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The Glacial Geology of Northern McIntosh County

Gary G. Thompson

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GLACIAL GEOLOGY
OF NORTHERN MCINTOSH COUNTY, NORTH DAKOTA

by
Gary G. Thompson

A Senior Thesis
Submitted to Dr. L. B. Gillett
in Fulfillment of Geology 420

Grand Forks, North Dakota
May 22
1962
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GLACIAL GEOLOGY
OF NORTHERN MCINTOSH COUNTY, NORTH DAKOTA

Gary G. Thompson

INTRODUCTION

Location

The area that was studied is situated in the westernmost 5½ townships of Range 132 North along the northern boundary of McIntosh County in south-central North Dakota. (See fig. 1.)

Previous studies

Todd first described the features of the Missouri Coteau in 1896 in a broad, sweeping survey of North and South Dakota.

Laird (1948) carried out a groundwater investigation in the vicinity of Zeeland, North Dakota, in southwest McIntosh County.

In 1952, Fischer mapped the geology of Emmons County which borders McIntosh County on the west.

Lemke compiled a glacial map of North Dakota in 1956 largely from aerial photo interpretation.

Master's theses on glacial geology were done in Logan County, immediately to the north, by Bonneville and Clayton in 1960. Clayton has mapped McIntosh County other than the area covered in this report.
FIGURE 1.--Index map and physiographic map of North Dakota (from Lemke and Colton, 1958).
and is presently incorporating his work, together with his work on Logan County, into a report for the North Dakota Geological Survey.

Field methods

This reconnaissance survey was preceded by a study of 33 aerial photos, scaled at one inch to the mile. The field work was done from June 5 to July 15, 1961. The photos were carried into the field and were very useful in showing the areal relationships of landforms.

Lithologies were checked in road cuts, stream cuts, or by hand-augering approximately every one-fourth mile along all passable roads (nearly all followed section-lines). The lithology, along with estimated surface boulder density, estimated local relief, and topographic features, was noted symbolically on a county base map scaled at one inch to the mile. The more significant exposures were described in detail.

Acknowledgments

Field work was done as a student assistant with the North Dakota Geological Survey. Mr. Lee Clayton, whom I assisted in the field, has given me innumerable hints and suggestions which have constantly stimulated my work. I thank Mr. S. J. Tuthill, who is studying the Pleistocene mollusks and has volunteered much valuable information.

PHYSIOGRAPHY

Drainage

Essentially, all streams in the area are tributary to the Missouri
River. All are ephemeral and during the field season nearly all were dry. The largest streams are tributary to Beaver Creek which flows within a mile of the northwest corner of the county. In the eastern half of the area, streams are short and flow into undrained depressions, forming many ephemeral saline lakes. Green Lake and Clear Lake are examples of the few permanent, fresh, spring-fed lakes found in outwash in the eastern half of the area.

Physiographic Divisions

Two physiographic districts have been recognized in the map-area. Lemke and Colton (1958, fig. 1) recognized the Coteau du Missouri district and an unnamed district of the Glaciated Missouri Plateau section in south-central North Dakota. Clayton (unpublished) refers to the unnamed district as the Coteau Slope district. The meltwater channel sloping to the northwest at the west edge of Wishek (see pl. 1) marks the approximate boundary between the Coteau du Missouri district to the east and the Coteau Slope district on the west.

Coteau du Missouri district

The Coteau du Missouri district is characterized by morainic topography. It is typically hilly with nonintegrated drainage and many undrained depressions.

Coteau Slope district

The Coteau Slope district is characterized by stream-eroded topography with completely integrated drainage.

This district is divided into two subdistricts (Clayton, in preparation). (See fig. 2.)
FIGURE 2.—Physiographic map of northern McIntosh County.
Beaver Creak subdistrict

This unit includes the Beaver Creek trench which is as much as 100 feet below the surrounding uplands. It is underlain by the Upper Cretaceous Fox Hills Sandstone and small isolated patches of drift. Local relief is up to 40 feet. Drainage divides are sharp and slopes are steep.

Wishek subdistrict

This unit includes the highest elevations in the map-area, reaching above 2200 feet. It is underlain by patches of Napoleon drift and Fox Hills Sandstone. Local relief is up to 20 feet.

**GEOMORPHOLOGY**

**End Moraine**

The Burnstad end moraine and the Streeter end moraines cross the map-area in a general north-south direction. In northern McIntosh County, the Burnstad is a prominent till ridge whereas the Streeter is made up of low linear ridges of till with much associated outwash.

The Burnstad end moraine is about five miles east of Wishek. It is a ridge up to three miles wide at its base and reaches to 300 feet above the surrounding depressions although generally it is about 100 feet high. Local relief within the moraine is up to 25 feet. Meltwater channels breach the moraine as deep valleys.

The Streeter end moraine crosses the eastern edge of the map-area. It is made up of ridges less than 15 feet high that are not apparent in
the field but clearly discernible on aerial photos. Collapsed outwash lies between these till ridges and lake sediment is closely associated with them in places. Five miles east and 3 miles south of Lehr is a push moraine that is part of the Streeter moraine. Broad uniform slopes about a hundred yards wide and up to a mile in length are apparently surfaces of thrust blocks made up of contorted till, outwash, and lake sediment. A slight readvance of the glacier apparently thrust this drift a short distance onto an abuttment and then retreated.

A small part of a third end moraine, the Venturia moraine, is about 5 miles south of Wishek. It is a high area of till but is less conspicuous than the Burnstad or Streeter moraines.

**Ground Moraine and Dead-ice Moraine**

Ground moraine formed of lodgement till or ablation till is present only in patches just northeast of Wishek and in the area of eroded bedrock topography of the western part of the area. In the eastern half of the area, where "normal" ground moraine would be expected, the topography is dead-ice moraine. Dead ice moraine is the surface expression of drift that has been let down from isolated sheets of stagnant ice.

**Hills and ridges of outwash**

West of Wishek, numerous gravel ridges are conspicuous, especially on aerial photos. They vary in width from about 20 to 100 yards at their bases, are roughly 10 to 20 feet high, and are up to one-half mile long. They are entirely sand and gravel in the exposures observed and exhibit no distinct bedding. Most are oriented in an east-west direction.
Also in this western portion, small gravel knolls dot the surface. They generally range in height from 5 to 30 feet and vary from 30 to 60 yards in diameter. In the extremely dissected area at the west edge of the map, these small gravel deposits cap isolated hills or ridges as high as 50 feet. The arc of gravel hills in sec. 17, T. 132 N., R. 73 W. is an example of these higher gravel-capped ridges. In some of these deposits the gravel is folded and faulted.

Whether these ridges and knolls are remnants of eskers or of crevasse fillings is difficult to say. Erosion has proceeded far enough to alter any original constructional topography so that any sinuous esker pattern or straight crevasse pattern is unrecognizable.

East and south of Lehr, low ridges of outwash also are clearly visible on aerial photos. They are associated with the dead-ice moraine and the low-ridged Streeter end moraine. A very prominent ridge of outwash in sec. 32, T. 132 N., R. 68 W. trends straight northeast-southwest and rises abruptly between two sloughs. It is about 25 feet high and three-fourths of a mile long with a nearly vertical side facing southeast and a gentle north-facing slope. It parallels the ridged push moraine which is less than a mile to the northwest and is probably due to similar ice-shove.

Disintegration trenches

In the extreme southeast corner of the map area a group of short blind valleys intersect in a polygonal pattern. All appear Υ-shaped in cross-section with their sides convex upward. They are about 100 yards
wide at the brim and about 15 feet deep. Clayton (in preparation) has recognized similar features in Logan County and elsewhere in McIntosh County has called them "disintegration trenches." He has outlined a very plausible hypothesis for their origin:

1. Supraglacial channels or crevasses that extend only part way to the base of the stagnant mass of glacial ice were filled with till or outwash (fig. 3a).

2. This till or outwash insulated the underlying ice as the surrounding ice melted, resulting in either straight (under the crevasse) or sinuous (under the stream channel) ice-cored ridges of till or outwash. Many of these "channel deposits which have been converted to ridge cappings by differential melting" have been observed by Sharp (1949, p. 295) near the stagnant terminus of the Wolf Creek Glacier in the Yukon (fig. 3b).

3. The ice-cored ridges of till or outwash were then covered with outwash (fig. 3c).

4. When the ice core melted, the overlying newly deposited outwash collapsed, producing trenches, the inverted equivalent of the ice-cored ridges (fig. 3d).

Perched lake plain

The town of Lehr is on a plateau underlain by lake sediment. The plateau is about one square mile in extent (see fig. 4). This surface is bounded by an escarpment on its north, northeast, and northwest. To the south, southeast, and southwest it slopes more gently to a lower undulating surface underlain by lake sediment and outwash that is gently folded. This undulating surface extends up to three miles to the southeast where it grades into collapsed outwash topography. (see pl. 1)

The lake sediment is predominantly laminated yellow silt. Sand and gravel are found especially in the northeast corner of the lake bed. Silt
FIGURE 3.--Diagramatic cross-section of sequence of events in the formation of disintegration trenches.
FIGURE 4.--Cross-section of perched Lake Lehr.
Elevations determined by Paulin Altimeter.
grades into sand towards the southeast. Gray clay interbedded with silt and sand was found in a freshly-dug schoolhouse basement in the town of Lehr.

Bonneville (1961) referred to this landform as a perched lake plain, composed of sediments deposited in Glacial Lake Lehr. He postulated that the Glacial Lake Lehr was restricted on three sides by a mass of stagnant ice and on the west side by the Burnstad end moraine. When the ice melted, the sediments that had accumulated in the basin were left standing in the form of a flat-topped hill partly surrounded by an ice-contact face. Clayton (in preparation) describes similar perched lakes in Logan County.

Two localities in Lake Lehr sand and silt have yielded abundant mollusk fossils. S. J. Tuthill has collected articulated clam shells, snail shells, and ostracode carapaces from fine sand in the NW sec. 21, T. 132 N., R. 69 W. Abundant snails and ostracodes were found in a road-cut through an ice-contact face of the lake bed in the NW 1/4 sec. 14, T. 132 N., R. 69 W.

The following fossils have been identified from Lake Lehr sediments.

Clams (identified by S. J. Tuthill)
Naiades (one containing large pearl)
Snails (identified by S. J. Tuthill)
Armiger crista (Linne)
Amnicola limosa say
Valvata tricarinata (say)
Promenetus exucuous (Baker)
Pisidium sp.
Gyraulus sp.
Physa sp.
Heliosoma antrosa (Conrad)

Ostracodes (identified by Denis Delorme of University of Alberta)

Limnocytherea sp.
Eucandona cf. caudata
Eucandona sp.
Eucandona swaini
Cyclocypris cf. C. forbesi
Cyclocypris sp.
Illyocypris bradyi
Illyocypris sp.
Illyocypris gibba
Eucandona cf. E. ohioensis
Cytheria lacustris

Bonneville described Lake Lehr as covering 25 square miles. Field evidence indicates that a better estimate would be 10 square miles. Also, Bonneville implied that all of the lake sediment is undisturbed, except for slumping near the ice-contact edges. The lower uneven surface with its disrupted bedding indicates that most of the lake bed has collapsed (see pl. 1). This part of the lake was not only ice-walled but also underlain by stagnant ice which eventually melted and caused the overlying beds to be let down and consequently slightly distorted.
Proglacial Landforms

Outwash Plain

The town of Wishek is on a flat to undulating surface that is underlain by outwash. This outwash plain extends in all directions from Wishek and covers approximately 12 square miles. The local relief on this surface is less than 10 feet except where it is cut by meltwater channels which are as much as 25 feet deep. Sand and gravel, as determined in some pit exposures, is at least 30 feet thick here and shows much cut-and-fill cross-bedding.

Collapsed Outwash Plain

In an area about 5 miles southeast of Lehr is a hummocky surface underlain by outwash. Local relief on this surface is about 10 to 15 feet. The term "collapsed outwash plain" is used for this landform in the sense that a flat plain of outwash was first deposited and later collapsed as the underlying ice melted. The total thickness of sand and gravel is not known, but in one pit gravel was found to be 12 feet thick.

Valley Trains

Long bodies of outwash are confined to some of the valleys. If most of the valley's flat-bottomed form is due to deposition of this outwash it is called a "valley train." In the western part of the area the valley trains usually have a cover of alluvium and are often entrenched by postglacial stream erosion. In the extreme southwest corner of the map-area (see pl. 1) a valley train is represented only by a dissected terrace.
Meltwater Channels

If a valley's topographic form is due to the erosive action of meltwater it is termed a "meltwater channel." In cross-section, a meltwater channel is usually U-shaped with a bottom that is broad and flat relative to its steep sides. The best example is the channel 1/2 mile west of Wishek. However, this meltwater channel loses its characteristic shape about three miles south of Wishek and becomes a valley train. Other examples are the small, steep-walled, channels that breach the Burnstad end moraine.

Non-glacial Landforms

Channel fill and linear drainage

Tributary drainage in the western part of the map-area is distinctly oriented at about north 50° west. On aerial photos other vague linear features parallel and accentuate this tributary pattern.

Flint (1955) described lineation having the same direction in South Dakota. He attributed it to drainage oriented by longitudinal dunes which migrated across the area under the influence of strong prevailing winds from the northwest. Streams were forced to flow in the bare interdune areas. Outwash, Fox Hills Sandstone, or Pierre Shale may have been the source for the dune material.

White (1961) did not accept the dune hypothesis. He found that relatively young tributaries of western South Dakota streams were aligned. If dunes were the cause for their alignment, the dunes should have still been present within historic time; but there is no evidence that they were.
White shows that prevailing northwesterly winds have eroded the soil layer from areas during times of drought or just after prairie fires (which were more frequent and extensive before man's settlement). This fine soil material is deposited in drainageways not aligned with the wind direction. By this mechanism, only those drainageways that are aligned with the wind direction remain unobstructed and thus can carry on more rapid erosion. Any channel deviating from the prevailing wind direction would tend to be filled. Larger streams would not be affected by the small amount of eolian material.

In the western part of the map-area, road-cuts expose a number of channel-fills, in Fox Hills silt and clay, none of which are oriented northwest-southeast. The channel-fill material is dark brown silt, apparently wind-laid, with a basal concentration of pebbles and cobbles covering the original channel surface in places (see fig. 5). These channel-fills could represent unaligned drainageways that had been filled with wind-blown material. This is evidence in support of White's proposed mechanism. However, blowouts and small dunes in unconsolidated Fox Hills sands and silts may contribute to the general northwest-southeast trend seen on aerial photos.

The time of channel-filling was most likely post-glacial in this area. The pebbles and cobbles at the base of the channels are probably residual from glacial till or outwash as the same lithologies are present in tills of the area. Also, no drift is found overlying the silt in the channel although boulders are strewn on the surface on either side of the channel-fill. Some of these boulders appear to be wind-polished.
FIGURE 5.--Road-cut showing cross-section of channel-fill, looking east.
Escarpments

Because of their prominence, two escarpments have been mapped (see pl. 1). One divides two physiographic units and the other is an ice-contact face.

The first of these is in the west and separates the Beaver Creek subdistrict and the Wishek subdistrict. It represents the limit of headward erosion by tributaries of Beaver Creek.

The second escarpment is in two segments around the perched Glacial Lake Lehr plain and within the collapsed outwash plain about four miles east and three miles south of Lehr. Part of it is an ice-contact face. The other part of it is the surface expression of a buried ice-contact face (the original deposits and the adjacent ice were, at one time, covered by outwash that fell over the true ice-contact face as the ice melted; see fig. 6).

Patterned Ground

Certain shallow road-cuts expose a very distinct pattern of nonsorted polygons (Washburn, 1956) extending from two to three feet below the surface of till or silt and clay bedrock (see fig. 7a). Darker silt and clay of the upper-most soil horizon have dropped into fractures in the parent material so that the pattern of these fractures is usually conspicuous against a light background. In one exposure, however, the fracture-fillings were white below 1.5 feet (see fig. 7a). It can be seen in the photo that the white pattern is below what appears to be a fairly well-developed "A" soil horizon. Apparently, calcium carbonate, which makes up most of the white material, is precipitated
FIGURE 6.—Diagram showing formation of buried ice-contact face.
FIGURE 7.--Road-cuts show patterned ground (a) shows lower white fracture fill.
preferentially in the "B" soil horizon of the fractures rather than the same horizon of the clay-silt parent material (bedrock in this case). An explanation of this might be that the material in the cracks is less compacted than the parent material and permits better circulation of ground water.

The exact mechanism which causes the fractures is unknown. Only a detailed study of the many exposures in the area could give evidence of their origin.

**STRATIGRAPHY**

**Upper Cretaceous Series**

**Pierre Shale**

The Pierre Shale underlies the eastern half of the map-area but does not crop out. Test drill holes show that the Pierre is overlain by as much as 200 feet of drift. This drift, especially in the eastern part of the area, contains abundant pebbles and cobbles of dark gray fissile shale that is characteristic of the Pierre. The nearest outcrop of Pierre is near Linton, in Emmons County to the west.

**Fox Hills Sandstone**

The Fox Hills Sandstone probably makes up all of the exposed bedrock in the map-area. Hesitation in distinguishing the Fox Hills as the only unit exposed results from the lack of good descriptions and correlation of bedrock units in the region.

One outcrop of hard siliceous sandstone is 0.5 miles south of the northwest corner of sec. 14, T. 132 N., R. 73 W. This sandstone crops...
out as a ledge in an escarpment (mentioned below) and appears to be at the same level as a butte-capping sandstone described by Fischer a few miles to the west in Emmons County, as the very top of the upper Colgate Member of the Fox Hills. The sandstone is massive, gray to dark gray, weathering reddish brown in some thin layers. Siliceous wood fossils, including branched pieces up to 2 inches in diameter and in an upright position, are abundant. Cone-like bodies about 1-2 cm in diameter were found in one zone.

For approximately forty feet below the sandstone, unfossiliferous brown, gray, and yellowish silt and clay layers predominate, with occasional thin limonitic layers. In a few exposures white, bedded sandstone concretions up to 3 feet in diameter were found in silts and clays.

Folding and faulting on bedrock due to ice-thrusting is evident in many exposures of the Fox Hills (see fig. 8). Besides being folded, the different lithologies disrupted into a checkerboard pattern crossed by calcium carbonate-stained joints.

Tertiary

The Tertiary is represented only in the form of erratics in the glacial drift. Boulders and cobbles of "pseudo-quarzite" are found in the older drift west of Wishek. This quartzite is very hard and is usually gray or light brown on a fresh surface with occasional red or dark brown stains. It is composed of angular quartz grains floating in a matrix of microcrystalline silica (Clayton, unpublished). It has a characteristic
FIGURE 8.—Ice-thrust bedrock structures. (a) horizontal fault through asymmetric fold, looking east, NW\(\frac{1}{4}\) sec. 21, T. 132 N., R. 73 W.
polished surface and often shows molds and impressions of stems or roots.

Hares (1928) described similar "pseudo-quartzites" in southwestern North Dakota. These occurred in the Tongue River Formation of Paleocene Age. According to Mitchell and Laird (1942) the rock is the result of case hardening at or near the surface above siliceous ash deposits.

Near the Emmons County line there are boulders of this rock up to 3 feet across that show indistinct bedding. About 0.2 mile west of the southeast corner of sec. 32, T. 132 N., R. 72 W., and also 0.2 mile north of the southeast corner of sec. 16, T. 132 N., R. 72 W., this "pseudo-quartzite" makes up an estimated 85 percent of the boulders and cobbles picked from the adjacent fields. This quartzite was apparently let down as the fine material of the Tongue River was eroded from this area. Later, during the Pleistocene, it was incorporated into glacial drift and most places it now represents a lag deposit of glacial boulders, again let down as the fine material of the till has been removed.

Pleistocene Series

Pre-Wisconsin drift

This area may have been glaciated before Wisconsin time. No evidence is found, however, that would indicate that earlier glaciations had extended as far west as the Wisconsin glaciation in this area.

Wisconsin Stage

Lower Wisconsin (?)

Napoleon Drift.--The Napoleon Drift is named for exposures near the town
of Napoleon, in Logan County. Bonneville (1961) first used this name for the lower Wisconsin drift in an area of integrated drainage as contrasted with the non-integrated drainage of the area underlain by the younger Burnstad drift. This unit corresponds to the Tazewell (?) of Lemke and Colton (1958). The Napoleon occurs in McIntosh County in the Wishek and the Beaver Creek physiographic subdistricts.

Napoleon till is exposed most often on the drainage divides. Up to 16 feet of till is exposed in road-cuts but the total drift thickness is probably as much as 50 feet. The highest elevation in the area, is underlain by Napoleon till and is about 100 feet above the top of the presumed flat surface of the upper margin of the Fox Hills sandstone. If no additional bedrock (which would have to be the Hell Creek Formation) overlies the Fox Hills, drift must make up this interval. The fact that nothing resembling Hell Creek was observed in the area and that none has been reported in adjacent areas, indicates that the Napoleon till must overlie the Fox Hills (as it does in many exposures) and fill the 100-foot interval. Away from the drainage divides, often only lag deposits of boulders and cobbles are left where the finer fraction of the till has been eroded. Here, the low concentration of erratics resting on bedrock indicates that the till was not more than a few to a few tens of feet thick. Had it been thicker a greater number of erratics would have accumulated. With this great variation in thickness of till, perhaps the thicker, 100-foot sequence was part of an end moraine whose topographic form has since been destroyed. The till is yellow, calcareous, and sandy (see table 1 for pebble and boulder counts in drift throughout the area).
TABLE 1.—Pebble and boulder percentages determined by pebble counts and estimates throughout northern McIntosh County

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<td>Limestone and dolomite</td>
<td>52 61 53 20</td>
</tr>
<tr>
<td></td>
<td>Granite and gneiss</td>
<td>15 13 20 33 20 19 14 7 10 13 18 18 50 60 60 50</td>
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<tr>
<td></td>
<td>Basalt and rhyolite</td>
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</tr>
<tr>
<td></td>
<td>Dark coarse crystalline</td>
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</tr>
<tr>
<td></td>
<td>Pierre Shale</td>
<td>13 3 12 3 6 8 9 16 7 - - - - - -</td>
</tr>
<tr>
<td></td>
<td>Siliceous (chert)</td>
<td>4 4 2 5 3 4 5 6 10 7 14 14 40 - 5 -</td>
</tr>
<tr>
<td></td>
<td>Miscellaneous**</td>
<td>3 6 5 23 12 12 6 4 4 15 15 - - 5 2 -</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>99 100 100 101 100 100 99 101 99 100 100 100 100 100 100</td>
</tr>
</tbody>
</table>

* T = till, O = outwash, B = boulders

** Large percentages are mostly iron-oxide concretion fragments.
Napoleon stratified drift

Napoleon stratified drift occurs in ice-contact deposits and in valley trains (see above). Gravel up to 10 feet thick occurs in some ice-contact deposits. In other places, only a thin silty veneer of lag gravel or small channel fills covered with a soil layer remain.

One radiocarbon determination is reported from Napoleon drift. In Logan County, peat from outwash was dated at greater than 38,000 years before the present (W-990).

Upper Wisconsin Substage

Burnstad Drift.—The Burnstad drift is named for exposures near Burnstad, in Logan County, about 10 miles to the north. It underlies the Burnstad, Streeter, and Venturia end moraines together with associated dead-ice and outwash topography.

Burnstad till is gray, sandy, and calcareous, appearing different from the older Napoleon till. In road-cuts it reaches 50 feet in thickness, but water well logs reveal that it is as much as 200 feet thick.

Burnstad stratified drift is in the form of sand, gravel, and lake sediment. Much of it is of the ice-contact type and often is collapsed so that it is folded and faulted.

Twenty feet of gravel is exposed in a pit in the southwest quarter of sec. 19, T. 132 N., R. 70 W. As shown in water well logs, lake silts are up to 80 feet thick and sand and gravel are 100 feet thick in the vicinity of Lehr.
Six carbon-14 determinations in the region show relatively close agreement on the age of the Burnstad drift. One date of 11,650 \( \pm \) 310 years before the present (W-974) was recently reported from the Streeter push-moraine, southeast of Lehr.

Postglacial deposits

Sedimentation has continued since the last glacial ice melted from the area. Alluvium has accumulated in many of the stream valleys and overlies outwash in most places. Also, in sloughs and lakes, fairly continuous deposition has persisted. A core taken from near the edge of a slough in the SW\( \frac{1}{4} \) SW\( \frac{1}{4} \) sec. 24, T. 132 N., R. 69 W., revealed a sequence of friable fresh-water limestone, marl, and peat overlying outwash.

GLACIAL HISTORY

Five phases are recognized in the glaciation of the map-area. Figures 9 through 10 show the different stages of landform development. The positions of the ice-margin have been determined by the positions of end moraines and/or the relationships of valley trains and meltwater channels. Aside from the carbon-14 date (above), no attempt is made to date the different phases.

Phase 1

The farthest advance of glaciation during Napoleon time is not known exactly but it was probably several miles west of the map-area. Figure 9a represents a stage during Napoleon deglaciation. The ice was thin, only a few hundred feet thick at most, and bedrock was being shoved and contorted by the thrusting movement of this thin ice. Ice-contact strati-
a. -- Phase 1

b. -- Phase 2

c. -- Phase 3

valley trains, outwash
ground moraine, bedrock
end moraine
kames, eskers, etc.

direction of meltwater flow
ice front
carpenters
stagnant ice

FIGURE 9. -- Sequence of events.
FIGURE 10.--Sequence of events.
fied drift was accumulating in small holes, stream channels, and crevasses in the ice. Meltwater was carried away to the south by three proglacial streams.

Phase 2

After deglaciation, following the formation of the Napoleon drift, erosion began to cut Beaver Creek valley. The valley was lowered while the stream's tributaries dissected the surrounding drift, leaving only isolated patches of till and outwash of lag deposits of boulders and cobbles on bedrock surfaces. Gravel and sand in ice-contact landforms nearest the stream, where erosion had proceeded farthest, resisted erosion and were left up high, capping hills and small buttes. Figure 9b represents the uneroded Napoleon drift surface. Figure 9c shows the dissecting stream pattern.

Phase 3

In Late Wisconsin time the ice again advanced into the area, reaching as far as Wishek. Figure 10a shows that the ice margin stood long enough to build the Venturia end moraine. The Wishek Meltwater channel was marginal to the Venturia ice and carried meltwater to the north. Since Napoleon time an advance of ice occurred south of the map-area which dammed the south-flowing water in the Wishek channel and caused it to spill over a low divide to the north in Logan County (Clayton, in preparation). This completely diverted subsequent meltwater to force it northward. The active Venturia ice margin retreated a few tens of miles, leaving stagnant sheets of ice behind. These sheets, which were insulated by a cover
of drift, persisted at least until the time of formation of the Burnstad end moraine.

Phase 4

Another advance closely followed phase 3 and brought the ice margin again within a few miles of Wishek. Figure 10b shows the Burnstad end moraine being formed while meltwater channels are carrying meltwater through the moraine and distributing outwash over the plain near Wishek and over the stagnant Venturai ice. The meltwater was collected in the Wishek channel and carried off to the north. The Burnstad active ice margin retreated, leaving sheets of stagnant ice. As this stagnant ice melted, drift collected on its surface and insulated it, thus slowing down the rate of ablation. Within part of this insulated ice was formed Glacial Lake Lehr with its clams, snails, and fish.

Phase 5

Figure 10c indicates the re-advance of the active ice margin and the formation of the Streeter end moraine. Outwash was spread over the stagnant Burnstad ice. The meltwater made its way through the Burnstad moraine, through the Clear Lake-Green Lake valley train, and into the Wishek channel. Sand and gravel deltas were being formed in Lake Lehr. The retreat of the active Streeter ice marked the end of glaciation in the map-area.

Phase 6

The buried stagnant ice may have persisted for as long as 2000 years after the formation of the Streeter end moraine (Clayton, in prepara-
tion). Figure 10d shows the surface of the debris-covered ice. Lake Lehr, which was supporting fresh-water life, had yet to be drained.

When the underlaying ice had melted enough to let down the wall of Lake Lehr, the lake water spilled out through the meltwater channel that trends southwest from Lehr.

Phase 7

After the stagnant ice was gone, lakes formed in depressions of the collapsed-drift and began to accumulate sediments from runoff and organic action. As the climate became drier and warmer these lakes gradually dried up until today only muddy sloughs occupy many of the depressions.
LITERATURE CITED


Flint, 1955, Pleistocene geology of eastern South Dakota, U.S.G.S. Prof. paper 262.


LANDFORM MAP OF NORTHERN MCINTOSH COUNTY NORTH DAKOTA


SCALE 1:63,000