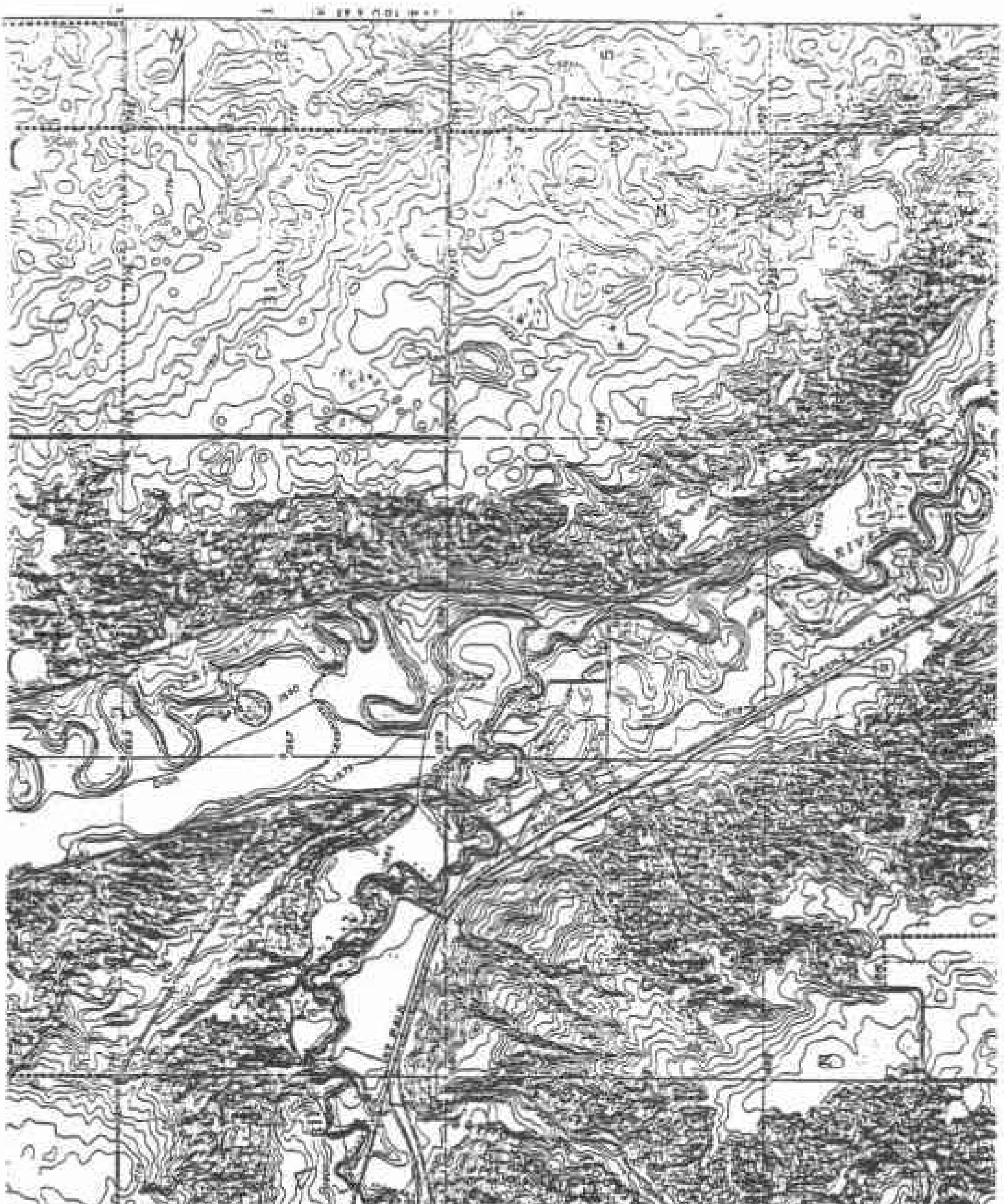
Along other parts of the Souris and Des Lacs Valleys, thin deposits of sand and silt were probably deposited by sheetwash close to the valley wall. These deposits interfinger with the alluvial-fan material.

Figure 50. Portion of U.S.G.S. topographic map of Sawyer 7.5' Quadrangle, North Dakota south of Minot along the Souris River showing numerous ephemeral streams and fans on the valley floor.



N E W P R A I
33
34
31
6
7
17
5
S A W Y E

Figure 51. Portion of U.S.G.S. topographic map of Burlington 7.5' Quadrangle in North Dakota showing numerous ephemeral streams entering the Souris Valley from the sides.



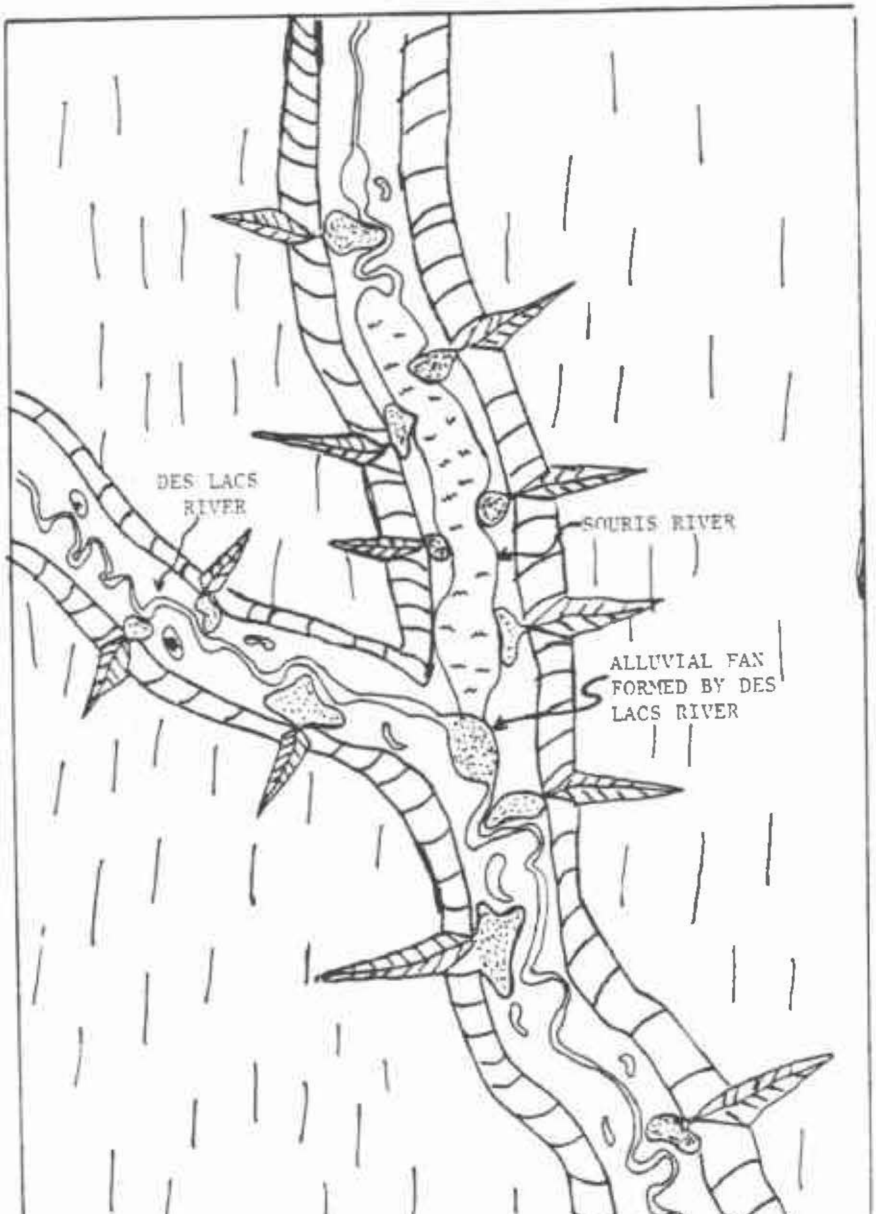
Initially, there probably was rapid deposition of alluvial-fan material in the valleys. The base level of tributary streams would have been low and ephemeral streams entering the valley would have downcut the valley sides rapidly while concurrently depositing material on the valley floors. At times the fans would have been sufficiently large to dam the rivers temporarily or divert the flow around them (Fig. 52).

Fluvial Setting

Both the Souris and Des Lacs Rivers are meandering fluvial systems. Generally, meandering rivers are characterized by lateral and vertical accretion. The meandering pattern results from a spiral secondary flow pattern (Friedman and Sanders, 1978, p.220). As a result, current flows toward the outside meander where water is "headed" up along the bank and is forced downward along the concave side, developing a spiral pattern (Fig. 53B). This process causes lateral erosion of the stream bank, and the sediment is deposited on the inside of the meander to form a point bar. The entire meander system slowly migrates downstream, keeping within the meander belt (Freidman and Sanders, 1978, p. 221).

Sometimes lateral migration will be impeded by resistant material. Upstream meanders will then catch up and cut this meander off to develop an oxbow lake (Friedman and Sanders, 1978 p. 228). This is a common occurrence in the Souris and Des Lacs Valley floors, where numerous

Figure 52. Schematic model showing alluvial fans along the Souris and Des Lacs Valleys and partially damming and diverting the rivers.


DES LACS RIVER
SOURIS RIVER
ALLUVIAL FAN FORMED BY DES LACS RIVER

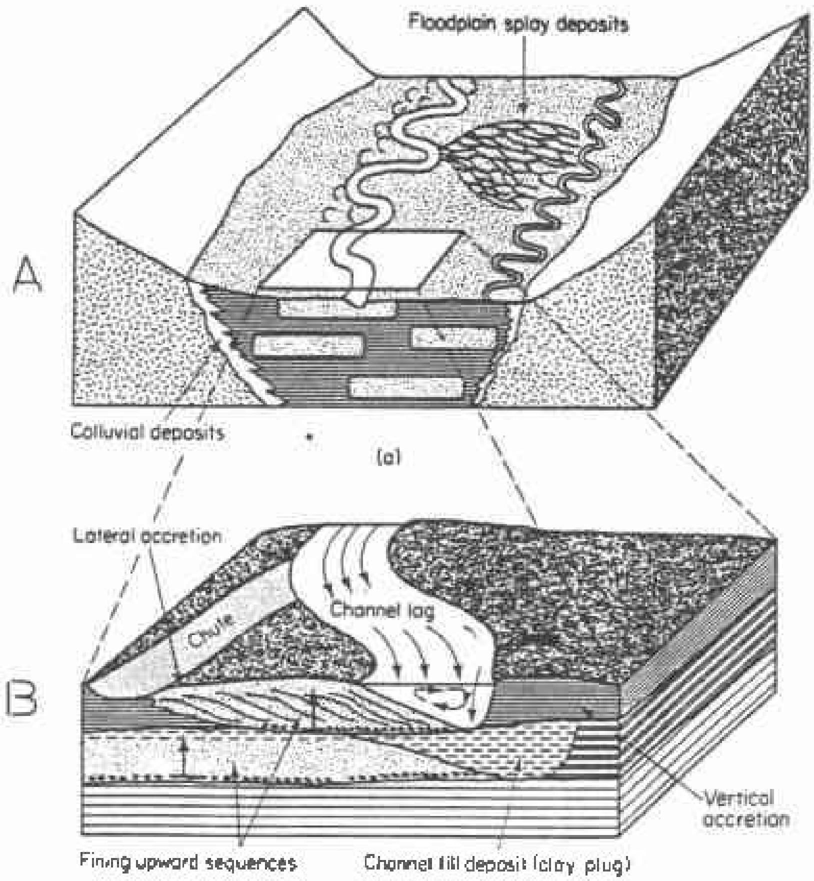
meander scars and oxbow lakes are visible. The resistant material probably is a clay lens from an abandoned meander or alluvial-fan sediment.

Vertical accretion involves the deposition of floodplain deposits that consist of very fine sand, silt, and clay. The water on the floodplain usually moves at a slower velocity than the channelized flow and fine-grained sediments with parallel laminations are deposited. During each flood, the clay and silt accumulate on top of the previous bed, building up the floodplain (Blatt, Middleton, and Murray, 1980, p. 635; Ritter, 1978, p. 264).

The cross sections show that in the middle of the valleys, there is generally fine-grained sand, silt and clay. These sediments consist of floodplain deposits, reworked alluvial-fan material, abandoned oxbow lake sediments, point bars, and lacustrine deposits.

The Souris Valley between the Soo Line and R-3 cross sections to the north, and the C-17 and C-25 to the south (Fig. 6) is characterized by sediments typical of a meandering fluvial system (Fig. 53A). I interpret the silts to be mostly of floodplain origin, though some probably are eolian in origin. Floodplain silt is deposited during spring floods and occasional severe floods during the warm months. Interspersed throughout the silt are fossiliferous clay plugs and sand lenses. I interpret these to be abandoned meander cutoffs and point bars, respectively. These clay plugs could also represent backswamp deposits that developed on the flood plain after

Figure 53 A and B. Diagram showing model of typical meandering fluvial system, characteristic of the Des Lacs and most of the Souris Valley (Blatt, Middleton, and Murray, 1980, p. 634).



Floodplain splay deposits
A
Colluvial deposits
(a)
Lateral accretion
Chute
Channel lag
B
Vertical accretion
Fining upward sequences
Channel fill deposit (clay plug)

the meander was cut off. Depressions on the flood plain would remain filled with water after a flood receded. From this standing body of water, clay would be deposited. Sometimes, these backswamps, because they contained water, would support aquatic life and plants. This would explain the occurrence of fossils and organic material in some of these deposits.

A different sedimentary sequence is present in the Souris Valley between the Burlington and Lake Darling cross sections (Fig. 6). A highly fossiliferous lacustrine lithotype is present in the center of the valley. Coarse alluvial sediment along the valley side interfingers with the clay at the valley center. The presence of the clay indicates a relatively quiet environment rich in aquatic and organic life. I interpret this clay section to represent a swamp/lake environment. Because the clay is continuous throughout the entire section, it is evident that this type of environment was present throughout most of the Holocene. Evidence for such an environment includes peat horizons, aquatic fossils, and possible varves at cross section C-8 (Figs. 6 and 29).

Fossils

Aquatic fossils are common in valley-fill sediments in the Souris and Des Lacs Valleys. These fossils include gastropods, pill clams, and mussels. As stated earlier, comprehensive identification of the fossils was not done, but where easily recognizable, individual fossils were identified to species level.

Within the Souris Valley, two distinct assemblages were identified. In the center of the Souris Valley between the Burlington and Lake Darling cross sections, gastropods are very common in the clays. These are both conispiral and planispiral shaped, with the most common being Valvata tricarinata, a conispiral gastropod. This snail is found mostly in lakes and ponds, but sometimes in small and large streams in North Dakota (Cvancara, 1983). Because of its abundance at the C-8, P.D., and Burlington cross sections, the presence of V. tricarinata provides supporting evidence for a lake or pond environment. The fossils are associated mostly with the organic horizons, but some are disseminated throughout the clay.

The second assemblage of fossils was observed in the remainder of the Souris Valley, including R.R. and R-3 to the north, and C-17 south to C-25. C-11 in the Des Lacs Valley also has this fossil assemblage type. In particular, at the R.R.-3 cross section, numerous pill clams and mussels were recovered. One mussel has been tentatively identified as Anodonta grandis, which prefers mostly small streams, through it has been observed in large streams (Fig. 41). This mussel is still found today in the Souris and Des Lacs Rivers (Cvancara, 1983). The mussels were extracted from an organic horizon composed of numerous stems that were dated at 8840 $\pm$ 100 years B.P.

Numerous pill clams were also recovered from the R.R.-2 cross section (Fig. 42). These have not been identified, but are mentioned because they occur throughout the Souris Valley, with the exception of the area of the central clay plug between Burlington and Lake Darling cross sections. Pill clam fragments, along with some gastropods, were recovered from C-25, C-17, C-23, R.R., and C-11 cross sections. Cvancara (1983) reported that various species of pill clams prefer to live in permanent streams and have also been found in intermittent streams.

A cap-shaped gastropod, Ferrissia rivularis, was recovered from the third core at the C-23 cross section (Fig. 14). This is the only individual of this species identified. In North Dakota, F. rivularis is dominantly found in intermittent and large streams, including the Souris River, and prefers coarse strata to attach itself to. It has been collected from samples inferred to be as old as 8,000 to 4,000 years (Cvancara, 1983).

Most of the planispiral and conispiral gastropods, along with the pill clams, have not been identified. Further work on the fossils would help verify the type of environment present. What the fossils do indicate are two distinct assemblages present in different parts of the Souris valley-fill sediments, reflecting two different environmental settings. Occasional mussel shell fragments were also recovered from the C-8 and P.D. cross sections. These shells were crushed, making identification impossible. It should be noted that these fossils were found in the clay and not in the organic horizons.

Regional Climate During the Holocene

The climate of the Holocene for the upper Midwest has been determined from numerous pollen studies at peat bogs in the surrounding areas. Study sites include Minnesota, South Dakota, and Nebraska (Wright, 1970; Watts and Bright, 1960; Webb, et al., 1983). These studies indicate that in the late Pleistocene to early Holocene, the Midwest was covered by a parkland forest with spruce common that followed the retreating Laurentide ice margin. Spruce pollen was recovered at Seminary, North Dakota and dated at 9900 years B.P. (Wright, 1970). Spruce remains were also recovered from the base of a pond near Tappen, North Dakota and dated at 11,480 years B.P. (Wright, 1970).

It has been shown that for this part of the Midwest, the spruce forest was followed directly by prairie, unlike the eastern plains of Iowa and eastern Minnesota, where a deciduous forest followed the spruce (Webb et al., 1983). At about 10,000 years B.P., prairie was well established in the region and the summers became warmer and drier. The early Holocene was still slightly cooler and wetter than the late Holocene (modern climate) because the wasting Laurentide Ice Sheet in Hudson Bay influenced the climate until about 7500 years ago (Webb, et al., 1983). What probably did trigger the general warming of the Holocene was the introduction of westerly winds from the Pacific, no longer blocked by the Laurentide Ice Sheet. As the westerlies crossed the Rocky Mountains, orographic descent occurred, warming and drying the air. This warm dry air initiated the dominance of prairie vegetation in the Midwest (Bryson et al., 1970; Webb et al., 1983).

From 8,000 years B.P. to about 4,000 years B.P., the area was warm and dry, with drought common during the summer. The vegetation was dominantly semi-arid grassland. This time is referred to as the Hypsithermal (Wright, 1978; Webb et al., 1983). Work in North Dakota indicates that this was a time of eolian deposition and rapid erosion on steep slopes by infrequent, intense rainfall (Clayton et al., 1976).

From 4,000 years B.P. to today, a cooler and more moist climate dominated the region with periods of dry, warm intervals similar to the dust bowl conditions of the 1930's. These conditions are indicated by the accumulation of peat in bogs in Minnesota, especially on the Glacial Lake Agassiz plain (Wright, 1968; Webb et al., 1983). Since that time, slope stabilization has occurred as a result of more abundant vegetation.

Local Climate During the Holocene

In North Dakota, Clayton and others (1976) recognized four members of the Oahe Formation (Fig. 49). The Aggie Brown Member is defined as late Wisconsinan and early Holocene in age. At its type section, the Aggie Brown Member is a dark paleosol suggesting a climate more moist than the present (Clayton et al., 1976). This indicates that the Aggie Brown formed when vegetation was abundant enough to stabilize steep slopes, allowing an organic horizon or paleosol to form. In North Dakota, the paleosol is referred to as the Leonard Paleosol. It is likely that this relatively cool, moist climate was sufficent to allow vegetation to stabilize the steep walls of the Souris and Des Lacs Valleys. Peat accumulated in shallow pond and swamp environments while shrubs grew along the river banks farther north, and below the Souris and Des Lacs River confluence.

During the 8,500 to 4,000 year-period of the middle Holocene, a warming trend occurred and the region became drier and warmer. At this time, the area was covered by semi-arid grassland vegetation with drought common during the summer (Clayton, et al., 1976). In North Dakota this is represented by deposition of the Pick City Member of the Oahe Formation, which is mostly eolian silt (Fig. 49) in the area where it was originally described. In the Souris and Des Lacs Valleys, little vegetation was available to stabilize the slopes and, consequently, more alluvial-fan deposition occurred from the entering ephemeral streams. Work by Hamilton (1967) in the North Dakota Badlands shows that during the 1930's drought, large amounts of sediment were washed from the steep valley sides. Probably some eolian deposition occurred in the valleys also, but it should be noted that the Pick City Member formed only on gentle slopes where eolian deposition tended to occur

(Clayton, et al., 1976). During this period, the Hypsithermal, the thick section of sediment above the first organic horizon in the Souris and Des Lacs Valleys was deposited. In addition, the higher gradient Des Lacs River may have dammed the Souris River with the deposition of more alluvium and caused a deeper lake to form. This deeper lake may have become a refuge for aquatic life.

The Hypsithermal was followed by a moist, cooler climate during the late Holocene, fluctuating with warm, dry periods. Clayton et al. (1976) defined the sediment deposited during this period as the Riverdale Member of the Oahe Formation (Fig. 49), which, based on its characteristics, formed in a climate much like today's. The two upper organic horizons suggest periods of cool, moist climate with vegetation stabilizing the Souris and Des Lacs Valley sides. The intervals of low organic-material deposition presumably represent a warmer and drier climate much like the 1930s. Although no dates are available, these organic horizons may be correlatives of the Lower and Upper Riverdale Members of the Oahe Formation.

GROUNDWATER SIGNIFICANCE

The stratigraphic model formulated in this study suggests that the coarser alluvial-fan sediments along the valley sides are favorable locations for well installation. In the section of the Souris Valley characterized by the lacustrine lithotype, little to no water production would be possible if a well were drilled into the valley center, but a good well could be located along the valley side in the coarse alluvium (Fig. 54).

This study also has implications regarding buried valley-aquifers in North Dakota. Aquifers in these buried valleys are common and very important in North Dakota for water supply. Figure 55 shows the location of the more important buried-valley aquifers in the state. The trend of the Spiritwood and New Rockford Aquifers is similar to the trend of the Souris and Des Lacs Valleys. This indicates that these buried valleys probably formed along ice margins.

Buried valleys have several features that are comparable to glacial-lake spillways. The most noticeable is the similarity of cross sections of buried valleys and surficial spillways. Figure 56 shows a typical cross section of the Souris Valley and a cross section of the New Rockford buried-valley aquifer. Note that the shape and dimensions of both valleys are similar and both are deeply incised into bedrock. These features suggest that the New Rockford Aquifer originated as a glacial-lake spillway

Figure 54. Diagram showing good and poor locations for water wells in the Souris Valley.

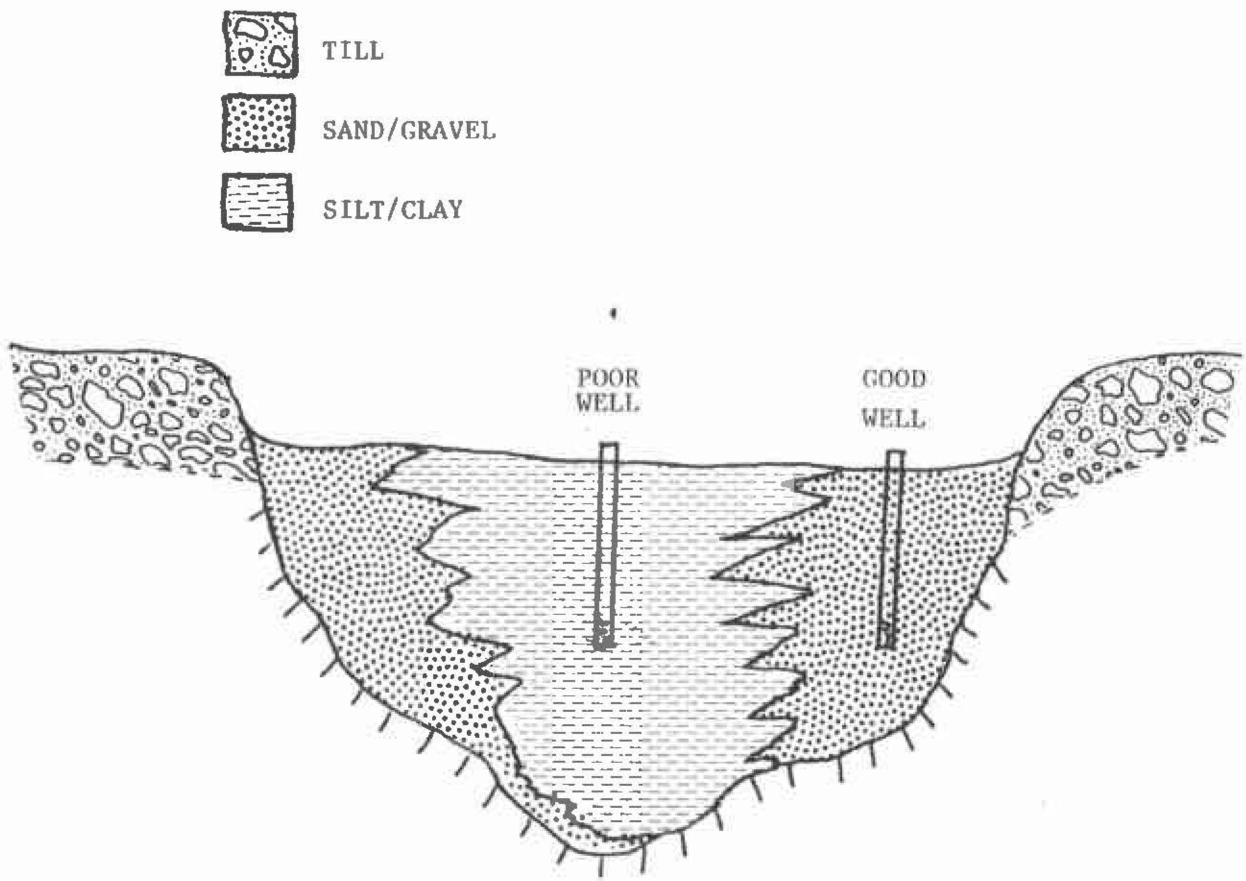

TILL
SAND/GRAVEL
SILT/CLAY
POOR WELL
GOOD WELL

Figure 55. Location of several important buried-valley aquifers in North Dakota (Kehew and Boettger, 1986, in press).

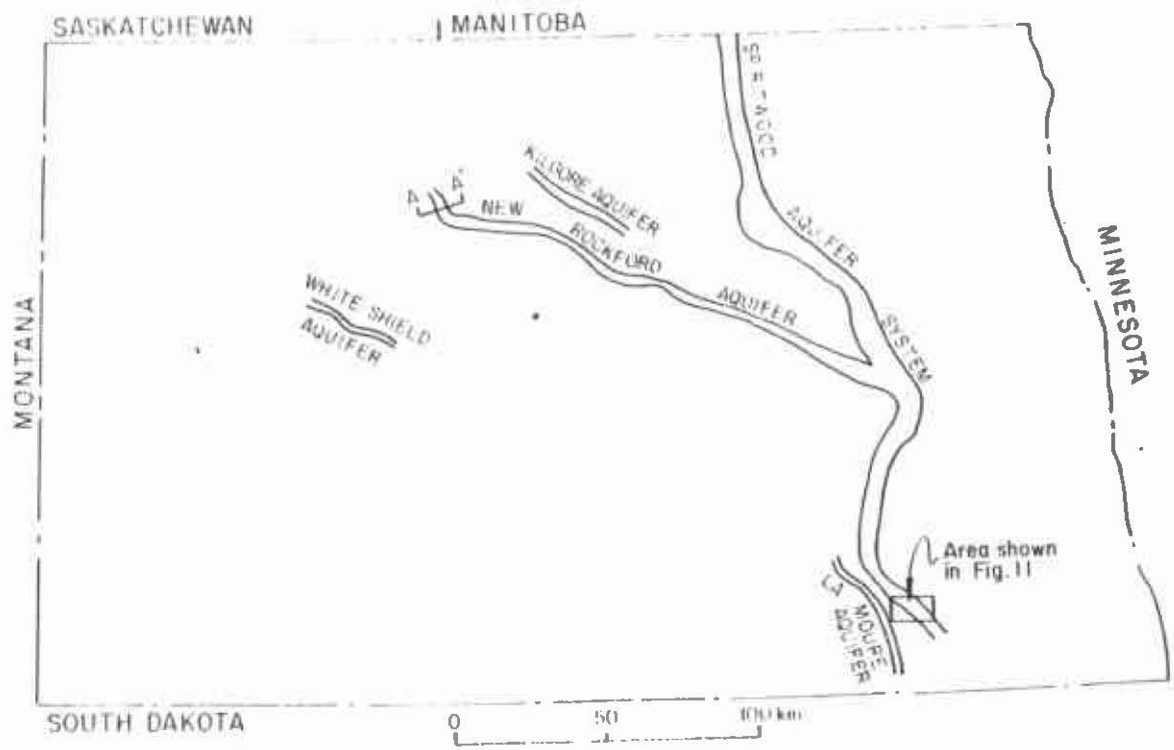
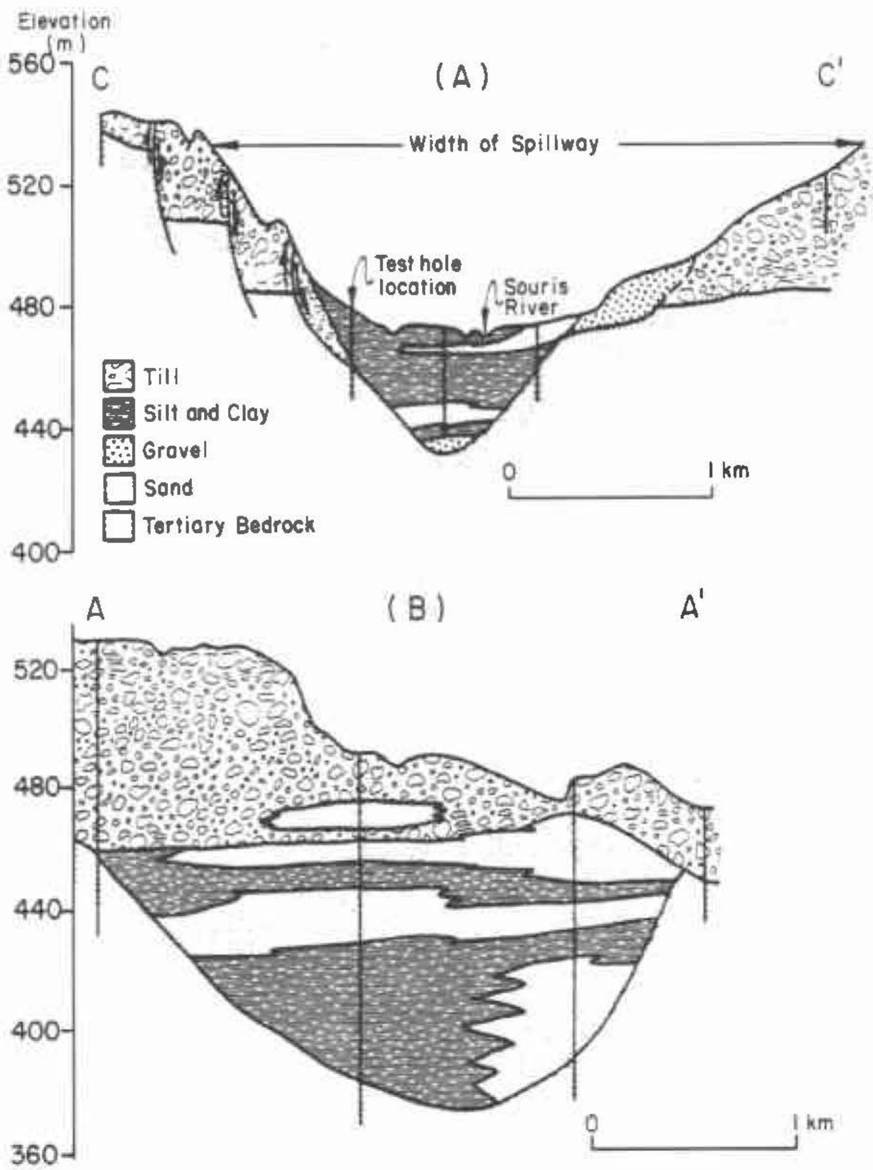

SASKATCHEWAN
MANITOBA
MINNESOTA
MONTANA
SOUTH DAKOTA
KILLDRE AQUIFER
NEW ROCKFORD AQUIFER
WHITE SHIELD AQUIFER
AQUIFER
SYSTEM
LA MOURE AQUIFER
Area shown in Fig. 11
A
A'
0
50
100 km

Figure 56. Typical cross section of the Souris Valley (A) near Minot, ND compared to the New Rockford buried-valley aquifer (B). See Fig. 54 for location (Kehew and Boettger, 1986, in press).



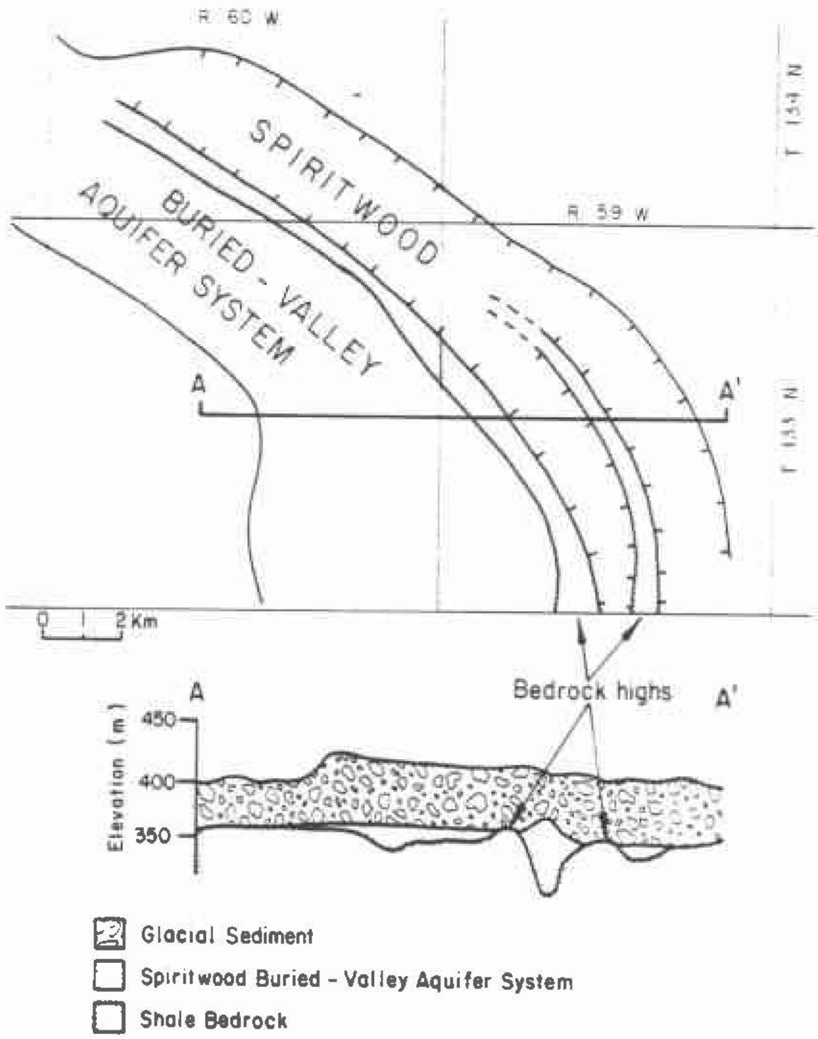
Elevation
(m)
560
520
480
440
400
C
(A)
C'
Width of Spillway
Test hole location
Souris River
Till
Silt and Clay
Gravel
Sand
Tertiary Bedrock
0
1 km
A
(B)
A'
520
480
440
400
360
0
1 km

during an earlier deglaciation of North Dakota and then filled with sediment of nonglacial origin, deposited during interglacial periods. If these valleys were occupied by slow, meandering rivers such as the Souris and Des Lacs Rivers, fine-grained fluvial and lacustrine material would be deposited with probable alluvial-fan deposits on the valley sides from tributary streams or sheetwash. In this situation, the best aquifers would lie along the valley side (Kehew and Boettger, 1986, in press).

The highly productive Spiritwood Aquifer system (Fig. 57) suggests that outwash may be present in the sequence. The partially filled spillway could have been a glacial meltwater channel during retreat after the glacier readvanced, filling the spillway with coarse-grained outwash sediment that would be a good aquifer (Kehew and Boettger, 1986, in press).

Buried-valley aquifers are important sources for groundwater in North Dakota and the midcontinent region. As more detailed studies of the lithology and stratigraphy of valley-fill sediments in buried valleys are made using surficial spillways as examples, a better understanding of the distribution and hydraulic properties of buried-valley aquifers will be possible.

Figure 57. The Spiritwood Aquifer system, location shown on Fig. 55 (Kehew and Boettger, 1986, in press).



CROSS SECTION A - A'

SUMMARY AND CONCLUSIONS

When the Souris Valley was being eroded during the last glacial-lake outburst flood, a headward migrating nickpoint formed and moved up the valley to its present location (Fig. 47). When the flood subsided, an aggrading, meandering Souris River reoccupied the valley. Initially, the valley sides were steep and slumping occurred into the valley.

Numerous ephemeral streams entered the Souris and Des Lacs Valleys and deposited coarse alluvial sediment along the valley sides that interfingered with finer material in the valley centers. Both rivers probably reworked the coarser material in the valley centers.

The Des Lacs River had a higher gradient and deposited an alluvial-fan at its confluence with the Souris Valley that was sufficient to dam the Souris River periodically. These conditions produced two distinct types of lithologies, fossil assemblages, and organic material in the Souris Valley valley-fill sediments. From the confluence with the Des Lacs valley north to the vicinity of the Lake Darling cross section, a lacustrine lithotype is present with three organic horizons. The lowest organic zone contains peat with the other two horizons composed of peat with rootlets common. Conispiral and planispiral gastropods are the most abundant fossils; one species present is known to prefer a pond/lake environment. The remainder of the Souris Valley and the Des Lacs Valley consists of a fluvial lithotype composed of silt with lenses of fossiliferous clay and sand. This lithotype is typical of a meandering fluvial system. Fossils in this lithotype include pill clams and mussels, with one identified gastropod that prefers streams. The organics are mostly woody stems with some rootlets.

Two dates on the lower organic horizon correlate with the Aggie Brown Member of the Oahe Formation, which is identified as having formed during a cool, moist climate during the early Holocene. Vegetation stabilized the sides of the Souris and Des Lacs Valleys and a thick organic soil formed. This was followed by a warming trend during the middle Holocene when vegetation became sparse and slope erosion was accelerated, along with rapid aggradation in the valleys. Slope erosion was associated with ephemeral streams dissecting the valley sides, which deposited alluvial-fans on the valley floor. This period is referred to as the Hypsithermal and is represented in the Souris Valley as a thick sequence of sediment above the lowest organic horizon.

The Hypsithermal was followed by a cool and more moist climate which enabled vegetation to again stablize the slopes. This period fluctuated with warm, dry periods of intense slope erosion, similar to 1930s. The two upper organic horizons probably represent cool periods during the late Holocene. These zones can be correlated with the Riverdale Member of the Oahe Formation.

The Souris and Des Lacs Valleys provide a unique opportunity to study the entire Holocene section in north-central North Dakota. The application of this work to buried valley aquifers will lead to a better understanding of the hydrogeology of these important sources of groundwater supply.

The primary conclusions of the study are:

1.) The sediments of both the Souris and Des Lacs Valleys were deposited by a meandering fluvial system with interfingering alluvial-fan deposits along the valley sides. A swamp/pond environment developed in a section of the Souris Valley due to damming by alluvial-fan sediments of the higher gradient Des Lacs River.

2.) C-14 dates of the lower organic horizon correlate with the Aggie Brown Member of the Oahe Formation of early Holocene age.

3.) Environmental setting indicates a cool, moist climate during the early Holocene, followed by a hot, dry climate in the middle Holocene, ending with a climate much like the modern climate.

4.) Coarse sediment at the base of some of the cross sections is interpreted to be till, redeposited by slumping of the valley sides after the last glacial-lake outburst flood.

Several aspects of this work should be studied further in order to better understand Holocene geologic history in this area. Pollen work on the peat material in the organic horizons could give a more detailed indication of the type of vegetation present. This, in turn, would help refine the interpretation of the environmental conditions. In addition, further study and identification of fossils would contribute towards an environmental reconstruction, Lastly, the thick sequence of woody stems at R.R.-2 core should be examined for fossil beetle assemblages and pollen.

APPENDICES

APPENDIX A

Core Descriptions

The samples collected by the N.D.G.S. drill rig will have their storage box number identified. The USACE will have which jar the sample is stored in identified.

C-25-1

Depth in Metres	Box	Descriptions
0-0.9	1	Silt; 2.5Y 4/2 dark greyish brown, 2.5Y 3/2 dark greyish brown (wet), rootlets, caliche.
0.9-1.5	2	Silt; medium, 10YR 3/1 very dark grey, 10YR, 2/1 black (wet), large cobbles scatterd throughout.
1.5-3.9	2-4	Silt; coarse, 5Y 4/3 olive, 5Y 4/2 dark olive grey (wet), pebbles, stiff, moist.
3.9-4.5	5	Silt; coarse, 5Y 8/2 white, 5Y 7/3 pale yellow (wet), oxide staining, gravel at base, moist.

C-25-2

Depth in Metres	Box	Descriptions
0-.46	1	Silt; 10YR 4/1 dark grey, 10YR 3/1 very dark grey (wet), rootlets, some pebbles.
.46-.9	1	Sand; fine, 5Y 6/6 olive yellow, 5Y 4/2 olive grey (wet), well sorted.
.9-1.5	2	Sand; fine, color same.
1.5-2.1	2-3	Sand; fine, color same, coarse sand at base.
2.1-2.4	3	Sand; fine, color same, rootlets, clay at base.
2.4-3.0	4	Sand; fine, color same.
3.0-3.9	5	Clay; 2.5Y 6/2 light brownish grey, 2.5Y 5/2 dark greyish brown (wet), moist, stiff, oxide stain.
3.9-4.6	5-6	Clay; same color, moist, plastic.

Depth in Metres	Box	Descriptions
4.6-5.1	6	Clay; same as above.
5.1-5.4	7	Clay; same as above, scattered plant stems.
5.4-6.0	7	Clay; same color, silt at base, organic material.
6.0-6.9	8	Silt; medium, 5Y 6/1 grey, 5Y 3/1 very dark grey (wet), organics, moist.

C-25-3

Depth in Metres	Box	Descriptions
0-1.5	1-2	Silt; 5Y 3/2 dark olive grey, 5Y 2.5/1 black (wet), rootlets, well sorted, massive.
1.5-5.16	2-5	Silt; medium, 5Y 6/4 pale olive, 5Y 4/4 olive (wet), organics in layers, some pebbles, occasional layer of gravel.
5.16-6.69	5-7	Silt; coarse, 5Y 6/3 pale olive, 5Y 5/3 olive (wet), scattered pebbles, oxide staining, moist.
6.69-8.2	7-8	Sand; very fine, 5Y 6/1 grey, 5Y 4/2 olive grey (wet), moist massive.

C-25-4

Depth in Metres	Box	Descriptions
0-1.5	1	Silt; 5Y 5/3 olive, 5Y 3/2 dark olive grey, rootlets, dry, stiff.
1.5-4.6	2-5	Silt; medium, 5Y 6/6 olive yellow, 5Y 4/3 olive (wet), organics, shell fragments, well sorted, clay lenses present.

Depth in Metres	Box	Descriptions
4.6- 5.4	6	Sand; medium, 5Y 6/3 pale olive, 5Y 4/3 olive (wet), well sorted, gastropods and pill clams, moist.

C-23-1

Depth in Metres	Box	Descriptions
0-1.5	1	Silt; 2.5Y 4/2 dark greyish brown, rootlets, dry, stiff.
1.5-3.9	2-3	Silt; very fine, 2.5Y 5/6 light olive brown, gravel at top, rootlets at base, moist.
3.9-5.2	3-5	Sand; medium, 2.5Y 6/2 light brownish grey, 2.5Y 4/2 dark greyish brown (wet), moist, rootlets, coarse sand at base.
5.2-6.7	6-7	Sand; very fine, 10YR 7/1 light grey, 2.5Y 6/2 light brownish grey (wet), sand pods, moist, plastic.
6.7-9.1	7-10	Clay; 10YR 6/1 grey, 10YR 4/1 dark grey (wet), organic material at base, pods of silt, moist.

C-23-2

Depth in Metres	Box	Descriptions
0-1.5	1-2	Silt; 2.5Y 3/2 very dark greyish brown, 10YR 2/1 black (wet), dry, rootlets, gravel at base, caliche.
1.5-4.6	2-4	Silt; coarse, 5Y 6/6 olive grey, 5Y 5/4 olive, scattered pebbles, lenses of gravel, scattered rootlets.

Depth in Metres	Box	Descriptions
4.6-8.2	5-8	Sand; coarse, 5Y 6/6 olive yellow, 5Y 4/4 olive (wet), pebbles throughout, moist, massive, clay lens at base.
8.2-9.0	8-9	Sand; very fine, color same, organic material, moist, clay lens at base.
9-10	10-11	Silt, very fine, 5Y 7/6 yellow, 5Y 6/8 olive yellow, moist, pebbles at base, plastic.

C-23-3

Depth in Metres	Box	Descriptions
0-0.9	1	Silt; 2.5Y 4/2 dark greyish brown, 2.5Y 3/2 very dark greyish brown (wet), rootlets, dry.
0.9-5.2	2-6	Silt; medium, 2.5Y 6/4 light yellow brown, 2.5Y 4/4 olive brown (wet), well sorted, moist, organic material with shell fragments at base, parallel laminations.
5.2-6.1	6	Silt; coarse, color same, moist, shell fragments, organic material, massive.

C-17-1

Depth in Metres	Box	Descriptions
0-0.6	1	Sand; fine, 5Y 6/6 olive yellow, 5Y 5/4 olive (wet), rootlets, dry, well sorted.
0.6-2.1	1	Gravel; color same, coarse, poorly sorted, subrounded cobbles.

Depth in Metres	Box	Descriptions
2.1-3.6	2	Sand; very fine, color same, scattered pebbles, moist, well sorted, coarse sand at base.
3.6-4.5		No recovery.
4.5-5.7	2-3	Silt; medium, 5Y 6/4 pale olive, 5Y 5/4 olive (wet), moist, plastic.
5.7-6.0	4	Sand; medium, color same, moist.

C-17-2

Depth in Metres	Box	Description
0-0.6	1	Silt; 5Y 5/3 olive, 5Y 3/2, dark olive gray (wet), rootlets, dry.
0.6-0.9	1	Sand; medium, 5Y 6/6 olive yellow, 5Y 5/4 olive (wet), pebbles at base.
0.9-2.1	2-3	Sand; very fine, color same.
2.1-2.4		No recovery.
2.4-3.6	4	Sand; very coarse, color same, subangular pebbles, organic material at base.

C-17-3

Depth in Metres	Box	Descriptions
0-0.9	1-2	Silt; fine, 5Y 5/2 olive grey, 5Y 3/2 dark olive grey (wet), rootlets, dry, caliche.
0.9-1.5		No recovery.
1.5-2.7	3	Silt; medium, 5Y 7/1 light grey, 5Y 5/1 grey (wet), moist.
2.7-3.6	4	Silt; coarse, 5Y 6/6 olive yellow, 5Y 4/4 olive (wet), moist.

C-17-4

Depth in Metres	Box	Descriptions
0-2.1	1-2	Sand; very fine, 5Y 4/1 dark grey, 5Y 2.5/1 black (wet), rootlets at top, dry.
2.1-3.0	3	Silt; medium, 5Y 7/4 pale yellow, 5Y 4/3 olive (wet), dry.
3.0-5.1	4-5	Sand; fine, 5Y 6/6 olive yellow, 5Y 4/3 olive (wet), organic material present, moist, plastic.
5.1-6.0	6	Clay; 5Y 5/1 grey, 5Y 3/1 very dark grey (wet), moist.
6.0-6.7		No recovery.
6.7-7.0	7	Sand; medium, color same, mussel shell at bottom in clay.

P.D.-1

Depth in Metres	Box	Descriptions
0-1.5	1-2	Gravel; coarse, 5Y 7/4 pale yellow, 5Y 4/3 olive (wet), poorly sorted.
1.5-2.1	2	Clay; 5Y 5/2 olive grey, 5Y 4/3 olive yellow (wet), gastropods, moist, plastic, gravel at base.
2.1-3.0	3	Gravel; 5Y 7/6 yellow, 5y 6/6 olive yellow (wet), moist.
3.0-5.4	3-5	Sand; medium, 5Y 6/1 grey, 5Y 4/1 dark grey (wet), moist, organic material including wood and fossils at base.

Depth in Metres	Box	Descriptions
5.4-6.7	6	Silt; fine, color same, organic material, mussel shell, moist.
6.7-7.0		No recovery.
7.0-7.6	7	Sand; fine, 5Y 6/2 light olive grey, 5Y 4/2 olive grey (wet), scattered pebbles, moist, some organic material.

P.D.-2

Depth in Metres	Box	Descriptions
0-3.0	1-4	Clay; 5Y 6/2 olive grey, 5Y 2.5/1 black (wet), moist, some organics and gastropod shells.
3.0-6.0	4-8	Clay; 5Y 5/1 grey, 5Y 4/1, dark grey (wet), stems and other organic material, mussel and gastropod shells present, moist, stiff.
6.0-9.1	9-12	Clay; same as above.
9.1-12.1	12-16	Clay; 2mm lenses of silt (varving), shell fragments, color same.
12.1-15.2	12-21	Clay; 5Y 6/3 pale olive, 5Y 4/2 olive grey (wet), mussel and gastropod shells, thin sand lens, occasional silt lens.

P.D.-3

Depth in Metres	Box	Descriptions
0-2.4	1-3	Silt; very fine, 5Y 5/1 grey, 5Y 5/3 very dark grey (wet), moist near base.
2.4-3.6	4-5	Sand; medium, 5Y 7/1 light grey, 5Y 5/1 grey (wet), moist, organic material.

Depth in Metres	Box	Descriptions
3.6-4.0	5	Gravel; color same, moist, subangular pebbles.

C-8-1

Depth in Metres	Box	Descriptions
0-2.4	1-3	Silt; medium, 5Y 4/1 dark grey, 5Y 3/1 very dark grey (wet), dry at top and moist at base.
2.4-3.0	3	Silt; fine, color same, moist, stiff.
3.0-3.9	4	Silt; coarse, color same, moist, some pebbles.

C-8-2

Depth in Metres	Box	Descriptions
0-3.0	1-3	Clay; 5Y 6/1 grey, 5Y 4/1 grey (wet), organics and fossils present.
3.0-6.0	4-6	Clay; 5Y 5/2 olive grey, 5Y 4/2 olive grey (wet), gastropods and mussel fragments.
6.0-9.1	6-10	Clay; color same, gastropods, organic layer.
9.1-12.1	10-13	Clay; color same, organic material, mussel fragments, gastropods.
12.1-15.0	14-17	Clay; same as above.
15.0-24.0	17-29	Clay; same as above, base highly organic and fossiliferous.

C-8-3

Depth in Metres	Box	Descriptions
0-3.0	1-5	Clay; 5Y 5/1 grey, 5Y 4/1 dark grey (wet), dry, stiff.
3.0-3.9	5-6	Silt, very fine, 5Y 5/2 olive grey, 5Y 3/2 dark olive grey (wet), gastropods, organic material, dry.
3.9-5.1	6-7	Silt; medium, 5Y 5/2 grey, 5Y 4/1 dark grey (wet), moist, clay pods.
5.1-5.4	8	Sand; medium, color same, moist.

C-8-4

Depth in Metres	Box	Descriptions
0-1.5	1-2	Clay; 5Y 4/1 dark grey, 5Y 3/2 dark olive grey (wet), rootlets, caliche, dry.
1.5-2.1	3	Gravel; 5Y 6/6 olive yellow, 5Y 5/4 olive (wet), moist.
2.1-3.0	4	Silt; coarse, color same, moist, some pebbles.
3.0-3.6	5	Gravel; color same, moist.
3.6-3.9	5	Silt; very fine, color same, moist, pebbles.

R-3-1

Depth in Metres	Box	Descriptions
0-0.9	1	Silt; 5Y 3/2 dark olive grey, 5Y 5/1 black (wet), caliche, dry.
0.9-2.1	2	Gravel; 5Y 6/6 olive yellow, 5Y 5/4 olive (wet), dry, caliche, angular pebbles.

Depth in Metres	Box	Descriptions
2.1-2.4	3	Silt; coarse, color same, moist.
2.4-3.6	3-4	Silt; fine, color same, moist, gravel lens at base.

R-3-2

Depth in Metres	Box	Descriptions
0-2.1	1-2	Clay; 5Y 6/3 pale olive, 5Y 4/3 olive (wet), rootlets, caliche.
2.1-3.6	2-3	Silt; medium, color same, organic material, moist.
3.6-5.1	4	Silt; fine, 5Y 6/2 light olive grey, 5Y 5/3 olive (wet), gastropods, moist, oxide stains, stem at base.

R-3-3

Depth in Metres	Box	Descriptions
0-0.9	1	Silt; 5Y 6/1 grey, 5Y 4/1 dark grey (wet), rootlets, dry, oxide mottle.
0.9-3.0	2-3	Clay; 5Y 6/1 grey, 5Y 4/1 dark grey (wet), organic material, gastropod fragments, moist.
3.0-5.4	3-6	Silt; fine, color same, organic material, shell fragments, moist.

R-3-4

Depth in Metres	Box	Descriptions
0-2.4	1-3	Silt; medium, 2.5Y N4/ dark grey, 2.5Y N2/ black (wet), rootlets, dry, scattered pebbles, stems at base.

Depth in Metres	Box	Descriptions
2.4-3.6	3-5	Silt; very fine, color same, moist.
3.6-7.0	5-8	Silt; medium, color same, pebbles throughout, black streaks, till(?).

R.R-1

Depth in Metres	Box	Descriptions
0-2.1	1-2	Silt; fine, 5Y 4/1 dark grey, 5Y 3/1 very dark grey (wet), rootlets, caliche, dry.
2.1-5.2	3-6	Silt; medium, color same, gastropods, oxide stains, moist, few rootlets at base.
5.2-6.7	6-7	Silt; very fine, 5Y 6/6 olive yellow, 5Y 5/6 olive (wet), oxide stains, moist.

R.R.-2

Depth in Metres	Box	Descriptions
0-4.6	1-4	Silt; medium, 5Y 5/3 olive, 5Y 4/3 olive (wet), moist, organic material, shell fragments at base.
4.6-7.0	5-7	Silt; medium, color same, numerous mussels, pill clams, and gastropods, wood and stems, moist, C-14 date of 8840 ± 100 years B.P.
7.0-8.2	8	Silt; fine, 5Y 6/3 pale olive, 5Y 5/3 olive (wet), moist, shell fragments.
8.2-8.5	9	Silt; coarse, color same, shell fragments, moist.

R.R.-3

Depth in Metres	Box	Descriptions
0-1.5	1-2	Silt; medium, 5Y 6/1 grey, 5Y 3/1 very dark grey (wet), oxide mottled, dry.
1.5-3.0	2-3	Clay; 5Y 5/1 grey, 5Y 4/1 dark grey (wet), dry, shell fragments.
3.0-5.4	4-7	Silt; coarse, 5Y 6/6 olive yellow, 5Y 5/6 olive (wet), moist.

R.R.-4

Depth in Metres	Box	Descriptions
0-1.2	1-2	Gravel; 5Y 7/6 yellow, 5Y 5/3 olive (wet), subangular pebbles.
1.2-2.7	2-3	Silt; medium, 5Y 6/8 olive yellow, 5Y 5/4 olive (wet), oxide stains, angular pebbles scattered throughout.
2.7-4.2	4-5	Sand; very fine, 5Y 6/4 pale yellow, 5Y 5/4 olive (wet), moist, oxide stains at base.
4.2-12.8	6-14	Till; clay-silt-sand matrix with pebbles scattered throughout.

C-11-1

Depth in Metres	Box	Descriptions
0-1.5	1-2	Silt; very fine, 5Y 5/3 olive, 5Y 4/2 olive grey (wet), dry, rootlets.
1.5-3.9	2-4	Silt; coarse, 5Y 6/3 pale olive, 5Y 5/4 olive (wet), moist, some organic material.

Depth in Metres	Box	Descriptions
3.9-5.1	5	Sand; medium, color same, some pebbles, organic layer, shell fragments, piece of wood.

C-11-2

Depth in Metres	Box	Descriptions
0-0.9	1	Silt; 5Y 6/3 pale olive, 5Y 4/3 olive (wet), dry, rootlets.
0.9- 3.6	2-4	Sand; fine, color same, scattered shell fragments, moist, oxide stains.
3.6-3.9		No recovery.
3.9-4.5	4	Sand; fine, color same, wood fragment, moist, shell fragments.
4.5-5.1		No recovery.
5.1-5.4	4	Sand; medium, color same, moist, shell fragments, some organic material.

C-11-3

Depth in Metres	Box	Descriptions
0-3.6	1-4	Sand; very fine, 5Y 6/3 pale olive, 5Y 4/3 olive (wet), rootlets, shell fragments, moist.
3.6-4.5	4-5	Sand; fine, color same, shell fragments, moist.
4.5-5.1	5-6	Clay; color same, moist, some gastropods.

C-11-4

Depth in Metres	Box	Description
0-2.1	1-2	Silt; medium, 5Y 6/4 pale olive, 5Y 5/4 olive (wet), dry, pebbles.
2.1-3.6	3-4	Silt; very fine, color same, moist.
3.6-6.7		No recovery.
6.7-7.0	5	Silt, medium, same color, angular pebbles, moist.
7.0-8.2		No recovery.
8.2-8.5	6	Sand; medium, color same, moist, angular pebbles.

Highway 5 74-50

Depth in Metres	Jar	Description
0-3.1	2	Clay; 5Y 6/1 grey, 5Y 4/1 dark grey (wet), organic material, oxide stains.
3.1-10.0	8	Silt; fine, 5Y 6/2 light olive, 5Y 4/2 olive grey (wet).
10.0-10.9	14	Sand; fine, 5Y 6/3 pale olive, 5Yy 4/3 olive (wet), oxide stains, shell fragments.
10.9-21.0	19	Silt; fine, same color, thin oxidized rootlets.
21.0-22.0	23	Sand; medium, 5Y 6/2 light olive grey, 5Y 5/3 olive (wet).
22.0-23.0	26	Sand; very coarse, 5Y 4/1 olive grey (wet), subrounded pebbles, still wet.

Highway 5 74-44

Depth in Metres	Jar	Descriptions
0-3.1	4	Clay; 5Y 6/1 grey, 5Y 4/1 dark grey (wet), oxidized rootlets.
3.1-7.3	8	Silt; very fine, 5Y 6/3 pale olive, 5Y 5/3 olive (wet).
7.3-9.4	11	Sand; very fine, 5Y 6/1 grey, 5Y 5/2 olive grey (wet), gastropod fragments, small amount of organic mater.
9.4-10.0	-	Silt.
10.0-17.6	21	Clay; 5Y 6/2 light olive grey, 5Y 4/2 olive grey (wet), some oxide staining.
17.6-18.0	24	Silt; very fine, 5Y 6/6 olive yellow, 5Y 5/4 olive (wet).

Depth in Metres	Jar	Descriptions
18.0-21.3	-	Sand.
21.3-24.0	-	Gravel.

Soo Line 76-77

Depth in Metres	Jar	Descriptions
0-3.1	-	Clay.
3.1-11.0	4	Silt; very fine, 5Y 6/3 pale olive, 5Y 4/3 olive (wet), wood fragments and organic material, numerous shell fragments, oxide staining.
11.0-18.0	14	Clay; 5Y 5/2 olive grey, 5Y 4/2 olive grey (wet), some shell fragments.
18.0-18.5	17	Silt; very fine, 5Y 6/3 pale yellow, 5Y 5/3 olive (wet).

Soo Line 76-76

Depth in Metres	Jar	Descriptions
0-4.5	-	Clay
4.5-5.0	2	Silt; very fine, 5Y 6/3 pale olive, 5Y 5/4 olive (wet).
5.0-10.6	6	Silt; fine, color same, wood wood, shell fragments.
10.6-17.0	7,11	Clay; color same.
17.0-18.0	15	Silt; fine, 5Y 6/3 pale olive, 5Y 5/3 olive (wet).

Soo Line 74-75

Depth in Metres	Jar	Descriptions
0-3.0	-	Clay

Depth in Metres	Jar	Descriptions
3.0-4.8	3	Silt; very fine, 5Y 6/3 pale olive, 5Y 4/2 olive grey (wet), few shell fragments.
4.8-12.0	5	Clay; 5Y 5/1 grey, 5Y 4/1 dark grey (wet), shell fragments, pieces of wood.
12.0-17.0	9	Silt; fine, color same, some rootlets.
17.0-17.3	14	Silt; coarse, 5Y 6/3 olive yellow, 5Y 5/2 olive grey (wet).

Soo Line 76-98

Depth in Metres	Jar	Descriptions
0-4.5	-	Clay.
4.5-7.6	-	No data.
7.6-10.0	-	Sand.
10.0-15.0	-	No data.
15.0-18.0	-	Sand.

Lake Darling 76-101

Depth in Metres	Jar	Descriptions
0-3.5	-	Clay; shell fragments, rootlets.
3.9-4.4	-	Sand; rootlets.

Lake Darling 76-98

Depth in Metres	Jar	Descriptions
0-6.0	-	Clay.
6.0-12.0	6	Sand; very fine, 5Y 5/1 grey, 5Y 4/1 dark grey (wet), rootlets.
12.0-15.0	12	Silt; very fine, color same.
15.0-17.0	18	Sand; coarse, 5Y 5/4 olive, 5Y 4/4 olive (wet).

Lake Darling 76-93

Depth in Metres	Jar	Descriptions
0-3.0	4	Clay; 5Y 5/4 olive, 5Y
3.0-6.0	-	Sand; coarse, color same, scattered pebbles.
6.0-7.6	-	Clay.
7.6-8.8	9	Silt; medium 5Y 6/3 pale olive, 5Y 4/3 olive (wet), wood fragments.

Lake Darling 76-95

Depth in Metres	Jar	Descriptions
0-1.5	-	Sand.
1.5-8.8	3	Clay; 5Y 4/1 dark grey, 5Y 3/1 very dark grey (wet), scattered pebbles.
8.8-9.4	10	Silt; coarse, 5Y 5/1 grey, 5Y 4/1 dark grey (wet), rootlets.
9.4-12.0	14	Sand; fine, color same.

Lake Darling 76-106

Depth in Metres	Jar	Descriptions
0-7.6	-	Clay
7.6-9.1	-	Silt
9.1-12.0	-	Clay
12.0-18.0	13	Sand; fine, 5Y 6/3 pale olive, 5Y 4/3 olive (wet).

Lake Darling 76-96

Depth in Metres	Jar	Descriptions
0-9.4	-	Silt; organic layer.
9.4-15.0	-	Sand.

Lake Darling 74-52

Depth in Metres	Jar	Descriptions
0-3.0	-	Clay.
3.0-6.0	-	Sand.
6.0-48.0	-	Clay; two organic horizons, silt lenses, sand lense at base.

Burlington 74-60

Depth in Metres	Jar	Descriptions
0-6.0	6	Silt; medium, 5Y 6/3 pale olive, 5Y 5/3 olive (wet).
6.0-15.2	14	Sand; coarse, color same, scattered subrounded pebbles.
15.2-17.9	-	Silt.

Depth in Metres	Jar	Descriptions
17.9-29.0	27	Sand; fine to medium,5Y 6/1 gray, 5Y 4/1 dark grey (wet), oxidized stems and wood imprint on sediment.
29.0-32.0	28	Silt; fine 5Y 6/3 pale olive, 5Y 5/3 olive (wet).
32.0-33.5	36	Clay; color same.
33.5-35.0	-	Silt.
35.0-36.5	-	Clay.

Burlington 74-55

Depth in Metres	Jar	Descriptions
0-1.5	6	Silt; coarse, 5Y6/6 dark olive grey, 5Y 5/3 olive (wet), scattered rootlets.
1.5-10.0	10	Sand; medium, color same, oxide stains.
10.0-16.0	17	Silt; coarse, 5Y 7/1 light grey, 5Y 6/1 grey (wet).

Burlington 74-26

Depth in Metres	Jar	Descriptions
0-5.5	4	Clay; 5Y 3/1 very dark grey, 5Y 2.5/1 black (wet), some scattered shell fragments.
5.5-9.1	6	Silt; very fine, 5Y 5/4 olive, 5Y 4/4 olive (wet), organic material and rootlets.

Depth in Metres	Jar	Descriptions
9.1-33.0	16,32	Clay; 5Y 3/2 olive grey, 5Y 4/3 olive (wet), two organic horizons, numerous gastropods with organic material.

Burlington 74-24

Depth in Metres	Jar	Descriptions
0-6.0	5	Clay; 5Y 5/3 olive, 5Y 4/3 olive (wet).
6.0-7.0	-	Silt.
7.0-11.0	-	Clay.
11.0-12.0	9	Sand; fine, 5Y 6/6 olive yellow, 5Y 4/4 olive (wet), rootlets, gastropods.
12.0-15.0	12	Silt; medium, color same, some oxide staining.
15.0-17.0	-	Clay; rootlets.

Burlington 74-30

Depth in Metres	Jar	Descriptions
0-1.5	-	Silt; rootlets.
1.5-6.0	3,9	Sand; medium, 5Y 7/4 pale yellow, 5Y 5/3 olive (wet).
6.0-16.7	13, 23	Silt; medium to fine, 5Y 6/4 pale olive, 5Y 5/3 olive (wet), rootlets.
16.7-18.0	-	Sand.
18.0-21.0	27	Clay; 5Y 7/2 light grey, 5Y 4/2 olive grey, scattered subrounded pebbles.

Depth in Metres	Jar	Descriptions
21.0-26.0	28,35	Sand; coarse, 5Y 6/6 olive yellow, 5Y 5/4 olive (wet), organic horizon with rootlets, oxide staining.
26.0-28.0	50	Silt; medium, 5Y 6/1 grey, 5Y 4/1 dark grey, scattered subrounded pebbles.
28.0-36.0	-	Till, silt-clay-sand with subrounded pebbles.

Burlington 74-29

Depth in Metres	Jar	Descriptions
0-4.5	3,6	Clay; 5Y 6/3 pale olive, 5Y 4/2 olive grey (wet).
4.5-9.1	9,12	Sand; coarse to fine, 5Y 6/3 pale olive, 5Y 5/3 olive (wet), layer of rootlets.
9.1-43.0	22,26 31	Clay; 5Y 6/2 light olive, 5Y 5/2 olive grey (wet), two organic (peat) layers, lower layer dated at 9440±100 years B.P., gastropods associated with peat, mussel shells present in clay, silt lens near base.

Burlington 74-25

Depth in Metres	Jar	Descriptions
0-4.5	3	Clay; 5Y 3/1 very dark grey, 5Y 2.5/1 black (wet).
4.5-6.0	7	Silt, very fine, 5Y 6/1 grey, 5Y 4/1 dark grey (wet), scattered wood fragments, rootlets.

Depth in Metres	Jar	Descriptions
6.0-30.0	14,17 20	Clay; 5Y 6/1 grey, 5Y 5/1 grey (wet), two organic (peat) layers with associated gastropod fossils, mussel shells in clay, silt lenses.
30.0-32.0	-	Sand.

APPENDIX B

Phi Values of Textural Analysis

The cores are arranged according to cross section. For each depth interval the median (Med), mean (mean), sorting (Sort), and skewness (Skew) is given. The cores provided by the U.S. Army Corps of Engineers are also arranged by cross section and the sample jar numbers are listed for each depth interval. Where no sample is avialable, no jar number is given, only information obtained from their stratigraphic information.

Below are the numerical ranges for the textural phi intervals and their significance (Folk, 1980).

Median: Half the particles by weight are coarser than the median, half are finer. Corresponds to the 50% mark on the cumulative curve.

Mean: -1.0 to 0.0, very coarse sand; 0.0 to 1.0, coarse sand; 1.0 to 2.0, medium sand; 2.0 to 3.0, fine sand; 3.0 to 4.0, very fine sand; 4.0 to 5.0, coarse silt; 5.0 to 9.0, silt; 9.0 to 14.0, clay.

Sorting: 0.35, very well sorted; 0.35 to 0.50, well sorted; 0.50 to 0.71, moderately well sorted; 0.71 to 1.0, moderately sorted; 1.0 to 2.0, poorly sorted; 2.0 to 4.0, very poorly sorted; +4.0, extremely poorly sorted.

Skewness: Measures the degree of symmetry and whether the sample has a coarse tail (-) or fine tail (+). A (+) tail indicates excess amounts of fines in the sample, and a (-) tail indicates excess amounts of coarse material.

Loc.	Depth	Med	Mean	Sort	Skew
C-25-1	0-0.9	3.8	5.1	3.6	0.51
C-25-1	0.9-4.5	2.7	4.3	3.3	0.72
C-25-2	0.9-3.0	2.2	2.3	0.8	0.32
C-25-2	3.0-6.0	8.8	9.0	3.0	0.71
C-25-2	6.0-6.9	5.0	6.1	3.1	0.54
C-25-3	0-1.5	4.8	5.8	3.4	0.42
C-25-3	1.5-5.6	4.9	5.7	4.0	0.23
C-25-3	5.1-6.6	3.3	4.9	3.9	0.44
C-25-3	6.6-8.2	3.1	3.5	1.9	0.63
C-25-4	1.4-4.6	4.9	6.1	3.3	0.52
C-25-4	4.6-5.4	1.8	1.8	0.6	0.11
C-23-1	0-3.9	8.7	8.9	2.4	0.08
C-23-1	3.9-5.2	1.9	1.6	3.1	0.07
C-23-1	5.2-6.7	7.5	8.2	2.8	0.31
C-23-1	6.7-9.1	10.1	10.0	2.6	-0.09
C-23-2	0-4.6	3.4	4.9	3.8	0.65
C-23-2	4.6-8.2	1.7	0.9	3.9	0.007
C-23-2	8.2-9.0	2.5	3.8	3.6	0.54
C-23-2	9.0-10.0	8.2	8.7	2.8	0.22
C-23-3	0-5.2	4.9	6.1	3.3	0.50
C-23-3	5.2-6.1	2.7	4.6	3.4	0.78
C-17-1	2.4-3.6	3.2	3.4	1.3	0.29
C-17-1	4.5-5.7	4.7	5.8	3.0	0.55
C-17-1	5.7-6.0	1.7	1.5	1.5	-0.22
C-17-2	0.9-2.1	3.2	3.3	1.2	0.17
C-17-2	2.4-3.6	0.07	-0.13	1.5	-0.13
C-17-3	0-0.9	7.0	7.2	3.7	0.02
C-17-3	1.5-2.7	4.0	5.2	3.1	0.59
C-17-3	2.7-3.6	3.1	4.0	3.7	0.29
C-17-4	0-2.1	3.3	3.5	0.9	0.41
C-17-4	2.1-3.0	5.2	6.4	3.3	0.48
C-17-4	3.0-5.1	2.7	2.7	0.5	-0.03
C-17-4	5.1-6.0	9.7	9.2	3.3	-0.15
C-17-4	6.7-7.0	1.3	1.1	1.2	-0.32
P.D.-1	1.5-2.1	10.5	10.3	2.3	-0.17
P.D.-1	3.0-5.4	1.7	1.6	0.9	-0.19
P.D.-1	5.4-6.7	6.9	7.6	2.6	0.42
P.D.-1	7.0-7.6	2.3	2.3	0.5	0.06
P.D.-2	0-3.0	9.2	9.1	2.5	-0.11
P.D.-2	3.0-6.0	9.5	9.7	2.5	0.06
P.D.-2	6.0-9.1	9.3	9.3	2.7	0.02
P.D.-2	9.1-12.1	8.6	9.0	2.6	0.18
P.D.-2	12.1-15.2	9.9	9.9	2.4	-0.01
P.D.-3	0-2.4	8.9	8.8	2.9	-0.007
P.D.-3	2.4-3.6	1.5	1.1	3.2	0.08

Loc.	Depth	med	Mean	Sort	Skew
C-8-1	0-2.4	5.8	6.5	3.3	0.20
C-8-1	2.4-3.0	7.2	7.8	2.6	0.31
C-8-1	3.0-3.9	2.7	4.0	4.0	0.44
C-8-2	0-3.0	10.0	9.9	2.4	-0.10
C-8-2	3.0-6.0	10.3	10.4	2.1	-0.04
C-8-2	6.0-9.1	8.9	9.2	2.3	0.19
C-8-2	9.1-12.1	8.6	9.0	3.0	0.14
C-8-2	12.1-15	9.3	9.5	2.4	0.15
C-8-2	15.0-24.0	9.7	9.8	2.1	0.05
C-8-3	0-3.0	10.5	10.4	2.2	-0.19
C-8-3	3.0-3.9	10.0	8.8	3.8	-0.37
C-8-3	3.9-5.1	3.4	5.1	3.5	0.65
C-8-3	5.1-5.4	1.5	1.7	4.2	0.24
C-8-4	0-1.5	9.6	9.3	2.6	-0.19
C-8-4	2.1-3.0	3.0	4.2	3.0	0.64
C-8-4	3.6-3.9	8.5	8.5	2.7	-0.01
R-3-1	2.1-2.4	3.2	4.1	3.9	0.36
R-3-1	2.4-3.6	5.8	7.0	3.8	0.33
R-3-2	0-2.1	8.6	9.0	2.7	0.19
R-3-2	2.1-3.6	5.3	6.9	3.5	0.57
R-3-2	3.6-5.1	5.8	7.2	3.2	0.52
R-3-3	0.9-3.0	9.5	9.4	2.6	-0.07
R-3-3	3.0-5.4	6.2	7.2	3.7	0.34
R-3-4	0-2.4	7.1	6.9	4.0	-0.07
R-3-4	2.4-3.6	7.9	8.0	4.1	-0.09
R-3-4	3.6-7.0	6.5	6.6	4.2	0.008
R.R.-1	0-2.1	5.8	7.0	3.2	0.49
R.R.-1	2.1-5.2	5.0	6.1	3.1	0.52
R.R.-1	5.2-6.7	8.4	8.7	3.0	0.17
R.R.-2	0-4.6	5.2	6.1	3.3	0.41
R.R.-2	4.6-7.0	5.2	6.2	3.3	0.44
R.R.-2	7.0-8.2	6.4	7.7	3.1	0.54
R.R.-2	8.2-8.5	3.8	5.4	3.5	0.64
R.R.-3	0-1.5	5.9	6.9	3.4	0.39
R.R.-3	1.5-3.0	10.0	9.9	2.7	-0.06
R.R.-3	3.0-5.4	3.9	4.9	3.2	0.49
R.R.-4	1.2-2.7	5.8	6.2	4.2	0.08
R.R.-4	2.7-4.2	3.0	3.2	1.2	0.34
C-11-1	0-1.5	7.6	8.3	2.6	0.39
C-11-1	1.5-3.9	3.3	4.6	3.1	0.66
C-11-1	3.9-5.1	1.7	1.7	0.9	0.23
C-11-2	0.9-3.6	2.8	2.8	0.5	-0.04
C-11-2	5.1-5.4	1.3	1.3	1.8	-0.01
C-11-3	0-3.6	3.1	3.2	0.9	0.23
C-11-3	3.6-4.5	1.3	2.6	3.3	0.64
C-11-3	4.5-5.1	8.9	9.2	2.7	0.13
C-11-4	0-2.1	6.1	6.4	3.7	0.11
C-11-4	2.1-3.6	8.1	8.4	3.0	0.18

Loc	Depth	Med	Mean	Sort	Skew
C-11-4	6.7-7.0	6.1	6.5	3.4	0.10
C-11-4	8.2-8.5	1.5	1.4	1.4	-0.04

Loc	Jar	Med	Mean	Sort	Skew
HW-5 74-50	2	8.7	9.0	3.2	0.09
HW-5 74-50	8	8.2	8.5	3.0	0.14
HW-5 74-50	14	7.5	7.8	2.4	0.18
HW-5 74-50	19	6.4	7.5	2.9	0.51
HW-5 74-50	23	2.1	2.4	2.9	0.51
HW-5 74-50	26	-0.6	-0.3	2.7	0.37
HW-5 74-44	4	9.5	9.6	2.8	0.05
HW-5 74-44	8	7.4	8.0	2.8	0.31
HW-5 74-44	11	8.5	8.5	2.7	0.08
HW-5 74-44	21	10.0	9.7	3.0	-0.14
HW-5 74-44	24	7.8	8.4	2.6	0.35
S.L. 76-77	4	7.8	8.5	3.0	0.28
S.L. 76-77	14	9.2	9.5	2.5	0.13
S.L. 76-77	17	8.0	8.5	2.9	0.23
S.L. 76-76	2	8.5	8.9	2.3	0.27
S.L. 76-76	6	6.0	7.1	2.5	0.58
S.L. 76-76	7	9.1	9.2	2.3	0.009
S.L. 76-76	11	9.0	9.2	2.2	0.11
S.L. 76-76	15	9.7	9.7	2.4	-0.00
S.L. 74-75	3	8.5	8.7	2.8	0.08
S.L. 74-75	5	9.1	9.2	2.5	-0.01
S.L. 74-75	9	7.0	7.9	2.9	0.43
S.L. 74-75	14	3.3	4.7	2.7	0.81
L.D. 76-98	6	3.4	3.5	5.2	0.09
L.D. 76-98	12	8.1	8.5	3.3	0.17
L.D. 76-98	18	1.6	0.9	3.4	-0.017
L.D. 76-93	4	9.0	9.1	2.9	0.02
L.D. 76-93	9	4.7	6.1	3.9	0.48
L.D. 76-95	3	10.3	9.8	2.9	-0.22
L.D. 76-95	10	4.6	5.3	3.3	0.25
L.D. 76-95	14	2.0	2.6	2.8	0.45
L.D. 76-106	13	2.1	2.4	3.9	0.24
BU 74-60	6	4.9	5.4	4.1	0.14
BU 74-60	14	0.2	0.4	3.3	0.39
BU 74-60	27	2.2	2.5	3.0	0.22
BU 74-60	28	8.5	8.7	3.1	0.13
BU 74-60	36	9.5	9.5	2.7	-0.005

Loc	Jar	Med	Mean	Sort	Skew
BU 74-55	6	7.3	7.8	2.6	0.22
BU 74-55	10	2.2	1.9	1.5	0.37
BU 74-55	17	1.9	4.3	3.7	0.87
BU 74-26	4	10.3	10.0	2.8	-0.15
BU 74-26	6	7.7	8.6	3.3	0.31
BU 74-26	16	9.3	9.3	2.5	-0.05
BU 74-26	32	8.9	9.1	2.3	0.07
BU 74-30	3	1.1	0.5	2.2	-0.25
BU 74-30	9	1.4	1.2	2.3	0.12
BU 74-30	13	3.9	5.2	3.8	0.39
BU 74-30	21	8.0	8.4	3.1	0.19
BU 74-30	23	2.7	4.0	3.7	0.49
BU 74-30	27	8.8	9.2	3.0	0.17
BU 74-30	28	1.1	0.87	3.3	0.16
BU 74-30	35	1.2	0.6	3.4	0.05
BU 74-30	50	3.5	5.0	3.5	0.53
BU 74-29	3	9.8	9.5	3.1	-0.14
BU 74-29	6	9.5	9.7	2.4	0.09
BU 74-29	9	0.5	0.3	2.1	-0.03
BU 74-29	12	1.8	2.2	2.3	0.53
BU 74-29	22	9.5	9.4	2.7	-0.03
BU 74-29	26	9.5	9.3	3.0	-0.07
BU 74-29	31	10.3	10.0	2.5	-0.14
BU 74-25	3	10.1	10.2	2.2	0.02
BU 74-25	7	8.6	8.9	2.9	0.15
BU 74-25	14	10.5	10.2	2.1	-0.24
BU 74-25	17	9.5	9.3	2.6	-0.12
BU 74-25	20	10.2	10.1	2.4	-0.09
BU 74-24	5	9.5	9.6	2.4	0.03
BU 74-24	9	2.2	2.1	1.8	0.03
BU 74-24	12	3.4	5.8	3.7	0.77

APPENDIX C

Percentages of Sand, Silt, and Clay in Selected Cores in the Souris and Des Lacs Valleys.

Core	Sand	Silt	Clay
C-8 Box 2 Stop 1	32	33	35
C-8 Box 4 Stop 1	71	13	16
C-8 Box 4 Stop 2	6	28	66
C-8 Box 10 Stop 2	20	20	60
C-8 Box 23 Stop 2	0	25	75
C-8 Box 6 Stop 3	23	15	62
C-8 Box 8 Stop 3	82	7	11
P.D. Box 4 Stop 1	96	4	0
P.D. Box 3 Stop 2	47	27	26
P.D. Box 4 Stop 2	0	40	60
P.D. Box 9 Stop 2	0	32	68
P.D. Box 13 Stop 2	0	37	63
P.D. Box 21 Stop 2	0	29	71
P.D. Box 5 Stop 3	47	27	26
C-23 Box 4 Stop 1	86	7	7
C-23 Box 7 Stop 2	84	8	8
C-23 Box 3 Stop 3	43	39	18
C-25 Box 4 Stop 1	69	17	14
C-25 Box 8 Stop 2	34	46	20
C-25 Box 6 Stop 3	83	6	11
C-25 Box 4 Stop 4	42	34	24
C-11 Box 6 Stop 3	6	45	49
C-11 Box 4 Stop 1	66	17	14
C-11 Box 4 Stop 2	93	7	0
C-11 Box 4 Stop 3	78	11	11
C-11 Box 2 Stop 4	31	37	32
C-11 Box 6 Stop 4	90	10	0
C-17 Box 2 Stop 2	73	26	1
C-17 Box 2 Stop 3	26	37	37
C-17 Box 2 Stop 4	84	15	1
C-17 Box 6 Stop 4	94	5	1
R.R. Box 5 Stop 1	16	54	30
R.R. Box 1 Stop 2	2	49	49
R.R. Box 5 Stop 2	34	42	24
R.R. Box 9 Stop 2	52	30	18
R.R. Box 2 Stop 3	50	25	25
R.R. Box 5 Stop 4	79	18	3
R-3 Box 3 Stop 1	63	21	16
R-3 Box 2 Stop 2	5	43	52
R-3 Box 3 Stop 2	23	47	30
R-3 Box 4 Stop 2	13	57	30
R-3 Box 5 Stop 3	29	38	33
R-3 Box 3 Stop 4	30	28	42
R-3 Box 5 Stop 3	77	10	13

REFERENCES

Attig, J., 1986, Verbal communication: Wisconsin Geological Survey, Madison, Wisconsin.

Baker, V.R., 1973, Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington: Geological Society of America Special Paper 144, 79p.

Blatt, H., Middleton, G., and Murray, R., 1980, Origin of sedimentary rocks 2nd ed.: Prentice Hall, Inc., Englewood Cliffs, New Jersey, 782p.

Bluemle, J.P., 1960, The face of North Dakota: North Dakota Geological Survey Education Series 11, 73p.

Bluemle, J.P., 1980, Guide to the geology of northwestern North Dakota: North Dakota Geological Survey Education Series 8, 38p.

Bryson, R.A., Barreis, D.A., and Wendland, W.M., 1970, The character of late-glacial and post-glacial climatic changes, in Dort, W., and Jones, J. K., eds., Pleistocene and recent environments of the central great plains: University Press of Kansas, Special Publication 3, p.53-74.

Carver, R.E., 1971, Procedures in sedimentary petrology: John Wiley and Sons, Inc., New York, 653p.

Clayton, L. and Moran, S.R., 1974, A glacial process-form model, in Coates, D.R., ed., Glacial Geomorphology: Publications in Geomorphology, State University of New York, NewYork, p.89-117.

Clayton, L., Moran, S.R., and Bickley, W.B. Jr., 1976, Stratigraphy, origin, and climatic implications of late Quaternary upland silt in North Dakota: North Dakota Geological Survey, Misc. Series No. 54, 15p.

Clayton, L., Moran, S.R., and Bluemle, J.P., 1980, Explanatory text to accompany the geologic map of North Dakota: North Dakota Geological Survey, Report of Investigation no. 69, 93p.

Clayton, L. and Moran, S.R., 1982, Chronology of Late Wisconsinan glaciation in middle North America: Quaternary Science Reviews, Vol. 1, p.55-82.

Cvancara, A.M., 1983, Aquatic mollusks of North Dakota: North Dakota Geological Survey, Report of Investigation No. 78, 141p.

Folk, R.L., 1980, Petrology of sedimentary-rocks: Hemphill Publishing Company, 185p.

Friedman, G.M., and Sanders, J.E., 1978, Principles of sedimentology: John Wiley and Sons, 792p.

Hamilton, T.M., 1976, Late-recent alluvium in western North Dakota, in Clayton, L., and Freers, T. E., eds., Glacial geology of the Missouri Coteau and adjacent areas: North Dakota Geological Survey, Misc. Series 30, p. 151-158.

Kehew, A.E., 1982, Catastrophic flood hypothesis for the origin of the Souris spillway, Saskatchewan and North Dakota: Geological Society of America Bulletin, Vol. 93, p.1051-1058.

Kehew, A.E., 1983, Geology and geotechnical conditions of the Minot area, North Dakota: North Dakota Geological Survey, Report of Investigation no. 73, 35p.

Kehew, A.E., and Clayton, L., 1983, Late Wisconsinan floods and developement of the Souris and Pembina Spillway system in Saskatchewan, North Dakota, and Manitoba, in Teller, J. T., ed., Glacial Lake Agassiz: Geological Association of Canada Special Paper 26, p. 187-209.

Kehew, A.E., and Lord, M., 1986, Origin and large-scale erosional features of glacial-lake spillways in the northern Great Plains: Geological Society of America Bulletin, Vol. 97, p. 162-167.

Kehew, A.E., and Boettger, W.M., 1986, Depositional environments of buried-valley aquifers in North Dakota: Ground Water, 1986, in press.

Klassen, R.W., 1972, Wisconsin events and the Assiniboine and Qu'Appelle Valleys of Manitoba and Saskatchewan: Canadian Journal of Earth Sciences, Vol. 9, p. 544-560.

LeFever, R., 1985, Verbal communication: Department of Geology and Geological Engineers, University of North Dakota, Grand Forks, North Dakota.

Lemke, R.W., 1960, Geology of the Souris River area North Dakota: United States Geological Survey Professional Paper no. 325, 138p.

Lord, M.L., 1984, Paleohydraulics of Pleistocene drainage development of the Souris, Des Lacs, and Moose Mountain spillways, Saskatchewan and North Dakota: M.S. Thesis, Grand Forks, North Dakota, University of North Dakota, 162p.

Pettyjohn, W.A., and Hutchinson, R.D., 1971, Ground-Water resources of Renville and Ward Counties: North Dakota Geological Survey Bulleton 50, pt. II, and County Ground-Water Studies III-Part III, North Dakota State Water Commission, 100p.

Ritter, D.F., 1978, Process geomorphology: Wm. C. Brown Company Publishers, Dubuque Iowa, 603p.

Rust, B.R., and Koster, E.H., 1984, Coarse alluvial deposits, in Walker, R. G. ed., Facies models 2nd ed: Geoscience Canada, Reprint Series 1, Ainsworth Press Limited, p. 91-104.

U.S. Army Corps of Engineers, 1978, Flood control Burlington Dam, Souris River, North Dakota; Design Memo. No. 2, Phase II-Project Design, Appendix B-Geology and Soils: St. Paul District, 26p., 110 pl.

Watts, W.A. and Bright, R.C., 1968, Pollen and mollusk analysis of a sediment core from Pickerel Lake, northeastern South Dakota: Geological Society of America Bulletin, Vol. 79, p. 855-876.

Webb, T. III, Cushing, E.J., and Wright, H.E. Jr., 1983, Holocene changes in the vegetation of the Midwest, in Wright, H. E. Jr., ed., Late-Quaternary environments of the United States, Vol. 2, the Holocene: University of Minnesota Press, p. 142-165.

Wright, H.E. Jr., 1970, Vegetational history of the central Great Plains, in Dort, W. Jr., and Jones, J. K. Jr., eds., Pleistocene and recent environments of the central Great Plains: University Press of Kansas, Special Publication 3, p. 157-172.