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Glacial Geology of south-central Kidder County, North Dakota

Barrett J. Williams
University of North Dakota

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GLACIAL GEOLOGY OF SOUTH-CENTRAL

KIDDER COUNTY, NORTH DAKOTA

A Thesis

Submitted to the Faculty

of the

Graduate School

of the

University of North Dakota

by

Barrett J. Williams

B.S., University of North Dakota, 1958

In Partial Fulfillment of the Requirements for the

Degree of Master of Arts

June 1960
This thesis submitted by Barrett J. Williams in partial fulfillment of the requirements for the Degree of Master of Arts in the University of North Dakota, is hereby approved by the Committee under whom the work has been done.

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Dean of the Graduate School

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GLACIAL GEOLOGY OF SOUTH-CENTRAL KIDDER COUNTY, NORTH DAKOTA

By Barrett J. Williams

ABSTRACT

South-central Kidder County is covered with deposits of drift brought by ice sheets which invaded the area from the northeast and east. Bedrock of Cretaceous age underlies the drift mantle. The drift on the surface in Kidder County represents the Cary and Mankato substages of the Wisconsin stage of the Pleistocene series.

Three types of moraines, ground, stagnation, and end moraines, are present in the area. Five late Wisconsin end moraines are distinguished and named in this portion of Kidder County. These are, from west to east and oldest to youngest, the Long Lake loop and Sibley Buttes loop of Cary subage and the Western Crystal Springs loop, McPhail Buttes loop and its southern extension the Eastern Crystal Springs loop, the Lake George loop of Mankato subage. It was impossible to distinguish between end moraines by color, composition and pebble counts since tills of these moraines were similar in composition.

Outwash deposits are generally present along the distal margin of end moraines; either ground or stagnation moraines is generally present along the proximal margin. An extensive outwash plain exists in the central part of the area. This originated from coalescing meltwater channels off the end moraines to the north and east. Numerous ice-contact features are present in the area. Kames are more numerous than eskers. Steela, North Dakota, is situated on a glacial lake bottom.
INTRODUCTION

Purpose

The purpose of this investigation is to describe and prepare a map of the glacial geology of the south-central portion of Kidder County, North Dakota. In addition to this, we also map the exposed bedrock and to indicate possible sources of gravel for the construction of roads.

Accessibility

United States Highway 10 extends east-west through the southern one half of the writer's area. North Dakota State Highway 3, a north-south highway, intersects Highway 10 one half mile west of Steele, North Dakota and continues south again from Dawson, North Dakota. Secondary roads, which form a network through the area, are all-weather roads and in good driving condition. Trails are usually present along the section lines where the land is relatively flat. Various localities in the end moraines are only accessible by jeep or on foot.

Field Work

Field work for this report was done during the summer of 1959. Kidder County was divided into four east-west strips and these were taken, from north to south, by Mr. James Chmalk, Mr. Wallace Bakken, the writer, and Dr. Jon L. Rau, who was assisted by Mr. Lee Clayton for six weeks.

Aerial photographs made by Aero Service Corporation, Philadelphia, Pennsylvania, (series no. CS-PT 1 02-1 143), with a scale of approximately 2.6 inches to the mile, and topographic maps made by the U. S. Geological Survey were used for mapping the contacts of the various glacial features.
The North Dakota State Highway map of Kidder County (scale 1:63,360) was used as a base map. It was also helpful in traversing the country and aided in land descriptions.

The Abney hand level and Brunton compass were used to measure the thickness of exposed till, and the Brunton compass was also utilized in taking the attitudes of the exposed Fox Hills sandstone.

Laboratory Work

Lithologic samples collected in the field were later processed in the laboratory. Outwash samples were sieved and separated into the various grade sizes; complete hydrometer analyses were run on the till samples. Dune sand, outwash, and till samples were examined with the binocular microscope to determine the dominant minerals present. The few fossils collected in the Fox Hills sandstone were also identified.

Acknowledgments

Thanks are due the North Dakota Geological Survey for providing economic assistance and supplying much of the equipment used for the field work and preparation of this report. Special thanks are extended to Dr. Jon L. Neu for suggesting the subject of investigation, and to Dr. Wilson M. Laird, Dr. Mark Rich, and Dr. F. C. Holland Jr., Department of Geology, University of North Dakota, for their criticisms, suggestions, and assistance in the preparation of the report. The Ground Water Branch of the U. S. Geological Survey provided drillers logs. Assistance given by Mr. Wallace Bakken, Mr. James Chestik, and Mr. Lee Clayton, University of North Dakota, is appreciated.

Previous Geologic Investigations

The Pleistocene geology in North Dakota has been described by many writers. Chamberlin (1893) named the Altamont moraine, which is the outer
or first moraine of late Wisconsin age, from the type locality near Alton, South Dakota. He also, in the same year, named the Gary moraine which he believed to be the second moraine deposited by the Wisconsin ice sheet. These moraines extend northwestward through North and South Dakota east of the Missouri River and nearly parallel to it. Chamberlin (1883) also mentioned that the moraines of the Missouri Coteau were not mainly a drift accumulation but a pre-existing plateau composed mostly of Cretaceous rocks that were dissected by preglacial drainage. Todd (1896) made a study of the region lying between the Missouri and James rivers, and between the latitudes of Jamestown, North Dakota and Huron, South Dakota. The moraines in the vicinity of Steele and Crystal Springs, North Dakota as well as the area to the south were studied by Todd (1896). Long Lake and Blue Lake loops in Kidder County were named by Todd in 1896. At approximately the same time as Todd was investigating the region between the Missouri and James rivers along the 47th parallel, Upham (1895) was doing extensive work on glacial Lake Agassiz.

A study of the glacial drift was made by Wilder (1902) in Ward County. However, this was the old Ward County which was much larger than at the present; it included a portion of Burke County. Wilder also made a study of the bedrock beneath the drift, and mapped the lignite deposits in the state. The eastern limit of lignite was placed by him along the western one-third of Kidder County within the margin of the Wisconsin drift.

It was stated by Willard and Erickson (1904) that the Missouri Plateau was a preglacial landscape feature and not formed by the ice of the glacial period. They mentioned that the surface was covered by glacial drift up to a depth of 150 feet. Willard and Erickson said that the term "coteau" was applied to the hills on top of the plateau. The area mapped
by them was the portion along the Northern Pacific railroad between Steele and Bismarck, North Dakota north to the northwestern corner of the state. Willard and Hibbard (1906) reported on the glacial drift deposits in the Tower quadrangle. The same year they also made a study of the glacial deposits related to the Sheseme and Maple rivers. Willard (1906) investigated the general geology and especially the glacial geology of the Jamestown-Tower district. The Altamont and Cary moraines as mapped by Todd in 1896 were similarly mapped by Willard (1906, Fig. 3; p. 185).

Leonard (1912) believed that the Altamont moraine marked the outermost or most westerly moraine formed by the Wisconsin ice. He stated that this moraine has a northwesterly trend and is from twelve to fifty miles east of the Missouri river in the south-central part of North Dakota. It about the same time Ward (1913) studied kames and eskers in the eastern part of Barnes County.

Campbell, et al. (1916) traced the Altamont moraine from South Dakota into the vicinity of Long Lake and Steele, North Dakota and westward passing west of Driscoll and angling northward in the area of Sterling, North Dakota. The Cary moraine in South Dakota was also traced by Campbell, et al. (1916) to the vicinity of Ladoga, which is approximately 4 miles west of Crystal Springs, North Dakota.

It was stated by Leverett (1922) that the Coteau des Prairies extends from the head of the Big Sioux River, in South Dakota, southeastward across Minnesota into Iowa. The Coteau consists of drift of all four glacial stages. Kansan and later drifts comprise only 100 to 150 feet of the 300 to 700 feet of drift present. Leverett stated that Chamberlin in 1878 thought that the Altamont moraine represented the outer moraine of the Des Moines lobe of the Wisconsin stage. However, in 1912 Leverett found that the moraine named from Altamont, South Dakota was not the outer
moraine of the Des Moines ice lobe. In 1921 he observed a rugged outer moraine which passed through Bemis, South Dakota, which is west of Altamont. Hence in 1922 Leverett proposed to apply the name Bemis to the outermost moraine of the Des Moines lobe.

Leonard (1924) mentioned that an outwash plain existed in Kidder County south of Tuttle, Robinson, and Pettibone and east of Teppen, North Dakota. He cited numerous other localities in the state where gravel of glacial derivation was present. Rasmussen (1945) also mentioned that the area of Dawson, Teppen, and Crystal Springs included an outwash deposit of the third recession moraine of the Wisconsin stage.

Townsend and Jenks (1951) stated that the term "Altamont" moraine had been loosely applied. The Altamont moraine at the type locality is narrow, eroded, and more or less well defined. They mentioned that the northwest end of this moraine is approximately 200 miles southeast of the closest part of the large moraine trending northeast from the vicinity of Bismarck, North Dakota. Hence Townsend and Jenks proposed the term Max moraine to supersede the term Altamont moraine for the morainic belt extending northwest of Bismarck, North Dakota into Canada. They also stated that Chamberlin's (1885) map showed the glacial deposits in the vicinity of Bismarck to be distinctly separate and dissimilar in outline from the Altamont moraines in the vicinity of its type locality. It was stated by Townsend and Jenks (1951) that early workers, concerned with the reconnaissance of extensive areas, carried the term Altamont to the northwest into North Dakota. They also mentioned that Leonard (1904, p. 173) and Alden (1932, p. 126-127) stated that the Altamont moraine was traced into North Dakota but they did not mention by whom.

Recent work by Paulson (1952) in the Streator area of Kidder, Logan, and Stutsman counties is some of the latest mapping of glacial features
near the area under investigation by the writer. This is approximately six miles south of the southeastern corner of the writer’s area. Two belts of end moraines, separated by an extensive glacial outwash area, are present that extend across the area in a southeasterly direction. Paulson tentatively assigned these end moraines to the Altamont and Gary systems. He accomplished this by extending the Altamont moraines as shown on Todd’s reconnaissance map in a northerly direction by the use of aerial mosaics.

The distribution of bedrock in North Dakota is shown in Hansen’s (1956) geologic map of the state. Randich (1958, unpublished Senior Thesis) has contoured the thickness of drift in North Dakota on the basis of information derived from test hole data of the Ground Water Branch of the United States Geological Survey.

Moir (1953) utilized radiocarbon dating of coniferous wood from an end moraine in Kidder County. Data from this radiocarbon dating indicated an age of approximately 11,480 years B. P. (before present) which correlated closely with the Two Creeks interstadial. This wood was buried beneath sandy material (outwash or till according to Moir) which Moir believes may date the maximum advance of the Mankato ice. A summary of the Pleistocene geology of North Dakota was made by Lamke and Colton (1958). Whipple (1959) made a study of the Quaternary geology of part of northeastern Montana and northwestern North Dakota.

The most recent work accomplished in Kidder County is by Clayton (1960, unpublished Senior Thesis). He made a detailed study of the various tills and attempted to differentiate them as to the substage of the Wisconsin stage. Lamke and Colton are in the process of completing a glacial map of North Dakota which will be published by the United States
Geological Survey in the near future. Their information has been derived from aerial photographs, published material, and reconnaissance over the state.
Physical Setting

The studied area is in Kidder County, North Dakota, and includes all of T. 139 N. and T. 140 N. and R. 70 W. to R. 74 W. Boundaries in terms of latitude and longitude are: 46° 43' and 46° 59' latitude and 99° 24' and 100° 04' W. longitude.

Kidder County is situated in the Coteau du Missouri portion of the Glaciated Missouri Plateau section of the Great Plains province (Fenneman, 1931, p. 73). The Coteau du Missouri is that part of the Missouri Plateau section which lies east of the Missouri River (see fig. 1). Total relief of the area does not exceed 500 feet (see plate 1). The lowest point, 1710 feet, overlies the assumed position of the "ancestral" Cannonball River channel. This is in sections 5 and 6, T. 140 N., R. 71 W. Maximum elevation of 2267 feet is on the moraine in what is herein named the Lake George loop in the southwest corner of the NE ¼ section 33, T. 139 N., R. 70 W.

Climate and Soils

North Dakota has a continental climate with extreme summer heat and winter cold, and rapid fluctuations of temperature. Maximum and minimum temperatures recorded in Kidder County were a high of 121° F. and a low of -54° F. (U. S. Department of Agriculture Yearbook, 1941, p. 1043-1046). Average annual distribution of rainfall varies between 16 and 18 inches (see fig. 3). At Steele, North Dakota the average annual precipitation is 17.51 inches. About 35 percent of the annual precipitation falls during May, June, and July (U. S. Department of Agriculture Yearbook, 1941, p. 1046).
FIG. 1 - GENERALIZED MAP SHOWING SELECTED PHYSICAL SUBDIVISIONS OF NORTH DAKOTA
(MODIFIED FROM LEMKE AND COLTON, 1958)
FIG. 2 - BEDROCK TOPOGRAPHY OF THE PRE-PLEISTOCENE SURFACE
SOIL TYPES
(U.S. DEPT. OF AGR. YEARBOOK, 1941, P.277)

AVERAGE ANNUAL PRECIPITATION (INCHES)
(U.S. DEPT. OF AGR. YEARBOOK, 1941, P.1053)

FIG. 3 — MAPS SHOWING SOIL TYPES AND AVERAGE ANNUAL PRECIPITATION
Kiddie County is in the area of chestnut soils (see fig. 3); these are dark brown soils of cool and temperate, subhumid to semiarid grasslands. Flint (1955, p. 19) stated: "Because of scanty moisture, only the more soluble salts are leached from these soils, and the calcium carbonate leached from the upper part of the soil profile is usually reprecipitated within 1 to 2 feet of the surface, where it forms conspicuous whitish layers."
PRE-PLISTOCENE ROCKS

Immediately underlying the Pleistocene drift in the area of investigation is bedrock of Cretaceous age. Formations known to be underlying the exposed bedrock are omitted as they have exerted little or no influence on the glacial deposits. The two formations exposed are from youngest to oldest:

Fox Hills sandstone (Upper Cretaceous)-Sandstone, medium-grained, poorly indurated, medium grey, olive-grey, to greenish-gray; ferruginous concretions, fossiliferous.

Pierre shale (Upper Cretaceous)-Shale, fissile, olive-grey to greenish grey.

The distribution of the bedrock units exposed at the surface or immediately underlying the drift in Kidder County are shown on a sketch map (see fig. 4).

Deformed Bedrock and Paleontology

Exposures of Fox Hills sandstone were found on the crests of the southern part of Sibley Buttes, in the W ½ of section 6, T. 140 N., R. 72 W. and in the S ½ of section 1, T. 140 N., R. 73 W. Bakken (1960, unpublished Master's Thesis) mentioned that the Fox Hills sandstone is also exposed in parts of sections 25, 26, 35, and 36, T. 141 N., R. 73 W., sections 30, 31, and 32, T. 141 N., R. 72 W.

The strikes of the sandstone beds are aligned with the general trend of the crests of the Sibley Buttes. Twenty dips and strikes were recorded on the exposures of the Fox Hills sandstone. Outcrops of the sandstone are generally on the crests and are responsible for the easte-
FIG. 4 - GENERALIZED OUTCROP MAP OF KIDDER COUNTY

(AFTER HANSEN, 1956)
like ridges. Variations in strike range from N. 21° W. to N. 64° E. and in dip from 7° W. to 71° W. Regionally the dip of the Fox Hills sandstone is to the southwest. Much of the sandstone exposed is not in place, hence it is difficult to get accurate attitudes of the strata. Most of the ridges have an arculate trend. Fox Hills sandstone is exposed in several places in the ditch of the road immediately to the east of Sibley Buttes in section 6, T. 140 N., R. 72 W. Sandstone in this outcrop is nearly horizontal (see fig. 3).

It is necessary to consider the preglacial topography in order to solve the problem of the structure of the Fox Hills sandstone in the Sibley Buttes. The map showing the pre-Pleistocene surface indicates the probability that the preglacial topography was of a naturally eroded surface (see fig. 2). This map was constructed from test hole data derived from the Ground Water Branch of the United States Geologic Survey. Test hole No. 1019 of the United States Geological Survey in the southwest corner of section 15, T. 140 N., R. 73 W. three and one-half miles southwest of Sibley Buttes indicates bedrock (shale) 115 feet below the surface. Another test hole No. 963 (NW cor. sec. 27, T. 140 N., R. 72 W.), approximately four and one-half miles southeast of Sibley Buttes shows shale at 190 feet below the surface. In a nearby well, the Prairie oil and gas well No. 2 (SW 1/4 SW 1/4 sec. 2, T. 140 N., R. 73 W.), Laird (1941, p. 23) stated there was 56 feet of drift overlying Pierre shale. Hence it may be assumed that the preglacial Sibley Buttes area consisted of a butte or buttes with Pierre shale underlying a Fox Hills sandstone cap rock. The adjacent surface to the east and south was shale (Pierre). Lack of adequate well data in the vicinity of Sibley Buttes creates a problem on the interpretation of the structure associated with Sibley Buttes and the bedrock topography. One of several explanations for the development
FIG. 5 EXPOSURES OF FOX HILLS SANDSTONE IN THE SOUTHEASTERN PART OF SIBLEY BUTTES LOOP
of the Sibley Buttes structure is that of thrusting due to ice above.
The underlying shale, because of its plasticity, would have been squeezed out along the distal flank by the southsoutheastward advancing glacier (see stage 1). Synchronously the sandstone beds would have been thrust in an upward and outward direction upon the squeezed-out shale (stage 2). As the glacier advanced, the weight of the overlying ice mass would have further depressed the sandstone downward into the plastic shale thus increasing the angle of dip (stage 3). (See fig. 6)

Fig. 6. Sketches showing possible causes of the deformation of the Fox Hills sandstone in Sibley Buttes area.

Evidence for the shale in this position is found in the North Dakota Geological Survey Circular No. 211 for the Magnolia Petroleum Company--North Dakota State "A" No. 1, which is located in the SSSE of the
III, of section 34, T. 141 N., R. 73 W. This well is situated on the flank opposite the dip slope of a ridge which is along the southern or distal flank of Sibley Buttes. The dominant lithology near the surface is shale according to Hansen (1959). After the initial deformation the ice mass then advanced onto the up-thrust bedrock and terminated in this position. Evidence for this are felsic igneous boulders overlying a relatively thin veneer of till on the surface. The semi-arcuate trends of the ridges and the wide variations in the strikes and dips may be attributed to differential movement of the sandstone blocks.

A similar situation to that of the first example is possible assuming that a "badland" type of topography was not originally present. Thrusting due to ice shove could occur in a zone of weakness in the horizontal bedrock. The weight of the overriding glacial ice would cause fracturing of the bedrock, and the forward movement of the ice mass could result in thrusting of the bedrock by ice-shove as illustrated below (see fig. 7).

![Diagram of Sibley Buttes](image)

Fig. 7. Sketches showing possible causes of the deformation of the Fox Hills sandstone in Sibley Buttes loop.
Another possibility may be that the underlying shale beneath the sandstone cap rock of the butte(s) may have become plastic because of the moisture associated with the advancing ice mass. The shale may have flowed out to the northeast from beneath the sandstone cap rock resulting in the slumping of the overlying bedrock. This could account for the northeasterly dipping strata (see fig. 3).

Fig. 3. Sketches showing possible causes of the deformation of the Fowl Hills sandstone in Sibley Buttes loop.

The overriding ice mass would have further deformed the slump blocks and a veneer of till containing feldspar igneous boulders would have been deposited.

The possibility of the force of the glacier overturning the sandstone cap rock and causing a northeasterly dip of the strata was also
given some consideration. However, the position of fossils in place in relationship to the strata was studied and no evidence of overturning was observed. The fossils contained in the sandstone were in a stable position of rest with their convex surface upward.

The possibility of faulting should not be overlooked as an origin for the Sibley Buttes structure. Fisher (1952, p. 32) mentioned the presence of a probable fault in central Midder County with the beds dipping steeply to the northeast against the regional dips. He did not go into any detail concerning this probable fault but the possibility exists that he was referring to the Sibley Buttes structure. Fisher believed that the trends were controlled by the northeast-southwest Precambrian structures and allied cross-faults.

In conclusion, the writer believes that the first two explanations, thrusting due to ice shove and slumping, offer the most likely modes of formation of bedrock structure in the Sibley Buttes.

Several fossils were found either embedded in the Fox Hills sandstone or associated with it. A crocodilian tooth, identified by the writer, was embedded in a slab of Fox Hills sandstone "float" in the SW ¼ SW ¼ sec. 35, T. 139 N., R. 73 W. In "float" in a road ditch along the eastern margin of Sibley Buttes in the SW ¼ NE ¼ SW ¼ sec. 6, T. 140 N., R. 72 W. were collected numerous plectronid fragments. These were identified as Ostrea (?) subtrigonalis Evans and Shumard by comparing with fossils collected and identified by Dr. F. D. Holland Jr. and Mr. S. E. Wilson. Fossils collected and identified by Holland and Wilson and also the writer in a nearby area southwest of Horsehead Lake, Midder County, in the NE ¼ sec. 36, T. 141 N., R. 73 W. are:

*Lucina occidentalis* Morton

*Anomia micronesae* Hook
GLEISTOCENE GEOLOGY

Glaciation

Leske and Colton (1953, p. 41) believe that with the exception of the southwestern corner, all of North Dakota was glaciated during the Pleistocene epoch (see fig. 1). No definite evidence of pre-Wisconsin glaciation has been found in the state. Pleistocene chronology is tentative and subject to revision as more data becomes available because of the difficulty of distinguishing the glacial drift sheet on the basis of lithology, color, or degree of weathering, the scarcity of loess deposits interbedded with the drift sheets, and the paucity of radiocarbon dates.

Evidence indicating that glacial ice entered Kidder County from the northeast or north, and flowed in a southerly or westerly direction is: the axial trend of the end moraines, which is at right angles to the direction of advance; and the lithology of the drift, which includes debris derived from the north and northeast but only locally, material derived from other directions.

The writer is not in agreement with Leske and Colton (1953, fig. 3) who stated that the drift of the Mankato substage is the only drift of the Wisconsin stage present at the surface in Kidder County (see fig. 9a).

Leske and Colton traced Flint's 3-1 and 3-2 advances of the Mankato substage into North Dakota. If the interpretation by Leske and Colton (1953, fig. 3) in North Dakota of Flint's 3-1 and 3-2 advances be correct, the following may be assumed: (1) The end moraines on the northern and eastern parts of Kidder County were formed during the Post-Cary advance of Leske and Colton (1953, fig. 3), which corresponds with the 3-1 advance of Flint (1955, fig. 31, p. 119) in South Dakota. (2) The remainder of the county is covered with till of the Post-Tascawall-Pre-Two Creeks sub-
Figure 9

a. Relationship of drift sheets (After Lemke and Colton, 1958, Fig. 3)

b. A possible interpretation for the presence of Cary drift in Kidder County (After Clayton, 1960)
Stage, which corresponds to Flint's P-1 Manhato advance (see table 2).

Radiocarbon dating of a wood sample from a moraine, the Twin Buttes
Icon, about 10 miles south of Tappen, North Dakota indicates an age of
11,480 years ± 300 B.P. (Novr, 1952, p. 110). This date corresponds
to the Two Creeks interstadial (see table 1). Lemke and Colton (1958,
p. 49) mentioned that it cannot be ascertained whether the drift of the
P-1 advance antedates or postdates the Two Creeks interstadial. This
is because of the lack of knowledge of the stratigraphic relationship
of the deposits overlying the radiocarbon dated material to the southeast.

Flint (1956, p. 77) stated:

The substages higher than the lower substages mark interruptions
that temporarily reversed the long process of deglaciation. That
glacial reexpansions took place is demonstrated by the evidence,
as all now agree. Furthermore the intervals between successive
reexpansions are known to have involved less extreme changes than
did the pre-Wisconsin interglacial ages, on the evidence of slight
weathering of the various Wisconsin drift sheets. For this reason
these drifts are considered substages rather than stages. However,
comparatively little is known about the extent of deglaciation
between any two succeeding expansions and about the relative lengths
of the corresponding time units.

Erosional effects of glaciation are generally concealed beneath
the drift. The fact that the drift includes considerable amounts of
material derived from the Pierre shale and Fox Hills sandstone, supports
the inference that glacial erosion of these underlying rocks has occurred.
However, striations have not been observed by the writer on these two
formations probably either because no striations were made on the bed-
rock or because they were not preserved. The latter is likely because
of the fissility of the Pierre shale and friability of the Fox Hills
sandstone.

Sorber and Anderson (1956, p. 103) stated:

The main factors which controlled the form and extent of glacial
lobes were (1) the preglacial topography; (2) the configuration of
<table>
<thead>
<tr>
<th>Leighton 1956, 1957</th>
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<th>Flint, 1955, fig. 31</th>
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<tr>
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Table 1. Substages of the Wisconsin Stage.  
(After Lamke and Colton, 1958)
the ice sheet, including the position of centers of outflow and its
regimen; and (3) deflections by adjacent ice lobes.

Horberg and Anderson (1956) believed that the origin of the glacial
lobes of the Mankato substage was from the Kewatin center west of Hudson
Bay. Flint (1943) questioned this concept. He believed that the evidence
was not sufficient and proposed returning to the concept of a single
Laurentide ice sheet. This ice sheet grew westward from a center in
Labrador and extended to the area of Hudson Bay at the maximum of glaci-
ation.

Pre-Wisconsin Deposits

Lenke and Colton (1938, p. 43-44) stated:

North Dakota might have been glaciated in pre-Wisconsin time.
A few scattered granitic boulders have been found several miles
beyond the Iowan drift border as mapped by W. H. Benson. How-
ever, the presence of some of these boulders can be explained
by ice rafting in a lake west of the Iowan ice.

They also mentioned, however, that Warren (1952, p. 1143-1156) presented
evidence of Illinoian stage glaciation in South Dakota. This was accepted
by Flint (1955, p. 30) who placed the Illinoian drift border along the
east side of the Missouri River in South Dakota. They believe that if
the above interpretation is correct, at least the southeastern part of
North Dakota was glaciated during the Illinoian.

Wisconsin Stage

Flint (1955, p. 77) stated that Leighton in 1933 subdivided the
Wisconsin stage into four substages, "... each of which marks a con-
spicious expansion of the Wisconsin ice sheet." These substages from
oldest to youngest are: Iowan, Tamswell, Cary, and Mankato (see table 1).
This classic time-stratigraphic subdivision of the Wisconsin stage has
been challenged by Frye and Willman (1960) who have proposed a new
classification based largely on radiocarbon dates. This new classification has come too late to be utilized in this report.

Substages of the Wisconsin stage in ascending order are:

Farndale substage (presence or absence of Farndale loess in North Dakota cannot at the present time be ascertained; Lemke and Colton, 1958)

Iowan substage (deposits of this time interval not exposed in Kidder County; Lemke and Colton, 1958)

Tazewell substage (deposits of this interval not exposed in Kidder County but crop out in Burleigh, Benson, Logan, and McIntosh Counties to the west and southwest; Lemke and Colton, 1958)

Cary substage (deposits of this time interval do not crop out in North Dakota but are exposed in central and eastern South Dakota; Lemke and Colton, 1958) However, Clayton (1960, unpublished Senior Thesis), Chevolik (1960, unpublished Master's Thesis), Badeen (1960, unpublished Master's Thesis), and the writer believe that Cary drift is present in Kidder County (see fig. 9b)

Mankato substage (Post-Cary drift; Lemke and Colton, 1958)

The possibility exists that what Lemke and Colton (1958) consider to be Post-Tazewell-Pro-Two Creeks drift in Kidder County is Cary in age. Evidence for this is as follows:

1. The topography of the Long Lake loop in western Kidder County is more subdued than the other end moraines in the county. This may be indicative of a longer duration of time exposed to the elements. However, there has not been sufficient time for the integration of drainage. No integrated drainage was observed in the field or from aerial photographs.
Flint (1955, p. 120) mentioned that Gary till in South Dakota is very thin. He said in most exposures it is only a few feet thick, and does not exceed 30 feet in any exposure. This same situation exists in the western part of Kitter County, where the drift is also very thin.

2. L. S. Clayton (1960, personal communication) believes that the Twin Buttes loop overlaps the southern portion of the Long Lake loop in Logan County. It was also stated by Clayton (1960, unpublished Senior Thesis) that the topography of the Twin Buttes loop resembles that of the S-1 Mankato advance to the northeast rather than the end moraines to the northwest which Leske and Colton assigned to the A-1 advance.

3. Flint (1955) did not mention the presence of any loess between the tills of the A-1 and S-1 advances of the Mankato substage. However, Clayton and J. L. Rau found what they considered to be loess between the till of the Twin Buttes loop and a previously deposited till which Clayton (1960, unpublished Senior Thesis) believes to represent a recessional moraine of the Long Lake loop. This exposure (0.3 miles north of the southwest corner of section 22, T. 136 N., R. 71 W.) was also observed by the writer in the summer of 1959. In this exposure there is approximately 4 feet of pale olive (5Y 6/3) till overlying a variable thickness of loess (0.2-0.3 feet) which in turn overlies an undetermined thickness of pale olive till.

4. Leske and Colton's correlation of the drift was mainly done with aerial photographs. A lesser amount of the correlation was accomplished by field reconnaissance study. It is believed by Clayton (1960, unpublished Senior Thesis) that at the critical point on the aerial photographs (X, fig. 9b), there is little evidence that the A-1 advance should be as in figure 9a, rather than as in figure 9b.
Glacial Markings

The area of Kidder County under investigation has numerous boulders strewn on the surface of the various moraines. Boulders are more prevalent on the end moraines than on ground or stagnation moraines. However, this may be more apparent than real. Plausible reasons for the concentration of boulders on the steeper surface of end moraines may be that runoff of the glacial meltwater and postglacial winnowing by sheetwash and stream action may have exposed a greater number of boulders on end moraines than on either ground or stagnation moraines. Aeolian action, more prevalent in areas of greater relief, may also have winnowed out the finer material thus aiding in the formation of the boulder concentration on the end moraines. The two dominant lithologies of the boulders are limestone and felsic igneous, the latter dominates.

Markings such as striations and grooves are not observed on the granite boulders or on the exposures of the Fox Hills sandstone. The friable Fox Hills sandstone is unsuited to receive striations or grooves or to retain them, once made.

Highly polished surfaces as well as some excellent faceting are present on many felsic igneous boulders (see fig. 10). Till, being clay-rich and acting as an abrasive, could have been responsible for the polished surfaces. However, some of the polished surfaces may be due to post-glacial action and organisms (e.g., cattle and buffalo). Depressions surrounding some of the larger boulders where cattle and no doubt buffalo scratched themselves bear out the possibility that some of the polish may be due
Fig. 10. Glacially faceted boulder on the surface of the McPhail Buttes loop in the SW₁⁄₄ SE₁⁄₄ NW₁⁄₂ section 3, T. 140 N., R. 70 W.
to this action. The northern exposed surface of the boulders, however, have a greater degree of polish than do the southern exposures. This may be due to solifluction action since the source of the wind in this area is generally from the north or northwest, as it more than likely has been in the thousands of years following the Wisconsin stage.

Character of the Till

The thickness of Late Wisconsin (Cary and Mankato) drift in Ridder County is extremely variable as evidenced by numerous test holes drilled by the Ground Water Branch of the United States Geological Survey. The greatest thickness in the area was approximately 240 feet in the southeast corner of section 8, T. 139 N., R. 71 W., test hole No. 979. However, there exists the possibility, even though the till was a continuous sequence, that some of the till may be older than Mankato.

The thickness of the drift overlying bedrock in the end moraines may exceed 240 feet. However, this may only be assumed since no test holes were drilled in any of the end moraines in the investigated area. Minimum thickness of the till, where present, is in the northwest corner of section 36, T. 140 N., R. 79 W. Data from test hole No. 1021 at this locality indicates a till thickness of 5 feet.

The tills in the areas observed appeared to be generally similar in their physical characteristics. Variations in color were not too apparent except for slight color differences especially in the gray hues. The Goddard et al. Rock Color Chart was used by the writer to distinguish the variations in till color. Wet till color ranged from medium olive gray (5Y 4/2) to yellowish light olive gray (5Y 6/2). Variance in color of the dry till was from light olive gray (5Y 5.5/2) to yellowish gray (5Y 7/2). Dominant color in the dry till is yellowish light olive gray.
(5 1/2) and that of the wet till, light olive grey (5Y 5 1/2). Locally the till had a yellow or orange mottled appearance.

Depth of leaching was negligible, although whitish calcareous zones of concentration are apparent in all or nearly all of the till observed. Dilute 3 percent hydrochloric acid was used to determine the depth of leaching. Flint (1955, p. 30) mentioned that distinguishing the Mankato drift from the Cary drift in this region by depth of leaching of calcium carbonate is not satisfactory. It was also stated by Howard (1946, p. 1204) that glacial chronology cannot be determined on the basis of depth of leaching in arid and semiarid climates.

Clay size particles comprise most of the fine-grained clastics of the till, however, sand and silt were also present (see histogram, pl. 2 and table 2). There are patches of sandy till in a few localities; this sandy till is the result of glacial movement over a nearby bedrock of sandstone or an outwash plain. Limonitic stains are present in the majority (90 percent or more) of the tills. These stains are responsible for yellow or orange mottled appearance. The degree of compaction of the till is relatively constant. Fifteen sand-silt-clay ratios of tills were plotted on a triangular diagram (fig. 11) in an attempt to differentiate the Cary and 3-1 (Mankato) till sheets. No differentiation is apparent. Histograms of the fifteen till samples are shown in plate 2 and the size composition and locations of the samples are in table 2 and figure 12, respectively.

Several writers (Howard, 1947 p. 1195; 1950, p. 1525; and Withkini, 1959, p. 17) have made pebble counts in North Dakota to distinguish between different drifts by the provenance of the pebbles. Withkini, whose pebble count results were similar to Howard's, found the lithology of the Mankato
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<td></td>
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<td>19</td>
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Table 2. Size composition of 15 samples of till.
FIG. 11 Triangular diagram of sand-silt-clay composition of 15 samples of till.
FIG 12—LOCATION OF SAMPLES ON WHICH SIZE ANALYSES WERE MADE

* T-16 = TILL ANALYSIS SAMPLE LOCATION
* S-7 = OUTWASH SAMPLE LOCATION
and early Wisconsin (?) drifts in northeastern Montana and northwestern
North Dakota to be very much alike. The middle Wisconsin (?) drift differed
from the Mankato and early Wisconsin (?) drift by the lesser amounts of
limestone and dolomite and a corresponding preponderance of crystalline
rocks. Flint (1955, 136-137) made pebble counts at 14 different localities
and found that the results revealed no significant details. Flint (1955,
p. 137) mentioned that the method has its limitations; the main one is that
shale is not represented in its true proportions. Shale has a tendency to
split into many fragments because of its fissility. The relatively friable
Fox Hills sandstone also breaks into small fragments. Thus the pebble
counts only represent the more durable rock types. Pebble counts show
that the lithologic percentage is not uniform in all cases. Limestones
and dolostones are the dominant pebbles in the till, felsic igneous
pebbles next. The writer made pebble counts at 53 localities and noted
no significant differences between the Cary and B-1 advances (see fig. 13).

The cobble and boulder content of the till varies immensely. The
most common cobbles and boulders are felsic igneous. Limestone and dolo-
stones are less abundant. Blocks of Fox Hills sandstone are present in
several localities, however, due to their friability, weathering is relatively
rapid accounting for their scarcity. Because of the fissility of shale,
no large fragments of shale are found. Eighty-one percent of the till
samples examined contained shale fragments; sandstone was present in 33
percent of the till samples.

An extensive study of the boulders on the surface of the till was
not made; however, they were noted. The majority of the time the distrib-
ution of the boulders cannot be observed since the area is under culti-
vation; hence the boulders are in piles. The largest boulder noted, which
FIG. 13 Triangular diagram of the three most prevalent rock types in pebbles in till of Cary and B-1 advances.
is in the Long Lake loop, has a length of approximately 6 feet. The "average"
long intercept of the boulders generally is from one and one-half to three
feet. Boulders embedded in the till are usually of lesser dimensions than
those on the surface. The boulders in the till range from 3 to 14 inches
in diameter.

Flint (1955, p. 60) mentioned two facts, also observed by the writer,
about the distribution of boulders in exposures of till and on the surface.
These two facts are that (a) there is a close relationship between fre-
quency of boulders on the surface and the angle of local slope; and (b) is
that boulders are generally more numerous in end moraines than in ground
moraine. The surface runoff will tend to carry away the finer material around
the boulders, hence in time leaving a boulder concentration; or, at least,
the exposure of the boulders will be greater than when originally deposited.
This is more effective on steeper slopes.

Reasons for the abundance of boulders in end moraine are in the
position of the boulders during ice movement. Boulders in the basal
portion of the ice mass are reduced to a lesser size due to attrition
by the local bedrock and other material in the basal part of the ice
sheet itself, while the boulders in englacial positions other than basal
would be less abraded. Also after the cessation of the glacier and the
resultant melting of the ice, the movement of meltwater over the surface
would carry away the finer clastics and leave the immovable boulders
stranded on the end moraine surface.
Stratified Drift

Stratified drift is distinct from till in that sorting and stratification have taken place by the action of meltwater. According to Flint (1955, p. 69) there are two subdivisions of stratified drift, these are: ice-free deposits and ice-contact deposits. The ice-free deposits may be further classified as stream deposits (outwash) and ponded water deposits.

Outwash

Approximately one-third to one-half of the area studied is covered by outwash. The most extensive outwash area is in T. 139 N. and 140 N., R. 71 W. and 72 W. This vast sheet of outwash was formed by the coalescing of meltwater streams from the end moraines that surround it. Evidence for this is that the apparent dip observed in various gravel pits slopes away from the end moraine. The gradual coarsening of the sand and gravel particles gives a good indication of the source direction. At or near the base or contact of the end moraine the outwash has a tendency to be considerably more gravelly and grades from coarser to finer particles with increasing distance from the end moraine or source area. The outwash forms due to the reworking of the till by the glacial streams or meltwater; the finest particles are carried away in solution or suspension, possibly to proglacial lakes, and the coarser fragments are sorted and deposited by the stream along its channel. The bedding of the outwash is variable and changes direction frequently, grading laterally from cross-bedded to evenly bedded (see Fig. 14). The slope of an outwash plain is greatest near the source.

Scattered about in some outwash bodies are patches of exposed till. Examples of these are found in section 1, T. 140 N., R. 72 W.
Fig. 14. Typical cross-bedding in outwash in a gravel pit in the NE\(^1\) NW\(^1\) section 23, T. 139 N., R. 74 W.
where several small knobs or hills composed of till surrounded by outwash are exposed. A more extensive area of till of high relief is situated west and southwest of Sibley Lake in sections 9, 10, 15, and 16, T. 140 N., R. 72 W. In sections 3 and 17, T. 140 N., R. 70 W., are other remnants of till flanked by outwash. This is a northern extension of the Western Crystal Springs loop.

The thickness of the outwash in this area varies considerably. Data gathered from test hole logs drilled for the Ground Water Branch of the United States Geological Survey were used in determining depth of surface outwash. Outwash thicknesses, derived from data from 16 test holes, averaged 23 feet. The greatest thickness is 40 feet and the least is 4 feet. Included within the belt of outwash are patches of younger alluvium or old lake or slough bottoms. Information obtained from sixteen other test holes pointed out the presence of a thin layer of clay at the surface, which is recent alluvium (slough or lake deposits). A thin veneer of colloid sand and silt overlies some of the outwash area, this is brownish, fine-grained, and quartz-rich.

The characteristic topography of this large outwash area is quite flat; however, in local areas it is gently rolling. The relief is, generally speaking, lower than that of ground moraine. In some localities boulders are observed at the surface; these may have been rafted in by floating ice blocks or their occurrence may be the result of saltwater in the channel cutting into the underlying till and leaving the boulders as lag deposits, then depositing a thin layer of outwash over the boulders. These boulders in time, as a result of frost action and erosion, have been partially re-exposed.

The central portion of the major outwash area is lower than the
eastern and western edges and the thickness of the upper outwash sand verifies that it was the center of the drainage basin of the various meltwater channels originating in the surrounding moraines. Abundant lakes and sloughs are present in this area. Several cross-sections, obtained from test hole data in this area, illustrate the presence of an old stream channel which is the channel of the pre-glacial Cannonball River. Long Lake now is situated where this ancient stream entered Kidder County; this stream flowed northeastward between the present vicinity of Dawson and Tappen, North Dakota. Then it angled more to the north toward Stony Lake and continued northward out of the area studied. Evidence for the presence of the pre-glacial Cannonball River is shown on the bedrock topography map (see fig. 2).

A minor area of outwash, in comparison to the one previously described, is in T. 139 N., R. 74 W., on both sides of U. S. Highway 10, approximately two and one-half miles west of Steele, North Dakota. This is an area of low to moderate relief in which are situated several gravel pits. Examination of these pits in the SE 1/4 NW 1/4 section 23 revealed that the dip of the various strata is in a southwesterly direction. The apparent dip varied, but it averaged approximately four degrees. Hence, the source of the sand and gravel was to the northeast and relatively near, as shown by the coarseness of the gravel. This gravel was derived from the reworked till of the northerly trending Long Lake loop. Runoff flowed into a low basin, which at the present is a small shallow lake, Lake Geneva, in sections 21 and 22, T. 139 N., R. 74 W. The western margin of the outwash area is dashed in on the map as the limit is not exactly known and hence is somewhat arbitrary (see plate 4).

The majority of the meltwater channels are floored with sand and
gravel and in some areas covered with a veneer of recent alluvium. The channel which trends east-west in the central portion of T. 140 N., R. 72 W. was instrumental in draining a segment of the Long Lake lobe of ice. A portion of the ice lobe that formed the Long Lake interlobate moraine was drained by a meltwater channel trending southeast-northwest in the northern one-half of T. 140 N., R. 72 W. and 73 W. The Lake George end moraine was drained by the northwest-southeast trending channel in the southwest part of T. 139 N., R. 70 W. An outlet for the meltwaters of the ice mass responsible for the McPhail Butte-Eastern Crystal Springs interlobate segment is a channel in the northcentral part of T. 140 N., R. 70 W. (see plate 4).

Ice-Contact Stratified Drift

The ice-contact stratified drift deposits show by their external form and internal character to be deposited in contact with the glacier. These deposits consist of relatively conical kames and elongate sinuous eskers.

According to Flint (1955, p. 66) two factors promote the development of ice-contact drift: "The first is a thin glacier; the second is a subglacial surface with pronounced relief, providing cleats and pockets that favor the separation of masses of marginal ice."

Kames

A kame is a low, steep-sided, mound of stratified drift, formed in contact with glacial ice. The origin of kames is by accumulation of sediments deposited in depressions or crevasses on the surface of stagnant ice. Upon further wasting of the ice the deposited material forms relatively conical or irregularly shaped mounds. Evidence of folding,
faulting (slumping), lensing, and, in some cases, a heterogeneous mixing of sediments are prevalent in kame. Glacial boulders and blocks of till may be embedded within the sediments.

The best "typical" kame observed is in the NW 3/4 section 10, T. 140 N., R. 72 W. Since the writer first observed this kame, much sand and gravel have been removed for road construction. Evidence of good stratification was observed in some portion of this kame and little or no bedding in others. Near the outer margin of the kame were lenses of fine to medium-grained sand and tilted beds of stratified sediments. These had the appearance of being faulted on a small scale. This was due to slumping from melting of the ice with which the sediments were in contact.

An irregular mound-like hill in the east central portion of section 7, T. 140 N., R. 74 W. has the external characteristics of a kame. However, there were no cuts made in this kame hence it was necessary to auger to sample the material. The upper portion of the auger core was soil, approximately 3 to 10 inches thick, and a lower unit was coarse sand with a few pebbles. Stratification was not observed in any of the auger cores because of the lack of induration of the sand.

In the SW 1/4 section 35, T. 139 N., R. 73 W. is another kame. The upper two to two and one-half feet consist of poorly stratified heterogeneous material from the size of sand to very large pebbles. Underlying the poorly stratified material are stratified sediments with numerous sand lenses. A block of till is embedded in the stratified material.

A large kame that is being used as a source of road gravel is in the NE 1/4 section 7, T. 140 N., R. 79 W. Interior features consist of
poorly to well-bedded material showing some degree of slumping.

At the junction of sections 24 and 25, T. 140 N., R. 71 W. and sections 19 and 30, T. 140 N., R. 70 W. is a conical hill whose apical portion is uncovered. Minor stratification and slumping were observed.

One of the smallest kames was observed in the SE 1/4 NE 1/4 section 23, T. 140 N., R. 70 W. The exposure was poor but there was some evidence of fair stratification and some slumping.

Four small kames are grouped together approximately 0.5 miles west of Steele, North Dakota. These are in the SE 1/4 section 18, T. 139 N., R. 73 W. Stratification is poor to absent in the exposures.

Another kame, utilized for its sand and gravel for the construction of U. S. Interstate Highway 94, is located in the SW 1/4 SE 1/4 section 25, T. 140 N., R. 70 W. This was relatively large and the sand and gravel deposits showed evidence of good bedding with some lenticular fine to medium-grained sand. Slumping or minor faulting was also present.

A former gravel pit that is presumed to be a kame, due to its features of slumping and stratified material, is located in the NE 1/4 section 21, T. 140 N., R. 73 W. The site of another former gravel pit of kame origin is in the N 1/4 section 26, T. 139 N., R. 70 W. Minor structure was lacking or at least not observed; any present would have been destroyed during excavation. Sediments are heterogeneous and the bedding is poor to fair.

One of the highest kames observed in the area is in the NE 1/4 section 23, T. 139 N., R. 70 W. This exceeds 50 feet in height. The eastern flank is exposed and shows stratified sand and gravel and some minor structure due to slumping.

Another kame is in the SE 1/4 NE 1/4 section 30, T. 139 N., R. 70 W.
Sediments observed are chiefly gravels with minor amounts of sand. The interior of this is not well enough exposed to determine if slumping and other internal characteristics of kames are present.

Eskers

Perhaps the most common origin of eskers is in tunnels at the basal portion of the glacier in a stagnant or near stagnant phase. These tunnels could not easily form or, once formed stay open unless the enclosing ice was stagnant or nearly motionless. The downward percolation of meltwater from the surface through crevasses forms tunnels at the base of the glacier. Eskers generally show evidence of some cross-bedding and poorly stratified deposits of sand and gravel. Flint (1957, p. 157) mentioned that unless the esker was protected by enclosing ice it would be buried beneath outwash or destroyed by proglacial stream erosion.

There are four eskers or esker-like features of various sizes in the area under study. The largest of these had been the site of an old gravel pit, hence the internal features were mostly destroyed. The trend is northeast-southwest and the surface length is approximately one-quarter mile. This esker is mainly in the SW 1⁄4 section 33, T. 140 N., R. 72 W., with a small portion in section 36.

An esker-like feature was observed in the E 1⁄2 section 3, T. 140 N., R. 70 W. The external features suggest an esker, however, due to lack of exposures the internal characteristics cannot be seen.

A small esker was noted in the SE 1⁄4 SW 1⁄4 section 12, T. 140 N., R. 71 W. Some bedding of the sand and gravel was evident with minor cross-bedding. This esker, only 200 to 300 feet in length, has a northeast-southwest trend.

A questionable esker is in the SE 1⁄4 section 12, T. 140 N., R. 70 W.
with a portion extending to section 7, T. 140 N., R. 69 W. in Statesman County. There are no exposures in this eiker-like feature; however, augering brought up sand and pebbles from beneath a thin veneer of till. The external form is quite indicative of an eiker, i.e. it has a sigmoid shape or shape of an open S [→] with an east-west trend. There exists the possibility, however, that this feature may be a crevasse filling.
Glacial Lake Deposits

Evidence for at least one glacial lake, herein named Glacial Lake Steele, was found in south-central Kidder County. Glacial Lake Steele is mainly situated in sections 3, 10, and 16, T. 139 N., R. 73 W. with minor portions in sections 7, 9, 12, 20, and 21, T. 139 N., R. 73 W.

Several auger holes were sunk in the vicinity of Steele, North Dakota; the first two were in the southwest corner of section 3, T. 139 N., R. 73 W. In the first hole below a thin soil zone, three feet of yellow brown clay and silt followed by three inches of silt of the same color were found. Laminations were not observed in the silt or clay. The second auger hole was in the ditch approximately 100 feet west of the first hole. The following lithologies, from top to bottom were found: two feet of rusty, clayey silt, 3 inches of rusty silt with embedded pebbles, 3 inches of rusty fine to medium-grained sand with associated pebbles, and 3 inches of what appeared to be a silty till. No laminations were present in either the upper clayey silt or the lower silt.

The ditch on both sides of U. 3, highway 10 west of Steele, approximately 200 feet west of the junction with highway 3, revealed medium brown un laminated silt that weathers a light brown beneath a thin soil layer.

Another hole was augered in the ditch in the southwest corner of section 16, T. 139 N., R. 73 W. Below a 6 inch zone of black soil are 4 feet 3 inches of yellow brown silty clay that becomes siltier toward the basal one and one-half feet. There were no laminations observed in this silty clay. On the surface in the ditch are pebbles up to one and one-half inches in diameter. In the adjoining field, south of the east-west section line road, are pebbles up to 4 inches in diameter. There is
a possibility that the laminations of the silt and clay were destroyed by augering.

A good exposure of laminated silt was observed in a recently excavated sewer trench 3 feet deep northeast of the school in Steele.

This is 0.2 miles due west of the southeast corner of section 17, T. 139 N., R. 73 W. A black soil zone one and one-half feet in depth comprised the upper portion of the sewer trench. Below this were six and one-half feet of gray and rusty laminated silt with occasional lenses of fine quartz sand. Sewer trench diggers report good sand in two basement excavations one block west of the above location.

Another layer of laminated silt was noted one block west of the school in a cut 7 feet deep. The upper one and one-half feet are comprised of black soil and below this is a thick sequence of yellow clay with brown laminated silt at the basal portion.

From the above evidence the writer believes a glacial lake was present in the area in which Steele, North Dakota is situated. The surface upon which Glacial Lake Steele was once present is relatively flat and lacks boulders. The circumference of Glacial Lake Steele, approximately 7.55 miles, was chosen mainly by the surface expression and not entirely by the occurrence of laminated clays and silt. This glacial lake seems to have been relatively short-lived because of the lack of strand lines or other marginal features.

Finally laminated buff silt and clay underlie two and one-half feet of dark gray outwash material in the northwest corner of section 34, T. 139 N., R. 72 W., near the western margin of Lake Isabel. In the side of a bank on the south side of Lake Isabel, southeast of the junction of highway 3 and the road leading to Camp Grassick, in the 30½ section
34, T. 120 N., R. 72 W., is another exposure. This bank exposes one and one-half to two feet of dark gray, dirty sand. Underlying the sand is three to three and one-half feet of buff silt which stands in a steep wall. At the base of the steep wall of silt occurs a deposit of buff laminated silty clay, of undetermined depth.

The buff silty clay and overlying silt indicates the possible site of another glacial lake. It is also possible that the steep-walled deposit may be loose derived from the dried bed of a former glacial lake, the majority of which is not covered by present-day Lake Isabel. The lack of other exposures and test hole data make it impossible to determine the extent of this probable glacial lake. Topography in the area does not give any evidence of old shore line features.

Flint (1955, p. 123) stated that it is probable that other lakes existed between the slopes of the Coteau and the glaciers in South Dakota. A similar situation may have existed in Midden County.
Unstratified Drift

Ground Moraine

There is only a small amount of ground moraine in the area; approximately one-quarter of the area is covered by this type of deposit. Most of this occurs in the western part of the area mapped.

Thwaites (1937, p. 46) mentioned that ground moraine was once thought to be a deposit of till under the bottom of moving ice. If such were the case, it would be impossible to explain what became of the debris in the ice when it melted. He also stated this interpretation is greatly aided by the modern idea of wholesale stagnation of ice sheets during dissipation. Ground moraine may resemble stagnation moraine; the difference being the abundance of kettle or "potholes" in the stagnation moraine.

The ground moraine in the vicinity of Driscoll, North Dakota is the oldest ground moraine in the investigated area. It was deposited by an earlier ice lobe than that responsible for the Long Lake loop (see p. 57), which overlies it. The moraine is located in the area immediately to the west of the distal flank of the Long Lake loop and connects with the moraine in the vicinity of Steels, North Dakota (see p. 51) by a narrow segment south of Lake Geneva and the minor outwash area near the center of T. 139 N., R. 74 W. Surficially this moraine is typical of ground moraine with low rolling topography with relief of generally less than twenty feet and without linear trends. The direction of downslope in the center sector is to the west at approximately one-eighth to one-quarter degree or 15 to 25 feet per mile. The southern portion slopes toward the northeast, i.e., toward the outwash area and Lake Geneva, the amount of slope, i.e., one-quarter to one-half degree, being nearly the same as the northern area.
An old saltwater channel in this moraine is in the west-central portion of T. 140 N., R. 74 W. This channel, several hundred yards wide and floored with coarse sand and gravel, was one of the main spillways that drained the saltwaters or runoff from the Long Lake lobe of ice.

Several kettle chains are present in the northern sector of the moraine. One is a continuation of a kettle chain that is in the Long Lake loop; the portion in the ground moraine is in sections 8, 9, and 17, T. 140 N., R. 74 W. These kettles as well as other kettles throughout the area were formed from masses or blocks of ice that were severed from the main part of the retreating glacier and buried under till or water-washed drift. With melting of the ice, kettles were formed. Most of the kettles are irregular in shape. Subsequently, many of these depressions have been filled with water.

The ground moraine in the vicinity of Steele, North Dakota was derived from the debris present in the ice lobe that entered Kidder County from the northeast and that nearly covered the entire area except for a small area in the western part of the county. This same ice sheet, when it reached its terminus, formed the Long Lake loop. The lower portion of the moraine was deposited as the ice lobe advanced over the area; the upper part then accumulated when the ice sheet receded after the formation of the Long Lake loop.

Fox Hills sandstone in which a crocodilian tooth was found is exposed in and near the eastern margin of the ground moraine. The bedrock in this area is covered with a thin veneer of till. Fox Hills sandstone is exposed in the SW1/4 SE1/4 section 26, T. 139 N., R. 73 W., near the surface on the southern slope of a post-glacial gulley. Bedrock is exposed along the ditch on the south side of highway 10 in the 31/2 SE1/4 SW1/4 section 7,
T. 130 N., R. 72 W. North of this in the W_1^2 section 6, T. 140 N., R. 72 W. Fox Hills sandstone crops out in the ditch on the east side of the north-south road and also in a farm yard between the house and the road. Additional Fox Hills sandstone is exposed in fresh road cuts approximately 6 to 7 miles southwest of Steele in between sections 16, 17, 20, 21, T. 138 N., R. 74 W. and in the SE_1^2 SE_3^2 NW_1^2 section 10 of the same township and range. All of these exposures are at an elevation of approximately 1800 feet. This indicates that the bedrock surface is relatively horizontal.

Taking into consideration the probability of the near horizontal bedrock surface, the increase in elevation of the topography to the west, and the thin veneer of till over the bedrock along the eastern margin; it may be assumed that the ground moraine generally thins from west to east.

This ground moraine appears to be connected with the ground moraine south of Lake Geneva. However, this moraine may not actually be ground moraine but a more subdued segment of the Long Lake loop. Nearby to the north, the Long Lake loop is quite low but the relief increases gradually in a northward direction. This may be an example of what Flint (1955, p. 113) meant when he said that lower relief resulted from a lesser amount of deposition in sectors of the ice lobe where the flow was slower or at times nonexistent. North of Steele the morainal surface is relatively flat with very little relief, approximately 10 to 15 feet. There is a gentle slope from both the north and south toward the extensive kettle chain in the lower one-third of T. 140 N., R. 73 W. South of Steele, in the southern one-third of the moraine, the relief is more pronounced. Pelagic igneous boulders are more prevalent in the southern portion of this ground moraine than in the northern area. The only reason the writer
can give for this is that the southern segment of the ice sheet contained a greater abundance of boulders than the northern segment. Hence, as mentioned previously, are scattered in three localities in this ground moraine.

A large meltwater channel, that has an east-west trend, is located in the northern portion of T. 140 N., R. 73 W. This is in part floored with gravel and sand; however the majority of the sediment visible is recent alluvium. The spillway sided in the drainage of the excess runoff from the interlobate portion of the Long Lake loop to the north. The runoff was in part responsible for some of the sand and gravel deposited in the large outwash plain to the east of the ground moraine.

The northwest-southeast trending outwash deposit southeast of Weber Lake in sections 31 and 32, T. 139 N., R. 73 W. has been veneered by alluvium by the reworking of the till in the area by recent stream action. This outwash area is approximately 50 feet below the surrounding area on the east and west. The eastern slope is the greatest and is scarred by numerous gullies formed by post-glacial downcutting streams flowing to the lower area of outwash deposits. This linear depression veneered with outwash may represent a southward flowing tributary of the pre-glacial Cannonball River. The possibility also exists that this linear depression may depict a glacial spillway or a bottle chain. It is possible that bedrock, since it is less than 3 miles distant, is shallowly underlying the glacial drift on the flanks of this linear depression. However, this is only an assumption since the Fox Hills sandstone was not observed along the flanks.

The contact with the extensive outwash area on the eastern margin of the moraine is very irregular and at places arbitrary; an exact com-
tact is difficult to place without more exposures such as road cuts being present. The outwash overlaps the ground moraine with a variable thickness.

A small patch of questionable ground moraine is present southwest of the western flank of McPhail Buttes and east of Stony Lake. The lithology of the till is varied; it consists of till intermixed with recent alluvium (slough deposits) and numerous pockets of sand and gravel. Numerous boulders, mainly felsic igneous, were observed on the rolling surface of the moraine.

This small area, the largest part of which is in sections 3 and 9, T. 140 N., R. 71 W., may better be described, however, as a portion of the McPhail Buttes and moraine rather than ground moraine. It may be a lower extension of the McPhail Buttes loop or end moraine caused by the jutting in front of the margin of the ice by a minor mass of the main lobe. In this case the low relief may be due to the ice mass remaining for a relatively short time, hence much less till was deposited than along the principal ice front. There is also a possibility that the surficial expression in part may be due to the northeastward extension of Stony Lake; this would account for some of the recent alluvium which is randomly scattered upon the surface.

End Moraine

End moraine is a ridgelike accumulation of drift deposited by an ice sheet at its furthest advance. The long axis of the ridge is transverse to the direction of glacial movement. According to Raisz (1957, p. 40): "In detail there is every gradation between simple smooth ridges, for the most part with very low gentle slopes, to the most amazing complex aggregations of knobs and ridges interspersed with enclosed
kettles . . ."

Flint (1955, p. 112) stated: "The initial form depends on the amount of rock material contained in the glacier and its vertical distribution within the ice, the rate of flow of the ice, rate of wastage in the terminal zone, and the relative amount of meltwater operative in the terminal zone." Another factor is the elapsed time during which the end moraine is built; the greater the elapsed time the bulkier the end moraine, if all other factors remain the same. The distal margin of an ice sheet also has a snow plow effect. Much debris is derived from underlying bedrock during the advance and is pushed in front of the ice sheet. The amount of material transported by this method may vary; this would be dependent on numerous factors of which the lithology would be a prime factor. Clayton (1960, unpublished Senior Thesis) in concordance with Sheppe (1953, p. 46-47), thinks the importance of the local source of till has been overestimated. Sheppe believed that only 20 to 30 percent of the till in northeastern Ohio was locally derived. Clayton mentioned that the till to the west of the Fox Hills sandstone and Pierre shale contact would be expected to have a higher percentage of sand and that till to the east of the contact would have a higher percentage of shale. He found that 14 samples east of the contact averaged 44 percent sand. Shale averaged 27 percent of the coarse fraction in samples east of the contact and 31 percent west of the contact. This may be due to the large amount of incorporated outwash in the till east of the contact. Thwaites (1957, p. 40) mentioned that not every ice advance is marked by an end moraine. No end moraines would form if the ice mass did not remain at its maximum position for a sufficient length of time.

The slope of the moraines for the most part is dependent upon the
lithology of the till. Till with a relatively high clay content will have gentle slopes and few kettles, while by contrast a permeable, sandy to gravelly till will have many kettles and steep slopes. The slopes of a till with a relatively high clay content will be gentle because runoff will carry the finer clay-size material down the slope and miniature alluvial fans may develop. In sandy to gravelly tills the runoff will be at a minimum because of the downward percolation of the water. Thus the slopes would have minimal erosion and would remain relatively steep.

In the end moraines are embedded local lenses or pockets of sand and gravel. These may best be explained by the statements of Holmes (1949, p. 1433) who said that melting and deposition of drift are believed to ensue in a zone that extends some distance back from the glacier margin thus meltwater must eventually find its way out from beneath the ice. Under these conditions sufficient size-sorting occurs to develop pockets or lenses of sand now enclosed in the till.

In mapping end moraines there is the problem of distinguishing between bedrock highs veneered with drift so they resemble end moraines and true end moraines. This is encountered in areas of conspicuous pre-glacial relief; Flint (1955) used five major criteria in the mapping of end moraine. Flint (p. 117) stated: "... and moraine was mapped only where cuts in the hills do not expose bedrock; where the topography shows no indication of a systemically stream-dissected pattern, where the surface is notably boulder-stream; where there is a general ridge having a distinct crest, and where outwash is present in favorable locations on the distal slope and beyond the distal toe of the ridge."

The distinction between end and recessional moraines is that
recessional moraines have arcuate trends which mark the position of stationary ice margins as the ice sheet melted back. The usual explanation for this stillstand is that for a space of time melting just balanced the rate of motion. Thwaites (1957, p. 41) mentioned that recessional moraines that show minor readvances "... are really end moraines in the strict sense of that term." Recessional and end moraines in this paper will all be undifferentiated and the term end moraine will be used.

Long Lake Loop

The Long Lake loop was derived from the farthest extent of the Caribou ice sheet that formed the ground moraine in the vicinity of Steele, North Dakota. This ice sheet entered Kidder County from the east and extended to the distal margin of what is now the Long Lake loop. Evidence that the glacier entered the county from the east is in the arcuate shape of the moraine with the concave side to the east.

A segment of the Long Lake loop is located in the eastern one-half of T. 140 N., R. 74 W., the western one-third of T. 140 N., R. 73 W., and the northeastern and southwestern portions of T. 139 N., R. 74 W. The northwestern corner of T. 139 N., R. 73 W. also includes a small portion of the loop.

Long Lake loop is the oldest end moraine in the area of investigation; it has a north-south trend in the medial section. The northern portion flexes to the northwest and continues into Burleigh County; the southern segment extends to the southwest to the vicinity of Long Lake. Numerous small, irregular-shaped lakes are scattered throughout this entire loop; drainage is poorly developed, and the majority of the streams are intermittent. The color of the dry till in this loop varied from yellowish gray (5Y 6.5/2) to dusky yellow gray (5Y 6.5/3), and the color
of the wet till varied from medium olive gray (5Y 4/2) to moderate olive brown (5Y 5.5/4).

Maximum relief in the medial portion is approximately 60 feet, however, the average local relief is between 20 and 30 feet. The surface is gently to moderately rolling and forms small and ample topography. To the eye the terrain resembles ground moraine in several localities, the gradual slope of the proximal and slopes can be very deceiving. The surficial expression in the medial section is more subdued than that to the north and south, where relatively rugged features are displayed. The relatively low relief in the medial portion of the moraine is due to several factors which are: the thinness of the lobe of ice in this area and the relatively short duration of the ice remaining in this position. Another factor may be that there was little debris in the ice. To the west of the medial portion in sections 6, 17, and 18, T. 139 N., R. 74 W. is an isolated segment of the main loop. This may have formed by the isolation of a block of ice from the main lobe that melted in place.

The northern part of the moraine has a gentle slope on the proximal side, whereas the distal face is much steeper. Erosion has subdued the rugged topography somewhat. Large felsic igneous boulders are randomly scattered about the surface of the moraine. Maximum relief over the entire northern portion is greater than 100 feet, however, the local relief is much less, approximately 30 feet. The surface has not been sharply dissected by streams, which would help to account for the less rugged topography. There is a gradual downward slope toward the medial segment to the south.

In the southern portion of the area the Long Lake loop has topographic features similar to those in the northern segment. One extensive
Bottle chain is present in sections 30, 29, 31, and 32, T. 139 N., R. 74 W. This bottle chain has a northeast-southwest trend. Maximum relief is close to 30 feet with the average local relief being much less, about 25 to 30 feet. The origin of these bottle chains is the same as that for the formation of kettles; however instead of individual blocks of ice being isolated from the main part of a glacier and buried under the till, several blocks in close succession were severed from the ice mass. Later melting of these blocks of ice formed irregular depressions or kettles. A narrow band of outwash and questionable ground moraine separates the southern and medial segments of the loop.
Interlobate Portion of the Long Lake Loop

The interlobate portion of the Long Lake loop is located mainly in T. 140 N. and T. 141 N., R. 73 W. This interlobate segment of the Long Lake loop was formed when the Long Lake lobe of ice was in juxtaposition with a lobe to the north also advancing in a southwesterly direction. This northern lobe developed the Sibley Buttes loop of Bakken (1960, unpublished Master’s Thesis). The interlobate portion of the Long Lake loop is the eastern part of what Bakken called the Sibley Buttes loop. The present writer has a Sibley Buttes loop in his area which is not the same feature as that described by Bakken under the same name (see fig. 15). This interlobate area has surficial features which very closely resemble the northern portion of the Long Lake loop, hence the writer believes them to be genetically related. There is a question of whether this topographic high is a true end moraine according to the criteria for mapping of end moraines given by Flint (1955, p. 117). Fox Hills sandstone is exposed in a road cut on the west side of highway 3 in the NE 1/4 SW 1/4 SW 1/4 section 33, T. 141 N., R. 73 W. One other known exposure along the main trend of this moraine was observed in Burleigh County as the moraine was traced westward (W. S. Bakken, personal communication, August 1959). These exposures of bedrock may be representatives of isolated pro-glacial buttes or mesas that exerted some control over the ice movement. The writer believes that these isolated buttes acted as buttresses to the ice movement by partially or totally causing the movement of the glacier to come to a halt. To do this, however, it is probable that the ice sheet was relatively thin and as it had almost reached its minimum thickness for movement. A larger and more powerful glacier would not have terminated in this position but would have overridden the buttes and continued westward. It may be
FIG. 15 TERMINOLOGY DIFFERENCES IN THE INTERLOBATE PORTION OF THE LONG LAKE LOOP
assumed that this may have been the case, i.e., a relatively thin glacier, if this lobe was related to the James lobe, which Flint (1955, p. 115) mentioned was very thin during the Mankato subage.

Fox Hills sandstone in the area adjacent to Sibley Buttes is relatively thin, being approximately 20 feet in thickness (D. E. Hansen, personal communication, May 1960). The bedrock is assumed to be nearly horizontal since this exposure (NE 1/4 NW 1/4 SW 1/4 section 33, T. 141 N., R. 73 W.) is at approximately the same elevation (1320 feet) as other exposures of bedrock in the immediate area. However, if the sandstone were of a greater thickness it could be possible that the exposed bedrock may have been different beds of the Fox Hills sandstone and thus indicating a greater dip. A variation of twenty feet over a distance of a mile would indicate a dip of less than one-quarter of one degree. If the above supposition is correct and the difference in elevation one and one-half miles to the southwest is 170 feet it can be assumed that the till is relatively thick and not just veneering the bedrock surface as generally is the situation in a true bedrock high. However, this would not be the situation if a pre-glacial butte or mesa was underlying that portion of the moraine where the difference in elevation is 170 feet. At the present time there is no accurate indication of the amount of drift over the bedrock. The presence of drilling data in this area would have aided this problem immensely.

Additional exposures of bedrock have not been observed in other parts of the moraine. Therefore the writer believes that this topographic high should be considered as the interlobate portion of the Long Lake loop and not a bedrock high.

The subdued topography of this portion of Long Lake and moraine is
one of moderate relief, with the maximum relief of approximately 100 feet at one locality (northwest corner of section 2, T. 140 N., R. 73 W.), the local relief is variable, generally between 25 and 30 feet. In the central portion more irregular depressions are apparent than in the western area.

Contact with the ground moraine to the southeast is quite irregular; an old saltwater channel (Ws sections 3 and 10, T. 140 N., R. 73 W.) veneered with recent alluvium forms the contact in the southwest sector. The slope of the end moraine down to the ground moraine is gradual and approximates that of the main portion of the Long Lake loop. From an overall aspect the interlobe segment has a general east-west trend.

The color of the dry till in this area was light yellowish olive gray (5Y 6/2); the wet till coloration was light olive gray (5Y 5.5/2).

Sibley Buttes Loop

Sibley Buttes represents a topographic high with Fox Hills sandstone acting as a ridge former. It is believed by the writer that the bedrock has been deformed either by faulting, slumping, or ice above or some combination of these. A more detailed discussion of the Sibley Buttes structure is given in an earlier section of this report. Although bedrock is exposed in Sibley Buttes (see fig. 16) the writer believes this topographic high to be an end moraine and is herein named the Sibley Buttes loop. Evidence for this is in the arcuated trend of the moraine as seen in the field and on aerial photographs. An elongate northwest-southeast trending valley, which narrows to the southeast, partially separates the Sibley Buttes loop and the interlobe portion of the Long Lake loop.

Till is very thin on the crest of the ridges but thickens on the flanks. The color of the dry till was light yellowish olive gray (5Y 6/2); the wet till coloration was light olive gray (5Y 5.5/2). The topography
Fig. 16. Fox Hills sandstone exposed in Sibley Buttes in the SE\(\frac{1}{2}\) NE\(\frac{1}{4}\) section 1, T. 140 N., R. 73 W.

Fig. 17. Distal flank of the Eastern Crystal Springs loop as viewed from a point two and one-half miles to the west in the NE\(\frac{1}{4}\) NE\(\frac{1}{4}\) section 16, T. 140 N., R. 70 W. Stagnation moraine topography is in the foreground.
is rugged with steep slopes, 10 percent grade, or 50 feet difference in
elevation in one-tenth of a mile. The overall relief is nearly 200 feet
with the local relief being at least 50 feet in many sectors.

Well developed drainage in the Sibley Buttes is not apparent in the
field, except for one intermittent stream in sections 31 and 32, T. 141 N.,
R. 72 W.; but dendritic drainage patterns can be seen on aerial photographs.
Early spring runoff during recent times is believed to have formed these
dendritic drainage patterns.

Between Buffalo and Sibley Lakes, in the central portion of T. 140
N., R. 72 W. is a subcircular area with an irregular perimeter. Sand and
gravel lap upon the till. The maximum relief is approximately 70 to 80 feet
and the local relief is from 20 to 30 feet. Irregular depressions are
common in the northeastern portion and generally are lacking throughout
the remainder of the area. The color of the dry till was light yellowish
olive gray (5Y 6/2) and that of the wet till light olive gray (5Y 5.5/2).

The surface between this isolated moraine and the Sibley Buttes
appears, as seen on aerial photographs, to be genetically related. This
surface is undulatory, much more so than would be expected in an outwash
plain, which may indicate a rolling morainal surface that has been veneered
with sand and gravel derived from glacial runoff. There is a possibility
that the moraine may be a southeastern extension of the Sibley Buttes in
which the underlying bedrock was not deformed. This would be feasible if
this sector was formed on the flank of the nose of the ice lobe where
movement would be less forceful. There is no evidence for this moraine
being a bedrock high. Another possibility is that the till may be a
remnant of an earlier period of glaciation. Clayton (1960, unpublished
Senior Thesis) believes that this isolated area of till may be a remnant
of a recessional moraine of the Long Lake lobe of ice. Another theory that this isolated moraine may be a remnant of the ground moraine, which occurs in the vicinity of Steele, North Dakota, which has been isolated by outwash. The elevations are similar to those on the eastern margin of this ground moraine.

Western Crystal Springs Loop

The end moraine is mainly in the western portion of T. 140 N., R. 70 W. The name of this end moraine, herein designated the Western Crystal Springs loop, was derived from the nearby village of Crystal Springs.

The northern portion of this generally north-south trending moraine has a more subdued profile than the central and southern sectors. The greatest relief is present in the central portion and the topography consists of numerous knobs and closed depressions, which are responsible for the somewhat rugged relief. The direction of the main trend is generally north-south, however, numerous minor ridges trend in all directions of the compass. The regional relief of the loop is approximately 120 feet, locally the average relief is from 30 to 40 feet. Scattered throughout this moraine are many lakes which vary in shape from ovoid to oblong.

Originally the northern sector of this moraine extended further northward, but since its formation it has been truncated by a later glacial advance that formed the McPhail Buttes loop. Evidence for truncation of the Western Crystal Springs loop by the McPhail Buttes loop is the small isolated segments of till of the northern extension of the Western Crystal Springs loop that protrude through outwash that originated from the McPhail Buttes loop. Melting water off the McPhail Buttes loop formed this outwash along the distal slope in sections 7, 8, 17, and
The distal margin of the moraine is overlapped by outwash, hence the boundary is not distinct. The proximal margin has a gradual slope downward to the stagnation moraine on the east.

The color of the dry till of the Western Crystal Springs loop was light yellowish olive gray (5Y 6/2) and that of the wet till was light olive gray (5Y 5.5/2).

This moraine was formed by a minor pulsation of the Mankato glacial ice sheet that flowed in a westerly direction and terminated. This termination is marked by the Western Crystal Springs loop, which is slightly arcuate in shape with the open end to the east. The lobe of ice that formed this moraine is believed to have been smaller in extent than that from which the Long Lake loop was derived, evidence for this being in the smaller plan view area.

The lower moraine to the southwest of the main portion of the Western Crystal Springs loop may be a lower expression of this end moraine. The surface is rolling and pitted with numerous knobs and kettles which resemble the topographic expression of the loop itself. However, comparing the surface with that of the stagnation moraine on the proximal margin of the end moraine, the two are notably similar. There is a possibility that this lower, pitted moraine may also be a remnant of an earlier moraine, although the surficial expression does not resemble that of the ground moraine that occurs in the vicinity of Steele, North Dakota.

McPhail Buttes Loop

The Mankato ice sheet or lobe from which this end moraine is derived entered what is now Kidder County from the northwest. Evidence for this is
in the parabolic shape of the moraine with the open end to the northeast. This advance of the ice was more than a minor pulsation; evidence for this is in the extensive area covered by the moraine. It is believed by the writer that this advance was in the form of two adjacent lobes, the southern of which formed the Eastern Crystal Springs loop and the northern lobe, the McPhail Buttes loop. The McPhail Buttes lobe of ice was the more arcuate of the two, evidence for this is the parabolic plan view of the moraine as observed from the aerial photographs.

The southern flank of this end moraine truncated the northern sector of the Western Crystal Springs loop. Meltwater carrying sand and gravel has all but covered any evidence of this older moraine’s northern portion. The only evidence of this northern extension still present are several small isolated patches of moraine.

The surficial expression of the McPhail Buttes end moraine with its linear trends on the aerial photographs is similar in appearance to those observed on the photographs of Sibley Buttes and hence suggest bedrock control. A reconnaissance of stream beds showed no exposures of bedrock. Dendritic drainage is the rule; however, streams are scarce; only one intermittent stream is shown on the Tappen North quadrangle, none were observed in the field.

The color of the dry till in this moraine varied from light olive gray (5Y 5.5/2) to light yellowish olive gray (5Y 6/2); the wet till coloration was medium olive gray (5Y 4/2).

The northern flank of the McPhail Buttes loop trend northeastward into T. 141 N., R. 70 W., and R. 71 W. Elevational differences between the crest of the moraine and that of the outwash to the south and southwest varies from 150 to 200 feet. The steepness of the distal slope is
greater along the southern flank than that along the nose of the loop to the northeast. Maximum relief is greatest in the western one-half of the moraine. Knob and kettle topography on the surface of this loop is not as distinct as that on the Long Lake and Western Crystal Springs loops; it has a rather distinct linear crest. The proximal flank of the moraine has a gentle slope to the north and adjacent to this is an area of stagnation moraine.

The writer cannot account for the long, finger-like projection that has a southwest-northeast trend from the nose of the McPhail Buttes and moraine. The surface expression appears to be that of an esker, however, the lithology which is till does not substantiate this. Augering to a depth of three to three and one-half feet at several positions on the crest did not uncover any sand or gravel. There is a possibility that this may be a remnant of an earlier moraine, although the till is very similar to that of the McPhail Buttes moraine.

Eastern Crystal Springs Loop

In comparing the adjacent ice lobes invading this area it is significant to note that the Eastern Crystal Springs lobe was of a lesser size than the McPhail Buttes lobe. Evidence for this is in the areal extent of the moraine developed.

The southern extension of the McPhail Buttes Loop is herein named the Eastern Crystal Springs loop. The reason for stating that the Eastern Crystal Springs loop is a southern counterpart of the McPhail Buttes loop is that in the interlobate segment there is no distinction between the topography or any evidence of truncation. The interlobate portion, in which the topography is more subdued, is in the northeastern corner of the area under investigation in T. 140 N., R. 70 W. The Eastern Crystal
Springs loop continues southward from the interlobate area to the south-
eastern corner of T. 140 N., R. 70 W. where it again swings eastward into
Stutsman County.

The northern and southern portions of the Eastern Crystal Springs
loop have the greatest relief, approximately 30 feet. Local relief of
40 to 50 feet is not uncommon. In the central portion the relief is less,
generally 60 feet; local relief is approximately 30 feet. A reason for
the lesser and more subdued topography may be due to a relative thinner
portion of the ice mass. Distinct linear trends are not as prevalent
on this loop as in the McPhail Buttes loop. Depressions marking the
position of former small lakes are evident to a minor degree.

An old spillway or meltwater channel drained the interlobate and
immediate surrounding area in part, drainage was to the northeast into
Chase Lake (T. 141 N., R. 69 W.). A lesser spillway extends in a south-
westernly direction to the vicinity of the unnamed lake north of Salt
Alkali Lake.

The distal margin of the Eastern Crystal Springs loop has an abrupt
slope as viewed from the west (see fig. 17). To the east the proximal
margin grades into stagnation moraine with knob and kettle topography.
The contact of the southern flank of the loop with the stagnation moraine
was picked at the general break in slope.

The dry till, according to the Goddard et al. Rock Color Chart,
has a color of light yellowish olive gray (5Y 6/2) and the wet till varied
in color from medium light olive gray (5Y 4.5/2) to light olive gray
(5Y 5.5/2).

Lake George Loop

This loop is named for Lake George, which is in the southern one-
half of T. 138 N., R. 70 W. The Lake George loop is believed by the writer to mark the last or next to the last advance of the Mankato ice sheet into this portion of Ridder County. Movement of the ice lobe was from the south-east to the northwest. The semicircular trend of the loop gives some indication as to the direction of glacial movement which was in a northwesterly direction. The lineation of the axis of an end moraine is assumed to be normal to the direction of ice movement. The presence of striations on the bedrock would have been an aid in definitely establishing the direction of the last glacial movement; however bedrock was not observed in this area. It is unfortunate that there is no positive method of establishing the age relationships of the McPhail Buttes and the Lake George loops. The principal reason for assuming the Lake George loop to be younger than the McPhail Buttes and Eastern Crystal Springs loops is in the difference in the direction of ice movement. This northwestern movement is anomalous with the general southwestern to western movements of previous ice lobes.

It may be assumed by the differences in the topographic features of this moraine that it was developed by two separate movements of the ice lobe. The distal portion of the loop has moderate relief and a more subdued aspect than the inner or proximal portion in sections 31, 32, and 33, T. 139 N., R. 70 W. Thirty to forty feet is the average relief in the western and northern sectors; the eastern portion has an overall relief of 40 to 50 feet with a maximum of approximately 115 feet along the Ridder-Stutsman County boundary. The surficial expression of the subdued portion is that of moderately rolling topography with a downward slope to the north and northwest. It is believed by the writer that the lower segment of the moraine was initially formed at the furthest advance
of the ice lobe. The lobe remained stationary in this position for a relatively short period of time before "retreating" to the south where it was at a stillstand for a much longer duration of time. Hence as a result of this a more rugged moraine has formed with a maximum relief of approximately two hundred feet.

The more rugged moraine has an average elevation of 150 to 200 feet above that of the subdued portion. There is a possibility that this topographic high may be because of a bedrock association, however, a reconnaissance was made by the writer and no exposed bedrock was observed. Well data, which is lacking in this area, would have been a deciding factor as to whether this higher portion is a topographic or a bedrock high. However, due to lack of evidence to the contrary, this high and more rugged portion is mapped as end moraine.

The color of the dry till of the Lake George loop ranged from light yellowish olive grey (5Y 6/2) to yellowish grey (5Y 6.5/3) and the wet till varied from medium olive grey (5Y 4/2) to light olive grey (5Y 5.5/2).

**Stagnation Moraine**

The writer is using the term "stagnation" moraine in much the same manner as Lenke and Colton (1952, fig. 3) used the term "dead ice" moraine. Stagnation moraine covered approximately one-tenth of the area under investigation.

Cook (1924, p. 159-160) believed that stagnation of glacial ice was the result of subsidence of the earth's crust under the weight of the ice sheet. Subsidence would reduce the slope along which the glacier was flowing and hence the movement would be impeded. It was stated by
Flint (1929, p. 267) that if the region that Cook designated (eastern New York State) were tilted back to coincide with the supposed glacial datum plane the result would not be a reverse (north-facing) slope. He concluded that topographic control was exerted not by the glacial crustal subsidence but by the preglacial configuration of the land surface.

Continued thinning of a glacier so as to reduce its pressure head would eventually lead to the cessation of flowage in the glacier and the result would be stagnant ice. Thornbury (1954, p. 363) stated that a true condition of stagnation could probably result only after the detachment of an ice mass from the main body of the glacier. After the glacial ice has reached the minimum thickness required for movement or when the ice mass has been severed from the main body of the glacier stagnation of the ice commences. Reduction in the thickness of an ice sheet decreases the plasticity of the deeper ice and forward motion becomes increasingly slower as time goes on. Stagnation results when there is too little force to overcome the internal resistance to flow (Thwaites, 1957, p. 15).

Flint (1957, p. 73) mentioned that as ablation thins the marginal portion of the glacier and movement ceases, the thrust surfaces (broken lines) of the glacier become inactive and ablation drift accumulates on the surface (see fig. 17). This superglacial debris acts as an insulating blanket and retards the rate of melting which is radially inward from the margins, top, and base. If the debris covering the ice has not been washed by water the debris will eventually be let down in confused dumps onto the underlying till as the ice melted out from beneath (Flint, 1929, p. 276). However, a large amount of water may be present as a result of downsloping of the ice. Hence most of the silt and clay fractions may be flushed out, leaving a course-textured till. This is generally found to be true in the areas of stagnation moraines observed; there is the
presence of pockets or lenses of sand and gravel and coarser till because of the washing-out of the finer material by meltwater during the settling process.

Fig. 16. Ideal radial section through terminal part of a glacier, showing transfer of load from basal to super-glacial position by ice movement along upward directed surfaces of thrusting. (After Flint, 1957, p. 73)

It was concluded by Cook (1924, p. 159-166) after studying eastern New York State that the last glacial ice sheet became stagnant and melted in place. Evidence which Cook cited for the stagnation of this ice sheet are the kettle-holes and kames which resulted from melting of buried ice blocks and alump respectively; kame terraces, and the absence of recessional deposits. Flint (1929, p. 263) believed that the absence of these recessional moraines was of prime importance for an explanation based on stagnation. The area of south-central Riddler County also has kettle-holes and kames and lacks recessional moraine. Hence this suggests a stagnant ice origin for the stagnation moraines. However, no kame terraces were observed in the area under investigation; apparently none developed because the pre-glacial topography did not favor their development. The topography was one of a relatively maturely eroded surface lacking slopes on which the stagnating ice would deposit kame terraces.
Thornbury (1954, p. 297) listed the following features that are commonly found where ice waved while stagnant: ablation moraine, crevassed fillings, eskers, kames, kame terraces, extra-marginal deltas, outwash plains, lacustrine deposits, spillways, ice-marginal and lateral drainage lines.

In this paper stagnation moraine will be used to denote a moraine which was to a greater or lesser degree deposited by stagnating ice and which is generally expressed as knob and kettle topography with no linear trends and with relatively low relief (approximately 30 feet).

It is probable that the stagnation moraines adjacent to the proximal portions of the McPhail Buttes, Western and Eastern Crystal Springs, and Lake George loops originated as stated above.

The lower area separating the Western and Eastern Crystal Springs loops is considered to be a stagnation moraine. An abundance of closed depressions or kettles are present as well as a rolling surface with generally not over 30 feet of relief. Its western contact with the Western Crystal Springs loop is gradational, however, the northern section, especially near the contact with the distal margin of McPhail Buttes moraine near the interlobate area, has more relief. In this sector the lakes are larger and the relief is approximately 50 to 60 feet.

There is a possibility that what is considered to be stagnation moraine on the distal margin of the southern one-half of the Western Crystal Springs loop should not be differentiated from the end moraine. Both surfaces are pitted with closed depressions and knobs; however, the stagnation moraine has a lower and more subdued topographic expression. The contact with the end moraine is arbitrary; it was mapped at the break
in slope. Linear trends in this lower moraine are absent, and the ridges tend to be oriented in no particular manner.

The stagnation moraine associated with the Eastern Crystal Springs loop is similar in appearance to that of the stagnation moraine between the Western and Eastern Crystal Springs loops. Knob and kettle topography is well developed and the relief is quite variable, being greater to the north. The contact with the proximal margin of the loop is very irregular and indistinct.

Stagnation moraine adjacent to the Lake George loop also has an irregular perimeter and extends easterly into Butte County and south-erly out of the area under investigation. The dominant difference in this moraine as compared with the others is in the greater amount of relief and the preponderance of kettle lakes and closed depressions. A larger percentage of the till in this area is coarser than that in the other moraines of this type also. Two names are associated with this moraine, they are in the NE\(^2\) NW\(^1\) section 26 and in the NW\(^2\) SE\(^1\) NE\(^2\) section 23, T. 139 N., R. 70 W.
PRE-GLACIAL DRAINAGE

Flint (1955, pl. 7) indicates that the Sheyenne River and all streams north of it flowed into Hudson Bay in pre-glacial time. Lamke and Colton (1958, p. 42) mentioned that work in North Dakota has substantiated Flint's interpretation. Fisher (1952, fig. 4; p. 27) illustrated that the pre-glacial Cannonball and Heart Rivers drained into the James River (?) via the old valleys of Badger and Apple Creeks in Emmons and Burleigh Counties respectively.

Long Lake is now situated over where the pre-glacial Cannonball River entered Kidder County from the southwest. This stream flowed northeastward between the present vicinity of Dawson and Tappen, North Dakota and then angled more to the north toward Stony Lake and continued northward out of the area under investigation. Evidence for the old stream channel is taken from test hole data and cross-sections (see fig. 2).

RECENT DEPOSITS

Sand Dunes

The dune sands shown on the glacial map constitute only a small portion of the solian sand present in the area. That portion mapped consists of sand which is thick enough to form distinct dunes. In the vicinity of Tappen, much of the outwash as well as portions of the end moraine to the east and south are covered by a thin veneer of solian sand. Because of the prevailing northwest wind, dune areas generally lie southeast of large outwash plains from which the sediments are derived.
The majority of the dune area is in sections 13, 14, and 15, T. 139 N., R. 71 W., southeast of Tappen (see plate 4). Maximum relief is up to 15 feet, however, the relief averages approximately 5 to 6 feet. The meager amount of vegetation on the dunes is not sufficient in preventing transport of the sand by strong wind. Contact with the outwash at numerous places is arbitrary and difficult to accurately place. The general trend of the dunes is in a northwest-southeast direction; this is due to the direction of the prevailing wind. The sand is fine to medium-grained and dark brown in color due to staining, quartz is the dominant mineral present. Quartz grains are generally frosted, as observed under the microscope, by the action of the wind. These sand dunes are of post-glacial derivation.

Boulder Line

Post-glacial or recent ice above has moved boulders into a row along the shore of the various kettle lakes in the area. Freezing caused an expansion of the water as it changed into the solid state. This would result in movement of the ice upward and laterally which would force boulders at or near the edge of the water further upon the shore. Puhalt (1957, p. 55) stated that is known as a boulder line. Other possibilities for the boulders lining the shore are that rainwash and wave action have winnowed out the finer sediments thus exposing the boulders.
SUMMARY OF THE SEQUENCE OF EVENTS

Lemke and Colton (1958, p. 41) pointed out that during the Pleistocene epoch all of North Dakota, with the exception of the south-western portion, was glaciated. Evidence of pre-Wisconsin glaciation is lacking. Glacial deposits ranging from the Iowa (?) substage of the Wisconsin stage to the Two Creeks interstadial (Cary-Mankato interval of Flint, 1955) have been tentatively identified.

Lemke and Colton (1958, p. 46) mention that the Iowa (?) drift if it exists in North Dakota lies in a northwest-trending belt mostly south of the Missouri River. Till in this belt is 20 to 40 miles wide and is thin and patchy. This is because of nondeposition and subsequent erosion. Advance of the ice over most of the area is validated only by the presence of erratic boulders. The Iowa (?) ice sheet advanced from a northeastern direction as indicated by the orientation of the drift border and associated features.

Tazewell (?) drift as interpreted by Lemke and Colton (1958, p. 47) lies mostly north and east of the Missouri River and forms a belt 15 to 30 miles wide. The ice sheet advanced from the northeast except in north-western North Dakota where the position of the moraines indicate a northern and northwestern source.

Lemke and Colton (1958, p. 58) stated that drift of the Cary substage is not exposed in North Dakota. They mentioned that the post-Tazewell-pre-Two Creeks drift (A-1 advance of the Mankato according to Flint, 1955) is composed of a series of prominent northwest-trending and moraines that extends from the south-central to the northwestern part of the State. Lemke and Colton (1958, p. 47-48) further believed that the
Gary drift is overlapped by the post-Tazewell-pre-Two Creeks drift in North Dakota. However, Bakken (1960, unpublished Master’s Thesis), Chmelik (1960, unpublished Master’s Thesis), Clayton (1960, unpublished Senior Thesis), and the writer believe that drift of the Gary substage exists in the eastern part of Kidder County. Hence the Gary substage is assumed to be equivalent to the post-Tazewell-pre-Two Creeks of Lemke and Colton and the A-1 advance of the Mankato substage of Flint.

Post-Gary maximum drift (advances 1-4) of Lemke and Colton (1958, fig. 3; p. 59) correspond to Flint’s (1955, pl. 1; p. 119) E-1 and later positions of the Mankato drift borders in South Dakota. The positions of the various end moraines indicate that the ice advanced from the northeast, however, local locations deviated somewhat from this trend.

During the Cary substage of the Wisconsin glacial stage a lobe of ice advanced from the east into the area which is now Kidder County. As a result the ground moraine in the vicinity of Driscoll, North Dakota, which was formed during an earlier ice movement, was partially overlapped. This lobe of glacial ice was present for a sufficient length of time to deposit what is now called the Long Lake loop. With the accompanying melting, outwash sediments were deposited in the central portion of T. 140 N., R. 74 W. The apparent dip of the beds indicates that the source of supply was from the north and northeast. A meltwater channel, with an east-west trend, in the central portion of T. 140 N., R. 74 W., acted as a passageway for the sediments being washed off the northern portion of the end moraine. These sand and gravels were transported varying distances depending on the velocity of the stream and the particle size. Outwash deposits in the old channel are coarser toward the source and become finer westward.
The interlobate portion of the Long Lake loop originated from the coalescing of two adjacent ice lobes, one in the area under study, that was following the valley of the pre-glacial Cannonball River and the other lobe to the immediate north, in a low between bedrock highs.

The basal portion of the ground moraine near Steele, North Dakota was planed down beneath the ice by the advance of the ice lobe that formed the Long Lake loop. The surficial deposits of this ground moraine were derived from englacial and superglacial debris deposited as the glacier melted back toward the source. At this time the kames present on this moraine were forming in the near stagnant ice. Glacial Lake Steele, formed in a shallow, near elliptical depression, was being filled with meltwater from the melting ice. The thickness of the debris deposited from the melting ice mass was gradually thinning to the east because of the lesser amount of ice present. The outwash area southeast of the present Lake also originated during this interval, however, some of the sediments may be of later origin due to reworking and runoff of small intermittent streams from the higher moraines that surrounds it.

Another advance of the Cary ice is marked by the crescent-shaped Sibley Buttes loop. The ice lobe advanced from the east or east northeast and overlapped the northern portion of the ground moraine in the vicinity of Steele and the proximal portion of the Long Lake interlobate moraine. A possible isolated portion of this moraine is in the area between Buffalo and Sibley Lakes to the southeast or this moraine may be a remnant of the above ground moraine or a recessional moraine of the Long Lake lobe of ice. Outwash was deposited in the immediate area to the south and east during and following the development of the end moraine or loop.

The Western Crystal Springs loop was formed by the next readvance or pulsation of the Wisconsin ice mass, the B-I advance of the Mankato
substage. This advance partially overlapped the eastern and northeastern portion of a stagnation moraine, that originated previously, along the southwestern margin of the loop. Another possibility is that the so-called stagnation moraine is a lower, more subdued portion of the Western Crystal Springs loop. If this is a stagnation moraine it was relatively high because it was not entirely covered by outwash from the Western Crystal Springs loop and succeeding loops. During the melting back of the lobe of ice that developed the Western Crystal Springs loop, a stagnation moraine formed along the proximal margin.

A later advance of the ice is marked by the presence of the McPhail Buttes loop and its southern extension, the Eastern Crystal Springs loop, which in the northeastern part of the area formed an interlobate moraine along the line of junction. The McPhail Buttes lobe truncated the northern segment of the Western Crystal Springs loop and the outwash, derived from the lobe of ice, nearly covered the northern segment. The Eastern Crystal Springs loop also overlapped the stagnation moraine that is present along its distal flank. Stagnation moraines formed at the proximal margins of the McPhail Buttes and Eastern Crystal Springs loops.

Another advance of the Mankato ice mass formed the Lake George loop. It is difficult to say which of the two last ice advances (that which deposited the McPhail Buttes and Eastern Crystal Springs loops or that which deposited the Lake George loop) was the last in this portion of Kildeer County. Stagnation moraine also developed along the proximal margin of this moraine as the ice melted.

The extensive sheet or sheets of outwash in the area west of the Western Crystal Springs, McPhail Buttes, Eastern Crystal Springs and Lake George loops formed partially from the runoff of the meltwater from
the ice which deposited the previously stated moraines and in addition from the Stidley Buttes and intermediate portion of the Long Lake Loop. Additional outwash material was derived from the moraines north of the area under investigation, where an extensive continuation of the outwash plain is also present.
CITED REFERENCES


APPENDIX
GLOSSARY

Boulder—a rock fragment, usually rounded, greater than 256 mm in diameter (Pettijohn, 1957).

Clay—an aggregate of mineral or rock material in which the individual particles are less than 1/256 mm in diameter (Pettijohn, 1957).

Cobble—a rock fragment, usually rounded, between 64 and 256 mm in diameter (Pettijohn, 1957).

Crevase filling—is a linear, generally flat-topped ridge of water sorted material deposited by a glacial stream in an open crack in the ice (Thwaites, 1957).

Drift—any rock material that is transported and deposited by a glacier or in water derived from melting of the ice (A. G. I. Glossary, 1957).

End moraine—is a ridgelike accumulation of drift deposited by an ice sheet at its furthest advance. Linear trends are generally present.

Esker—a sinuous, narrow ridge of drift which is believed to represent filling of a glacial stream channel (Thornbury, 1954). They are commonly oriented at right angles to the direction of ice movement.

Fissility—the property of splitting easily into thin sheets.

Groove—a line on the bedrock surface, deeper than a striation, believed inscribed by rocks embedded in the base of the ice sheet.

Ground moraine—"...is a moraine having low relief devoid of transverse linear elements. It forms undulating plains marked by gently sloping swells, sags, and basins, the whole commonly having a local relief of less than 6 meters." (Flint, 1957, p. 131)

Interlobate moraine—is a special variety of end moraine that is built along the line of junction of two adjacent glacier lobes (Flint, 1957).

Kame—a low, steep-sided, mound of stratified drift, formed in contact with glacial ice.

Kettle—a depression in drift formed by wastage of a detached mass of glacial ice that was either buried or partly buried in the drift (A. G. I. Glossary, 1957).

Kettle chain—group of related kettles occurring in a more or less linear pattern.
Morsina—drift deposited by direct glacial action, and having constructional topography independent of influence of the underlying surface on which the drift lies (Flint, 1955).

Outwash—stratified material that is deposited by meltwater streams beyond the active glacier ice (A. G. I. Glossary, 1957).

Pebble—a mineral or rock fragment ranging from 4 to 64 mm in diameter.

Sand—an aggregate of mineral or rock grains ranging between 1/16 mm and 2 mm in diameter (Pettijohn, 1957).

Sandstone—the indurated equivalent of sand.

Shale—the indurated equivalent of clay which generally exhibits the property of fissility.

Silt—an aggregate of particles ranging from 1/16 mm to 1/256 mm in diameter.

Stagnation morsina—drift believed to have been let down from a superglacial or englacial position through the melting of underlying stagnant ice.

Stratified drift—is drift that has been deposited by water and exhibits both sorting and stratification (A. G. I. Glossary, 1957).

Striation—a fine cut line on the bedrock surface believed inscribed by the rock particles embedded in the base of the overriding glacier (Flint, 1957).

Till—unstratified and unsorted ice-laid material which may range from clay to boulders in size.

Unstratified drift—is drift that has not been formed or deposited in beds or strata.
PLATE 3  Histograms of analyses of 16 outwash samples