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# Latest Cenozoic stratigraphy of Lake Sakakawea area, northeast Mercer County, North Dakota

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LATEST CENOZOIC STRATIGRAPHY OF LAKE SAKAKAWEA AREA

NORTHEAST MERCER COUNTY, NORTH DAKOTA

by

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This thesis submitted by Donald Keith Sackreiter in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Title LATEST CENOZOIC STRATIGRAPHY OF LAKE SAKAKAWEA AREA NORTHEAST MERCER COUNTY, NORTH DAKOTA

Department Geology

Degree Master of Science

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Date April 6, 1973

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ABSTRACT

The latest Cenozoic in northeast Mercer County, North Dakota, is represented by five formations. They are, from bottom to top: the Charging Eagle Formation, the Medicine Hill Formation, the Snow School Formation, the Coteau Formation, and the Oahe Formation.

The Charging Eagle Formation is mainly fluvial sediment. Most of the sediment was derived from the west with only minor amounts from the northeast. It contains the first evidence of glaciation in the area.

The lower Medicine Hill Formation is mainly sediment deposited by a northeast-flowing ancestor of the Missouri River and by melt-water streams. The upper Medicine Hill Formation is glacial sediment. The upper member contains the oldest preserved glacial sediment in the area. Many large inclusions of gravel, sand, and clay characterize the upper member.

The lower Snow School Formation is mainly fluvial sediment deposited by a northeast-flowing ancestor of the Missouri River and by melt-water streams. The upper Snow School Formation is glacial sediment. The upper member contains the youngest glacial sediment in the area. The lithologic homogeneity, columnar jointing, and a weathering profile characterize the upper member.

The Coteau Formation is mainly alluvium and slopewash sediment. It is found at the base of steep hillslopes. Much of it was deposited during unstable (warm and dry) climatic conditions, probably contemporaneously with much of the Oahe Formation.

The Oahe Formation (late Wisconsinan and Holocene) is mainly wind-blown silt. It is found on the hilltops and in gentle depressions. The characteristics of the four members (the Mallard Island, Aggie Brown, Pick City, and Riverdale Members) are controlled by changes in hillslope stability resulting from climatic changes.

# INTRODUCTION

## Purpose

This paper presents the results of an investigation of the geology along the bluffs of southeastern Lake Sakakawea in northeastern Mercer County, North Dakota. The main objective of the study was to establish the latest Cenozoic stratigraphy to serve as a framework for understanding the latest Cenozoic history and the hydrogeology of the area.

## Area of Study

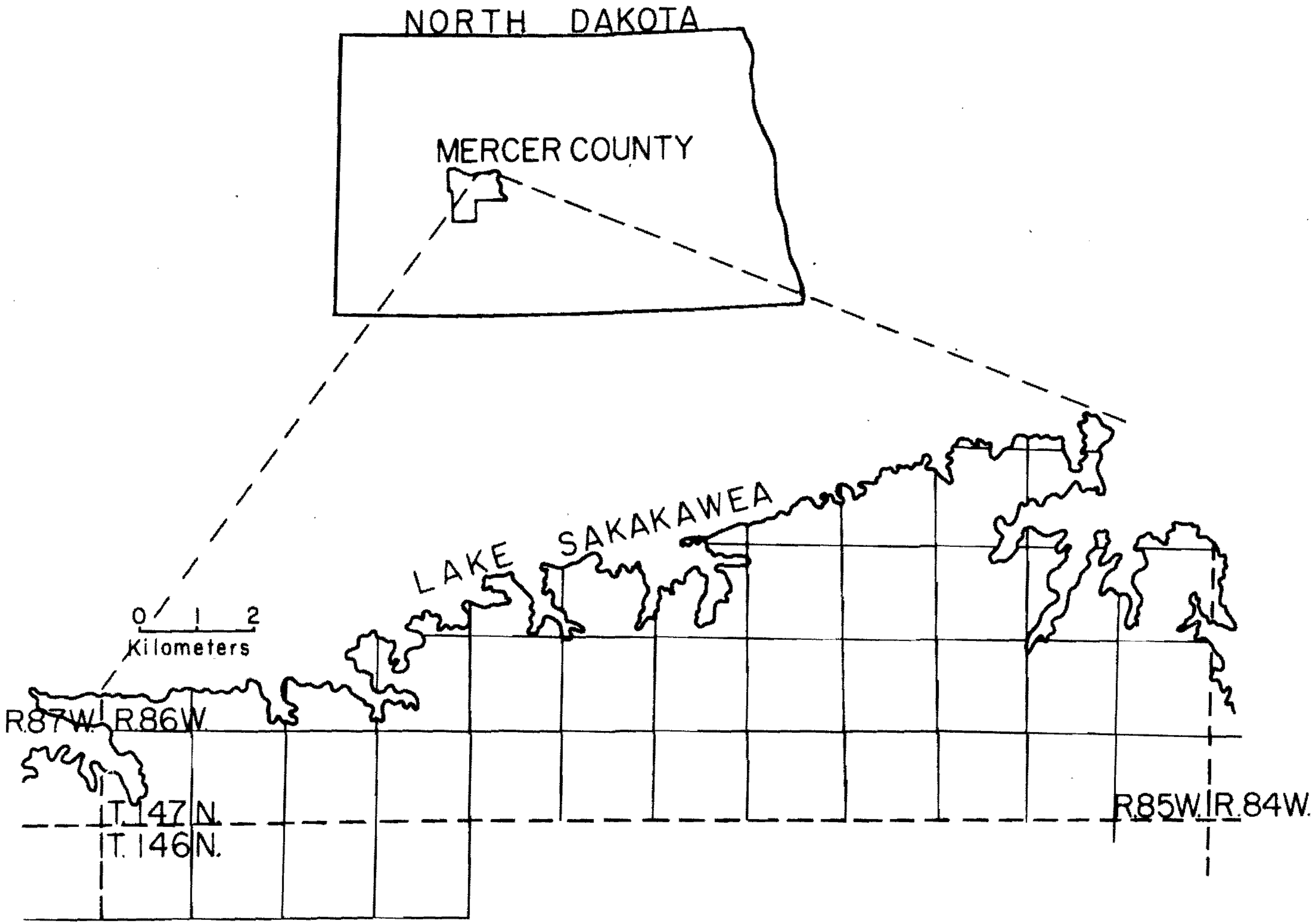
Vertical bluffs as high as 30 meters occur along the southeastern shore of Lake Sakakawea at the margins of the Missouri River trench. The stratigraphy of the bluffs was determined between section 13, T.147N., R.85W. west-southwesterly and section 36, T. 147N., R.87W., Mercer County (Figure 1).

## Methods of Study

Most of the field work was completed during June and July of 1972.

Topographic maps of the 7.5 minute series, air photos (scale 1:20,000), and North Dakota State Highway Department county maps (scale 1:36,380) were used as base maps. Stratigraphic information was obtained by boating and walking along the shoreline. Samples for laboratory analysis were collected using a chair on a rope where

Fig. 1.--Location of the study area (between dashed lines) within Mercer County and North Dakota.


NORTH DAKOTA
MERCER COUNTY
LAKE SAKAKAWEA
0 1 2
Kilometers
R.87W.
R.86W.
T.147N.
T.146N.
R.85W.
R.84W.

the bluffs were too steep to climb. All of the bluffs were photographed to provide details of correlation and thicknesses between the measured sections.

# STRATIGRAPHY

## General Statement

Mercer County is located on the eastern flank of the Williston Basin, a structural basin containing a thick sequence of sedimentary rocks. Bluemle (1971), Carlson and Anderson (1965), and Carlson (in press) have outlined the general geology of the area.

One Paleocene formation, the Sentinel Butte, outcrops in the study area. Five latest Cenozoic formations have been recognized. They are, from bottom to top, the Charging Eagle Formation, the Medicine Hill Formation, the Snow School Formation, the Coteau Formation, and the Oahe Formation (Figure 2).

## Charging Eagle Formation

### Source of the name

The Charging Eagle Formation is here named for Charging Eagle Bay of Lake Sakakawea in Dunn County, North Dakota.

### Type section

The type section of the Charging Eagle Formation is in the SW¼, SE¼, NE¼ section 20, T.147N., R.85W., in a north-facing bluff of Lake Sakakawea, a few hundred meters north of the only farm buildings in that section. For a detailed description of the lithology of the type section see Appendix I.

Fig. 2.--Stratigraphic column for exposed units in the study area.

| Age | Unit Name | | Dominant Lithology |
| --- | --- | --- | --- |
| Holocene | Oahe Formation | Riverdale Member<br>Pick City Member<br>Aggie Brown Member<br>Mallard Island Member | Coarse silt |
| - - - ? - - - | Coteau Formation | | Dirty (containing organic material), poorly sorted, gravelly, sandy, silty clay |
| | Snow School Formation | | Bouldery, pebbly, sandy, silty clay (pebble-loam) |
| | Medicine Hill Formation | | Bouldery, pebbly, sandy, silty clay (pebble-loam) |
| - - - - ? - - - - | | | |
| Pliocene? | Charging Eagle Formation | | Silty sand and sandy silt |
| Paleocene | Sentinel Butte Formation | | Sandstone and shale |

Reference section

Reference sections are located in the bluffs of Lake Sakakawea in the NE¼, SE¼, NW¼ section 21, T.147N., R.85W., and the SE¼, SE¼ section 15, T.147N., R.85W., Mercer County, North Dakota.

Description of the formation

The Charging Eagle Formation is predominately silty sand and sandy silt. At the type section, the lower 9 meters is composed of 15 to 20 percent coarse to fine sand, 60 to 70 percent very fine sand, and 15 to 20 percent silt and clay. The next 4 meters at the type section is composed of 10 percent coarse to fine sand, 40 percent very fine sand, and 50 percent silt and clay. Pebbles make up less than 1 percent of the sandy silt and silty sand facies of the formation. In general, there is a decrease in grain size from the bottom to the top. Most of the formation is poorly sorted.

Color differences are due primarily to grain size and secondary mineral cementation. The sandier parts are typically whitish gray to grayish white. The siltier parts are grayish yellow to yellowish gray. White carbonate and gypsum concretions are scattered throughout the formation. Reddish iron-oxide stains are especially common in the flat-bedded sand and gravel. At the first reference section, large amounts of lignite disseminated through the sand gives an overall black appearance to the sand (Figure 3).

The formation is generally unconsolidated, but some of the siltier parts of the formation are slightly consolidated.

The sand-sized portion of the formation is composed largely of feldspar, gypsum, quartz, lignite, and small amounts of igneous

Fig. 3.--Contact (dashed line) of the Charging Eagle Formation with the underlying Sentinel Butte Formation, a few tens of meters south of measured section 10.

and metamorphic minerals. A handful of pebbles from the sandy part were about 50 percent limestone and dolomite, 25 percent locally derived sandstone and shale, and 25 percent granite and basalt. Strong reaction with dilute hydrochloric acid takes place throughout the formation. Secondary gypsum, locally in the form of large crystals, is scattered throughout the coarser parts of the formation.

Much of the unit has high-angle, small-scale and large-scale, trough-shaped, grouped crossbedding. Some high-angle, large-scale, erosional, irregular, solitary crossbedding is also present (Figure 4).

No fossils have been found in the Charging Eagle Formation.

### Nature of the contacts

The contacts of the Charging Eagle Formation with the underlying Sentinel Butte Formation (Figure 3) and the overlying Medicine Hill Formation (Figure 5) are abrupt. The contact of the Charging Eagle Formation with the overlying Snow School Formation (Figure 4) is abrupt where the Medicine Hill Formation is missing.

### Regional extent and thickness

The Charging Eagle Formation occurs between the Sentinel Butte Formation and the Medicine Hill Formation or Snow School Formation. The lateral limits of this formation are not known. The Charging Eagle Formation may be equivalent to the upper unit of the Empress Group in southern Saskatchewan (Whitaker and Christiansen, 1972). The Charging Eagle Formation ranges in thickness from a few tens of millimeters to 14 meters.

Fig. 4.--Contact (dashed line) of the Charging Eagle Formation with the overlying Snow School Formation at the type section of the Charging Eagle Formation.

Fig. 5.--Contact (dashed line) of the Charging Eagle Formation and the overlying Medicine Hill Formation at measured section 6.

Differentiation from other units

Stratigraphic position, lithology, and nature of the contacts distinguish the Charging Eagle Formation from other formations. An erosional contact on the Sentinel Butte Formation makes it possible to distinguish between the two formations (Figure 3). Sharply contrasting lithologies (poorly sorted sands and silts of the Charging Eagle Formation and unsorted pebble-loam of the Medicine Hill Formation and the Snow School Formation) makes it possible to distinguish the Charging Eagle Formation from other overlying formations.

Origin

On the basis of crossbedding, sorting, and nature of contacts, the Charging Eagle Formation is interpreted to be fluvial sediment.

Age

The age is unknown. The presence of dolomite, limestone, basalt, and granite pebbles suggests that the Charging Eagle Formation was deposited some time after the first latest Cenozoic glaciation in the area.

Source

Most of the sediment was derived from west of the study area. A small amount of the sediment was derived from northeast of the study area.

## Medicine Hill Formation

The Medicine Hill Formation has been named formally by Ulmer (in preparation) who mapped the latest Cenozoic stratigraphy on the eastern shoreline of Lake Sakakawea.

Carlson (in press) mapped the geology of Mercer and Oliver counties. In his report he recognized the presence of two glacial deposits. He called the lower glacial deposit the "Mercer till." This report will use the lithostratigraphic name "Medicine Hill Formation" instead of the genetic name "Mercer till."

In the study area, the formation is composed of two members.

Description of the lower member

The lower member is composed of poorly sorted gravelly sand and sandy gravel. Limestone, dolomite, granite, basalt, and concretions are the dominant lithologies in the gravel. Iron oxidation has stained most of the member red.

Description of the upper member

The upper member of the Medicine Hill Formation is pebble-loam. On the basis of 19 textural analyses, the formation averages 29 percent sand, 42 percent silt, and 29 percent clay (Table 1). The sand and clay percentages are more variable than the silt percentage.

A few percent of the pebble-loam is made up of boulders, cobbles, and pebbles. Pebble counts were made on ten samples. One hundred pebbles and granules were counted from each sample. The results show that shale is the dominant lithology in the Medicine Hill Formation (Table 2). The shale is probably derived from the Pierre, Tongue River, and Sentinel Butte Formations. The carbonate fraction makes up nearly 30 percent of the pebble-loam; dolomite is the most abundant carbonate. The carbonates are typically creamy

TABLE 1

TEXTURAL ANALYSES OF THE LOAM FRACTION OF THE MEDICINE HILL FORMATION AND THE SNOW SCHOOL FORMATION IN MERCER COUNTY

| Formation | Sand | | Silt | | Clay | |
|---|---|---|---|---|---|---|
| | Percentage | Standard Deviation | Percentage | Standard Deviation | Percentage | Standard Deviation |
| Snow School | 26 | 2 | 41 | 4 | 33 | 4 |
| Medicine Hill | 29 | 8 | 42 | 4 | 29 | 8 |

TABLE 2

COMPOSITION AND SOURCE OF VERY COARSE SAND AND PEBBLES IN THE LOAM OF THE MEDICINE HILL FORMATION IN MERCER COUNTY

| Lithology | Source | Percentage | Standard Deviation |
|---|---|---|---|
| Limestone and dolomite | Paleozoic Manitoba | 29 | 6 |
| Light-colored igneous and metamorphic rocks | Canadian Shield | 13 | 4 |
| Dark-colored igneous and metamorphic rocks | Canadian Shield | 6 | 2 |
| Shale | Cretaceous and Tertiary(?) Systems of North Dakota, Manitoba, and Saskatchewan | 40 | 8 |
| Concretions, sandstone siltstone, and siliceous rocks | Locally derived (Cretaceous and Tertiary Systems of North Dakota) | 11 | 6 |

white. Some of the carbonates have a black manganese dioxide coating with some well developed dendrites. Some of the carbonates have reddish iron-oxide stain on the surface. The carbonate-shale ratio is 3:4. Granite and basalt derived from the Canadian Shield are the principal lithologies of the igneous and metamorphic fraction of the pebbles and the granules. The remaining fraction is made up of sandstone, siltstone, concretions, and siliceous minerals, all probably derived from local sources. Lignite chips are present but were not included in the counts.

The color of the upper member is variable as a result of the amount of weathering. The color ranges from light yellowish brown (2.5Y 6/4) on weathered surfaces to yellow (2.5Y 7/6) on fresh surfaces (colors from Munsell Soil Color Chart). The upper member is typically lighter in color in the study area than at the east end of Lake Sakakawea.

The upper member has distinctive jointing (Figure 6), it breaks into irregular sheets and plates. Small amounts of secondary accumulations of carbonate, gypsum, and iron oxide occur along the jointing planes.

Inclusions of sand, silt and clay, and gravel are characteristic of the upper member. The inclusions range from less than a meter to tens of meters across. A few hundred meters west of measured section 12, a large intact block derived from the Charging Eagle Formation has been included in the upper member (Figure 7). Many inclusions have been folded and faulted. Most of the inclusions are clayey silt and crossbedded sand and silt. Only in a few places was gravel found in inclusions. It appears that the Charging Eagle Formation was the source of the clayey silt and silty sand inclusions and the lower member of the Medicine Hill Formation the source of the gravel inclusions. No inclusions derived from the Sentinel Butte Formation were observed in the upper member.

Regional extent and thickness

The lower member is thin (averaging less than a few meters) and occurs discontinuously.

Fig. 6.--Contacts (dashed lines) between the Sentinel Butte Formation, the Medicine Hill Formation, and the Snow School Formation at measured section 10.

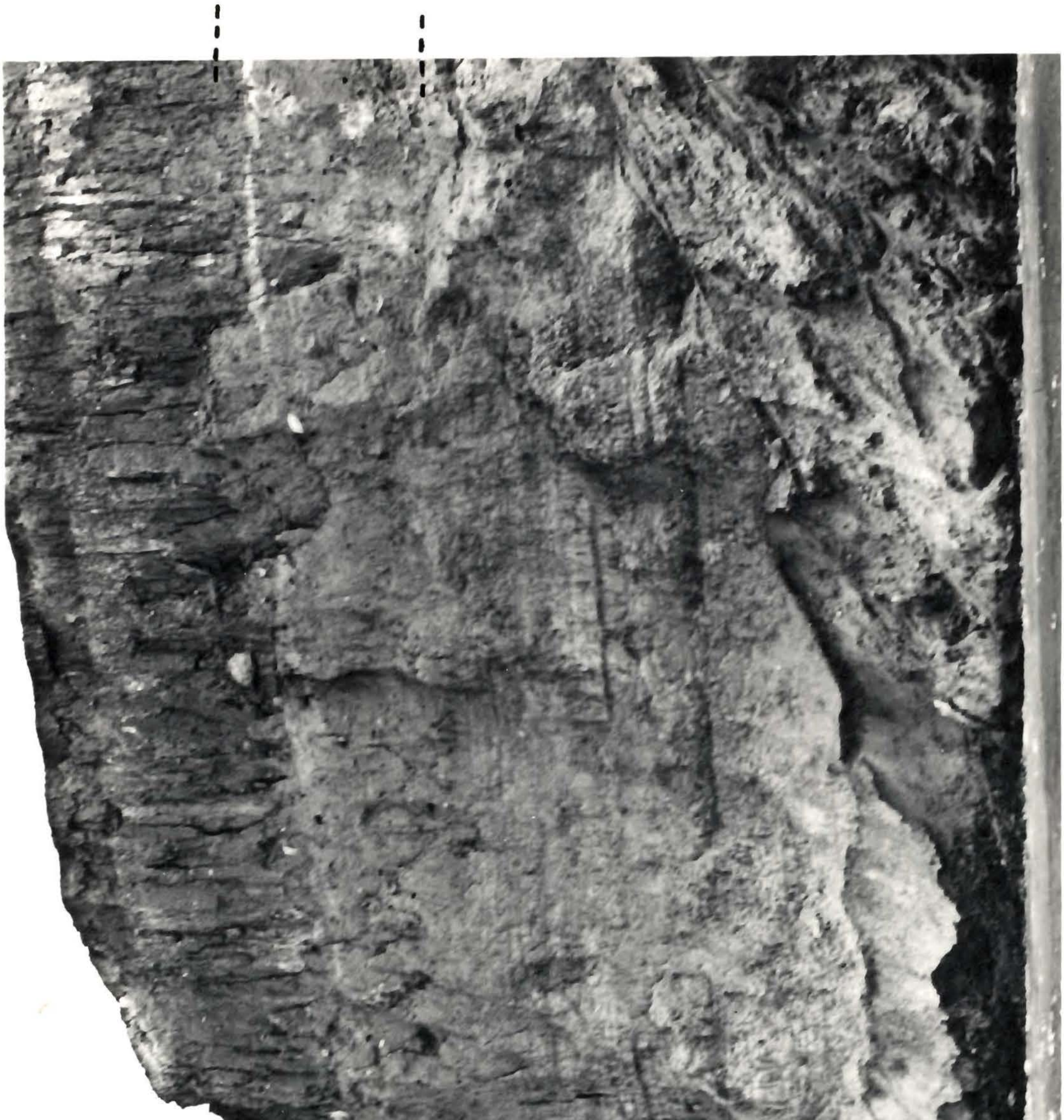
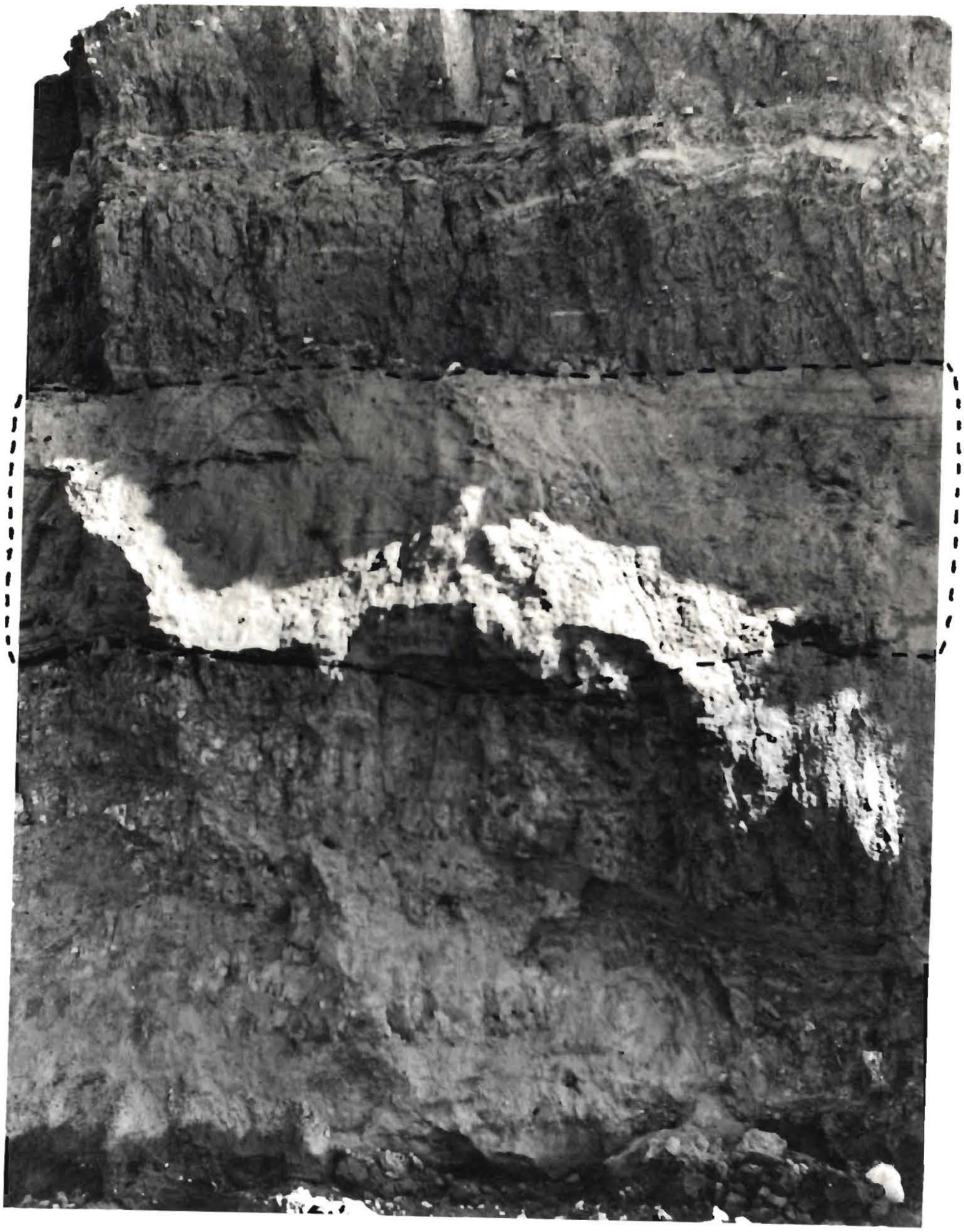


Fig. 7.--Inclusion (within the dashed line) derived from the Charging Eagle Formation found in the Medicine Hill Formation near measured section 13. Upper few meters of darker sediment is the upper member of the Snow School Formation.



The upper member occurs sporadically throughout the study area. The easternmost extent of it is on the west side of the island where the first section was measured (Figure 1). It is exposed at the westernmost point in the study area (Figure 1). Carlson noted the presence of the "Mercer till" (upper member of the Medicine Hill Formation?) and the "Napoleon till" (upper member of the Snow School Formation?) to the west of the study area (SE¼, NE¼ section 7, T.146N., R.87W.). Carlson also noted the presence of the surface till (upper member of the Snow School Formation?) lying on a buried till (upper member of the Medicine Hill Formation?) still farther west (sections 1, 2, 11, 12, T.146N., R.89W.).

The upper member of the Medicine Hill Formation ranges from a fraction of a meter to nearly 16 meters in thickness (Plate 1).

Differentiation from other units

The upper Medicine Hill Formation could be confused with the upper members of the Horseshoe Valley and Snow School Formations. Because the upper Horseshoe Valley Formation is similar to the upper Snow School Formation, the means of differentiating these three formations is discussed under the Snow School Formation.

Origin

On the basis of bedding and sorting, the lower member of the Medicine Hill Formation is interpreted to be fluvial sediment. On the basis of sorting, extent, and topographic position, the upper member of the Medicine Hill Formation is interpreted to be glacial sediment.

Age

The age is unknown. It is no older than latest Cenozoic. It is older than late Wisconsinan.

Source

The large amount of shale (40 percent) and small amount of limestone and dolomite (29 percent) in the upper Medicine Hill Formation in comparison with the small amount of shale (17 percent) and the large amount of limestone and dolomite (48 percent) in the upper Snow School Formation could be interpreted to indicate a different source area for the ice that deposited the pebble-loam of the two formations. The flow was probably from the north for the upper Medicine Hill Formation and from the northeast for the upper Snow School Formation.

## Snow School Formation

The Snow School Formation has been named formally by Ulmer (in preparation). In the study area, the formation is composed of two members.

Description of the lower member

The lower member is largely alternating beds of poorly sorted gravelly sand and sandy gravel. Most of it is flat-bedded. Limestone, dolomite, granite, basalt, and concretions are the dominant lithologies in the gravel. The color is grayish white. Iron oxidation has stained some of the member red. The lower member is unconsolidated except where it is cemented with iron oxide.

Description of the upper member

The upper member is pebble-loam. On the basis of 55 textural analyses, the loam averages 26 percent sand, 41 percent silt, and 33 percent clay (Table 1).

A few percent of the upper member is made up of boulders, cobbles, and pebbles. Twenty-three separate samples were collected. One hundred pebbles and granules were counted from each sample (Table 3). Dolomite and limestone are the dominant lithologies.

TABLE 3

COMPOSITION AND SOURCE OF VERY COARSE SAND AND PEBBLES IN THE LOAM OF THE SNOW SCHOOL FORMATION IN MERCER COUNTY

| Lithology | Source | Percentage | Standard Deviation |
|---|---|---|---|
| Limestone and dolomite | Paleozoic Manitoba | 48 | 6 |
| Light-colored igneous and metamorphic rocks | Canadian Shield | 16 | 5 |
| Dark-colored igneous and metamorphic rocks | Canadian Shield | 9 | 3 |
| Shale | Cretaceous and Tertiary(?) Systems of North Dakota, Manitoba, and Saskatchewan | 17 | 8 |
| Concretions, sandstone, siltstone, and siliceous rocks | Locally derived (Cretaceous and Tertiary of North Dakota). | 10 | 7 |

Dolomite and limestone make up nearly 50 percent of the pebbles and the granules. The dolomite and limestone of the Snow School Formation has much the same appearance as that of the Medicine Hill Formation (see description of the Medicine Hill Formation for the comparison). Shale, granite, basalt, siltstone, sandstone, concretions, siliceous minerals, and lignite make up the remaining fraction.

The color of the upper member is variable as a result of the amount of weathering, the amount of organic accumulation, and the amount of calcium carbonate accumulation. The color ranges from grayish brown (2.5Y 5/2) on weathered surfaces to light yellowish brown (2.5Y 6/4) on fresh surfaces. Where the calcium carbonate has accumulated, the color is whiter. Where organic material has accumulated, the color is blacker. Where all of the above colors occur on an exposed face, the color sequence from top to bottom is typically (1) about 1/2 meter of dark pebble-loam containing abundant organic material, (2) 1 or more meters of white pebble-loam containing abundant calcium carbonate, and (3) several meters of weathered or fresh surface with some occasional patches of white calcium carbonate accumulation (Figure 6).

The upper member has distinctive jointing (Figure 6). Well-developed columns starting from the base of the dark zone and ending abruptly at the base of the upper member are typical of this member. Where the member thickens (greater than 2 or 3 meters), the spacing of the columns become greater and many columns fail to maintain continuity throughout the member.

Regional extent and thickness

The lower member is thin (averaging less than 1 meter) and occurs discontinuously (Plate 1).

The upper member maintains a fairly constant thickness and occurs nearly continuously throughout the study area (Plate 1). Ulmer (in preparation) observed the upper member on the east side of Lake Sakakawea in McLean County. A preliminary reconnaissance along the northern shoreline of Lake Sakakawea south of Garrison, North Dakota, showed scattered exposures of both the Medicine Hill Formation and the Snow School Formation.

Differentiation from other units

The pebble-loam of the Snow School Formation is distinguished from the pebble-loam of the Medicine Hill Formation by (1) the texture of the loam (the Medicine Hill Formation is sandier and less clayey than the Snow School Formation), (2) the range in texture of the loam (the Medicine Hill Formation has a much greater range than the Snow School Formation), (3) the pebble and granule lithology (the Medicine Hill Formation contains more than two times as much shale and less than three fifths as much dolomite and limestone as the Snow School Formation), (4) the color (the Medicine Hill Formation is yellower and the Snow School Formation is browner), (5) the type of jointing (platy, sheet-like joints of the Medicine Hill Formation and columnar joints of the Snow School Formation), (6) the inclusions (many in the Medicine Hill Formation and few if any in the Snow School Formation), and (7) the variation in continuity (the Medicine Hill Formation thins and thickens rapidly whereas the Snow School Formation undergoes more gradual changes).

The upper Horseshoe Valley Formation is hard to distinguish from the upper Snow School Formation. Ulmer (in preparation) has found (1) the upper Horseshoe Valley Formation to be a thin and discontinuous (much more so than the Medicine Hill Formation) unit, (2) a dark horizon commonly found near the top of the upper Snow School Formation is absent from the upper Horseshoe Valley Formation, (3) the upper Horseshoe Valley Formation averages 29 percent sand, 36 percent silt, and 34 percent clay, and (4) the upper Snow School Formation averages 28 percent sand, 38 percent silt, and 33 percent clay (which is more nearly like the upper Snow School Formation in Mercer County, see Table 1) in McLean County. For the reasons listed above, the uppermost pebble-loam in the study area is interpreted to be the upper Snow School Formation. The Horseshoe Valley Formation is missing from the study area.

## Origin

On the basis of bedding, sorting, and nature of contacts the lower Snow School Formation is interpreted to be fluvial sediment; it was probably deposited by glacial meltwater streams. On the basis of sorting, extent, and topographic position the upper Snow School Formation is interpreted to be glacial sediment.

## Age

The age is unknown. It is no older than the latest Cenozoic. It is probably older than latest Wisconsinan.

## Source

Differences in pebble and granule lithology between the Snow School Formation and the Medicine Hill Formation suggest a different source area for the ice that deposited each of the upper members of the formations. The large amount of dolomite and limestone (probably derived from Paleozoic outcrops in Manitoba) suggests that the ice flowed from the northeast.

## Coteau Formation

The Coteau Formation has been informally named by Bickley (1972). In his definition, the Coteau Formation has two facies:

> One facies, the black, organic, silty clay facies is very common in the closed depressions of the Missouri Coteau. The other facies is found mainly in drainage bottoms and along the base of hillslopes. This facies is a dirty gray, organic, slightly pebbly, sandy silt and clay.

### Description of the formation

In the study area, the Coteau Formation consists of alternating dirty black, gray, and brown beds of pebbly sand, sandy silt, and silty clay (quite similar to the second facies of Bickley's definition).

The unit is found along the base of hillslopes (Figure 8).

### Regional extent and thickness

The unit occurs sporadically throughout the study area (see Bickley, 1972, for a discussion of the distribution of the unit outside of the study area).

The unit ranges from a few tens of millimeters to a few meters in thickness.

### Differentiation from other units

The only other unit the Coteau Formation could be confused with is the Oahe Formation. The Coteau Formation contains poorly sorted sediment, whereas the Oahe Formation contains well sorted sediment.

Fig. 8.--Contact (dashed line) of the Coteau Formation with the underlying Sentinel Butte Formation a few meters east of measured section 9. Note the paleosols in the Coteau Formation.

The Coteau Formation occupies the depressions between fairly steep hillslopes, whereas the Oahe Formation occupies the hill tops. Where the hillslopes are very gentle the Coteau Formation is missing and the Oahe Formation is draped down into the depression and up along the side of the hill (Figure 9). Several truncated paleosols are common in the Coteau Formation, whereas one continuous paleosol (in the Aggie Brown Member) is found in the Oahe Formation.

Origin

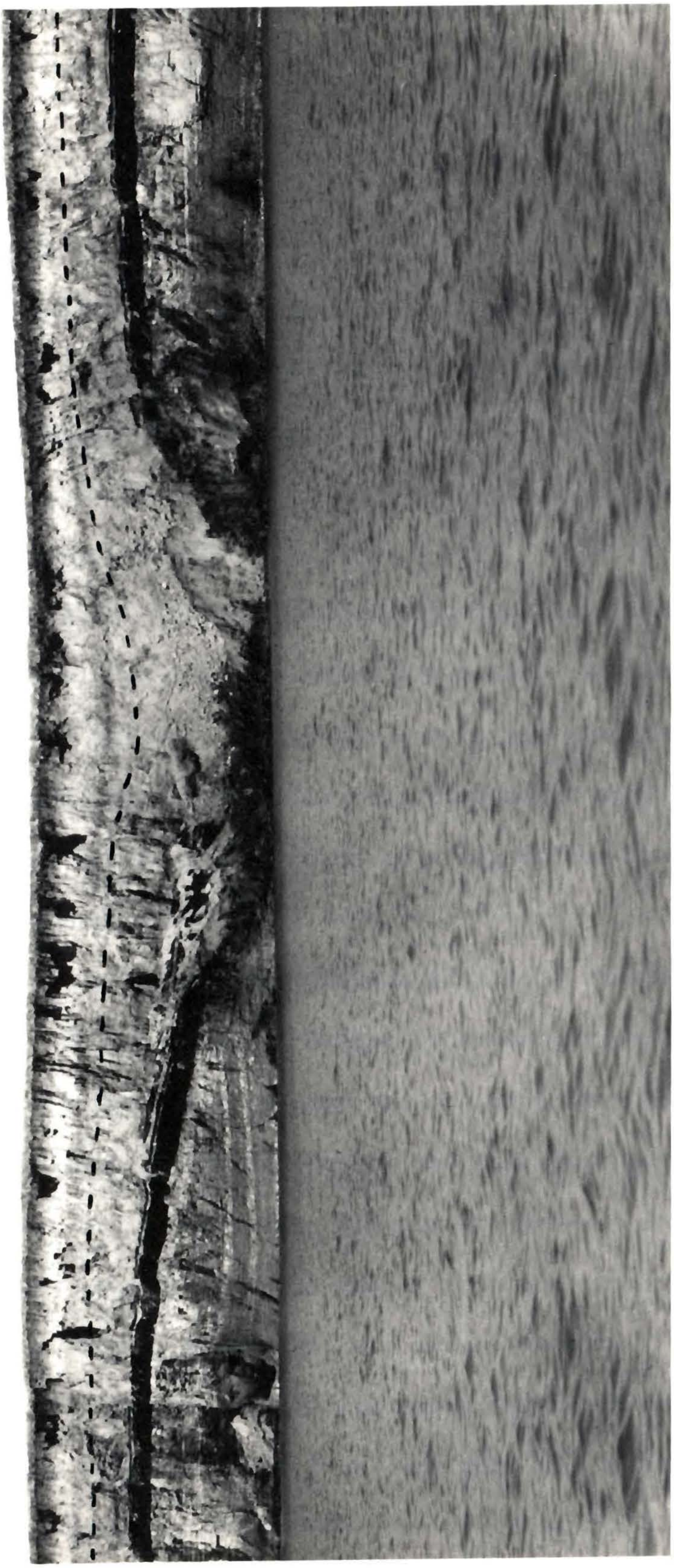
In the study area, the Coteau Formation is fluvial (valley fill) sediment and slope-wash sediment with minor amounts of windblown sediment.

Paleosols formed during stable (cool and moist) climatic conditions and were truncated by gullying during unstable (warm and dry) climatic conditions (Hamilton, 1967). Slope-wash processes contributed more sediment to the unit during unstable climatic times.

Age

The Coteau Formation rests on units at least as young as the upper member of the Snow School Formation. The Coteau Formation is the surface stratigraphic unit in many of the valley bottoms throughout the study area. The different number of paleosols from smaller to larger valleys makes detailed stratigraphy within the Coteau Formation difficult at this time. Considering the large amount of erosion that took place during unstable climatic conditions, it is unlikely that sediment deposited at the base of hillslopes would remain there for long periods of time. If this is the case, the

Fig. 9.--Oahe Formation (above dashed line) draped into a "pre-Snow School Valley."



age of the Coteau Formation would be much younger than the age of the upper Snow School Formation.

## Oahe Formation

### Description of the Formation

The Oahe Formation (described by Bickley, 1972) is subdivided, from bottom to top, into the Mallard Island Member, the lower and upper parts of the Aggie Brown Member, the Pick City Member, and the lower, middle, and upper parts of the Riverdale Member (Clayton, Moran, and Bickley, in preparation).

The Mallard Island Member ranges from less than 0.1 meter to 1.0 meter thick. It averages about 0.4 meter. The color is yellowish brown (10YR 5/6 moist). On the basis of a few samples, it averaged 12 percent sand, 66 percent silt, and 21 percent clay. Carbonate-coated pebbles are typically found as a lag at the base of the unit. The unit is unbedded.

The Aggie Brown Member ranges from less than 0.1 meter to 0.4 meter thick. The Aggie Brown Member is a conspicuously colored zone between the Mallard Island Member and the Pick City Member. The lower part is dark brown (7.5YR 3/2 moist) and the upper part is very dark gray (10YR 3/1 or 3/0 dry, from Clayton and others, in preparation). In outcrop the lower part looks redder than the upper part. The unit is texturally similar to the Mallard Island Member.

The Pick City Member is typically thicker than the underlying Mallard Island Member (ranges from less than 0.1 meter to 1.5 meters). The Pick City Member quite commonly is twice as thick as the Mallard

Member. The Pick City Member contains more silt and less sand ay than the Mallard Island Member. On the basis of 6 textural es, the member averages 9 percent sand, 73 percent silt, and cent clay. The member contains a few scattered pebbles. When ck City Member and the Mallard Island Member are moist, their appear similar. When the Pick City Member is dry, the color ht gray (2.5Y 7/3, after Clayton and others). The unit appears than the more yellow Mallard Island Member.

The Riverdale Member was not studied in detail to warrant a te description here. In general, the Riverdale Member consists om bottom to top, a dark zone (paleosol), a light zone (loess), dark zone (A, horizon of the modern soil). The thickness ranges ess than 0.1 meter to 1.0 meter. At places a third dark zone ying a depression on the top of the Pick City Member or on the loess above the Pick City Member) is found.

The Oahe Formation has well developed columnar jointing. The are typically more closely spaced in the Mallard Island and Brown Members than in the overlying units.

al extent

Part or all of the Oahe Formation is present throughout the n the highest bluffs (see Plate 1 for distribution). The unit sent on bluffs that are over 25 meters above lake level in the n part and on small islands that are only a few meters above ter level in the eastern part. The unit is draped over the ape. It is not present on every high bluff (Plate 1). Some s are typically missing when the Oahe Formation is exposed.

e most continuous members of the Oahe Formation are the Mallard land, Aggie Brown, Pick City, and the upper part of the Riverdale.

West of the study area in Mercer County along the shoreline Lake Sakakawea, Carlson (1972) notes the presence of the unit on attered bluffs.

fferentiation from other units

The only other unit the Oahe Formation could be confused with the Coteau Formation. Differentiation between those two units ve already been discussed under the Coteau Formation.

The presence of the Aggie Brown Member (consisting of a lower dder part and an upper darker gray part) between the lower, thinner, llowish Mallard Island and upper, thicker, light colored Pick City lows the two members to be differentiated. The overlying dark beds oth past and present A1 soil horizons) do not have a lower reddish rt as in the Aggie Brown Member.

igin

The Oahe Formation is interpreted to be wind-blown sediment. e dark beds in the unit are interpreted to be paleosols formed as result of changing climatic conditions.

e

Clayton and others (in preparation) summarize:

> It is probable that the Mallard Island Member was deposited during the late Wisconsinan glaciation, the Aggie Brown Member was deposited in the postglacial part of latest Wisconsinan time and in early Holocene time, the Pick City was deposited during the middle part of the Holocene, and the Riverdale Member was deposited during late Holocene time.

# GEOLOGIC HISTORY

## Latest Cenozoic History

### Preglacial history

The preglacial rivers in North Dakota flowed east-northeasterly toward Hudson Bay. The rivers carried clay, silt, sand, and gravel. The gravel and part of the finer material was derived from the Rocky Mountains or Black Hills. The pebbles are composed of porphyric igneous rock types, quartz, chert, chalcedony, agate, and "scoria." In the western part of the state, the Flaxville Formation of Pliocene (?) age is an example of this kind of preglacial fluvial deposit. In the study area, the Charging Eagle Formation was deposited in a river system that paralleled the preglacial river system. By late Tertiary and early Pleistocene time the major valleys had already been established in this area.

### Glacial history

The pebbles derived from the northeast in the Charging Eagle Formation represent the first evidence of glaciation in the area. The pebbles were transported by glacial meltwater. The glacier or glaciers that transported these pebbles may never have reached Mercer County.

The first conclusive evidence of glaciation in the area is the lenses of proglacial outwash gravel included in the pebble-loam of the Medicine Hill Formation. As the glacier that deposited the pebble-loam of the Medicine Hill Formation advanced through topographic lows (preglacial drainage system) it eroded the underlying fluvial sand and gravel that was in the valley bottoms. Complete mixing within the ice did not occur (Figure 7). Where the glacier advanced over the Sentinel Butte Formation, some subglacial thrusting occurred (Figure 10). At measured section 16 the thrust plane followed a weak clay bed that yielded under stress. The direction of the thrust indicates that the force of the glacial ice was from the east-northeast to the west-southwest (Figure 10 and measured section 16). As the glacier melted, it deposited its load. Many blocks eroded from the underlying Charging Eagle Formation were deposited intact. Many blocks were folded and faulted in the process of glacial erosion or as the glacier deposited its load. The net result of glacial deposition was a leveling effect--an individual layer of glacial sediment reaches its maximum thickness in old valley bottoms and thins as it goes up the hillslopes (the upper Medicine Hill Formation is probably found in many of the larger bays of Lake Sakakawea outside of the study area).

After an unknown amount of time and an unknown number of glaciations in North Dakota, Mercer County was again glaciated resulting in the deposition of the glacial sediment in the Snow School Formation. Extensive glaciation is indicated by the deposit of the glacial sediment of the Snow School Formation (Plate 1). By the time the glacier had come into the area, erosion had removed much of the glacial sediment from the hillslopes, leaving only thick deposits found in valley bottoms. As

Fig. 10.--Thrust block derived from the Sentinel Butte Formation (dashed line indicates the position of the glide plane of the thrust) at measured section 16.

the ice retreated, fluvial activity further modified the glacial deposit. This was the last record of glacial advance in Mercer County.

Late Wisconsinan and Holocene

The history of the late Wisconsinan and Holocene in Mercer County is interpreted from the sediment of the Oahe and Coteau Formations.

The silt of the Mallard Island Member is interpreted to have been derived from silt deposited on the Missouri River floodplain by glacial meltwater. The overlying members are interpreted to have formed as a result of climatic variations that took place after about 13,000 B.P. (Clayton, Moran, and Bickley, in preparation).

Stable climatic conditions (cool and moist) in North Dakota result in sod covered hillslopes. Unstable climatic conditions (warm and dry) in North Dakota result in hillslope erosion. The light-colored beds (the Pick City Member and the middle part of the Riverdale Member) were deposited as wind-blown silt (loess) eroded from unstable hillslopes. The dark colored beds (the Aggie Brown Member and the lower and upper part of the Riverdale Member) were deposited when the hillslopes were covered by vegetation.

As deposition of the Oahe Formation was going on the hilltops and in the gentle valley sides, deposition of the Coteau Formation continued in the valley bottoms. The valley bottoms had a fairly continuous supply of water during dry times; many paleosols are present. The water was supplied by discharging groundwater at the base of the hillslopes. Local floods carried sediment eroded from the hillslopes and covered soil that was in the valley bottom. At places it even cut through the vegetation cover in the valley bottom. This process repeated itself many times (more than twelve paleosols were counted at one locality). This process of valley cutting and filling, on a small scale within a single valley, has probably been going on ever since the ice that deposited the Snow School Formation left the area. The Coteau Formation is not thicker because sediment was continually being flushed from the smaller into the larger valley. Erosion of the hillslopes supplied the material deposited in the valley bottoms during unstable times. The sod covered hillslopes restricted erosion to the valley bottoms during stable climatic conditions.

Erosional surfaces occur on each of the formations in the study area. At places the surface is undulating and in places the surface is nearly horizontal. Although many preglacial valleys were partly filled by glacial deposits, the postglacial drainage system in part began to pattern itself again after the preglacial network. I saw no conclusive evidence of episodes of valley formation but rather one of valley activation. It appears that each time unstable climatic conditions prevailed, the valleys widened as a result of hillslope erosion. The sequence of events for some large valleys is as follows (1) glacial sediment of the Medicine Hill Formation filling deep preglacial valleys, (2) after a long interval of time erosion of the Medicine Hill Formation formed a new valley at the site of the preglacial valley, (3) glacial sediment of the Snow School Formation draped into post-Medicine Hill valleys, (4) after a long interval of time, erosion of the Snow

School Formation formed a new valley at the site of the post-Medicine Hill valley, (5) and finally there occurred a series of episodes of valley activation (hillslopes were eroded, deposits on hilltops were truncated, and alluvium was deposited in valley bottoms) and valley stabilization (vegetation covered the hillslopes, protecting them from erosion) from late Wisconsinan time up to the present.

The weathering profile on the top of the upper Snow School Formation was formed after the valleys on the upper member had formed (because calcium carbonate and organic accumulation follow the topography and are not truncated).

# HYDROGEOLOGY

Groundwater moves most rapidly through permeable sediment. In the study area the most permeable sediment is sand and gravel of fluvial origin. Sand and gravel are found typically within or between individual till sheets. The sand and gravel occupied the topographic lows on the preexisting topography. Groundwater also flows readily at the contact of different lithologic units and along joints. At these boundaries chemical precipitation occurs: (1) calcium-carbonate-rich zones in the pebble-loam (especially the Snow School Formation), (2) iron-oxide-cemention in gravel and sand, (3) and gypsum crystallization along joint planes in the pebble-loam and disseminated throughout some sand bodies.

Groundwater moves towards topographic lows. The major topographic low in the study area is Lake Sakakawea. Discharging groundwater at the base of the bluffs enhances the erosive activity of the lake's waves by lowering the resistance to stress of the sediment. Slump blocks are a common result. At one locality (a few meters northeast of measured section 8) a block about 5 meters thick, 15 meters high, and 30 meters long slumped. Slumping was enhanced at that place because sands of the Charging Eagle Formation underlie the block.

The permeable units (which may yield water and could be easily polluted) are the Charging Eagle Formation, the lower Snow

School Formation, and a few scattered lenses of sand and gravel lying in the depressions of the upper-eroded surface of the Snow School Formation. Of these units, only the Charging Eagle Formation yields enough water for small domestic needs (see Plate 1 for physical framework representation).

# APPENDIX I

## DESCRIPTION OF THE TYPE SECTION OF THE CHARGING EAGLE FORMATION

The elevation of Lake Sakakawea was 563 meters at the time the llowing description was made.

The type section from bottom to top consists of the following: ) 1 meter covered, (2) 0.7 meter of black, calcareous, partly lami- ted, silty clay, and clayey silt, (3) 1.4 meters of gray, calcareous, gnitic, poorly sorted, clayey, silty and containing kappa and nu oss-stratification (classification of cross-stratification from len, 1963), (4) 6.8 peters of gray, calcareous, lignitic, gypsum- aring, very slightly pebbly, silty sand with predominately large- ale, grouped crossbedding and some small-scale, grouped crossbedd- ;, (5) 0.4 meter of gray, calcareous, lignitic, poorly sorted, yey, silty sand containing kappa and nu cross stratification, 0.5 meter of yellowish, calcareous, lignitic, poorly sorted, yey, silty sand containing some small-scale crossbedding, and 4.1 meters of grayish-yellow, calcareous, lignitic, poorly ted, very slightly pebbly, silty sand and sandy silt, both of ch contain small-scale crossbedding and planar beds.

APPENDIX II

TABLE 4

TEXTURAL ANALYSES OF THE LOAM

| Measured Section | Texture (Sand-Silt-Clay Percentage) | | | Formation |
|---|---|---|---|---|
| 1 | 24.0 | 37.9 | 38.1 | Snow School |
| 1 | 24.8 | 42.7 | 32.5 | Snow School |
| 2 | 29.1 | 40.5 | 30.4 | Snow School |
| 2 | 28.4 | 43.4 | 28.2 | Snow School |
| 3 | 25.2 | 43.4 | 31.5 | Snow School |
| 3 | 25.7 | 42.3 | 32.0 | Snow School |
| 3 | 30.0 | 35.1 | 34.9 | Snow School |
| 3 | 27.2 | 45.1 | 27.7 | Snow School |
| 3 | 28.1 | 37.8 | 34.1 | Snow School |
| 4 | 23.0 | 42.7 | 34.2 | Medicine Hill |
| 4 | 22.6 | 41.5 | 35.8 | Medicine Hill |
| 4 | 24.2 | 42.0 | 33.7 | Snow School |
| 4 | 26.5 | 42.0 | 31.5 | Snow School |
| 4 | 26.4 | 40.5 | 33.1 | Snow School |
| 5 | 21.8 | 46.8 | 31.4 | Medicine Hill |
| 5 | 22.6 | 42.1 | 35.3 | Medicine Hill |
| 5 | 22.7 | 48.3 | 29.1 | Snow School |
| 5 | 23.3 | 46.8 | 29.9 | Snow School |
| 6 | 22.1 | 33.0 | 44.8 | Medicine Hill |
| 7 | 25.0 | 44.5 | 30.6 | Medicine Hill |
| 7 | 24.6 | 47.0 | 28.5 | Medicine Hill |
| 7 | 23.1 | 37.8 | 39.1 | Snow School |
| 7 | 22.7 | 39.7 | 37.6 | Snow School |
| 8 | 30.6 | 42.6 | 26.8 | Medicine Hill |
| 8 | 49.6 | 34.0 | 16.5 | Medicine Hill |

TABLE 4--Continued

| easured Section | Texture (Sand-Silt-Clay Percentage) | | | Formation |
|---|---|---|---|---|
| 8 | 23.8 | 39.2 | 37.0 | Snow School |
| 8 | 29.8 | 42.5 | 27.6 | Snow School |
| 9 | 38.7 | 41.9 | 19.4 | Medicine Hill |
| 9 | 43.6 | 47.9 | 8.4 | Medicine Hill |
| 9 | 17.1 | 54.9 | 28.0 | Snow School |
| 9 | 23.1 | 41.2 | 35.7 | Snow School |
| 9 | 24.3 | 41.0 | 34.8 | Snow School |
| 10 | 25.8 | 43.3 | 30.8 | Snow School |
| 10 | 24.7 | 42.2 | 33.1 | Snow School |
| 11 | 30.9 | 40.7 | 28.4 | Medicine Hill |
| 11 | 33.5 | 38.5 | 28.0 | Medicine Hill |
| 11 | 24.2 | 40.1 | 35.7 | Snow School |
| 11 | 25.0 | 40.5 | 34.5 | Snow School |
| 12 | 26.5 | 39.0 | 34.5 | Snow School |
| 12 | 24.8 | 42.7 | 32.5 | Snow School |
| 13 | 14.7 | 42.9 | 42.4 | Medicine Hill |
| 13 | 24.3 | 41.9 | 33.9 | Medicine Hill |
| 13 | 23.7 | 37.2 | 39.0 | Snow School |
| 14 | 25.4 | 40.5 | 34.1 | Snow School |
| 14 | 26.3 | 38.7 | 34.9 | Snow School |
| 15 | 25.8 | 41.8 | 32.4 | Snow School |
| 15 | 26.6 | 34.7 | 38.7 | Snow School |
| 17 | 26.8 | 38.5 | 34.7 | Snow School |
| 17 | 22.8 | 36.8 | 40.1 | Snow School |
| 18 | 24.5 | 37.0 | 38.5 | Snow School |
| 18 | 27.0 | 35.3 | 37.7 | Snow School |

TABLE 4--Continued

| easured Section | Texture (Sand-Silt-Clay Percentage) | | | Formation |
|---|---|---|---|---|
| 19 | 26.7 | 37.8 | 35.5 | Snow School |
| 19 | 26.9 | 38.3 | 34.8 | Snow School |
| 20 | 27.4 | 36.8 | 35.8 | Snow School |
| 20 | 27.4 | 37.0 | 35.5 | Snow School |
| 21 | 27.8 | 42.1 | 30.1 | Medicine Hill |
| 21 | 29.2 | 39.8 | 31.0 | Medicine Hill |
| 22 | 33.4 | 45.8 | 20.8 | Medicine Hill |
| 22 | 32.2 | 39.6 | 28.2 | Medicine Hill |

The locations of the measured sections are found on the map on late 1.

The following textural analyses of loam were made from samples collected at localities that were not included in the measured sections.

TABLE 5

TEXTURAL ANALYSES OF THE LOAM NOT IN THE MEASURED SECTIONS

| Location | N # | Texture (Sand-Silt-Clay Percentage) | | | Formation |
|---|---|---|---|---|---|
| NW¼, NE¼ sec. 26 | N 1056 | 28.9 | 50.0 | 21.0 | Snow School |
| T.147N., R.85W. | | 27.6 | 43.0 | 29.4 | Snow School |
| SW¼, SE¼ sec. 14, | N 1057 | 29.6 | 39.8 | 30.5 | Snow School |
| T.147N., R.85W. | | 28.9 | 44.8 | 26.3 | Snow School |
| | | 27.8 | 49.3 | 22.9 | Snow School |
| | | 30.4 | 39.3 | 30.3 | Snow School |
| NE¼ NE¼ sec. 24, | N 1058 | 27.0 | 39.9 | 33.2 | Snow School |
| T.147N., R.85W. | | 25.1 | 42.0 | 33.0 | Snow School |
| SW¼, SE¼ sec. 13, | N 1059 | 28.3 | 37.6 | 34.0 | Snow School |
| T.147N., R.85 W. | | 27.8 | 38.4 | 33.8 | Snow School |
| | | 27.8 | 42.1 | 30.0 | Snow School |
| SE¼, SE¼ sec. 23, | [illegible] | 27.5 | 40.7 | 31.8 | Snow School |
| T.147N., R.85 W. | | 27.3 | 38.9 | 33.7 | Snow School |
| SE¼, SW¼ sec. 14, | [illegible] | 21.7 | 45.9 | 32.4 | Snow School |
| T. 147N., R.85W. | | 23.0 | 43.4 | 33.6 | Snow School |

# APPENDIX III

One hundred pebbles and grains of very coarse sand were taken out of blocks of the pebble-loam and were separated into five lithologic categories.

"S.S." and "M.H." indicate Snow School and Medicine Hill Formations. Where a block was taken other than from a measured section, its location is given in the column titled measured section. For the location of the measured sections see the map on Plate 1.

TABLE 6

PEBBLE AND VERY COARSE SAND LITHOLOGY IN THE LOAM OF THE MEDICINE HILL AND SNOW SCHOOL FORMATIONS

| Limestone and Dolomite | Light-Colored Crystallines | Dark-Colored Crystallines | Shale | Concretions Sandstone and Siliceous Rocks | Formation | Measured Section |
|---|---|---|---|---|---|---|
| 46 | 19 | 17 | 8 | 10 | S.S. | 1 |
| 56 | 20 | 11 | 9 | 4 | S.S. | 2 |
| 60 | 15 | 6 | 15 | 4 | S.S. | 3 |
| 29 | 10 | 10 | 42 | 9 | M.H. | 4 |
| 43 | 16 | 15 | 22 | 4 | S.S. | 5 |
| 29 | 7 | 3 | 52 | 9 | M.H. | 6 |
| 26 | 15 | 6 | 26 | 27 | M.H. | 7 |
| 40 | 6 | 6 | 39 | 9 | M.H. | 8 |
| 46 | 14 | 7 | 27 | 6 | S.S. | 8 |
| 29 | 14 | 3 | 51 | 3 | M.H. | 9 |
| 48 | 17 | 13 | 14 | 8 | S.S. | 9 |
| 42 | 20 | 4 | 24 | 10 | S.S. | 10 |
| 20 | 21 | 8 | 34 | 17 | M.H. | 11 |
| 50 | 15 | 8 | 20 | 7 | S.S. | 11 |
| 49 | 17 | 12 | 17 | 5 | S.S. | 12 |
| 26 | 16 | 6 | 45 | 7 | M.H. | 13 |
| 55 | 16 | 5 | 18 | 6 | S.S. | 13 |

TABLE 6--Continued

| Limestone and Dolomite | Light-Colored Crystallines | Dark-Colored Crystallines | Shale | Concretions Sandstone and Sili-ceous Rocks | Formation | Measured Section |
|---|---|---|---|---|---|---|
| 42 | 21 | 13 | 20 | 4 | S.S. | 14 |
| 30 | 16 | 5 | 43 | 6 | M.H. | 15 |
| 51 | 15 | 9 | 13 | 12 | S.S. | 15 |
| 52 | 10 | 7 | 23 | 8 | S.S. | 17 |
| 51 | 13 | 10 | 19 | 7 | S.S. | 18 |
| 40 | 12 | 10 | 29 | 9 | S.S. | 19 |
| 38 | 7 | 9 | 7 | 39 | S.S. | 20 |
| 27 | 15 | 6 | 41 | 11 | M.H. | 21 |
| 38 | 11 | 6 | 31 | 14 | M.H. | 22 |
| 54 | 13 | 3 | 9 | 21 | S.S. | NW¼, NE¼ sec. 26, T.147N., R.85W. |
| 53 | 24 | 9 | 7 | 7 | S.S. | SW¼, SE¼ sec. 14, T.147N., R.85W. |
| 56 | 18 | 11 | 6 | 9 | S.S. | NE¼, NE¼ sec. 24, T.147N., R.85W. |

TABLE 6--Continued

| Limestone and Dolomite | Light-Colored Crystallines | Dark-Colored Crystallines | Shale | Concretions Sandstone and Sili-ceous Rocks | Formation | Measured Section |
|---|---|---|---|---|---|---|
| 44 | 30 | 12 | 10 | 4 | S.S. | SW¼, SE¼ sec. 13, T.147N., R.85W. |
| 52 | 16 | 8 | 9 | 15 | S.S. | SE¼, SE¼ sec. 23, T.147N., R.85W. |
| 39 | 7 | 11 | 35 | 8 | S.S. | SE¼, SW¼ sec. 14, T.147N., R.85W. |
| 42 | 14 | 8 | 21 | 15 | S.S. | SW¼, NE¼ sec. 23, T.147N., R.85W. |

# APPENDIX IV

TABLE 7

X-RAY ANALYSES OF THE CLAYS IN THE LOAM

| Measured Section | Formation | Montmorillonite | Illite | Kaolinite |
|---|---|---|---|---|
| 4 | M.H. | 73 | 14 | 13 |
| 5 | M.H. | 68 | 17 | 15 |
| 6 | M.H. | 72 | 17 | 11 |
| 7 | M.H. | 73 | 14 | 13 |
| 7 | M.H. | 67 | 16 | 17 |
| 11 | M.H. | 66 | 17 | 16 |
| 13 | M.H. | 68 | 11 | 20 |
| 13 | M.H. | 72 | 15 | 15 |
| 1 | S.S. | 73 | 13 | 14 |
| 1 | S.S. | 72 | 14 | 15 |
| 3 | S.S. | 73 | 16 | 11 |
| 2 | S.S. | 65 | 18 | 16 |
| 5 | S.S. | 68 | 17 | 16 |
| 4 | S.S. | 73 | 15 | 12 |
| 12 | S.S. | 66 | 21 | 14 |
| 13 | S.S. | 70 | 15 | 15 |

The locations of the measured sections are found on Plate 1. "S.S." and "M.H." indicate Snow School and Medicine Hill Formations. Number in the clay column indicates percentage.

The average for the Medicine Hill Formation is 70 percent montmorillonite, 15 illite, and 15 percent kaolinite. The average for the Snow School Formation is 70 percent montmorillonite, 16 percent illite, and 14 percent kaolinite.

See Ulmer (in preparation) for a description of the procedure used in analyzing the clays and how the percentages were calculated.

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## REFERENCES

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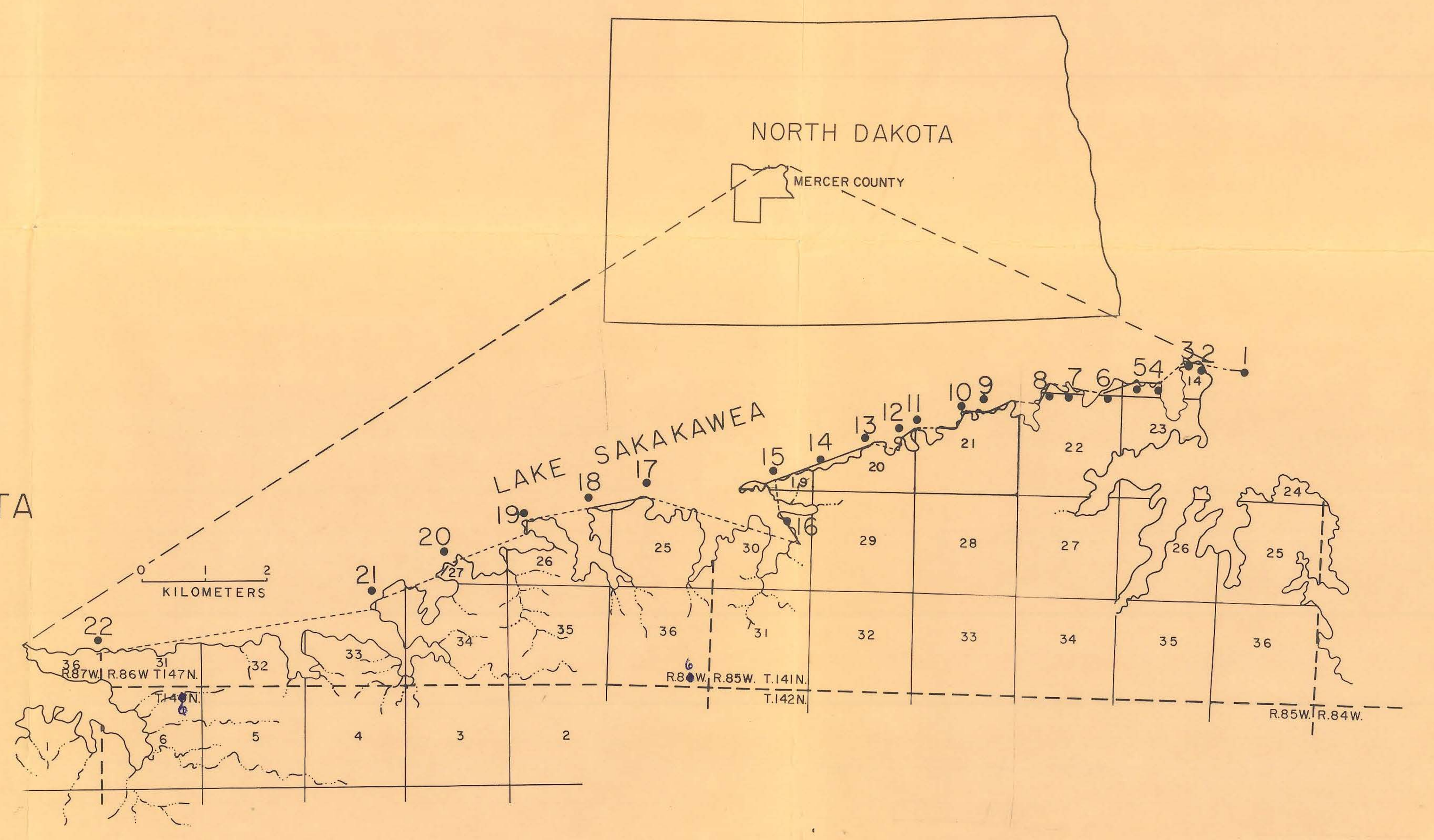
# PLATE I  STRATIGRAPHIC CROSS SECTION OF NORTHEAST MERCER COUNTY, NORTH DAKOTA




## EXPLANATION

- Upper Oahe Formation, includes the Pick City Member and Riverdale Member (the heavy line represents the lowest bed of the Riverdale Member)
- Lower Oahe Formation, includes the Mallard Island Member and the Aggie Brown Member
- Coteau Formation
- Upper Member of the Snow School Formation
- Lower Member of the Snow School Formation
- Medicine Hill Formation
- Charging Eagle Formation
- Sentinel Butte Formation (the heavy line represents various marker beds)
- Silt
- Sand, (the heavy line represents crossbedding)
- Sand and gravel
- Gravelly, sandy, silty clayey organic-rich sediment
- Pebble-loam
- Carbonate accumulation
- Lignite
- Alternating beds of sand, silt and clay


Scale for the stratigraphic cross section