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The glacial geology of eastern Sheridan County, North Dakota

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This thesis submitted by Thomas G. Gustavson in partial fulfillment of the requirements for the Degree of Master of Science in the University of North Dakota is hereby approved by the committee under whom the work has been done.

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GLACIAL GEOLOGY OF EASTERN SHERIDAN COUNTY, NORTH DAKOTA

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The thesis, here abstracted, was written under the direction of Dr. John R. Reid and approved by Dr. Wilson M. Laird and Mr. Nicholas N. Kohanowski as members of the examining committee, of which Dr. Reid was chairman.

ABSTRACT

During late Pleistocene time two ice advances affected parts of eastern Sheridan County, North Dakota. The first advance deposited the Burnstad, Streeter and Grace City drifts, and covered the whole county. The second advance deposited the Martin drift and occupied only the northern quarter of the county.

The Streeter drift, characterized by dead-ice landforms and nonintegrated drainage, is separated from the Burnstad drift by a large partly collapsed outwash plain on the distal side of a pronounced end moraine. The Grace City drift, characterized by a low relief ground moraine and poorly integrated drainage, is separated from the Streeter drift by the Lincoln Valley end moraine and the Missouri Coteau escarpment.

Total ablation of the Grace City ice in this area must have occurred before formation of the Martin end moraine because large portions of outwash from an uncollapsed outwash plain were incorporated into the Martin end moraine north of Lincoln Valley. The Martin drift is characterized by high relief ground moraine, nonintegrated drainage

and a slightly sandier lithology than that of the Streeter and Grace City drifts. North of the Martin end moraine several "shear" moraines and a small area of dead-ice moraine are present. The ice retreated from Sheridan County less than 12,000 years ago.

Several large potential sources of ground water are present in eastern Sheridan County; four large outwash plains each contain large quantities of shallow ground water. The buried channel of the ancient Knife River may also contain large amounts of ground water.

Future economic growth of this area will depend partly on effective development of its large ground water resources and to a lesser degree on development of its abundant sand and gravel deposits.

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by

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INTRODUCTION

PURPOSE

This report describes in detail the glacial geology and chronology of the eastern half of Sheridan County, North Dakota (Fig. 1). Plate 1 shows the areal distribution of major glacial landforms and location of bedrock outcrops. Since there are only a limited number of bedrock outcrops in this half of the county, the bedrock is described only briefly.

The benefits which may be expected from this study are: (1) a map, which may serve as the basis for future ground water and soils studies, and which will aid in the location of construction materials, future highways, and construction sites; and (2) an interpretation of the glacial history which will increase the overall knowledge of the regional glacial history.

FIELD TECHNIQUES

Every passable road in eastern Sheridan County was traversed by automobile. Section lines without roads were traversed on foot when necessary and in some cases before final conclusions were made even more traverses were completed to determine the exact areal extent of the landforms. Lithology checks were made at 0.2 mile intervals along roads and section lines and otherwise wherever necessary. Till, outwash, and lake sediment samples were collected for subsequent laboratory analysis in order to provide information concerning till composition and, in the case of stratified sediments, to determine if fossil material was present. Fourteen pebble counts were made to determine the composition of the larger detrital particles. Field mapping was done

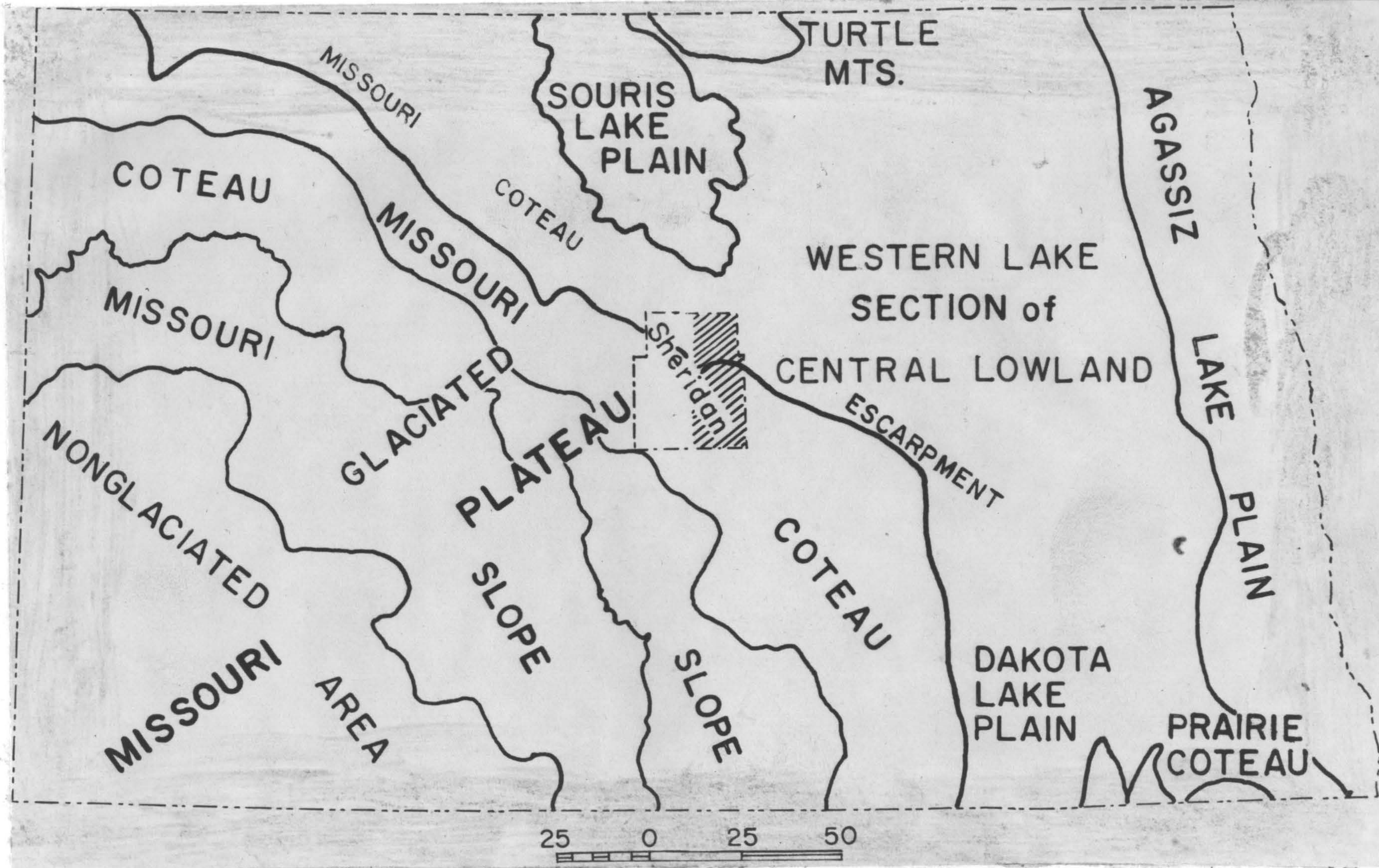

Figure 1.--Index map of location of eastern Sheridan County and physiographic units of North Dakota, modified from Clayton, 1962. Hachured area is the area of this report.

on aerial photographs, scale 3.1 inches to the mile, obtained from the United States Department of Agriculture, Commodity Stabilization Service. Topographic coverage of eastern Sheridan County is not complete (Fig. 2); but, United States Geological Survey topographic maps, 15 and 7.5 minute series, were used to supply topographic information whenever possible.

Data plotted on aerial photographs were subsequently transferred to the General Highway Map of Sheridan County, scale one inch to the mile, prepared by North Dakota Department of State Highways, State Wide Highway Planning Service, in Cooperation with the United States Department of Commerce, Bureau of Public Roads.

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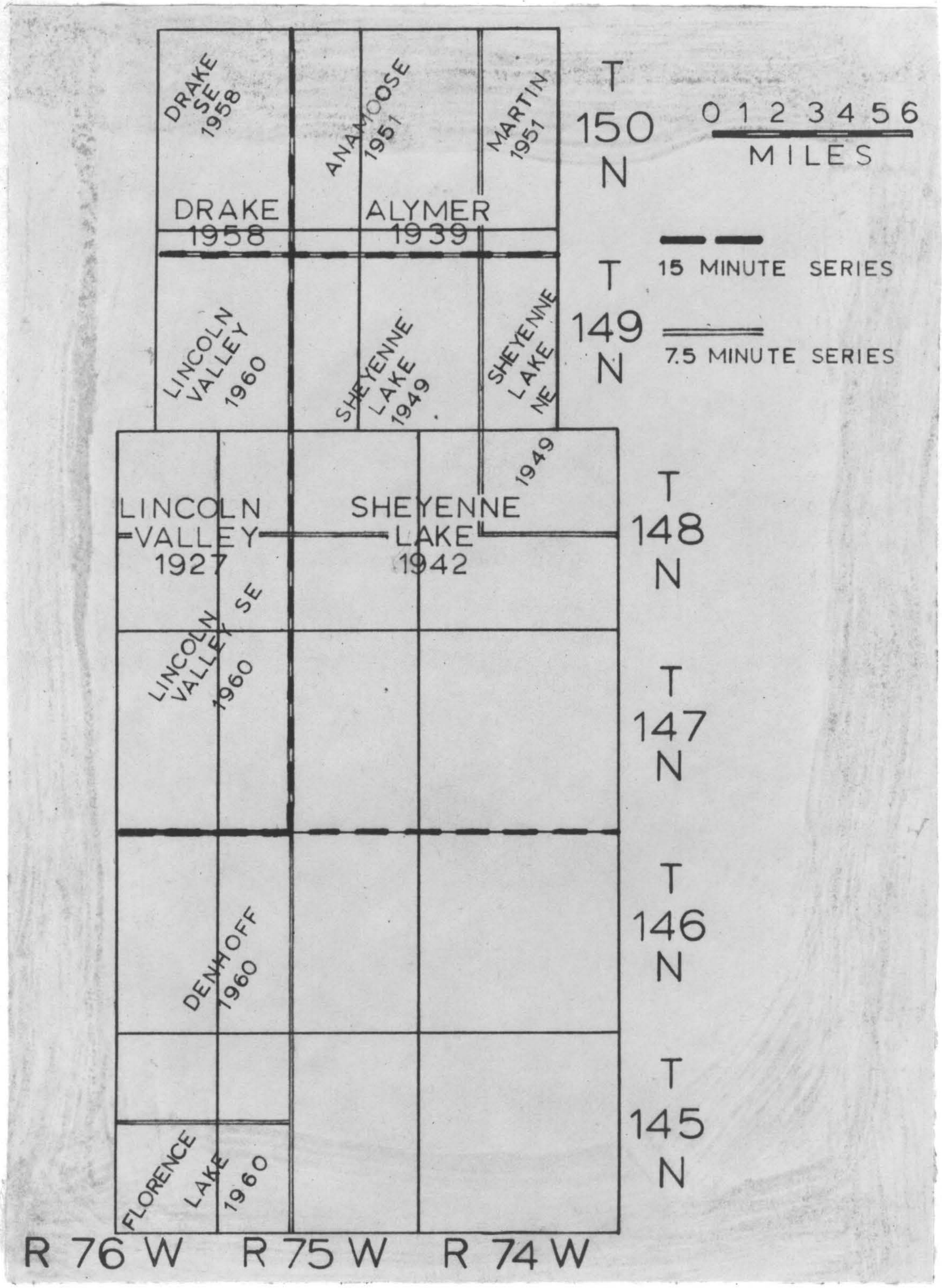


Figure 2.--Index map showing areas covered by topographic maps in eastern Sheridan County.

from well cores taken in eastern Sheridan County.

PREVIOUSLY PUBLISHED WORK

Regional Studies

Portions of eastern Sheridan County have been included in four existing regional studies. Andrews (1939) discusses the development of several spillways that drained waters from Lake Souris into the Sheyenne River. He concluded that the Kruger Lake and Bently Lake spillways, which include Kruger Lake in western Sheridan County and Guyes Lake in eastern Sheridan County respectively, emptied into the Sheyenne River about five miles north of Lincoln Valley. As the ice sheet retreated these waters were diverted through the Wintering River spillway to the present-day course of the Souris River.

Lemke and Colton (1958) published a comprehensive summary of the Pleistocene geology of North Dakota. They indicate the presence of four drift sheets in Sheridan County, the Burnstad, Streeter, Grace City and Martin drift sheets. They state that all these drifts except the Burnstad are Post-Cary maximum. They believe that the Burnstad is Post Tazewell pre-Two Creeks.

Lemke (1960) disagrees with Andrews interpretation of the Kruger Lake spillway. Lemke shows that a divide exists at an altitude of 1,680 feet in the vicinity of Kruger Lake. This suggests that there are two channels, (presumably outwash channels) one which drains northwest and one which slopes southeast into the present headwaters of the Sheyenne River. He also points out the existence of a deep channel in the vicinity of Guyes Lake which coincides with Andrews (1939) Bently Lake Spillway.

Colton, Lemke and Lindvall (1963) published a preliminary glacial map of North Dakota. On an earlier unpublished version of this map (1958), Lemke and Colton were the first workers in North Dakota to map stagnation or collapse moraine (dead-ice moraine). Many of the larger glacial landforms of Sheridan County are portrayed on these maps which have served as a useful reference for this thesis.

Studies of Specific Adjacent Areas in Central North Dakota

Brophy (1962, unpublished report, North Dakota State University) studied a portion of central Sheridan County, Kume and Hansen (North Dakota Geological Survey Bulletin) mapped Burleigh County, Sherrod (1963, unpublished Master thesis, University of North Dakota) mapped western Sheridan County, and Faigle (1963, unpublished Master thesis, University of North Dakota) and Kresl (1963, unpublished Master thesis, University of North Dakota) mapped Wells County.

GEOGRAPHY

Location and Size

Sheridan County (Fig. 1) encompasses 1008 square miles and is located in the center of North Dakota. It is approximately 180 miles west of Grand Forks, North Dakota, 55 miles north of Bismarck, North Dakota, and 20 miles east of Garrison Reservoir.

Population, Towns, and Roads

Kaseck and Reid (1962, p. 630) report the 1960 population of Sheridan County as 4,550 and the populations of each of the four towns in the eastern half of Sheridan County as Goodrich, 392; Denhoff, 164; Lincoln Valley, 90; and Martin, 146.

There are three paved highways in eastern Sheridan County, North Dakota State Highways 7, 14 and 52. In addition, there are many hundreds of miles of unpaved section line roads which vary considerably in their adequacy.

Climate

Sheridan County, situated in the center of the North American interior plains, has a climate typical of continental areas. There are neither large forested areas nor large bodies of water to temper the climate. Thus, Sheridan County is subject to rapid daily weather changes. According to the United States Department of Agriculture (1941, p. 117), the mean January temperature is 6.2 F. The average yearly precipitation is 16.47 inches and the average number of frostfree days in a year is 109. The average wind is from the northeast at about ten miles per hour. Thornthwaite (1948, pl. 1) classified the climate of Sheridan County as dry subhumid and mesothermal.

Soil

The major zonal soils of Sheridan County, chernozem soils and chestnut soils, have been mapped and classified into several sub-units by Omodt and others (1961). The sub-units are based on organic content, grain size, and topographic position. The following soils are present:

1. The Barnes Svea soil, a loam and clay loam, is developed on nearly level to gently rolling land. It consists of chernozem soils with very limy subsoils (calcareous solonchak).
2. The Maddock Barnes soil is a sandy loam and loam with a sandy substrata similar to the Barnes Svea soil.
3. The Barnes Buse soil is a loam developed on rolling topography.

It consists of chernozem soils developed on steeply rolling topography with a thin surface layer (regosol).

4. The Buse Barnes is developed on hilly and steeply rolling land and consists of a thin surface layer (regosol and lithosol) and soils with a thick surface layer (chernozem or chestnut).

The Barnes Svea and Maddock Barnes soils are generally developed on ground moraine, lake plain topography, and low-relief dead-ice moraine of medium relief. The Buse Barnes soil is developed on high-relief dead-ice moraine and end moraines which exhibit high local relief.

Land Use and Vegetation

The primary land uses in Sheridan County are farming and stock raising. The majority of the tillable land is used to grow cereal grains, sun flowers, flax, or corn. The stock that is raised consists of various breeds of cattle and sheep, and turkeys. The natural vegetation consists of various types of grasses, weeds and bushes and a few trees which are found in protected areas near permanent bodies of water. Additional trees have been planted around farm houses, towns, and fields as wind shelter belts. Sagebrush and several types of cacti are abundant in a few areas.

PHYSIOGRAPHIC UNITS AND LANDFORMS

Eastern Sheridan County lies partly within the Glaciated section of the Missouri Plateau of the Great Plains province and partly within the Western Lake section of the Central Lowland province (Fenneman, 1946). The southern half of eastern Sheridan County, including portions of townships T. 145-148 N., R. 76-74 W., lies within the Missouri Coteau portion of the Glaciated section of the Missouri Plateau. The northern half of the report area, which lies in the Western Lake section, has been divided into the Sheyenne River area, and farther north, the Martin area.

MISSOURI COTEAU

General

The Missouri Coteau, bounded on the west by the Missouri River and on the east by the Western Lake section, extends in North Dakota from Divide County in the northwest to McIntosh and Dickey Counties in the southeast. This physiographic unit ranges from fifteen to twenty-five miles in width and is characterized by the monotonous repetition of hummocks and hollows (dead-ice moraine) and by lack of integrated drainage. Some of the hills exceed 300 feet in relief. Locally lacustrine deposits are nearly horizontal and extend for more than four miles in one direction.

According to Townsend and Jenke (1951, p. 848-849), the topography in the northern part of the Missouri Coteau is bedrock controlled and the bedrock is covered by a thin layer of drift. In the northern part of the Coteau Escarpment, it is essentially an erosional bedrock escarpment, but to the southeast the Coteau is essentially a depositional feature formed largely of drift (Fig. 3). The buried bedrock escarpment counterpart is 20 to 30 miles west of the topographic escarpment (Clayton, 1962, p. 27). In eastern Sheridan County, however, on the western boundary of Sec. 30, T. 148 N., R. 74 W., 0.2 miles north of section 31, an outcrop of slightly plastic, poorly indurated, black shale occurs less than 0.2 miles south of the topographic escarpment. This material is probably part of the Cannonball Formation. Therefore, the escarpment in Sheridan County is at least locally bedrock controlled.

Glacial Landforms

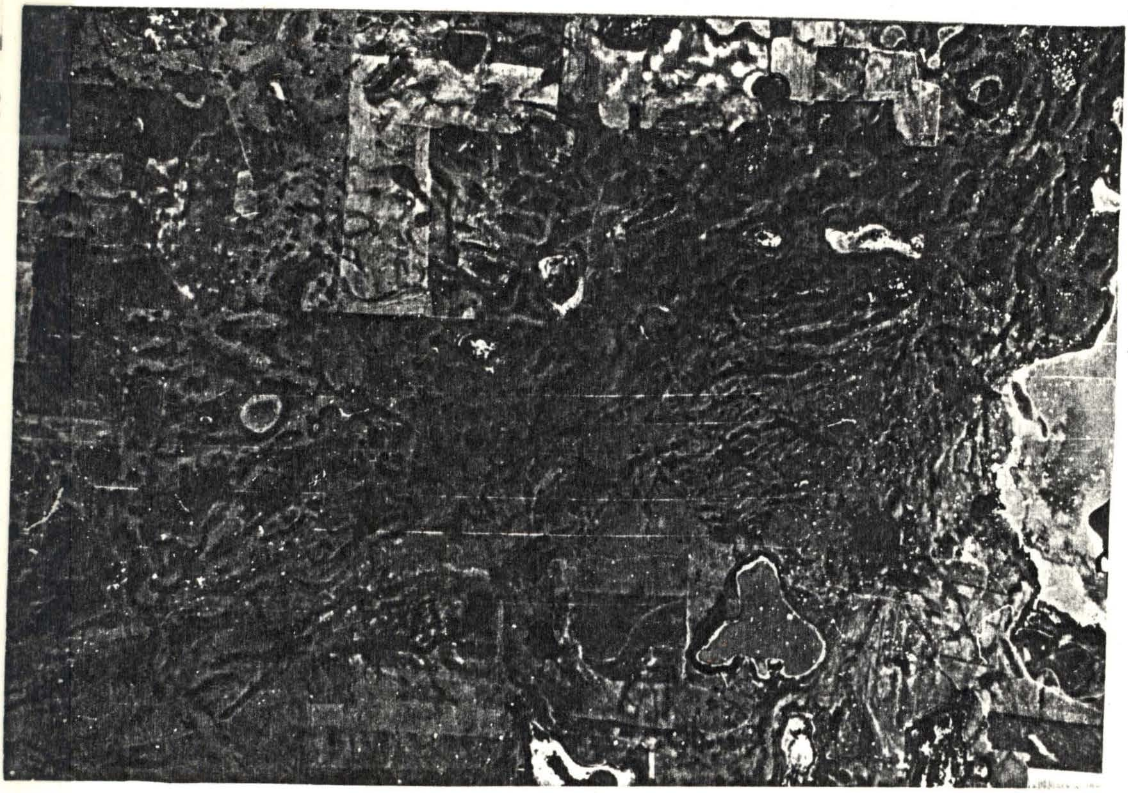
End Moraine

An end moraine is a topographic feature that is the result of deposition by thrusting, shove, and, or dumping of glacially transported debris at the margin of an active glacier. The most important characteristic of an end moraine is its linearity, either an overall linearity of the end moraine as a unit, or linearity expressed by the alignment of depressions and ridges within the moraine.

Streeter Moraine.--The Streeter moraine extends from Dickey County in the southeast, through McIntosh, Logan, Kidder, and Wells Counties, to western Sheridan County. The end moraine of the Streeter drift (Plate 1 and Fig) is also present along the southern boundary of eastern Sheridan County. To facilitate discussion, this end moraine has been divided into four units:

1. The Woodhouse Lake Loop is the eastern-most segment of the Streeter moraine (named by Rau, Bakken, Chmelik and Williams, 1962, p. 29).

Figure 3.--Looking south-west across portions of the Sheyenne River Valley to the escarpment of the Missouri Coteau (T. 148 N., R. 74 W.).



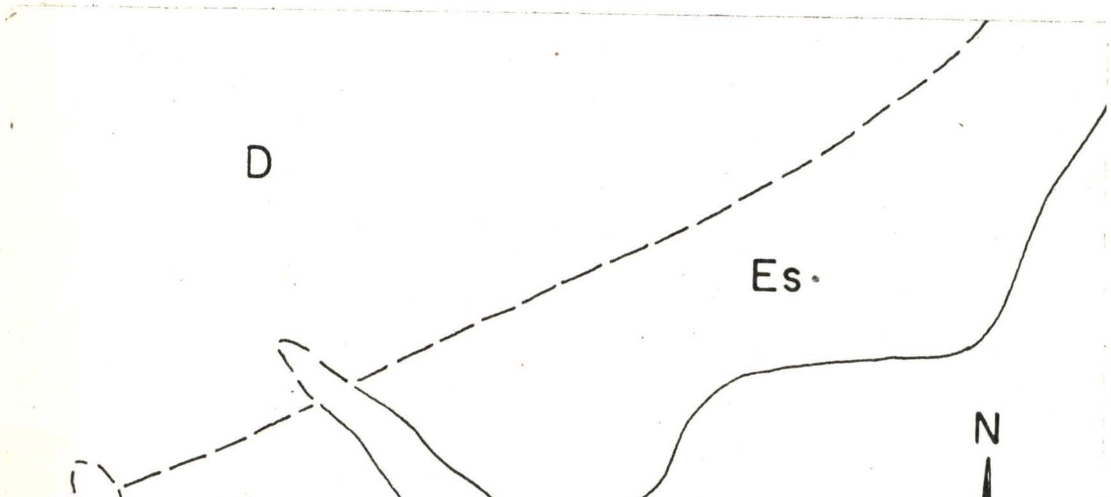


Figure 4.--Two meltwater channels (Mwc) beginning in dead-ice moraine (D), transecting the Streeter end moraine (Es) and entering collapsed outwash topography (Oc) (Sec. 27, 28, 33, 34, T. 145 N., R. 74 W.).

2. The <u>Sperry Lake Loop</u>, in the central portion of the end moraine, is named herein for Sperry Lake (Sec. 20, T. 145 N., R. 75 W.) which lies between segments of the loop.

3. The <u>Salt Lake Loop</u>, in southwest portion of the report area, is named herein for Salt Lake (Sec. 31, T. 145 N., R.75 W.) which is found near this portion of the end moraine.

4. The <u>Denhoff moraine</u>, which trends north from the junction of the Sperry Lake and Salt Lake Loops, is herein named for the town of Denhoff, North Dakota, which lies slightly to the north of this segment of the moraine.

The Sperry Lake Loop segment of the Streeter moraine is connected to the Woodhouse Lake Loop on the east and to the Salt Lake Loop on the west. It is narrow, only locally exceeding one mile in width, and its greatest relief rarely exceeds 70 feet. This loop, along with the rest of the Streeter moraine, is conspicuous on aerial photographs in that its linear features are well developed.

The ridges, hills and valleys are sub-parallel, sinuous, or randomly oriented in map view. Generally, the linear features are about 250-500 feet wide and variable in length. Boulders are not conspicuous on this loop, but they are more abundant than on the dead ice moraine to the north. The radius of curvature of this loop is about eight miles. The topography becomes coarser to the north, where it loses its linearity and grades into dead-ice moraine.

The Woodhouse Lake Loop is topographically similar to the Sperry Lake Loop. The region of junction between the two loops is an area through which great amounts of outwash-laden meltwaters formerly issued. This is evidenced by large areas of collapsed outwash between the two loops, and extending farther south into Kidder County.

The Salt Lake Loop is almost three miles wide. The topography is coarser and steeper than other portions of the end moraine, and the relief increases northward to more than 130 feet. The slopes of several of the hills approach 15 degrees. Like the Sperry Lake Loop, it exhibits lineations, but they are much less distinctive. The linear features diminish to the north where the Salt Lake Loop merges with the Denhoff moraine.

The Denhoff moraine, extending southward from Denhoff, is the most conspicuous landform in eastern Sheridan County. It is approximately six miles long and two miles wide and is elevated as much as 270 feet above the surrounding dead-ice moraine. The topography is very coarse textured and hills with slopes exceeding 15 degrees are fairly common. There are no linear features in this moraine and it grades into dead-ice moraine to the east and west. Boulders are conspicuous, more numerous than in any other portion of the report area, and they range up to 10 feet in diameter, although the average diameter is about 1.5 feet. The Denhoff moraine may reflect a bedrock high or it may be simply an interlobate moraine.

Much poorly sorted, fine, silty sand occurs in the vicinity of Sec. 1, .2, T. 145 N., R. 76 W. This material appears similar in texture to recent dust storm deposits in Grand Forks, therefore it is probably an eolian deposit. The Denhoff Hills were mapped as interlobate moraine but further investigation may reveal that this is actually a bedrock high.

Todd (1896, p. 18, 34) was the first to recognize the Streeter moraine and he called it the "Antelope Valley Loop" of the "First, Outer or Altamont moraine" in McIntosh County. In Logan County he applied the name of "Blue Lake Loop" of the "Second or Gary moraine".

Lemke and Colton (1958, p. 49, Fig. 5) proposed the name Streeter. Because Todd applied the term "Blue Lake" to both the Burnstad and Streeter moraines, and because correlation with the type Gary or Altamont in eastern South Dakota is not possible at this time, the name "Streeter" is used in this report.

Clayton (1963, p. 34) indicates three possible correlations with the moraines in South Dakota:

1. The Streeter moraine may bend southwest and correlation with Flint's (1955, Fig. 31) "Bl Mankato", which does not have the prominent looped-ridge form that is typical of the Streeter.
2. It may be truncated by Flint's "Bl Mankato".
3. It may "correlate with another moraine with a different form east of the Missouri Coteau."

South of the Streeter moraine is a fairly large outwash deposit which, in turn, is bordered to the south by dead-ice moraine of the Burnstad drift. The outwash is collapsed in the interlobate areas between the Woodhouse Lake Loop and the Sperry Lake Loop on the east and between the Salt Lake Loop and the Sperry Lake Loop on the West. Between these two areas, however, lies a small deposit of uncollapsed outwash. This deposit which is approximately six miles long ranges up to slightly more than one mile wide. The presence of uncollapsed outwash may interpreted in two ways: 1) in order for the outwash to remain uncollapsed in front of the Streeter moraine, sufficient time must have elapsed prior to deposition of the Streeter drift for the stagnant ice of this portion of the Burnstad ice sheet to have ablated, or 2) deposition of the Streeter drift occurred earlier and deposition of outwash on the distal side of the Streeter end moraine was restricted to the interlobate areas until the ice south of the Sperry Lake Loop ablated. In either case there is no significant time break between the two drifts.

Jones Lake Moraines 1 and 2.--The Jones Lake moraines, named herein for Jones Lake (Sec. 15, 16, 21, 22, T. 147 N., R. 75 W.), are two minor "shear" moraines (Bishop, 1957) which have little importance in the interpretation of the geologic history of the area, but, for the sake of completeness, they are described here.

These two moraines which trend north-south are located two miles north of Denhoff. Their linear features are clearly seen on aerial photographs (Fig. 5), but they are difficult to distinguish on the ground. Both moraines are convex to the west. They exhibit a fine-grained topography with a total relief of approximately 80 feet. These landforms grade into dead-ice moraine on all sides and appear as though they may be slightly collapsed.

These features were formed in one of two ways:

1. Shear planes developed in active ice as it moved over an obstruction. Obstructed flow causes ice to move upward along shear planes frequently bring lodgement till into the ice and perhaps to the upper surface (Nye, 1952). Subsequent stagnation and ablation caused the debris to accumulate in a form similar to an end moraine.
2. After stagnation of the peripherial portion of the Streeter ice sheet, the ice sheet may have reached a new point 1

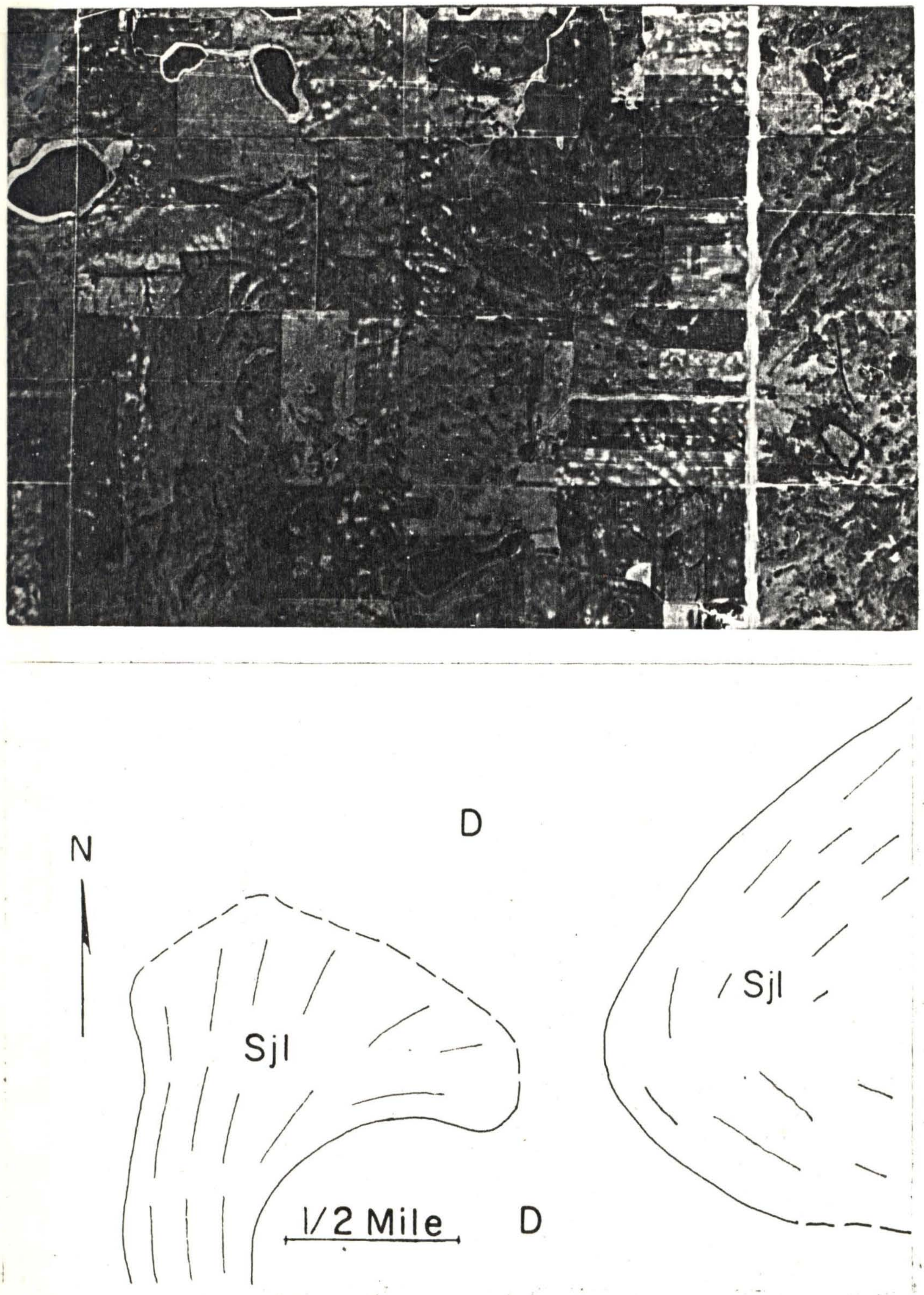


Figure 5.--The Jones Lake "shear" moraines (Sjl) surrounded by dead-ice moraine (D) (T. 147 N., R. 75 W.).

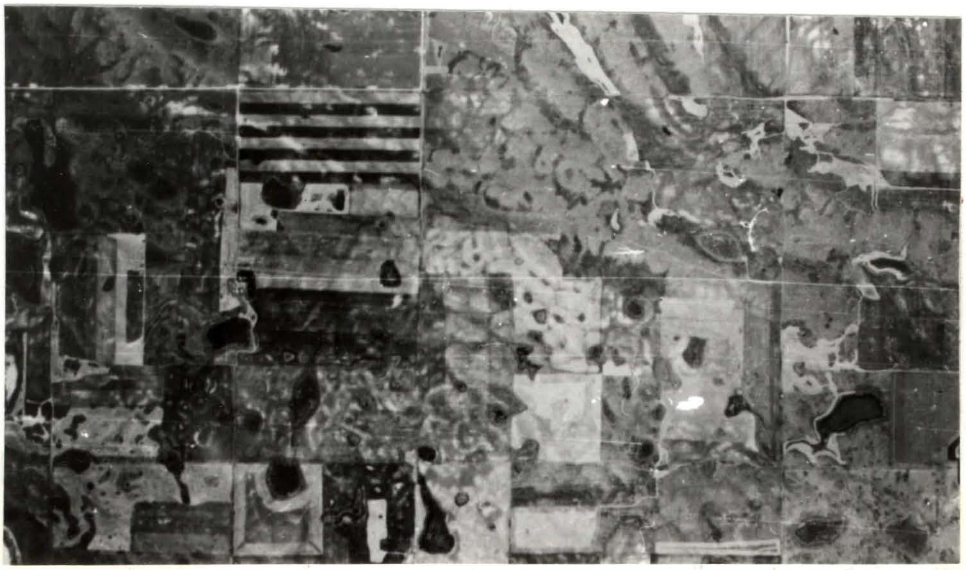
2. After stagnation of the peripherial portion of the Streeter ice sheet, the ice sheet may have reached a new point of equilibrium and deposited the Jones Lake moraines as end moraines. Their shape suggest deposition by ice lobes that advanced to the west. If this were the case, however, outwash deposits would be expected along the distal side, but they are found only to the south separated from the southernmost "shear" moraine by more than 0.1 mile of dead-ice moraine.

Lincoln Valley Moraine.--The Lincoln Valley moraine (Fig. 6) (T. 147-8 N., R. 76 W.) is herein named for the town of Lincoln Valley (Sec. 13, T. 148 N., R. 76 W.). This moraine, trending northeast-southwest, is striking in the development of its linear features. The nearly parallel ridges are extremely elongate and rounded, and exhibit a local relief of about 60 feet. The undrained depressions between the ridges contain numerous large sloughs and ephemeral ponds.

Interpretation of the significance of this moraine in the history of this area is discussed with the Lincoln Valley ground moraine (Page) under Glacial Landforms of the Sheyenne area of the Western Lake province.

Dead-Ice Moraine

The terms "dödismoran" and "toteismoräne" have been used for several years in northern Europe (Hoppe, 1952, p. 1-3; Lindquist, 1959, p. 19; Woldstedt, 1954, p. 52). Clayton (1962, p. 34) defines dead-ice moraine as "...a type of moraine whose topography is primarily the result of large scale glacial stagnation." In addition, he



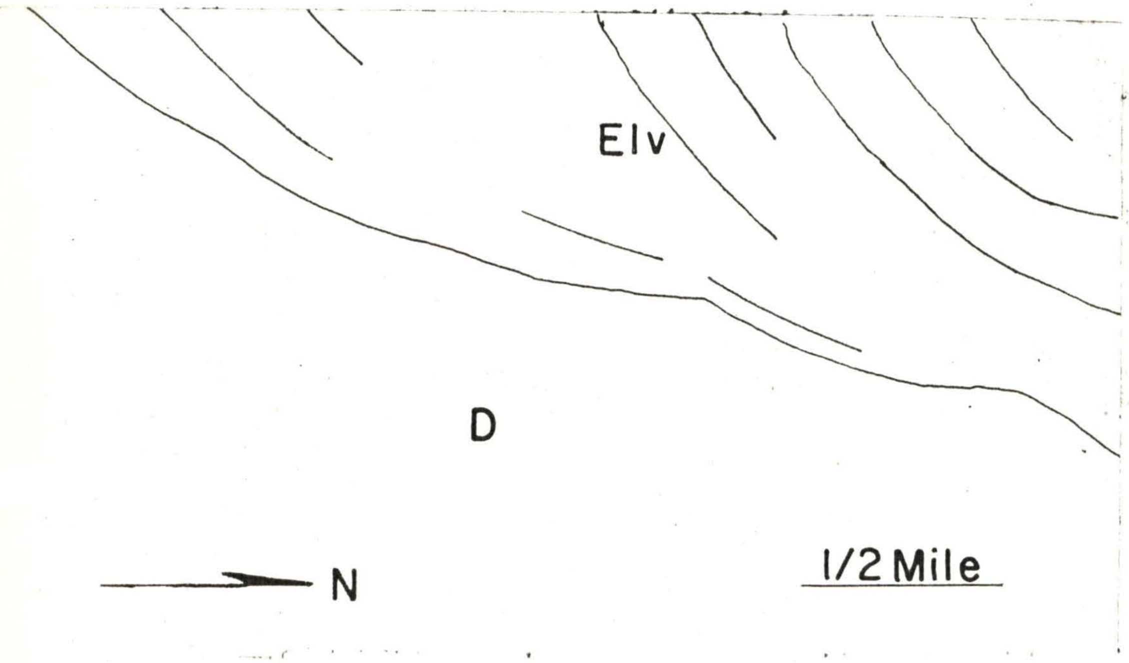


Figure 6.--Lincoln Valley end moraine (Elv), bordered to the east by dead-ice moraine (D), showing the nature of its well developed linear ridges (Sec. 2, 3, 10, 11, T. 147 N., R. 76 W.).

discusses in detail the evolution of terminology for this landform (1963, p. 34-35).

Two of the most important problems confronting workers who study dead-ice landforms are: what is the origin of the drift of the landforms and how did it come to its present position. A discussion of these problems is presented below.

Origin of Drift.--Numerous theories have been proposed to explain the origin of dead-ice drift. They are summarized below:

1. Hoppe (1952) and Stalker (1960) feel that englacial and superglacial debris are unimportant, and that nearly all the drift originates from below the ice.
2. Flint (1955) states that thin terminal ice may exist in valleys or other topographic lows in front of the active ice sheet and that subsequent overriding will deposit a thin layer of lodgement drift on the ice. With renewed wasting the buried ice blocks melt out and the overlying drift collapse.
3. Flint (1957, Fig. 5-14) and Bishop (1957) illustrate the process of ice thrusting whereby basal debris is brought up into the ice and some cases onto the surface of the ice. Subsequent ablation concentrates the drift in depressions on the surface of the ice. Complete ablation again results in collapse of the drift.
4. Clayton (1963, p. 37) states "that nonglacial alluvium from east-flowing streams and some glacial outwash and lake sediment may be accumulated on top of a west-sloping glacier."

Features formed according to the "ice-pressing" theory of Hoppe (1952) and Stalker (1960) are necessarily comprised of lodgement drift. Collapse features are mostly comprised of drift brought to the surface by shearing. In some cases, it is not possible to tell conclusively whether disintegration features were formed by collapse or by ice-pressing. Until some means to distinguish between deposits of the two processes is developed both processes must be considered important.

Drift deposited on overridden ice may be important in other areas but, there is no indication that any of the features in eastern Sheridan County were formed by this process. Of the four processes mentioned, this process is probably the least significant.

Approximately 10 percent of the collapsed drift area of eastern Sheridan County is comprised of stratified drift. Thus, glacio-fluvial processes can account for a significant portion of the drift associated with dead-ice.

Origin of Relief.--Numerous hypotheses have been proposed to explain the formation of dead-ice moraine (Fig. 7). They are summarized as follows:

1. Origin of Ablation:

As the glacier wastes, the debris within the ice accumulates on the surface. The relief of the ice causes the surficial drift to collect in depressions in the ice. Clayton (1964) shows that karst topography may develop on stagnant ice. The karst solution features could provide excellent basins for large scale drift accumulation. With continued ablation the irregular accumulations of drift are let down to the ground to form "ablation moraine" (Flint,

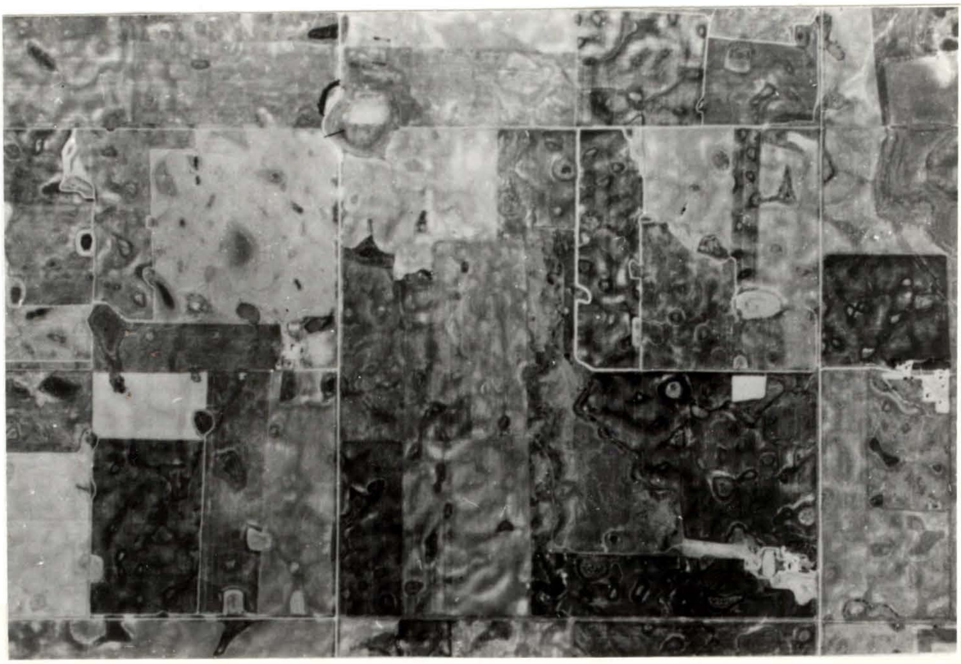


Figure 7.--Typical dead-ice moraine showing numerous undrained depressions and closed disintegration ridges (Sec. 19, T. 147 N., R. 74 W.).

1957, p. 120). Gravenor (1955, p. 477) believes that "hummocky moraine" (dead-ice moraine) is probably the reflection of irregular accumulations of debris on the ice.

2. Origin by Pressing:

Hoppe (1952) and Stalker (1960) advocate that dead-ice features were formed beneath the ice by pressing of water-saturated drift into cavities in the undersurface of the ice. The ice provided the necessary weight for forcing the drift into the openings. They do not explain how the cavities originated, but state only that the ice must be largely stagnant to prevent filling of the cavities by plastic flow.

3. Combination Theory:

Gravenor and Kupsch (1959, p. 60) state that the processes of ablation and till squeezing are not mutually exclusive and that in the formation of dead-ice features both processes may have been operating to varying degrees.

Gravenor and Kupsch's combination theory is the most cogent theory presented to date. Certainly a block of ice resting on water-saturated drift would tend to force some of the drift into openings in its base or out around its periphery, and surficial drift would certainly move towards basins of accumulation. The unanswered question is which of the processes supplied the major portion of the relief. Perhaps detailed till fabric studies will shed some light on this subject. Until such information is available, the combination theory remains the most exceptable.

Disintegration Ridges.--Disintegration ridges are one of the most characteristic features of dead-ice moraine. Three general types are found; closed, and linear disintegration ridges (Gravenor and Kupsch, 1959), and broken rim ridges (Stalker, 1960). The term closed disintegration ridge designates regular and irregular forms and as such is purely descriptive. Modifying adjectives such as circular, eliptical or oval may be applied to the more regular forms. According to Gravenor and Kupsch (1959, p. 53) most authors agree that these features formed around blocks of stagnant ice, even though they do not agree as to the mechanics of deposition.

The broken rim ridges are commonly called "puckered lips" in North Dakota and are thought to have formed at the edges of sink holes or other depressions in stagnant ice (Clayton, 1962). The breeches probably occurred when buried ice melted leaving the two low saddles. Neither of these terms implies that the ridge material was limited to sources on the glacier. They may be partly or wholly derived from subglacial drift.

Linear disintegration ridge (Gravenor and Kupsch, 1959, p. 54) is a useful term implying only that the linear feature was formed during stagnation or near stagnation of the ice sheet.

Circular disintegration ridges are not well developed on the Missouri Coteau in eastern Sheridan County, but, some of the larger linear ridges are clearly defined. The linear ridges rarely exceed one mile in length and are rarely more than several hundred feet wide. Their lithology includes till and stratified drift, and combinations thereof. Although difficult to identify on the ground, they are fairly obvious on aerial photographs. The ridges are visible as light-toned areas surrounded by dark flat areas. The shade differences arise from the fact that runoff removes dark organic debris from the ridges and concentrates it in the depressions. The increased moisture in the depressions also allows a heavier growth of vegetation seen as a darker tone on the photos (Fig. 8).

Collapsed Outwash

Collapsed outwash (Fig. 9) is similar topographically to dead-ice moraine except that it is composed of sand and gravel. These deposits result from valley trains or outwash plains being deposited on stagnant ice. During subsequent total ablation, the strata are disturbed by slumping.

On the Missouri Coteau in eastern Sheridan County there are about 15 square miles of collapsed outwash deposits. Generally, this material is composed of sand and pebble-size detritus; locally, however, silt cobble, and boulder beds are found. Although on the ground there is no distinctive landform associated with collapsed outwash, the relief, soil texture, and lithology usually confirm photo interpretation. Minor folding and slumping observed in sand and gravel pits also aided in indentifying collapsed outwash. The most characteristic features of collapsed outwash, as identified on aerial photographs, are disintegration trenches and the light tone of sandy soil.

Collapsed outwash is arbitrarily defined as having more than 50 percent of its area collapsed (Clayton, 1962, p. 17).

In nearly every exposure of outwash, whether collapsed or not, beds with varying percentages of organic debris were observed in

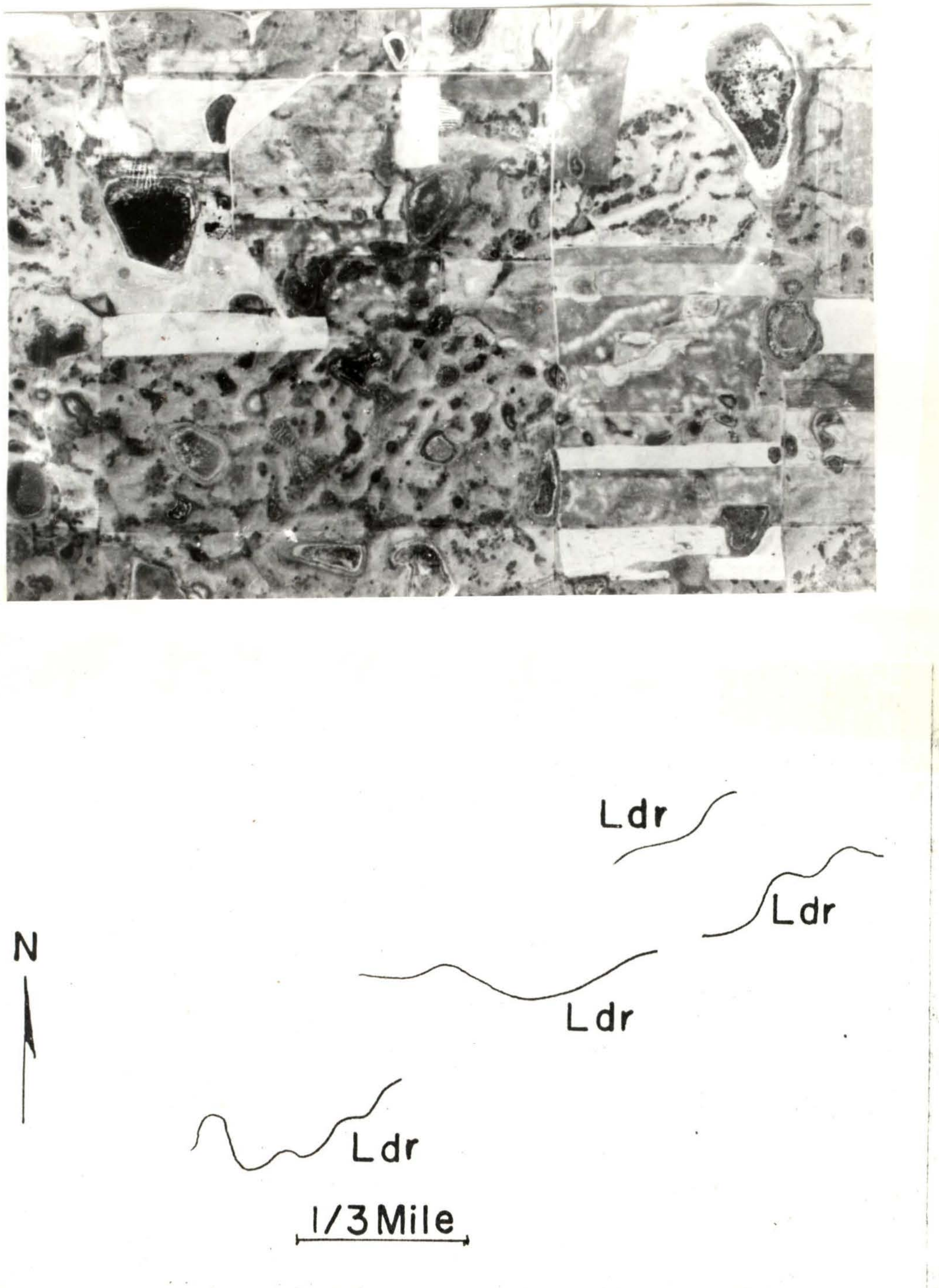


Figure 8.—Dead-ice moraine (Sec. 29, 30, T. 145 N., R. 74 W.) showing some of the linear disintegration ridges (Ldr) indicated by dark lines.

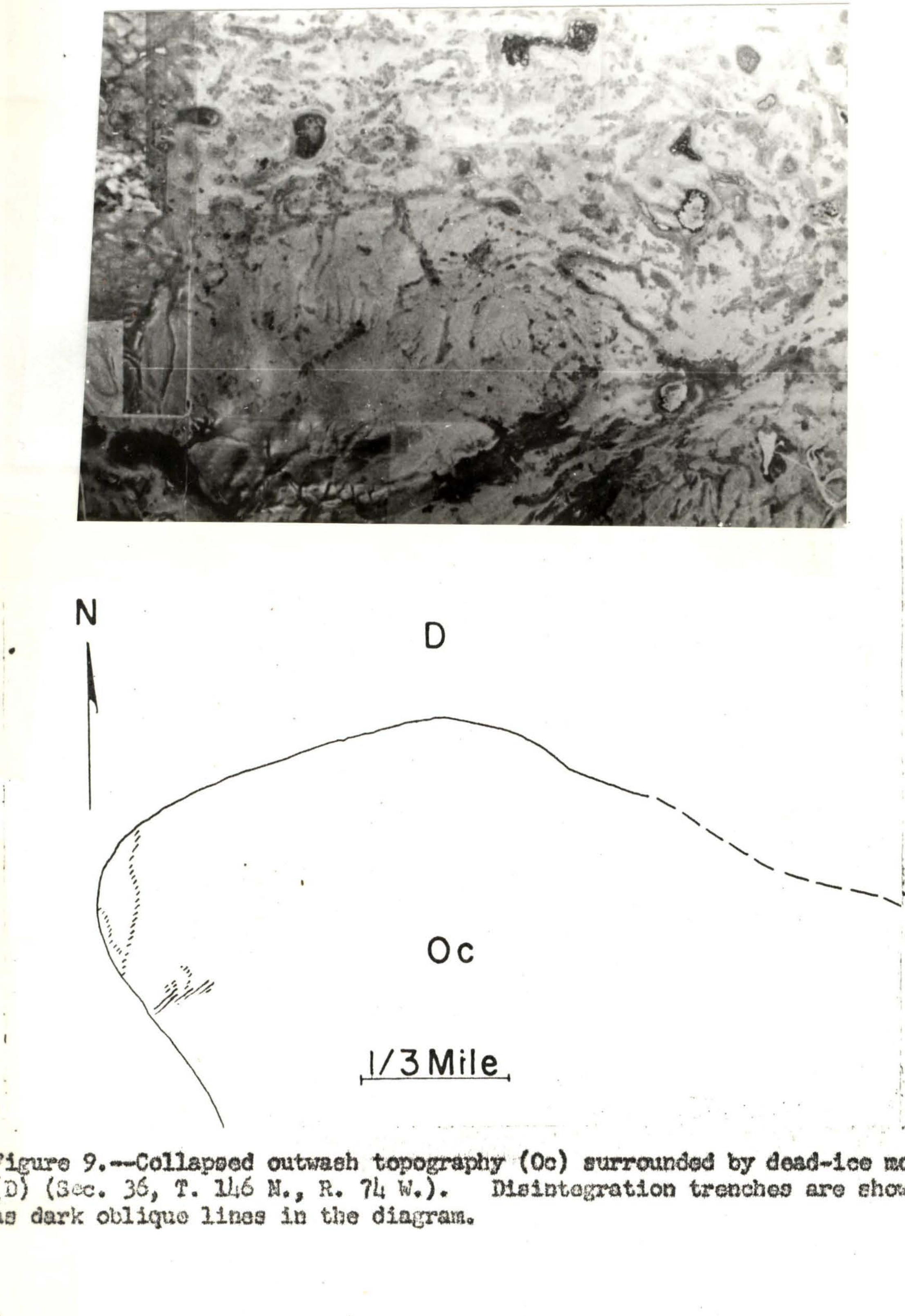


Figure 9.--Collapsed outwash topography (Oc) surrounded by dead-ice moraine (D) (Sec. 36, T. 146 N., R. 74 W.). Disintegration trenches are shown as dark oblique lines in the diagram.

thicknesses ranging from less than an inch to several inches. This material appears to be finely divided organic debris intimately mixed with fine sand. The upper and lower contacts of these beds are sharply defined and their lateral extent is usually limited to a few hundred feet.

Three possible sources of this material are: 1) lignitic debris within the drift or ice sheet, 2) finely ground plant debris picked up by the advancing ice sheet which may have been concentrated in the outwash and subsequently carbonized, and 3) plants growing on the drift may have provided the necessary organic debris. The major source, however, was probably lignite fragments from within the drift. The light finely divided material was probably concentrated by flotation in areas of stagnant or slowly moving water where it settled and was subsequently covered by additional outwash.

Disintegration trenches are probably the most distinctive feature of collapsed outwash (Fig. 10). Clayton (1962, p. 42) has described them as "...a sort of very long kettle." They are probably best defined as the result of the following sequence of events:

1. A channel, trench or crevasse in the ice is filled with drift.
2. Ablation causes inversion of topography leaving the channel drift as the mantle of an ice cored ridge.
3. The ice cored ridge is buried by outwash.
4. The ice core melts and the overlying sediments collapse to form the disintegration ridge.

These features occur only in collapsed outwash, and they are

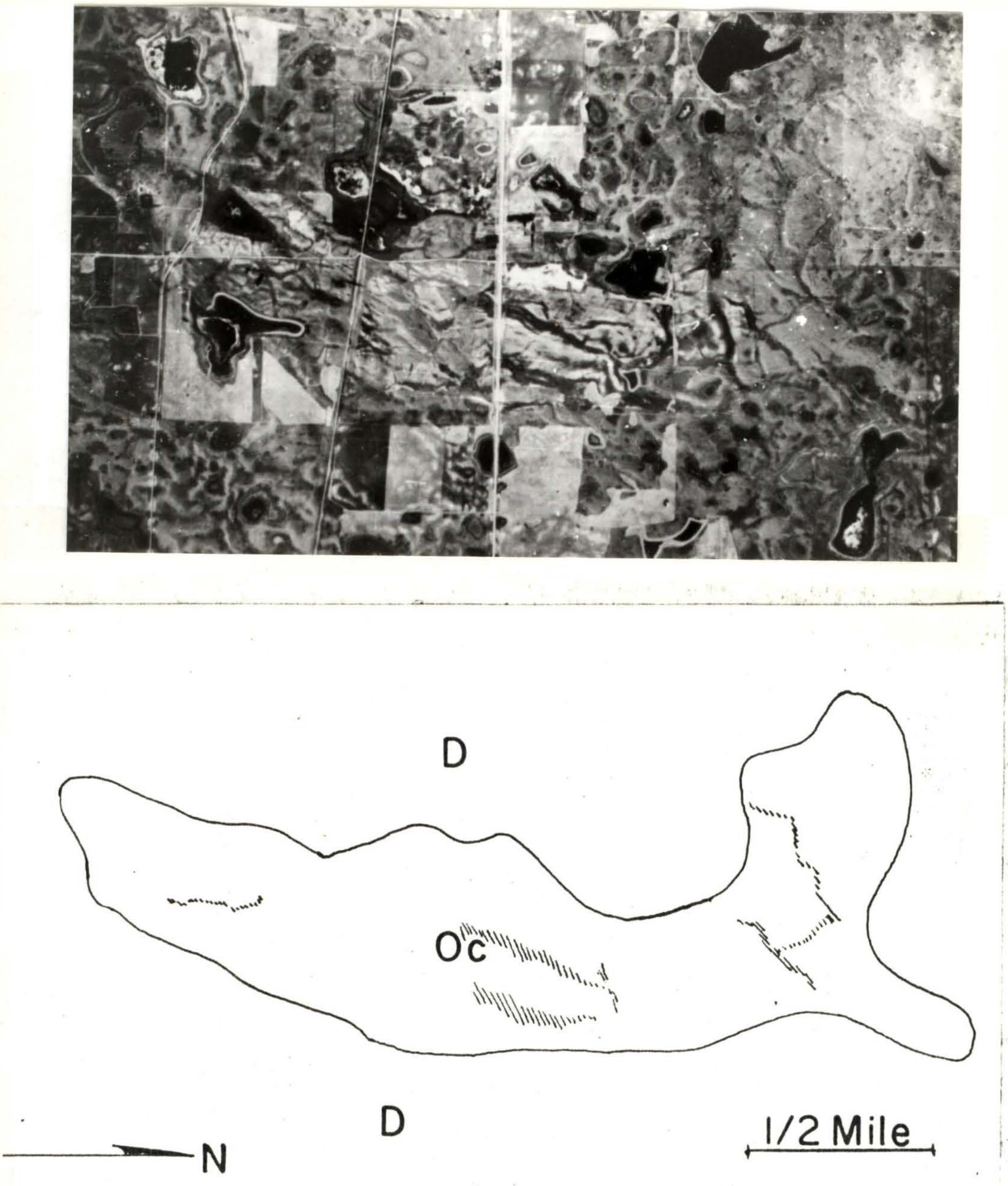


Figure 10.—Collapsed outwash topography (Oc). In dead-ice moraine(D), shows numerous disintegration trenches, a few of which are indicated by dark diagonal lines (Sec. 6, 7, T. 146 N., and Sec. 1, 12, T. 146 N., R. 76 W.).

present in most of the larger areas of collapsed outwash in Sheridan County. They are roughly parallel or polygonal in outline and are difficult to see on the ground, but easily observed on aerial photographs. The trenches appear as dark jagged "gashes" bordered by areas of lighter tone.

Collapsed Lake Sediment Topography

This topography is similar in origin to dead-ice moraine and collapsed outwash topography but it is more subdued (Figs. 11 and 12). If there are no exposures where distorted bedrock may be observed, it is difficult to determine whether the relief of a lake plain is due to collapse, differential deposition, subsequent erosion, the reflection of buried topography, or a combination of causes.

Collapsed lake sediment topography is formed of clay and silt originally deposited on stagnant glacial ice which subsequently melted. In comparison to collapsed outwash, the bedding is usually folded instead of faulted and the surface is free of cobbles and boulders. Undrained depressions are present because of the more impervious nature of the finer sediments. On aerial photographs lake sediment topography appears as cultivated patches of very low relief, even when the lake occurs within high relief end moraine. Some of the collapsed lake sediment topography in eastern Sheridan County is elevated slightly above the surrounding drift and, or exhibits a rim. Thus, the lakes were also ice-walled prior to collapse.

Ice-Walled-Lake Plain

"Ice-walled-lake plains (Fig. 13) are elevated areas of smooth

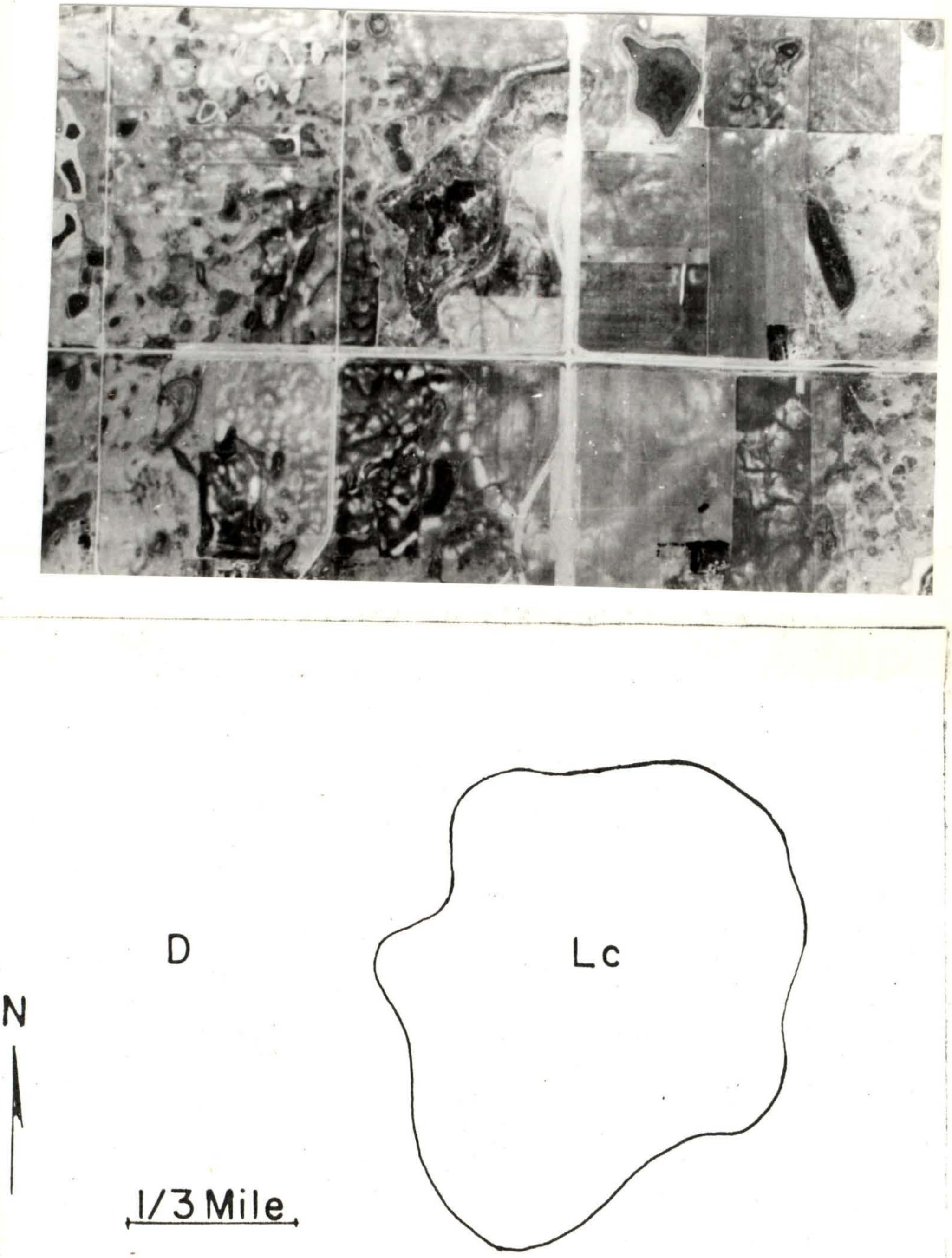


Figure 11.--Collapsed lake plain (Lc), surrounded by dead-ice moraine (D), showing ice-contact faces on the east and south, with a small rim of till on the southeast margin (Sec. 4, 5, 8, 9, T. 149 N., R. 75 W.).

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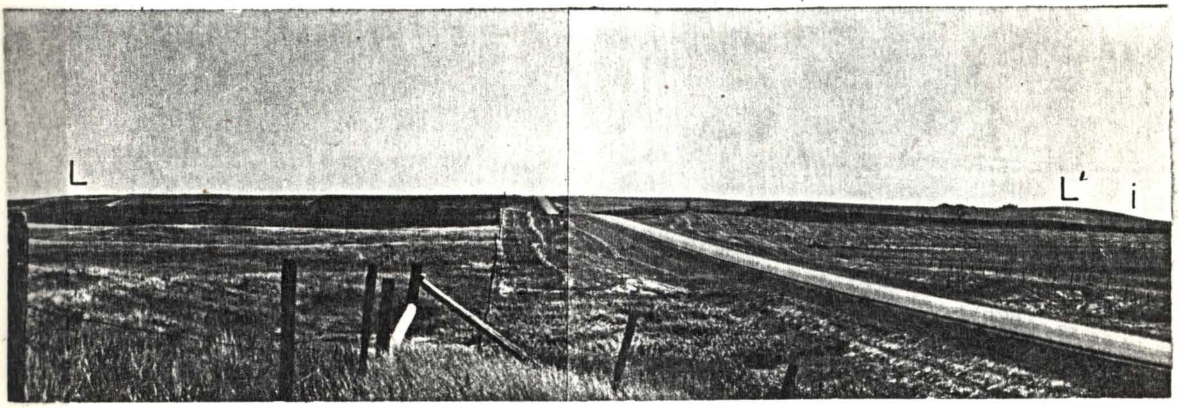


Figure 12.--Elevated collapsed lake-plain topography along the horizon L-L' showing an ice-contact face (i) on the right (Sec. 4, 5, 8, 9, T. 149 N., R. 75 W.).

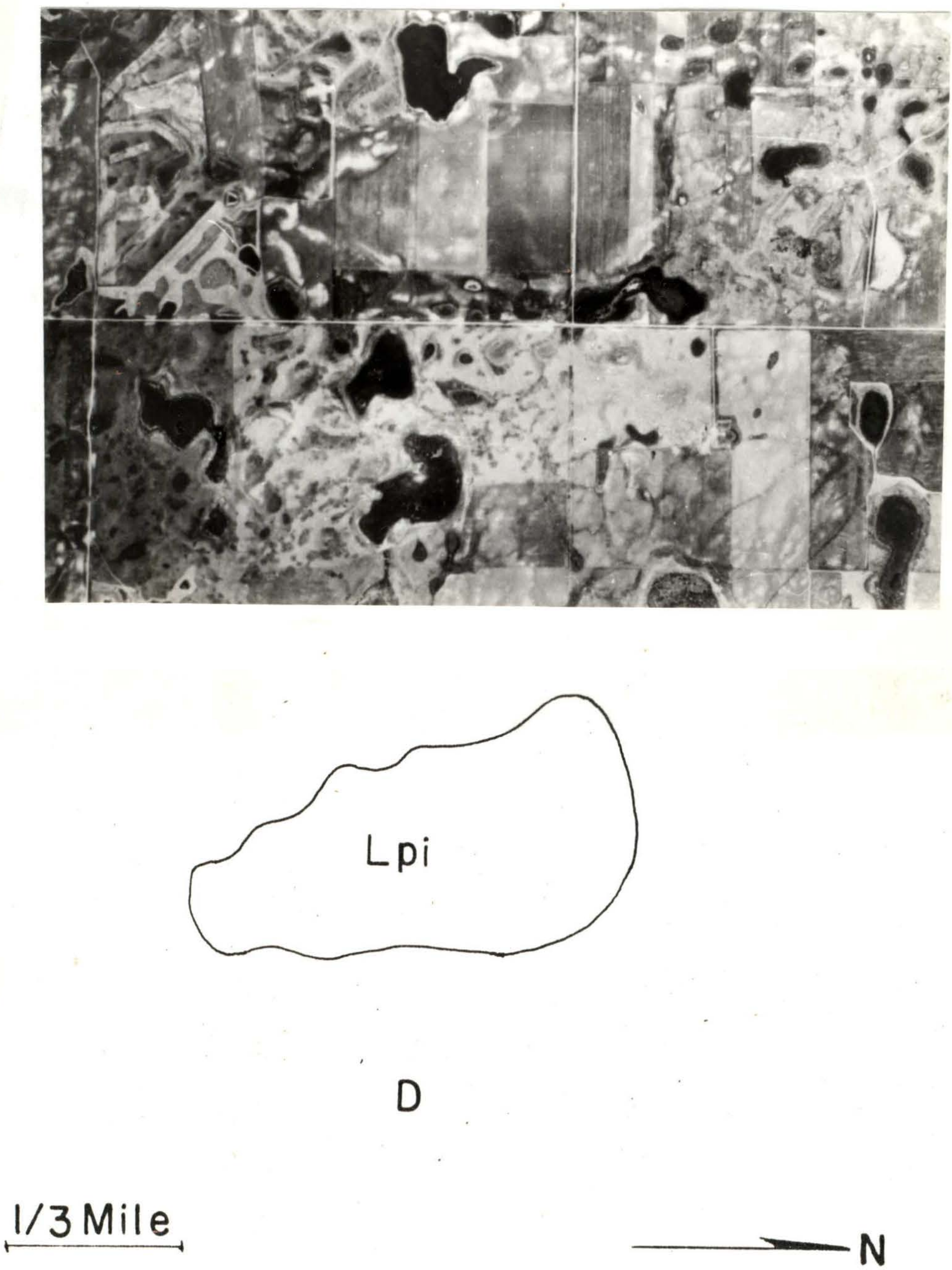


Figure 13.--Former ice-walled-lake plain topography (Lpi) surrounded by dead-ice moraine (D) (Sec. 27, 34, T. 146 N., R. 74 W.). The feature displays a till rim.

and nearly flat topography underlain by horizontally-bedded silts and clays that were deposited in a glacial lake that was more than one-half walled by stagnant ice" (Clayton, 1962, p. 39).

A few miles north and east of Goodrich, a number of small, rimmed ice-walled-lake plains occur (Fig. 14). There are about twenty lakes in this complex, all less than one-half square mile in area. Each is surrounded by a till rim from one to five feet high.

Lake Plain Topography

The largest lake plain in Sheridan County, Lake Goodrich (T. 146 N., R. 74-5 W.), named herein for Goodrich, North Dakota, is about seven square miles in area and was ice-walled on portions of its eastern, western, and southern sides (Fig. 15). The depth of lake sediment is not known but the former ice-walled surface reaches heights up to 15 feet.

Kames

"A kame is a prominent and conspicuous hill of ice-contact sand and gravel" (Clayton, 1963, p. 40). Only one definite kame occurs in eastern Sheridan County on the west flank of the Denhoff Moraine (Sec. 1, T. 145 N., R. 76 W., and Sec. 36, T. 146 N. R. 76 W.) (Fig. 16). The kame has from 90 to 150 feet of local relief and consists of two elongate oval hills trending west northwest-east southeast. It represents the highest elevation in eastern Sheridan County and is mantled by a coarse gravel, locally a boulder gravel, interspersed with pockets of sand.

Kettles

Kettles are the depressions remaining in glacial drift after wholly

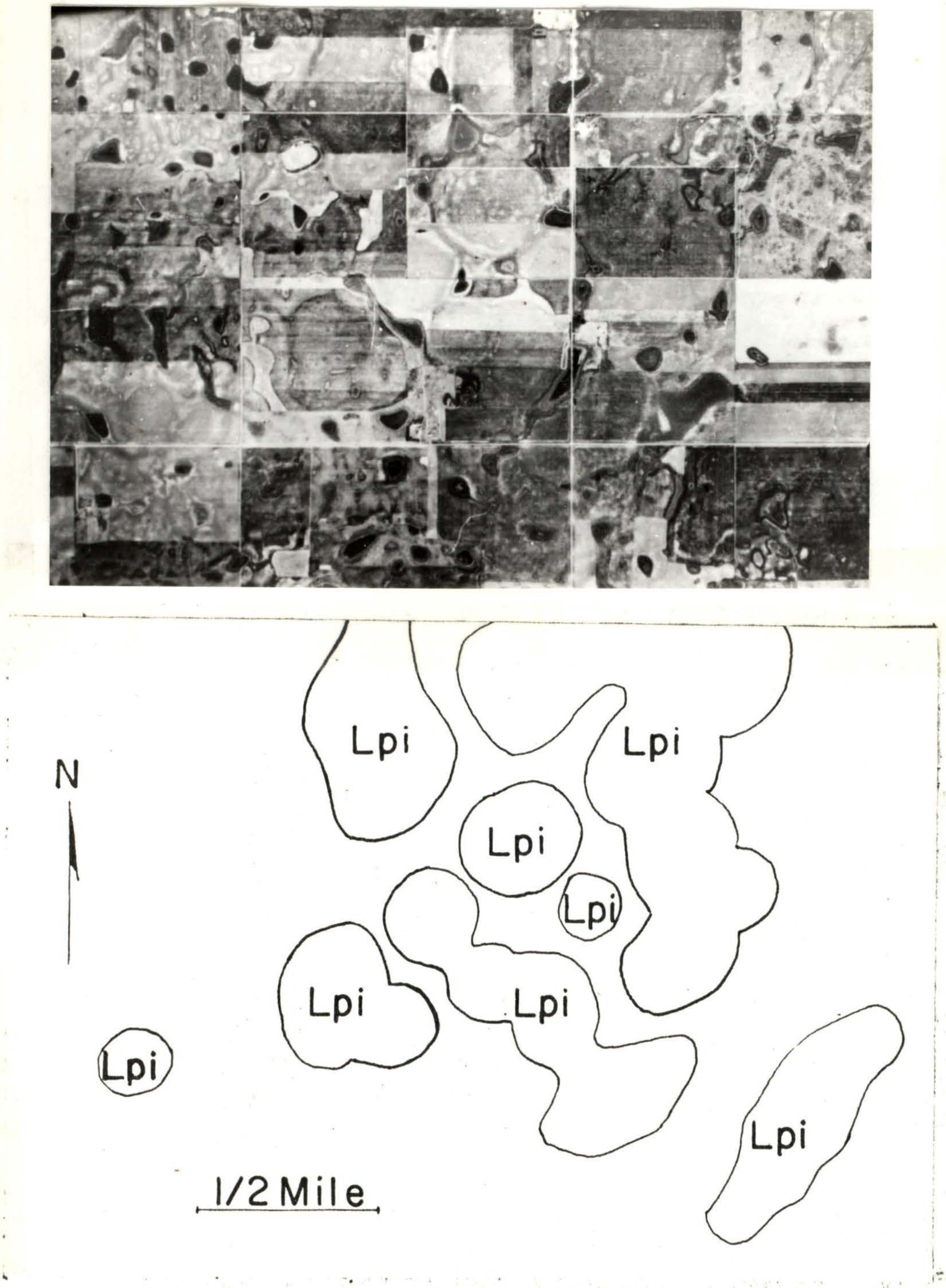


Figure 14.--Elevated former ice-walled-lake plains (Lpi) in dead-ice moraine (D). Low rims of till exist around each plain (Sec. 2, 3, T. 146 N., R. 74 W.).

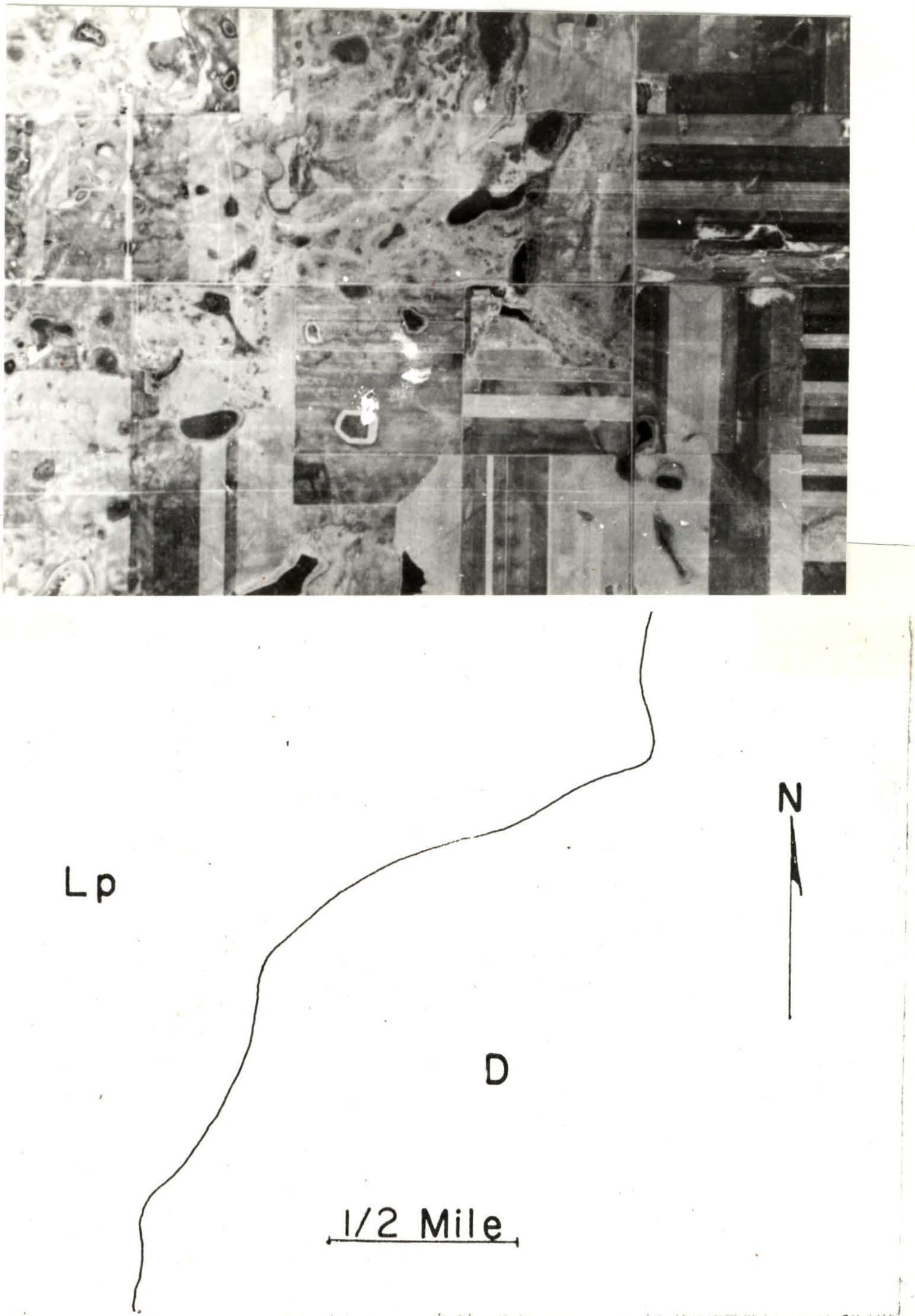


Figure 15.--Lake-plain topography (Lp) and dead-ice moraine (D) (Sec. 25, 26, 35, 36, T. 146 N., R. 74 W.). The lake plain is slightly elevated and shows a slight rim along the southeast margin. This is the southeast end of glacial Lake Goodrich.

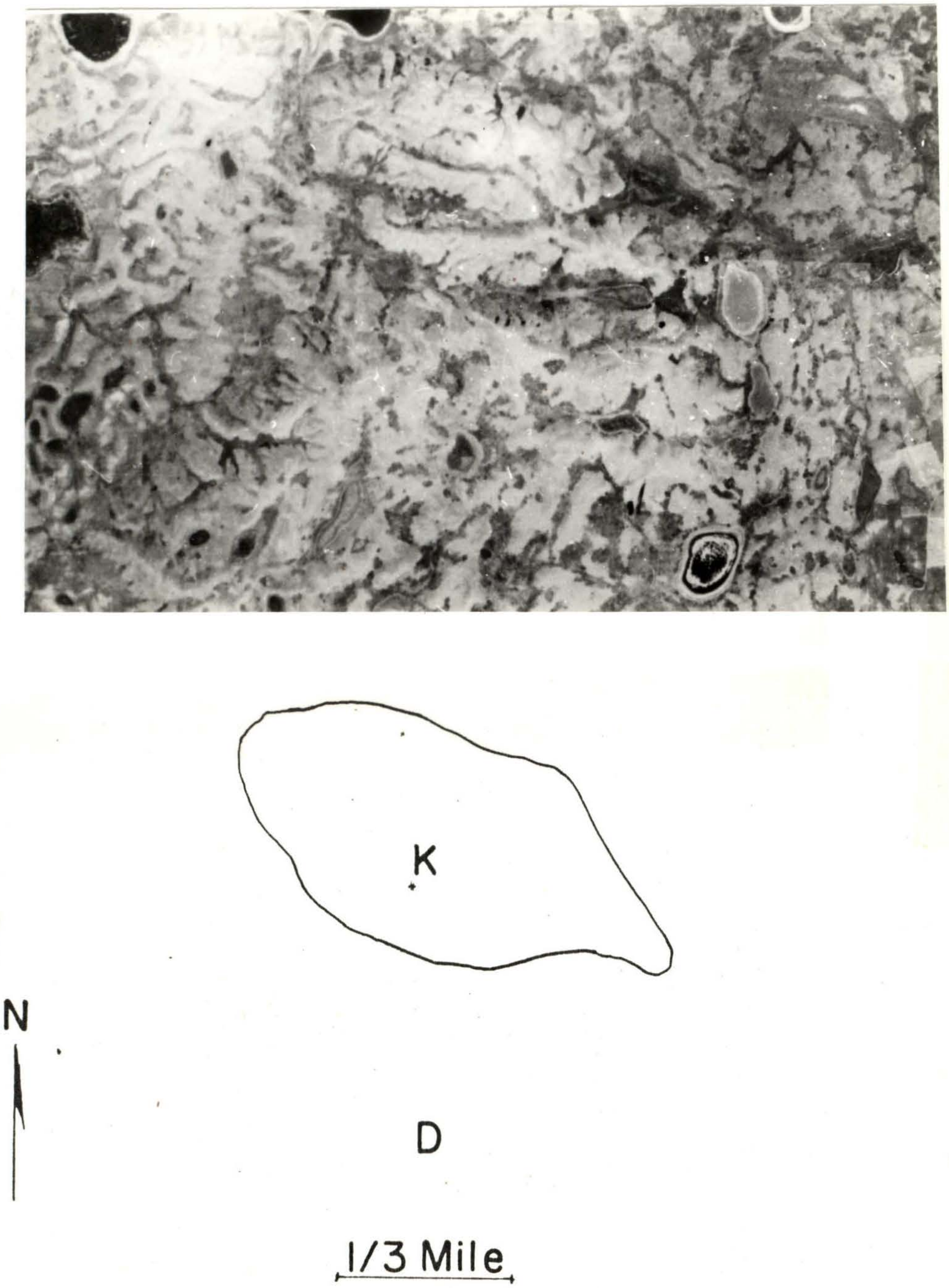


Figure 16.--Large dissected kame (K) on top of the Denhoff interlobate moraine (D) in T. 145-6 N., R. 76 W.

or partly-buried blocks of glacial ice have melted. In dead-ice moraine the only depressions that can definitely be recognized as kettles are those that possess former ice-contact faces. Other depressions in dead-ice moraine are the result of inversion of the topography that existed on the surface of the ice sheet prior to or during melting. Only a few unquestionable kettles were identified on the Missouri Coteau.

Meltwater Channels

All of the meltwater channels of the Missouri Coteau portion of eastern Sheridan County occur in the Streeter end moraine. A system of meltwater channels occurs in the eastern portion of the Salt Lake Loop (T. 145 N., R. 75 W.) and appears to be partly buried or collapsed or both (Fig. 17). It is a series of elongate depressions that are ill-defined at the southern county boundary and well-defined to the north. The channel continues north for abount two miles and becomes deeper before heading east and ending at the margin of the Streeter end moraine. At its northern end are two distributaries, trending east-west, which also terminate at the south-east margin of the Salt Lake Loop of the Streeter end moraine.

A drop in elevation of about 50 feet in a distance of 4 miles, from the southern extremity to the northern end of the meltwater channel indicates the former direction of the water movement. The floor of the channel is obscured in many places by sloughs, but in the exposed areas sands, gravels, and tills are present.

In the eastern portion of the Sperry Lake Loop (T. 145 N., R. 74 W.), two short meltwater channels occur which are less than one-half mile

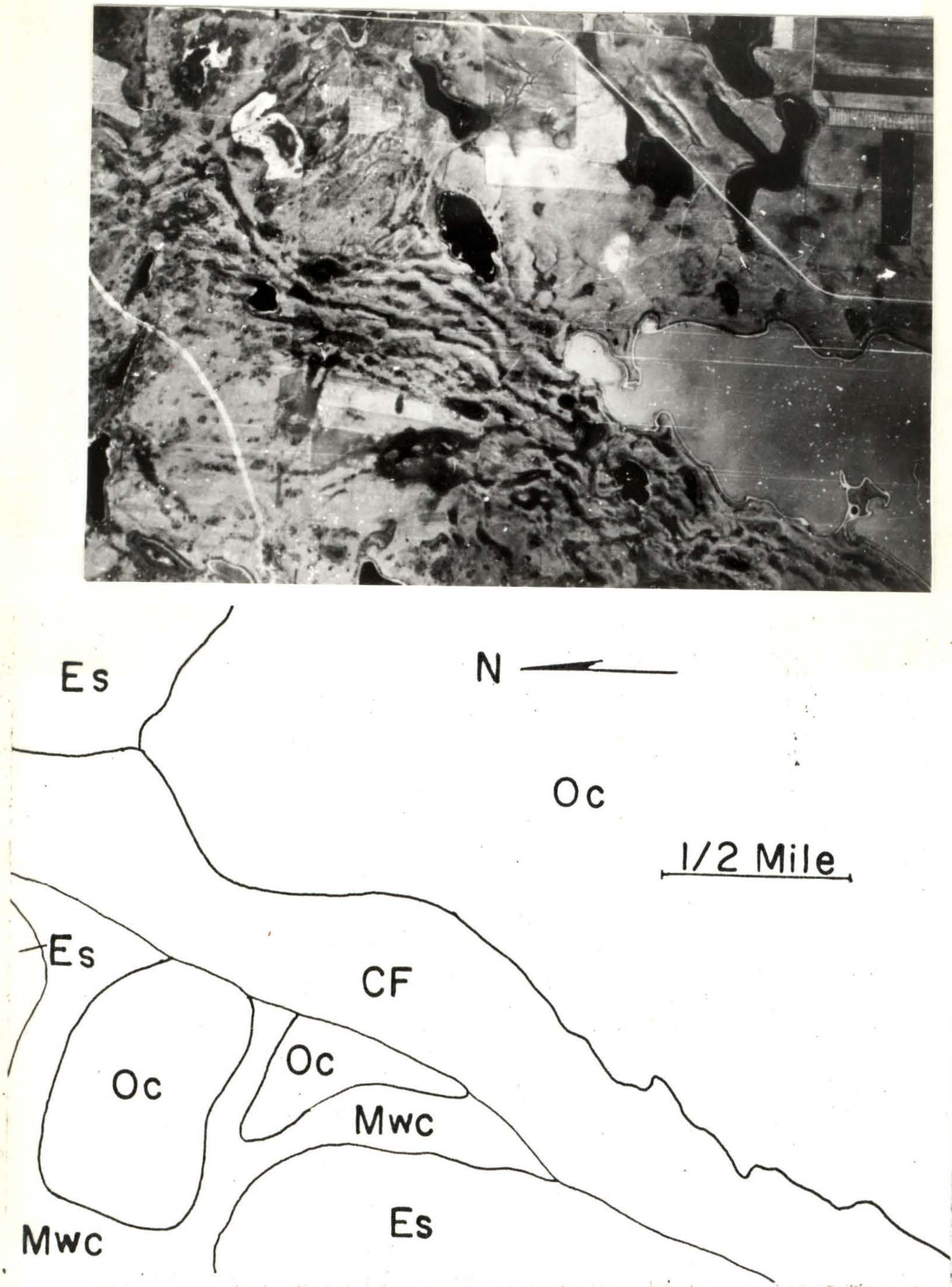


Figure 17.--Crevasse fillings (CF) extending through collapsed outwash (Oc) and intersecting the east margin of the Streeter end moraine (Es). The crevasse fillings have also truncated the mouths of three melt water channels (Mwc) (Sec. 29, 30, 31, 32, T. 145 N., R. 75 W.).

long. They have been completely obliterated by collapse north of the Sperry Lake Loop (Fig. 4). The floors of these features consist of sands and gravels which locally have a high percentage of boulders.

Discussion of the Relationship Between Disintegration Ridges, Crevasse Fillings, and Eskers

It is apparent, after a cursory review of the literature pertaining to disintegration ridges, crevasse fillings, and eskers, that the terms, crevasse fillings and eskers, have at times been confused and that, in fact, some authors have described crevasse fillings and still called the feature an esker. To add to the confusion, many synonymous and similar terms have been proposed for these features. Consequently, the terminology is discussed here and definitions of the terms as used in this report are presented.

The term "disintegration ridge" or more specifically "linear disintegration ridge" as proposed by Gravenor, Green, and Godfrey (1950) is, by their definition synonomous with crevasse filling. Gravenor (1956, p. 10) suggested that the term "till crevasse filling" be employed to distinguish till ridges from the ridges of stratified drift called "crevasse fillings" by Flint (1928, p. 415). In 1959, Gravenor and Kupsch redefined linear disintegration ridges as a general term which implies that only the ridge originated during stagnation of the ice-sheet.

The term "crevasse fillings" was introduced by Flint (1928, p. 415), and includes only those flat-topped, short, steep-sided, non-sinuous accumulations of stratified sand and gravel, deposited in fissures or crevasses, at the edge of stagnant ice.

Stone (1899) described as reticulated eskers, features which were composed of material deposited in crevasses. He defined an esker as "...any mass or ridge of glacial gravel irrespective of genetic classification" (1899, p. 87). Dryer (1901) in discussing several irregular and disconnected "heaps" of sand, gravel, boulders, and till postulated that they were deposited in crevasses or ice-walled canyons, formed when roofs of sub-glacial tunnels collapsed. These features were simply called peculiar eskers (Dryer, 1901, p. 123).

Armstrong and Tipper (1948) discuss in detail several features which they refer to as "compound eskers." They indicate that portions of the features were formed by material dropped into crevasses. They state that deposition of the upstream end occurred in crevasses, the central portion in a sub-glacial tunnel and the terminus around ice-blocks from the collapsed roof of the tunnel.

In 1959, Leighton reviewed Leverett's (1899) work on the ridged drift of the Kaskaskia Basin in southwestern Illinois. Leverett described some of the landforms as "ridges", "ridged drift" or systems of drift, but did not call them moraines. In reviewing Leverett's work Leighton called these features crevasse fillings. Furthermore, he was able to show that the ridges were related to trenches and the trellis stream pattern of the area. The trenches denote areas of erosion by streams flowing through crevasses where the crevasses reached the base of the glacier. He describes the crevasse fillings as exhibiting the following characteristics:

1. Marked alignment of ridges, occasionally offset.
2. Narrow, linear, steepsided in outline.
3. Oriented in the general direction of ice movement.

4. Associated with crevasse controlled channels.

Deane (1950, p. 14) proposed the term "ice-block ridges". He used this term to describe crevasse fillings which are indicative of stagnant ice composed of till and closely associated with ground moraine.

Stalker (1960, p. 11) used "moraine ridges" for crevasse deposits in dead-ice moraine and "plains ridges" for corresponding features in ground moraine. He further states that these features were formed by till squeezed from beneath the ice sheet into systems of open crevasses.

Close (1867), in Ireland, used the term "esker" in reference to ridges of stratified drift as distinguished from hills of till which he called "drumlins". Chamberlin (1883) proposed the Swedish term "as" (plural asar) for ridges of stratified drift parallel to ice movement and the Scottish word "kame" for ridges transverse to the direction of ice movement. Stone (1899) and Trowbridge (1914) used the term "osar" (derived arbitrarily from asar). Stone (1899, p. 359) defined "osar" as a longitudinal gravel "system" which represents internal drainage of the ice, and "esker" as "...any mass or ridge of glacial gravel irrespective of genetic classification." In Ireland "esker" refers to all mound or ridge-like accumulations of stratified drift; in Scandinavia, the term "as" is used and in Great Britain "esker" is being superceded by "ose" (Charlesworth, 1957). At present, in the United States, the term "esker" is used in reference to sinuous ridges of stratified drift deposited by a glacial stream.

Trowbridge (1914) believes that eskers are essentially elongate kames formed of glacio-fluvial sediments deposited at the margin of the ice sheet. Winchell (1873), Hummel (1874), and Charlesworth (1957) suggested that eskers were actual casts of glacial streams. Others have postulated a subglacial, englacial or superglacial origin for the eskers. The subglacial theory is perhaps the most widely accepted. This theory is supported by Lewis (1949a, p. 314) who reported an esker in the process of formation, in Scandinavia, issuing from a subglacial tunnel.

For the purposes of this paper each of the features discussed above are defined as follows:

1. Linear disintegration ridge is a general term which refers to linear ridges of drift, usually till, deposited in crevasses or at the edge of a block of stagnant ice, by squeezing of drift from under the ice and, or by movement of drift from the ablating surface of the ice. These features vary from straight to sinuous and from irregular to even-topped. This term is preferred for the ridged features in dead-ice moraine when it cannot be determined whether deposition occurred in crevasses or at the edge of isolated walls or blocks of stagnant ice.

2. Crevasse fillings are composed of stratified drift and, or till. Sediments were deposited in crevasses by squeezing of drift from under the ice, by mass movement of drift from the ablating surface of the ice or by glacio-fluvial processes. They may be continuous with disintegration ridges. Crevasse fillings are distinguished from eskers by their rectilinear pattern with occasional offsets and intersections and sometimes by their composition, which

may be 100 percent till. In crevasse fillings of the stratified drift type, a flat top is generally characteristic.

3. Eskers are composed entirely of stratified drift deposited by a glacial stream; however, they may be mantled by drift let down during ablation of the roof ice. They are generally sinuous and exhibit a pattern similar to that of a terrestrial stream. Although they tend to follow the topographic lows, they may also be found on elevated areas, thus indicating that the stream was probably enclosed and under the influence of a hydrostatic head. Eskers may merge with either crevasse fillings or disintegration ridges.

Crevasse Fillings

The ridges that trend north-south through the west end of the Sperry Lake Loop, are ill-defined laterally (Fig. 17). Although called crevasse fillings in this report, the former cracks in the ice in which the material was deposited may not have been true crevasses, but interblock separations. At their northern extremity they appear to be associated with a small collapsed outwash deposit. Midway along their length they transect the topographically higher Sperry Lake Loop. In the area of Sperry Lake two meltwater channels are truncated by the crevasse fillings. Farther south the three distributory meltwater channels described above are truncated by the crevasse fillings.

The characteristic topographic features of the crevasse fillings are that they consist of five to twenty feet high, subparallel, sinuous, discontinuous ridges. The lithology of the ridges is variable.

Some are composed entirely of till, some entirely of sand and gravel, some water-washed till, and some are combinations of these lithologies. The lithology of the ridges and their relation to the other features indicate that the ridges are composed of material trapped in crevasses and that the ridges were formed when the ice walls of the crevasses melted.

Farther to the east, in the interlobe area between the Sperry Lake Loop and the Woodhouse Lake Loop, a second set of crevasse fillings occur which exhibit the same characteristics as the crevasse fillings discussed above.

Proglacial Landforms

Outwash Plain

There is one nonpitted outwash plain, south of the Sperry Lake Loop (T. 145 N., R. 174-5 W.) in the Missouri Coteau portion of eastern Sheridan County (Fig.). The deposit consists of sand, silt, gravel and a few scattered boulder beds. The outwash plain is extremely flat, exhibiting a local relief of less than two feet. It rises slightly to the north as it comes in contact with the Sperry Lake Loop. At this margin the relief increases slightly due to a minor amount of collapse.

Pitted Outwash Plain

Directly west of the Sperry Lake Loop outwash plain described above is a small area of pitted outwash. Pitted outwash is less than 50 percent collapsed but more than 5 percent collapsed (Clayton, 1962, p. 45). The pitted outwash is contemporaneous and gradational with the collapsed outwash plain to the west and with the outwash plain to the east.

Postglacial Landforms

Lakes and Sloughs

The most apparent features of the Missouri Coteau are the numerous sloughs and lakes. The lakes that occur in outwash usually are a surface representation of the true water table and they remain fairly fresh because of the circulation of water. The fresh water lakes have a water level that fluctuates only slightly and they support numerous species of animal life and vegetation. Lakes and sloughs which are till-floored, on the other hand, have a high salt concentration and their water levels vary greatly with the amount of evaporation and rainfall. In addition, they support fewer numbers of plants and animals.

Streams and Gullies

Only a few ehimeral streams exist on the Missouri Coteau. Most of these drain northward to the Sheyenne River. There are also a few short streams which are tributaries to some of the larger undrained depressions.

Gullies are well-developed along the eastern third of the Missouri Coteau Escarpment (T. 148 N., R 74 W.) (Fig. 18). None of these gullies, however, are more than one mile in length.

SHEYENNE RIVER AREA

General

The Sheyenne River area in North Dakota is bordered on the south

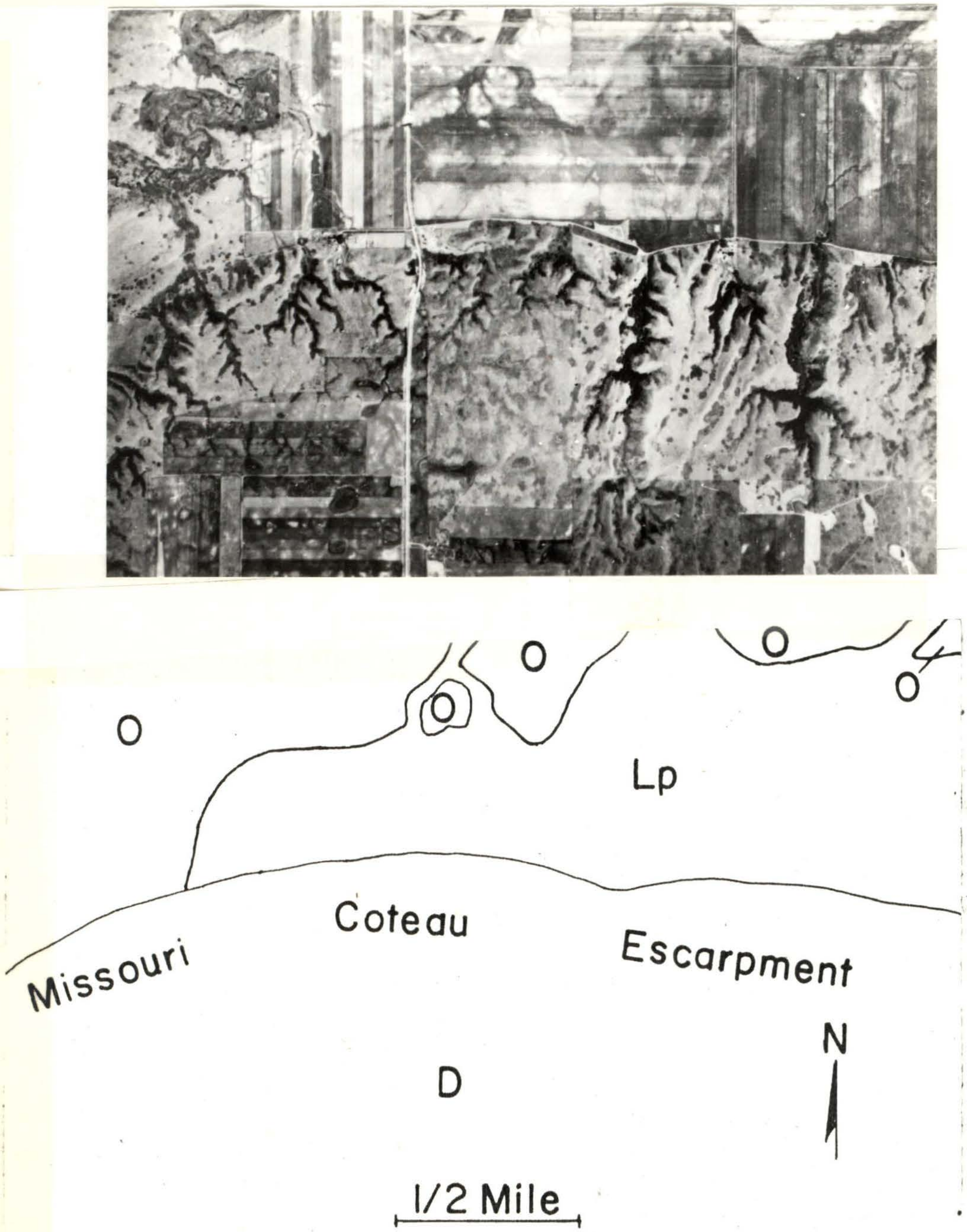


Figure 18.--The photo shows gullies developing southward from the Missouri Coteau Escarpment into dead-ice moraine (D) (Sec. 15, 16, T. 148 N., R. 74 W.). The areas north of the escarpment are composed of outwash (O) and lacustrine sediments (Lp).

by the Missouri Coteau escarpment which marks the northern limit of the Missouri Coteau district (Fig. 1). To the north, the Sheyenne River area is bordered by the Martin end moraine and by the northern limit of outwash plains derived from the Martin end moraine. The Sheyenne River area extends from western Sheridan County to Wells County with the eastern boundary at the drainage divide between the Sheyenne River and the James River. It covers nearly 150 square miles in eastern Sheridan County. The drainage system is limited to the Sheyenne River and its tributaries, most of which drain the Missouri Coteau escarpment. In general, the Sheyenne River area is characterized by low relief ground moraine and by poorly integrated drainage.

Glacial Landforms

End Moraine

The Sheyenne Lake End Moraines (T. 148-9 N., R 74-5 W.) are named herein for Sheyenne Lake which is about one mile north of the moraine. The moraines are characterized by an even surface and by a lack of lineations. They are elongated in a northwest-southeast direction and protrude about 140 feet above the surrounding ground moraine. Boulders are not conspicuous and bedrock outcrops are apparently absent. Their even surface and the lack of associated outwash suggests that they were formed and then over-ridden by the Grace City ice sheet.

Ground Moraine

The ground moraine deposited north of the Lincoln Valley end moraine (p. 21) lies within two topographic units, west and southwest of Lincoln Valley and north and northeast of Lincoln Valley. In the Lincoln Valley Sag, west and southwest of Lincoln Valley, the ground moraine is characterized by irregular to gently rolling topography. North and northeast of Lincoln Valley the relief is low. The surface declines to the northeast at a constant rate of about 60 feet per mile for a distance of about three miles. The drift is rich in sand and silt and has a pronounced lack of particles larger than coarse sand. The drift in this area exceeds 50 feet in depth (Fig. 19-22). The silt and sand rich sediment is probably due to modification of glacial debris by glacio-fluvial processes in fact, the entire topographic unit may be a poorly developed lacustrine deposit. An alternate explanation is that the topography may be a reflection of a buried alluvial fan-like deposit laid down by the pre-glacial Knife River where it flowed out of the Missouri Coteau.

Brophy (1962, unpublished report, North Dakota State University) mapped these two units and reported a lag deposit between washed and unwashed drift. The existence of this lag deposit is doubtful. In one outcrop exposure of this feature only a few small boulders roughly aligned in a horizontal plane were observed. Farther to the northeast, south of the Sheyenne River, the sandy ground moraine grades into a large outwash deposit. East of the water modified drift area, the ground moraine is normal in composition although locally it contains a high percentage of silt and sand. Here, the topography is gently rolling, but with less local relief than the ground moraine in the southwestern portion of the Lincoln Valley Sag.

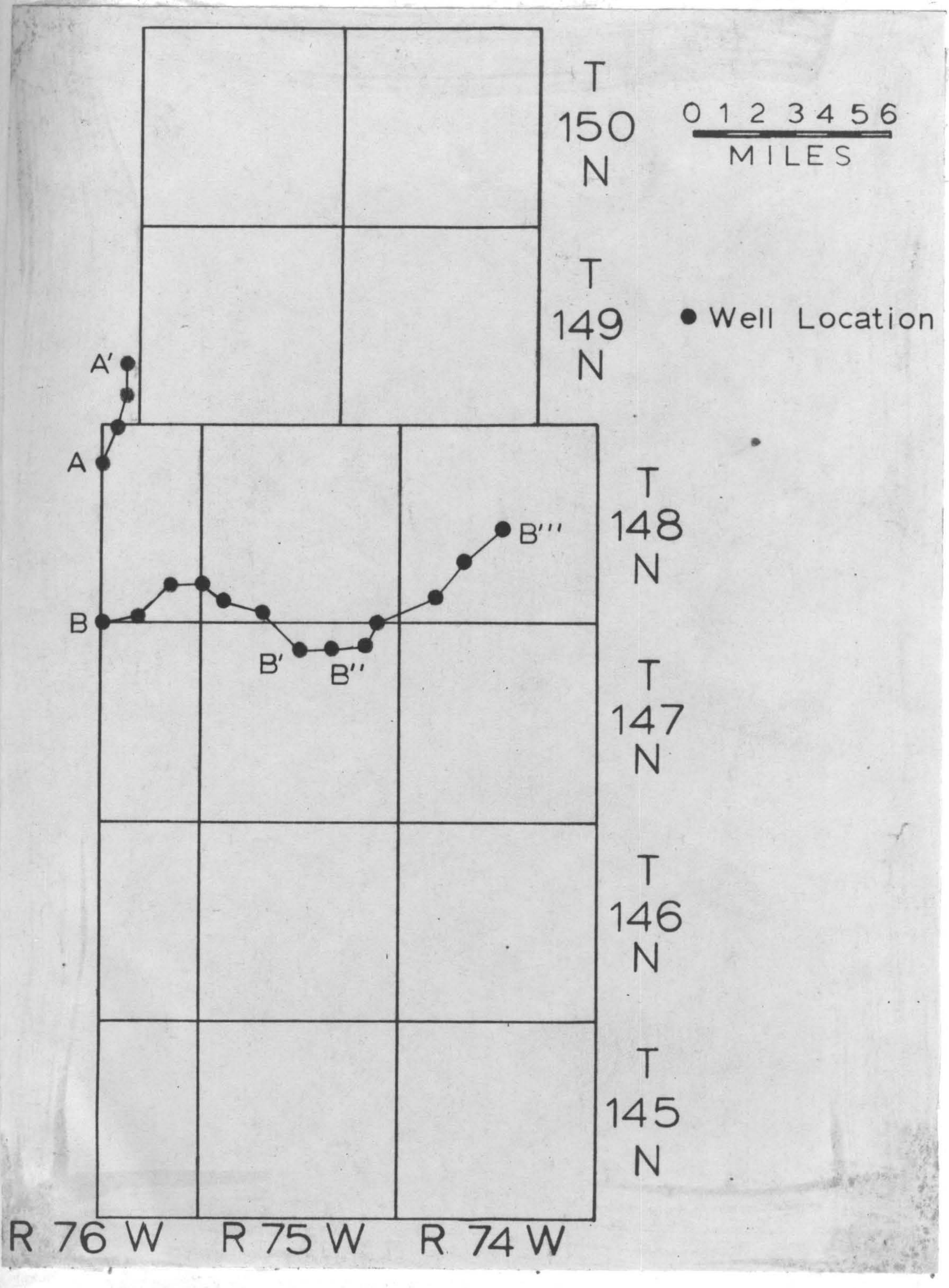


Figure 19.--Location map for cross-sections A-A', B-B', B"-B"'.

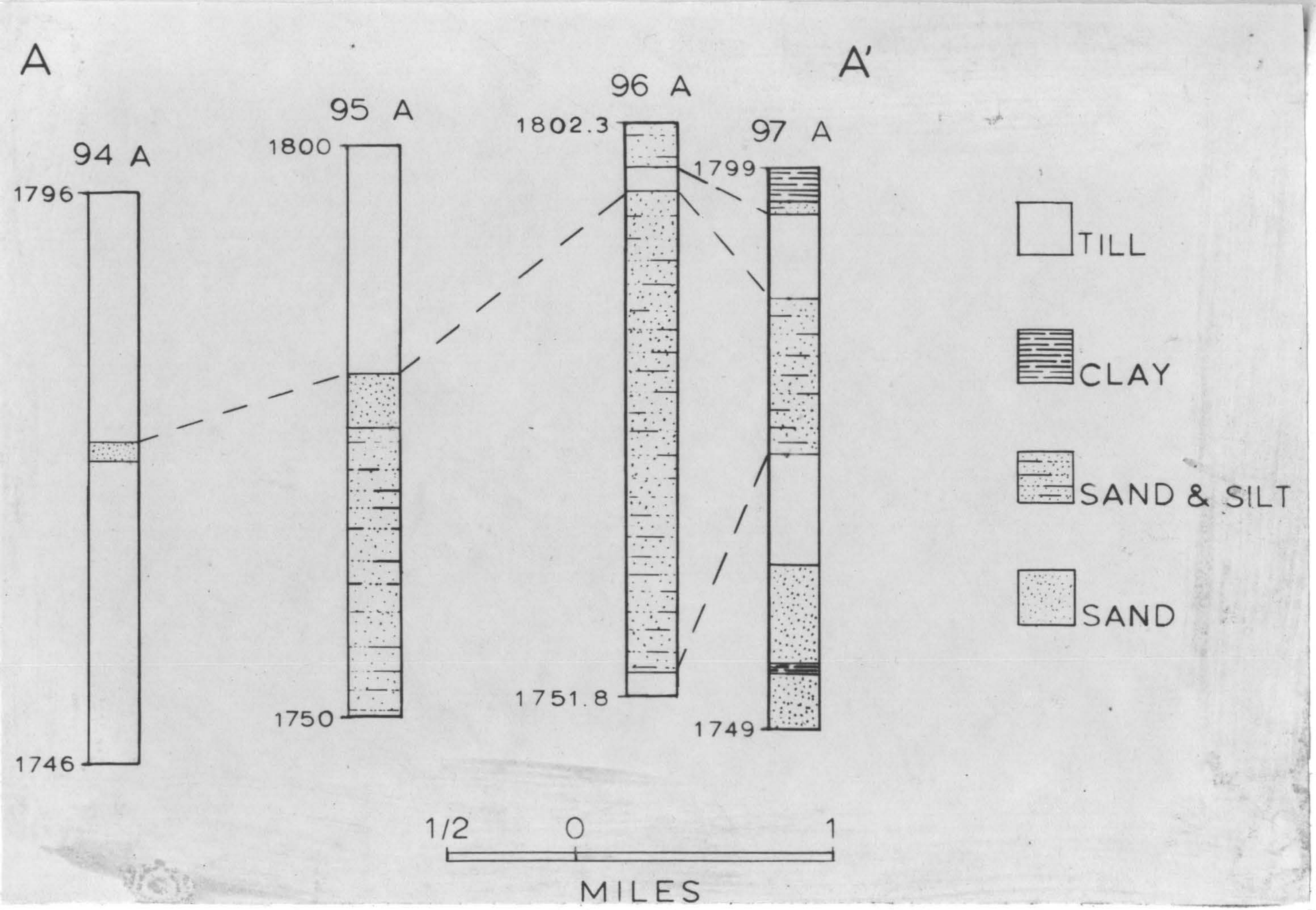


Figure 20.--Cross-section A-A'.

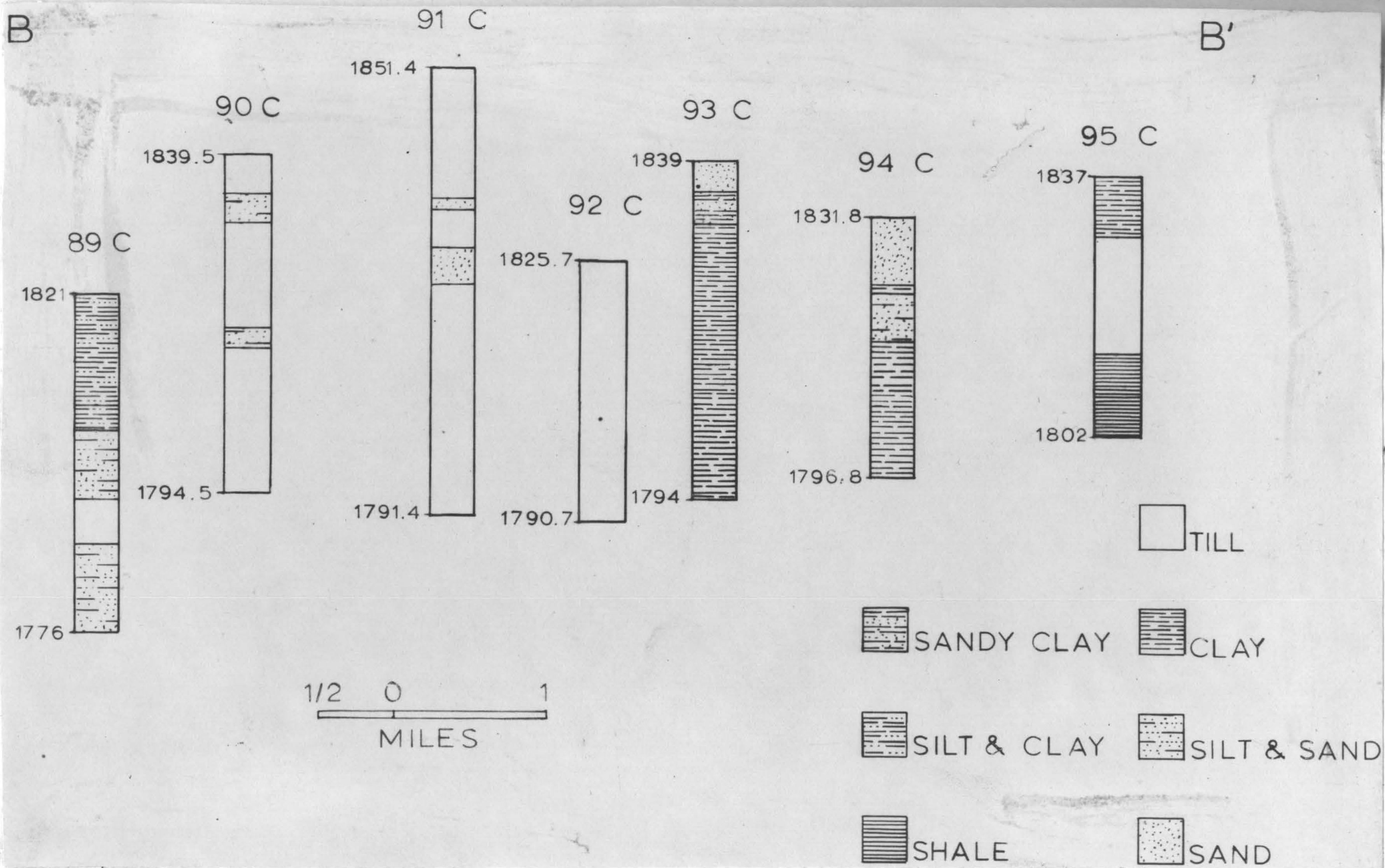


Figure 21.--Cross-section B-B'.

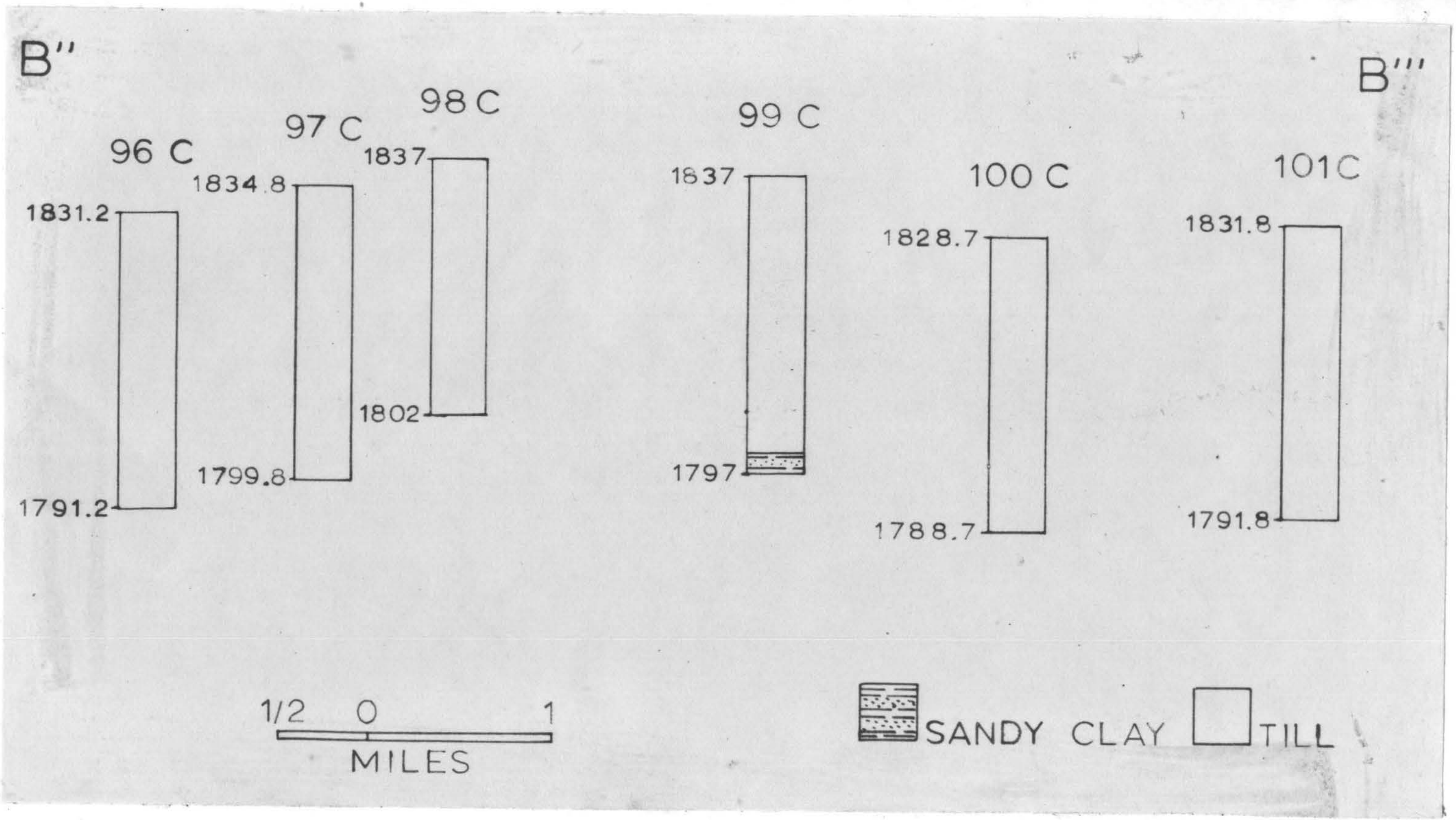


Figure 22.--Cross-section B"-B'".

Furthermore, Brophy has interpreted the ground moraine in the southwestern portion of the Lincoln Valley Sag as having been deposited by ice from the Leeds Lobe. He interprets the water-modified material northeast of Lincoln Valley as, being derived from the Souris Lobe. The Leeds Lobe moved into North Dakota around the east flank of the Turtle River Mountair; while the Souris Lobe advanced around the west side of the mountains. The drift northeast of Lincoln Valley may have been derived from Souris Lobe, but the Leeds Lobe did not enter Sheridan County.

Colton, Lemke, and Lindvall (1963) show the Grace City end moraine extending from Hawks Nest, in southwestern Wells County, along the Missouri Coteau to the Lincoln Valley end moraine in central Sheridan County. Faigle and Kresl (1964, oral communication, University of North Dakota) state that there is no Grace City end moraine west of Sykesville, in Wells County. There is also no correlative moraine east of Lincoln Valley end moraine in eastern Sheridan County. Because of the break between the two segments of end moraine is about fifty miles, it is felt that correlation between them is not justified at this time.

The ground moraine north of the Missouri Coteau escarpment is continuous with the Grace City ground moraine north of the Grace City end moraine in eastern Wells County and is, therefore, considered to be Grace City ground moraine.

The boundary between the Grace City drift and the Streeter drift is arbitrarily defined as coinciding with the Missouri Coteau escarpment because:

1. Segments of end moraine are present along the Missouri

Coteau escarpment and they may represent the southern limit of the ice sheet that deposited the Grace City drift.

2. There is a definite difference in the type of landform found to either side of the escarpment. Disintegration features, present to the south, are not found north of the escarpment.

These obvious differences do not negate the possibility that the Streeter and Grace City drifts are the deposits of a single continuous ice sheet. Sherrod (1963) considers the Grace City drift to be part of the Burnstad drift.

The Lincoln Valley and Grace City end moraine (T. 147 N., R. 76 W., T. 145 N., R. 68 W.) could be "shear" moraines developed as the ice sheet moved up and over the escarpment. The difference in landforms is at least partly due to more debris being present in and on the late Wisconsinan ice south of the escarpment. Thus, the landform differences may have been initially controlled by buried bedrock topography. The author favors the hypothesis that the two drifts were deposited by a single ice sheet, but he retains the use of Grace City drift and Lincoln Valley end moraine until more detailed mapping to the east shows whether or not the Grace City drift is a valid morphostratigraphic unit.

Eskers and Crevasse Fillings

A small indistinct esker was observed along the Wells County-Sheridan County border. It trends north-west-southeast from Sec. 24 to Sec. 11, T. 149 N., R. 74 W. Its maximum relief is about seven feet. The feature is discontinuous and is paralleled by low areas on each side. An ephemeral stream occupies the southern linear depression. Several other low ridges of stratified drift were observed in Sec. 9, 10, and 14 of T. 149 N., R. 74 W. Some were oriented at right angles to each other suggesting that they are actually crevasse or perhaps disintegration ridges.

Kettle Chains

Two kettle chains were mapped in T. 148 N., R. 75-6 W. In both cases, they are sites of contemporary sloughs at least partly rimmed by former ice-contact slopes. They are bounded to the south by the Missouri Coteau escarpment and are floored with silts and clays that are rich in organic debris. Both kettle chains merge into outwash plains related to former tributaries of the Sheyenne River.

General Discussion of Sequence of Landform Development in Sheyenne Area

Two stream channels enter the Sheyenne River from the south, one at the point where the Sheyenne River enters Sheyenne Lake and one about two miles south of Coal Mine Lake (Plate 1). At present both streams are ephemeral, but in the past these streams carried large amounts of water and debris. That the original streams were affected locally by ice damming is particularly evident in the stream that enters the Sheyenne River near Sheyenne Lake. The channel of this stream is a trench 90 feet deep in the southwestern unit of the overriden Sheyenne Lake end moraine. In order for this trench to have been cut, meltwaters at least partly dammed by ice must have collected south of the moraine. The ponded waters rose and flowed to the north through the lowest point in its margin and cut the trench through the end moraine.

The stream that enters the Sheyenne River near Coal Mine Lake flows roughly northeast and parallels the escarpment of the Missouri Coteau. Everywhere along its length the southeast bank is about 40 feet higher than the northwest bank. The difference in the height of the banks and the fact that the stream flows to the east on land that slopes to the north suggests that the stream originated at the margin of an ice sheet which lay to the northwest. This stream also exhibits several terraces of stratified drift which lie some 70 to 90 feet above the present-day Sheyenne River. The elevation of the terraces along the streams drops approximately 60 feet over a distance of three miles. Thus, the gradient of this stream was at least 20 feet per mile to the northeast. The present-day stream gradient is also approximately 20 feet per mile, so crustal rebound due to deglaciation apparently did not alter the stream gradient significantly, presumably because the stream was parallel to the ice-front. The stream gradient and the elevation of the terraces suggest that this stream flowed into a body of water in the vicinity of Sheyenne River, whose surface was about 50-60 feet above the present Sheyenne River. This body of water was bounded to the south by the Missouri Coteau escarpment and was ice-walled on the north.

In Sec. 13-16, T. 148 N., R. 74 W., the Missouri Coteau escarpment is about 125 feet high. From the lower limit of the escarpment to the edge of the Sheyenne River outwash plain, the land is flat surfaced and sloping to the north at about 50 feet per mile. Drift from this area contains a high percentage of silts and few cobbles and boulders. A few patches of clayey till protrude through what appears to be lacustrine deposits subsequently altered by alluvial action.

The sequence of events that produced the features in this district may be interpreted as follows:

1) The ice sheet that deposited the Grace City drift formed the Lincoln Valley end moraine either near its terminus or as a "shear" moraine where it passed over the Missouri Coteau escarpment.
2) As the ice north of the escarpment began to ablate, a channel developed in the ice near the Missouri Coteau escarpment in the vicinity of the Sheridan-Wells County border. This channel developed as an ice-marginal stream which is represented by the present-day tributrary to the Sheyenne River two miles south of Coal Mine Lake.
3) Subsequent ponding of meltwaters and deposition of lacustrine sediments occurred south of the present-day Sheyenne River in eastern Sheridan County and western Wells County.
4) The ponded waters drained to the southeast and the Sheyenne River deepened its channel where it crosses the Sheridan-Wells County border. The channel reaches bedrock here, which is probably Cannonball Formation, about 90 feet below the surrounding ground moraine.
5) Later, the Sheyenne River extended headward farther to the northwest as the Grace City ice sheet continued to ablate to the northwest.

Pro-glacial Landforms

Outwash Plain

Along the northern limit of the Sheyenne River area, south of the Martin end moraine, there is nearly ten square miles of outwash plain. The sediment, deposited on the distal side of the Martin end moraine, was derived from the Souris Lobe and is transected by a large meltwater channel which extends from Wells County to northern Sheridan County. This outwash plain is characterized by up to 15 feet of relief and by a reticulate pattern suggestive of deposition by network of distributaries or by a braided stream (Fig. 23)

Extensive deposits of stratified drift occur north and south of the Sheyenne River. This is an outwash plain composed in part of material derived from the Grace City ice sheet, and in part of material derived from the Martin drift. No effective boundary can be drawn between the two units, but most of the stratified drift east of the western end of the Sheyenne Lake is derived from Martin drift while to the west the material is mostly derived from the Grace City drift.

The southern edge of the Martin end moraine is composed of well-sorted sand and gravel. Stratification is still observable in this material and the lithology is identical to the stratified drift of Sec. 15, 16, 17, 21, 22, T. 145 N., R. 75 W. in which the end moraine terminates. Apparently the Martin end moraine has incorporated outwash deposits that were formed as the Grace City ice sheet ablated or as the Martin ice advanced. Small portions of this area are slightly collapsed and they have been mapped as pitted outwash.

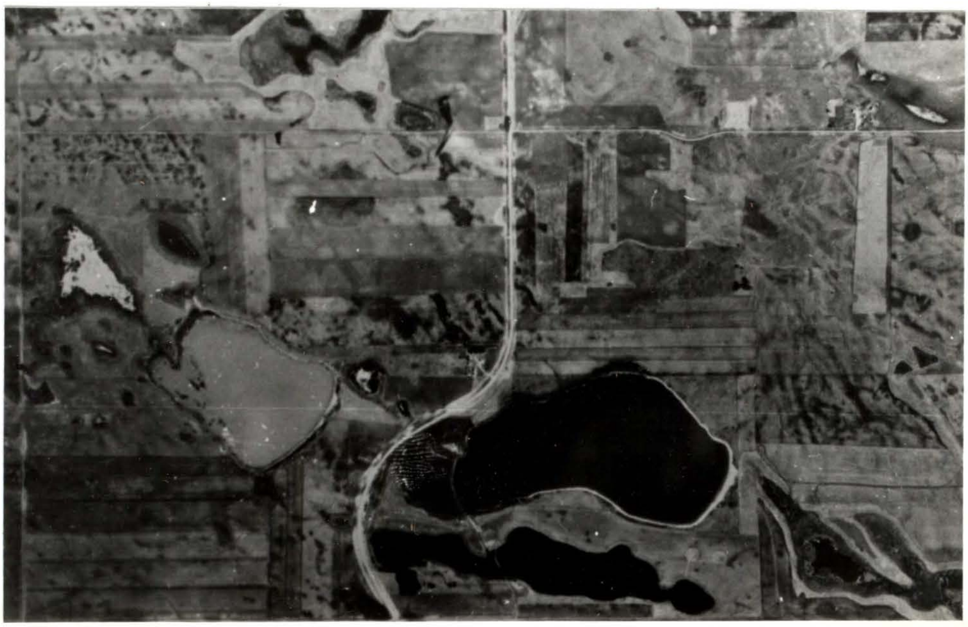


Figure 23.--Outwash plain topography located in Sec. 34, 35, T. 150 N., R. 74 W. The feature displays a depositional pattern that could have been constructed by a system of distributaries or a braided stream.

Meltwater Channels

Two meltwater channels are present in the Sheyenne River area. Both channels have a greater portion of their length in the Martin area and therefore, discussion of these features is undertaken as part of the description of the Martin area landforms (p.).

River Terraces

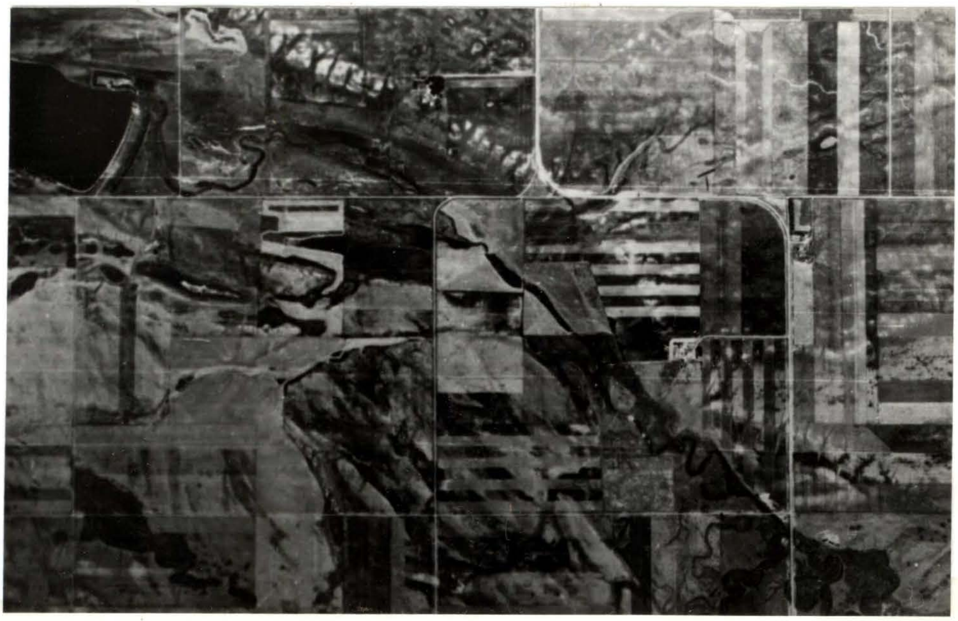
The Sheyenne River exhibits numerous well-developed terraces along its north side and several poorly developed terraces above the old river channel occupied by the present-day Sheyenne River (Fig. 24). The three levels may be seen along the section line between Sec. 3 and 4, T. 148 N., R. 74 W. The two lower levels are floored with stratified drift while the upper level is in till. The two upper levels can be traced across eastern Sheridan County.

<u>Non-glacial Landforms</u>

Lakes and Sloughs

There are three major lakes in this area, Lone Tree Lake, a natural lake, and Sheyenne Lake and Coal Mine Lake which are man-made lakes. All three lakes are floored by stratified drift and are therefore fresh water lakes whose surfaces are an extension of the ground water table. Coal Mine Lake is a wildlife refuge and Sheyenne Lake is a recreation area with beaches and numerous cottages.

The sloughs of this area are not as numerous as the sloughs in the Missouri Coteau district. Moreover, they generally are smaller and not as well defined. This is because the drainage is better integrated and the topography has less relief than the Missouri



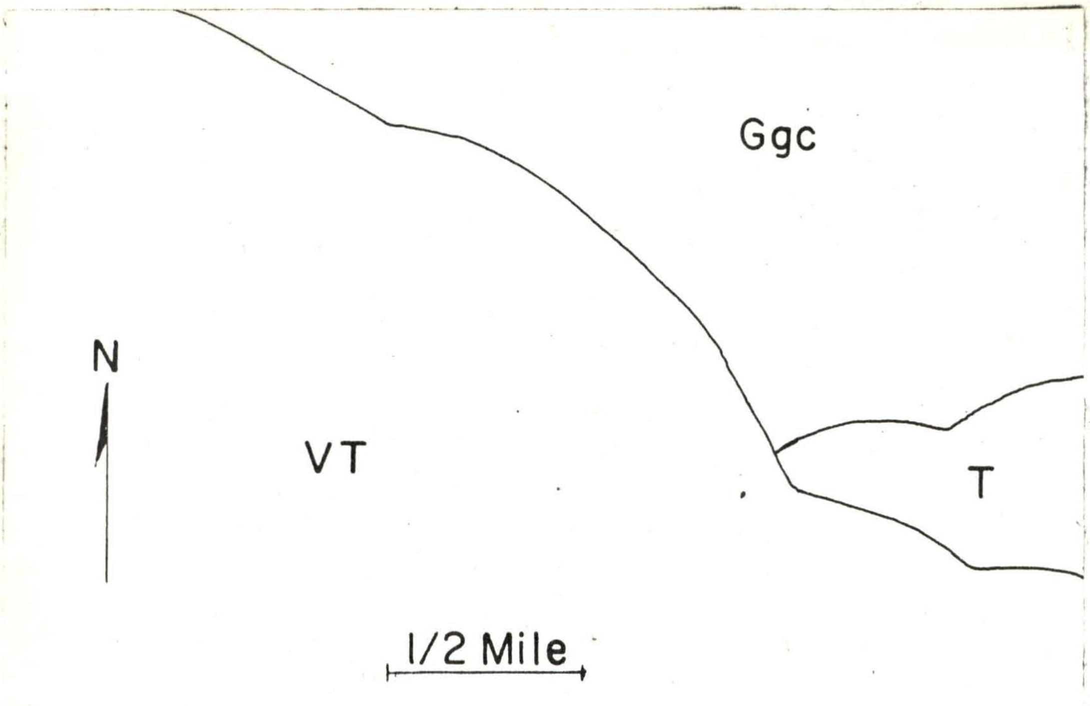


Figure 24.--Terraces (T) are present along the northern edge of the Sheyenne River outwash plain (Sec. 33, 34, T. 149 N., R. 74 W., Sec. 4, 5, 6, T. 148 N., R. 74 W.). Grace City ground moraine lies to the north (Ggc).

Coteau District.

MARTIN AREA

General

The Martin area, comprising approximately 84 square miles, is restricted to the northern one-fifth of eastern Sheridan County. The southern limit of the area is defined as the boundary between the Martin end moraine and the Grace City ground moraine or between the Martin end moraine and the outwash plains derived from it. There are no streams ephemeral or otherwise in this portion of the Martin area. Thus, the drainage of the area is not integrated. During ablation of the Martin ice, however, meltwater streams were present and drained to the south. The undrained depressions and isolated hills are generally larger, but less numerous than on the Missouri Coteau district. Although there are areas of high relief ground moraine with many undrained depressions, there is only one small area near Martin, North Dakota, that exhibits features characteristic of dead-ice moraine.

Glacial Landforms

End Moraine

Lemke and Colton (1958, p. 50) named the Martin moraine for the town of Martin which lies in the northeast corner of Sheridan County. The Martin end moraine trends eastnortheast across the northern portion of the report area. The end moraine is especially well defined at its eastern and western limits within the report area. Good linear features, ridges and valleys trending northeast, and a sharp break in topography at its southern limit define the western portion that is west of North Dakota Highway 14. The eastern portion that is east of Wolf Lake is defined by its overall linearity, a lack of lineations, and by a sharp break in topography along its southeastern limit. The southern limit of the central portion of the end moraine is less well-defined. The chosen boundary is interpreted as the topographic break that coincides with the northern limit of the outwash plains derived from the Martin drift (p.). The western portion is characterized by high relief, up to 175 feet per square mile, large numbers of surface boulders, and a sandy till that grades into stratified drift in the southern portion of this area. The central and eastern portions of the end moraine are characterized by a clay till, few boulders, and a relief that is only slightly higher than the surrounding ground moraine.

The northern limit of the Martin end moraine is marked by a series of "shear" moraine segments which form two interlobate and three lobate areas. The elevation of these segments ranges from 30 to 60 feet above the surrounding ground moraine. All the segments show an elongate form with some having aligned ridges and valleys features. Ground moraine separates the segments of the "shear" moraine from each other and from the main mass of the Martin end moraine, which lies a few miles to the south.

The Martin end moraine marks a stage in the retreat of Souris Lobe which moved into North Dakota from Canada around the west side of the Turtle River Mountains. The southeast trending linear grooves and elongated drumlins southeast of Velva, North Dakota, along with washboard moraines, concave to the northwest, confirm ice flow from the northwest.

Christiansen (1956) considers the Souris River Lobe to be a portion of the Mankato ice advance. Lemke and Colton (1958, p. 51) consider this unit, which extends from the Tirtle Mountains to the Lincoln Valley Sag, as post-Cary in age. Undoubtedly, more conclusive estimates of the age of this unit will be make as soon as more radiocarbon dates are obtained.

Dead-Ice Moraine

A small, about 4 square miles, area of dead-ice moraine occurs in the northeast corner of the county. The presence of closed disintegration ridges, linear disintegration ridges and broken rim ridges distinguishes the dead-ice moraine from the Martin end moraine to the south. Local relief is approximately 25 feet and irregular hills and undrained depressions are numerous. To the north, the dead-ice moraine grades into ground moraine. The topographic break between the two landforms is the result of ground moraine having lower relief and fewer, though larger, undrained depressions. Composition is generally a clay till, but locally the drift is mainly sand and gravel, but still exhibiting definite dead-ice features.

Ground Moraine

The Martin ground moraine has an irregular topography with numerous hills and low areas. Locally, the relief exceeds 70 feet within a square mile. Towards the northwest corner of the report area, along the northern limit of the Martin end moraine, the ground moraine loses its clay till character and becomes distinctly silty and sandy, and eventually grades into pitted outwash. This sandy and silty drift probably consists partly of eolian sediment derived locally and from the Souris Lake basin to the north, and partly of valley train deposits laid down by waters draining southward from Lake Souris.

Crevasse Fillings

Three possible crevasse fillings occur in Sec. 6, 18, 19, T. 150 N., R. 74 W. They are poorly defined deposits of stratified drift whose linear trend and angular relationship to one another suggest that they were formed from material deposited in a system of former crevasses. They may, however, reflect deposition between isolated blocks of stagnant ice.

Pro-Glacial Landforms

Outwash Plain

Only one small area of uncollapsed, unpitted outwash occurs in the Martin area. Sec. 12, 13 and 14, in T. 150 N., R. 75 W. contain portions of an uncollapsed outwash plain that is evidently associated with the Martin "shear" moraine.

Pitted Outwash Topography

In the extreme corner of the report area there is about five square miles of pitted outwash. The sediment is composed of silts, sands, and gravels and some small areas have high percentages of fine sands and silts. Much of the surface material is a fine dark silt. The origin of this material is thought to be a combination of eolian material derived from Lake Souris and glacio-fluvial deposits derived from the ablating Souris Lobe and the glacial Lake Souris.

Collapsed Outwash Topography

A large collapsed outwash deposit extends northward along the western edge of the Martin end moraine. The deposit was developed along an outwash channel in which water flowed southward from glacial Lake Souris into the Sheyenne River. It is composed of sands, silts and gravels and is marked by numerous lakes and ponds, some which are kettle-hole lakes. The kettle holes are aligned parallel to the direction of drainage, indicating the possiblility of a buried channel. Lemke (1960, p. 109) reports that the depth of drift in the vicinity of Guyes Lake is 240 feet which supports this conclusion.

Meltwater Channels

Two meltwater channels are present in this portion of the county. The meltwater channel near the western limit of the report area extends north-south through the southwestern portion of the Martin end moraine (Fig. 25). The channel is floored by till and colluvium, and lies about 80 feet below the bordering end moraine at its deepest part. The presence of this meltwater channel through the Martin end moraine suggests that waters were ponded behind the Martin end moraine as the Souris Lobe ablated. High land masses to the east and west of the present channel partly contained the waters. Ice blocking, a large low area between two portions of the Martin end moraine, today occupied by two large kettle-hole lakes aided in containing the water. The ponded waters eventually breached the Martin end moraine, and cut a deep channel as they drained southward into the Sheyenne River.

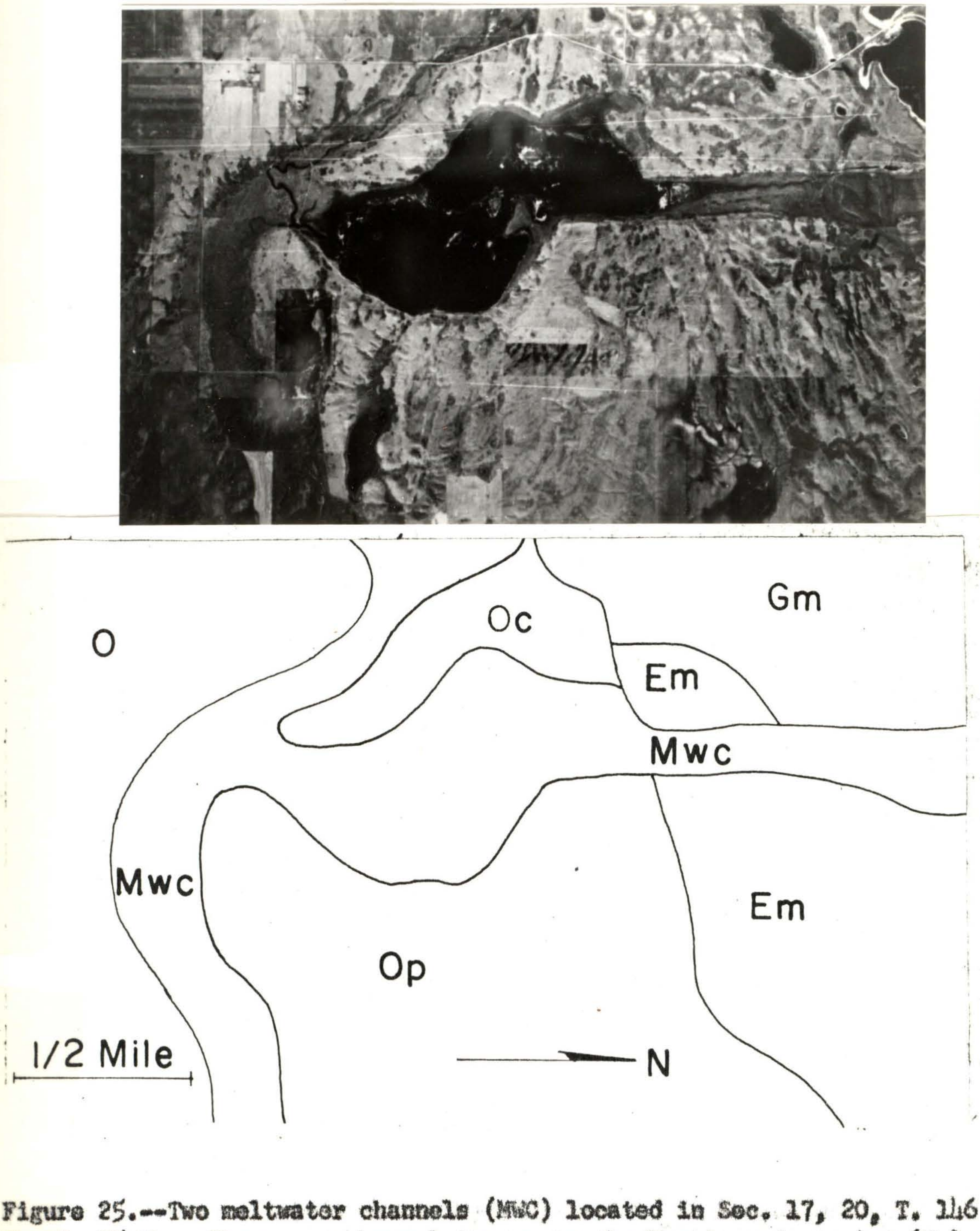


Figure 25.--Two meltwater channels (MWC) located in Sec. 17, 20, T. 146 N., R. 75 W. The upper channel transects the Martin end moraine (Em) and joins the meltwater channel to the ancient Sheyenne River. The present-day Sheyenne River flows east-west in the lower meltwater channel. Much of the lighter area consists of outwash (O) and pitted outwash (Op) of the Sheyenne River outwash plain.

A second meltwater channel, perhaps partly buried, lies in the northeastern portion of the report area. It trends northwest-southeast and extends from the Sheyenne River in Wells County into Sheridan County through the Martin end moraine northwestward into Pierce and McHenry Counties. Although it exceeds 25 feet in depth where it passes through the Martin end moraine, there is no present-day stream in the channel. The channel is partly floored with stratified drift and partly with a black, fine-grained organic-rich material.

Non-Glacial Landforms

Lakes and Sloughs

There are a large number of permanent lakes in the Martin area. Most of these lakes are fresh water lakes associated with outwash deposits.

Sloughs are numerous and may be partly filled by dense vegetation providing an excellent habitat for the numerous water fowl in the area.

BEDROCK TOPOGRAPHY

Only a few closely spaced water test wells drilled by the Bureau of Reclamation (Figs. 19-22) and a few widely spaced petroleum "wildcat" wells described by Nelson (1954), Haner (1954), and Peterson (1957), have reached bedrock in eastern Sheridan County (Table 1). Consequently, almost nothing is known of the pre-glacial topography of this area.

Topographic maps, however, show several features that are probably reflections of buried bedrock topography. For example, the Missouri Coteau escarpment strongly suggests a buried bedrock escarpment to the south and bedrock outcrops a few miles south of the escarpment support this conclusion. The Denhoff interlobate moraine south of Denhoff may be underlain by a bedrock high. Southwest of Lincoln Valley, the escarpment is broken by the southwesterly trending Lincoln Valley sag. This sag is thought to be the topographic expression of the pre-glacial Knife River Valley where it passed through the bedrock of the Missouri Coteau. At the northeast end of the sag, the drift has an extremely flat surface and slopes at a constant rate to the northeast. It is possible that this area reflects a buried alluvial fan-like deposit of the Knife River. North of the Lincoln Valley Sag, ground moraine and stratified drift obscure any further evidence of bedrock topography.

Lemke (1960, p. 109) reports that a well drilled in Sec. 6, T. 149 N., R. 75 W., penetrated 240 feet of surficial deposits before bedrock was reached. At present this area is covered with stratified drift and it is part of the floor of Bently Lake-Guyes Lake spillway.

	N.D.G.S. Well #337	N.D.G.S. Well #665	N.D.G.S. Well #735
Cretaceous System			
Pierre Formation	510	422	610
Niobrara Formation	2013	1415	1654
Greenhorn Formation	----	2054	2112
Dakota Group Sandstones	2535	2597	2625
Jurassic System		2883?	2915
Piper Limestone	3052	3210	3220
Triassic System			
Spearfish Formation	3182	3445	3420
Mississippian System			
Charles Formation	3305	3576	3470
Mission Canyon Formation	3560	3940	3755
Lodgepole Formation	3840	4187	4020
Englewood Formation	----	4789	4594
Devonian System			
Lyleton Formation		4811	4610
Nisku Formation		4840	4622
Duperow Formation		4890	4654
Dawson Bay Formation		----	4870
Winnepegosis Formation		----	4952
Ashern Formation		5555	5030
Silurian System			
Interlake Group		5575	5070
Ordovician System			
Stony Mountain Formation		5772	5395
Red River Formation		5962	5500
Winnepeg Formation		6560	6115

Table 1.--Locations and depths of formation tops in three wells in eastern Sheridan County. Data from North Dakota Geological Survey Circulars No. 63, 145, and 169.

N.D.G.S. Well #337, C NE SE Section 22, T. 148 N., R. 74 W.
N.D.G.S. Well #665, C NE NE Section 15, T. 148 N., R. 76 W.
N.D.G.S. Well #735, Section 16, T. 146 N., R. 74 W.

Lemke states that this great thickness of drift suggests the presence of a buried channel trending northward from the Lincoln Valley sag.

From the analysis of these cursory data, it appears that highlands and perhaps a few buttes were present in the southern half of the report area prior to glaciation. The highlands were cut by the northeast trending pre-glacial Knife River which may have continued to the north near the area of the present-day Guyes Lake.

STRATIGRAPHIC UNITS AND LITHOLOGY

PRE-PALEOCENE BEDROCK

More than 6200 feet of sediments lie between the base of the Paleocene Cannonball Formation and the lower portions of the Ordovician Winnipeg Formation, the oldest formation penetrated by petroleum wells in eastern Sheridan County. The formations that comprise the bedrock of Sheridan County generally thicken several feet per mile to the northwest towards the center of the Williston Basin. The "Dakota Group Sandstones", also called the Fall River Formation, is between 2500 and 2700 feet deep in eastern Sheridan County (Hainer, 1954). This is an important ground water aquifer in many parts of north central United States. Table 1. gives the location of three of three test wells drilled in this area and the depths to the tops of some of the formations encountered.

PALEOCENE SERIES, CANNONBALL FORMATION

There are only a limited number of bedrock outcrops in the report area and they consist entirely of exposures of the Cannonball Formation. The outcrops occur both south (Sec. 30, T. 148 N., R. 74 W.) and north of the Missouri Coteau escarpment (Sec. 12, and 13, T. 148 N., R. 75 W. and Sec. 12, T. 148 N., R. 74 W.). In every case the lithologies are similar; they include poorly indurated, slightly plastic when wet, silty to sandy black mudstone which fracture into small blocks, and unconsolidated buff to gray calcareous sandstones with discontinuous lignitic stringers. No fossil evidence was found.

The sandstone outcrops show considerable contortion of lignite and sand beds due to overriding by the ice sheet. This is generally evidenced by small folds overturned and drawn out to the south.

PRE-GLACIAL KNIFE RIVER GRAVELS

While studying the bedrock outcrops in the report area residual concentrations of gravel were frequently found overlying the bedrock. Collections of pebbles were made from each of the outcrops and analyses were made for shape, roundness, and lithology. Two sites were found to contain abundant well rounded quartzite pebbles, while the other three sites contained an abundance of rounded to subrounded carbonate pebbles.

The carbonate rich samples probably were derived from the Paleozoic carbonate sequences in southern Canada. The quartzite pebbles, however, have their nearest present-day occurrence in southwestern North Dakota (Leonard, 1907-8). Here quartzite gravels make up the lower member of the White River Formation exposed in White Butte.

It is the author's interpretation that the quartzite pebbles were probably eroded from the White River Formation and transported northward by the Knife River to the vicinity of the Lincoln Valley Sag. The pebbles were deposited here and later picked up by an ice sheet that carried them to the southeast. Sample sites south of Missouri Coteau escarpment and west of the Lincoln Valley Sag do not contain any of the well rounded quartzite pebbles, which suggests that the ice sheet moved south-southeast, parallel to the Missouri Coteau escarpment.

PLEISTOCENE SERIES

Time-Stratigraphic Terminology

Only two divisions of the Pleistocene Series apply to eastern Sheridan County, the Wisconsinan Stage and the Post-Glacial Stage. Sub-Wisconsinan drift may exist below the Wisconsinan drift, but this will not be known until North Dakota drifts are more completely dated. A suggested correlation of Sheridan County drifts with several systems of time-stratigraphic terminology is shown in Figure 26.

The geologic climate unit described in the Code of Stratigraphic Nonemclature (Art. 39 and 40) is not used because it is time transgressive and because it would make a complex terminology even more complex and awkward.

The Recent Stage is not used in this report because students of the Pleistocene cannot agree on the lower limit of this stage. Some deposits, however, have been interpreted as post-glacial because of their stratigraphic position. These deposits, especially in their lower portions, may lie chronologically near one or the other of the Wisconsinan Stage-Recent Stage boundaries as shown in Figure 26.

Lithostratigraphic-Morphostratigraphic Terminology

All the drifts of eastern Sheridan County are mapped as morphostratigraphic units. This unit, proposed by Frye and Willman (1960, p. 7-8), is redefined by Clayton (1962, p. 53) as "...a body of drift that is identified by its surface form and position and consists of all the drift deposited from the glacial ice and associated meltwater from a significant glacial advance, including the till of associated end moraine, dead-ice moraine, and ground moraine, the washed drift of

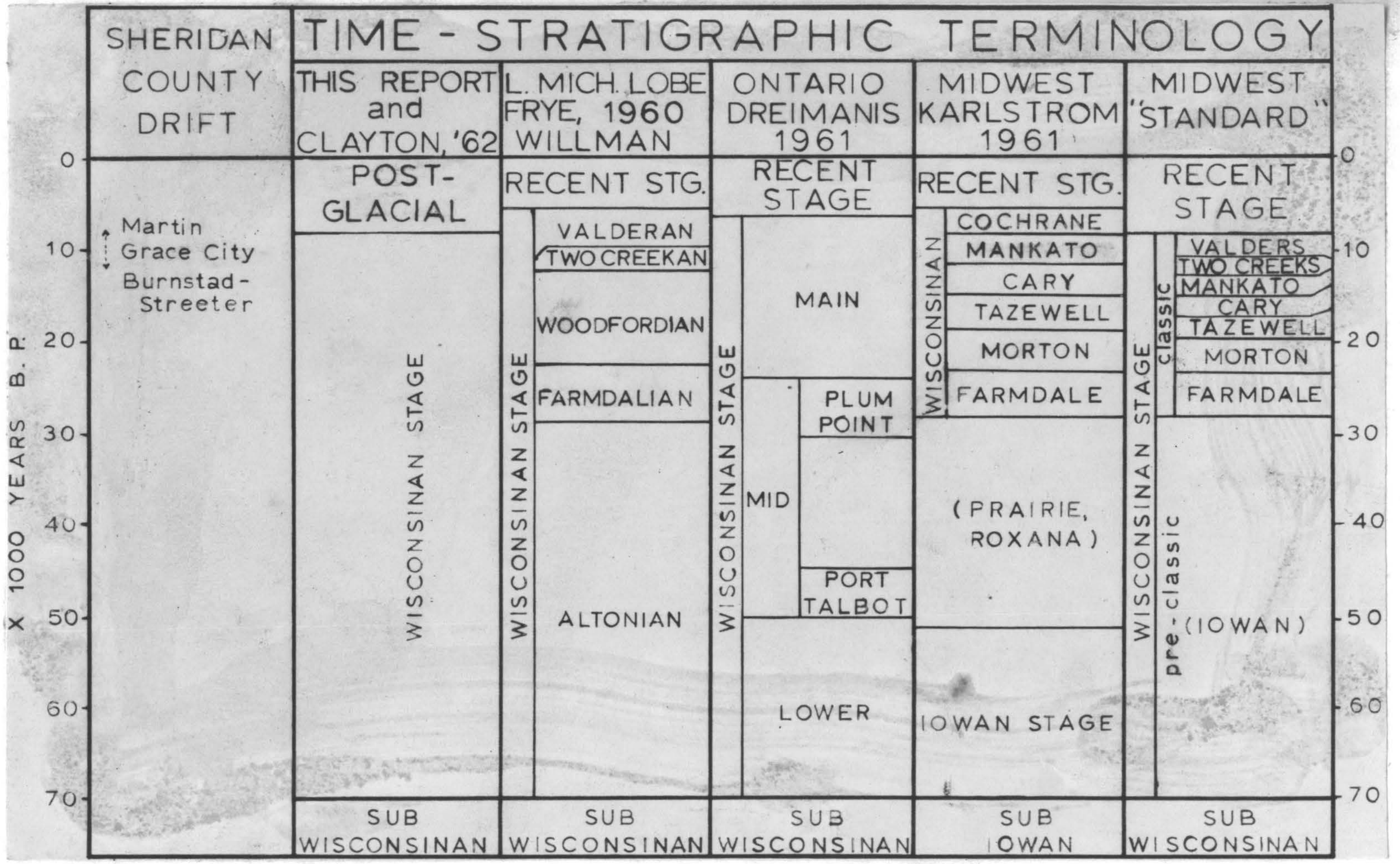


Figure 26.--Approximate correlation of eastern Sheridan County drifts with various time-stratigraphic terminologies. Modified from Clayton, 1962.

associated lake plains and outwash plains, and associated subsurface drift."

The morphostratigraphic unit is preferred over rock stratigraphic units because the similarity of lithology and surface form does not facilitate division into rock stratigraphic units as defined in the Code of Stratigraphic Nomenclature (Art. 4a, c, d, e).

Sub-Wisconsinan Stage

Clayton (1962) and Bonneville (1961) report an iron-cemented, jointed till that, according to Clayton (1962, p. 55) is older than the Napoleon drift which is probably lower Wisconsinan. If Clayton's estimation of the age of this drift is correct, then it is quite possible that sub-Wisconsinan drift is present in eastern Sheridan County. At present, however, there is no suggestion of this iron-cemented, joined till below Wisconsinan drift either in outcrop or in well cores.

Wisconsinan Stage

Lithology

There is little difference in the lithologies of the three drifts present in eastern Sheridan County. At the surface the tills are various shades of brown and generally contain from five to ten percent granules or larger size particles.

Pebble counts were made in each drift, and although few in number, the counts suggest that the source areas for each drift sheet are lithologically identical (Table 2). The consistently high carbonate percentage is a reflection of the Paleozoic carbonate sequences of southern Canada, the metamorphic, granitic and basic rocks are probably

granitoid	23	1	4	17	8	5	11	8
quartzitic	4	1	2	-	1	3	3	2
basic	7	1	1	3	3	3	2	6
foliated metamorphic	7	7	5	24	11	6	3	2
carbonate	44	34	26	33	44	38	49	40
sandstone	4	6	8	8	1	6	5	9
shale	6	12	24	7	5	10	24	13
chert	-	-	1	-	1	1	1	-
iron concretion	5	18	8	3	6	4	1	9
lignite	-	20	21	5	18	24	-	9
misc.	-	-	-	-	2	-	1	2
Total	100	100	100	100	100	100	100	100

Table 2.--Lithologies of pebbles collected from the Martin, Grace City and Streeter drifts in eastern Sheridan County.

Martin drift; samples 56 (Sec. 12, T. 150 N., R. 84 W.), 58, (Sec. 8, T. 150 N., R. 74 W.), 59 (Sec. 33, T. 150 N., R. 75 W.), 60 (Sec. 23, T. 150 N., R. 75 W.).

Grace City drift; samples 63 (Sec. 11, T. 147 N., R. 75 W.), 64 (Sec. 14, T. 147 N., R. 76 W.).

Streeter drift; samples 65 (Sec. 16, T. 145 N., R. 75 W.), 66 (Sec. 28, T. 145 N., R. 75 W.).

derived from the Canadian Shield, and many of the sandstone, shale, iron concretion, and lignite pebbles are presumably locally derived.

The sand-silt-clay diagram for till samples from the three drift sheets is shown in Figure 27. The Grace City drift is represented by a lack of a characteristic particle size distribution indicating heterogeneous source materials. The Streeter and Martin drifts, with one exception each, are closely grouped and overlap only slightly. If the Grace City and Streeter drifts are considered as the product of one major ice sheet, the pattern is somewhat diffuse, but it definitely suggests that, with respect to particle size distribution, the Grace City-Streeter drift is different from the Martin drift. This suggests that the Grace City and Streeter ice sheets may have made passes over bedrock of differing particle size distribution.

The reported depths of oxidation of till in eastern Sheridan County range from 14.6 to 48.2 feet (Department of Interior, Bureau of Reclamation, Report on Garrison Diversion Unit, Appendix VI - Geology, drill holes 89C - 101C, 94A - 97A). The depths of oxidation for wells 94A - 97A, drilled in Grace City drift, range from 24 to 48.5 feet. Oxidation depths in drill holes 89C - 101C in the Streeter drift range from 14.6 to 41.5 feet. The depths of oxidation are similar enough to prevent separation on this basis. No information is available on the depths of oxidation of the Martin drift.

All of the drift sheets are crudely jointed locally, and frequently contain gypsum crystals oriented parallel to the joint plane.

Stratified drift deposits include both outwash and lacustrine sediments. The outwash varies from crudely sorted deposits, close to related end moraines, to well sorted sands that are generally

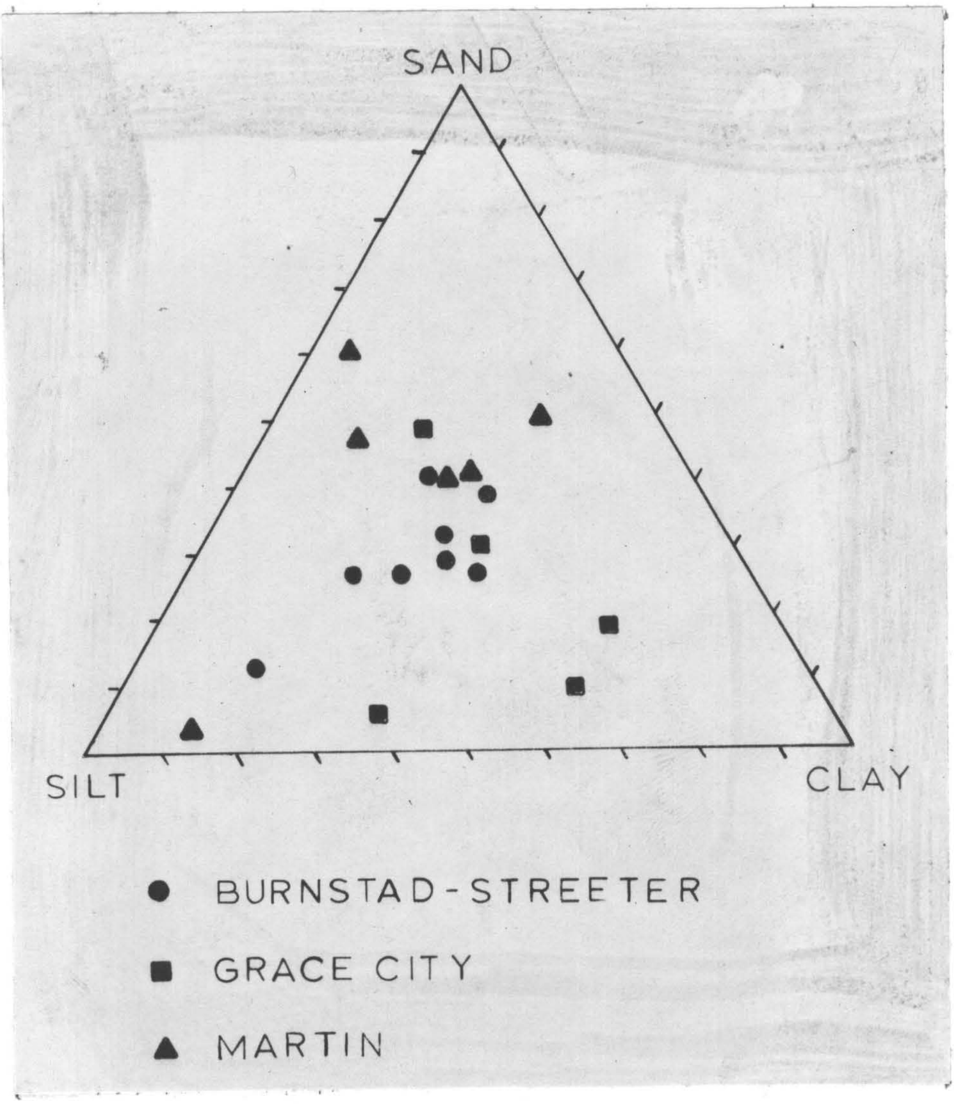


Figure 27.--Sand, silt, and clay percentages of till samples from the Streeter, Grace City and Martin drifts.

found several miles in front of the end moraines. The lacustrine sediments vary from gray brown clays to yellow brown silts and buff sands. Normally, the beds are a few millimeters thick in the silts and clays, but they are locally several centimeters thick. Varved clays were not observed in eastern Sheridan County. No well-developed loess deposits were recognized although in several places the drift appears to have been modified by wind-blown material.

Streeter Drift

The Streeter drift is considered to be part of the Burnstad drift as defined by Clayton (1962, p. 62-3). By virtue of its well developed end moraine, the Streeter drift is an easily distinguished morphostratigraphic unit in eastern Sheridan County. The Streeter drift as used in this report is the morphostratigraphic unit which includes till of the Streeter end moraine, its associated outwash deposits to the south, and all the drift to the north that was deposited by the same glacial ice. The Streeter drift extends northward to the Lincoln Valley end moraine. Where the Lincoln Valley end moraine is not present, the northern limit of the Streeter drift has been arbitrarily defined as coinciding with the Missouri Coteau escarpment.

The Streeter drift differs from the Grace City drift only in the type of landform development; dead-ice features are not present in the Grace City drift.

Morphostratigraphic Correlation.--The Streeter drift is equivalent to the area designated as Post Cary maxium by Lemke and Colton in central and southeastern North Dakota (1958, Fig. 4).

Time Stratigraphic Correlation.--Clayton (1962, Fig. 4, p. 68-9) discusses the significance of several radiocarbon dates which were taken from material in Streeter drift in Stutsman, Logan and McIntosh Counties. If these radiocarbon dates are correct, the Streeter drift is upper Wisconsinan in age. The time-stratigraphic correlation chart (Fig. 30) shows the correlation of the Streeter drift with the time stratigraphic units of other workers. It presumably correlates with either the Two Creekan or Valderan of Frye and Willman (1960).

Fossil.--Fossil material from this unit is limited to one niad (pelecypod) fragment found in perched lacustrine sediments collected along North Dakota Highway 14 about one-fourth mile south of North Dakota Highway 7.

Grace City Drift

The Grace City drift occupies nearly the entire area of the Sheyenne area in eastern Sheridan County. Lemke and Colton (1958, p. 51) named the Grace City end moraine for the town of Grace City, North Dakota. As used in this report the Grace City drift is defined as a morphostratigraphic unit consisting of all the drift of the Lincoln Valley end moraine, the Grace City end moraine and other associated drift that was deposited by the same glacial ice north of the Missouri Coteau escarpment.

In eastern Sheridan County, except in the vicinity of the Lincoln Valley end moraine, the boundary between the Grace City drift and the Streeter drift is arbitrarily defined as coinciding with the Streeter drift by the absence of dead-ice landforms and by the presence of a poorly integrated drainage system. Lithologically, the two drifts are identical.

Morphostratigraphic Correlation.--The Grace City drift is equivalent to the upper portion of the Burnstad drift, the Lincoln

Valley end moraine and its associated drift (Sherrod, 1963, p. 63). To the east, it is equivalent to the drift associated with Lemke and Colton's Advance No. 2 (1958, p. 50) which formed the Grace City, Kensel and Oakes end moraines.

Time Stratigraphic Correlation.--Leighton (1957, p. 1-2) suggests that equivalents of the Grace City drift are Valderan in age. Kresl (1964, oral communication, University of North Dakota) has obtained from the United States Geological Survey a radiocarbon date, 9860± 400 years B. P., (W-1369) for a spruce log that was found in the Grace City drift. This figure, however, is a minimum date.

Generalized time-stratigraphic terminologies of other researchers are shown in Figure 26. The Grace City is probably equivalent to either the Valderan or Two Creekan of Frye and Willman (1960).

Fossils.--The only fossil material obtained from this area are from lake sediments just below recent organic slough deposits (Sec. 18, 147 N., R. 74 W.). They include fresh water gastropod shells, ostracoda carapaces and stonewort zygospora. The following is a complete list of the fossils identified from this deposit:

Fossil Specimens	Number
Promenetus exacuous	4
Ostracoda	3 (valves)
Chara	4
Helisoma sp. H. cf. H. anceps	5
Pisidium sp.	6
Physa sp.	1
Lymnaea humilis	12
Valvata tricarinata	18

Martin Drift

The Martin drift occurs primarily in the Martin area of the Western Lake Section, but partly in the Sheyenne area. This unit is named for the town of Martin, which is in northeastern Sheridan County. The Martin drift is here defined as morphostratigraphic unit consisting of the till of the Martin end moraine and all the other drift originating from that glacial advance.

The Martin drift is recognized by its topographic expression and its inferred geologic history. In the vicinity of the Lincoln Valley, the Souris Lobe incorporated parts of a previously formed Grace City outwash plain proving that the Martin drift is younger than the Grace City drift. The Martin drift contains areas of dead-ice moraine and is somewhat sandier than the Grace City drift.

Morphostratigraphic Correlation.--The Martin drift is equivalent to the Post Cary maximum #3 of Lemke and Colton (1958, Fig. 4). The Martin drift extends from the vicinity of the Turtle Mountains southward to the Missouri Coteau, where it then swings parallel to the Coteau and extends northwestward into Canada.

Time-Stratigraphic Correlation.--There have been no radiocarbon dates made on material from the Martin drift. Its position indicates only that it is younger than the Grace City and Burnstad-Streeter drifts. Time-stratigraphic correlations with terminologies of other researchers is shown in Figure 30, and the Martin drift probably correlates with either the Valderan or Two Creekan of Frye and Willman (1960). The time lapse between the ablation of the Grace City ice sheet and the advance of the Souris Lobe can not be determined because of a lack of radiocarbon dates of the drifts.

Fossils.--Numerous fossil gastropods shells, ostrocod carapaces, and Stonewort (Chara) zygrospora cases were found in a marl bed at Sec. 1, T. 150 N., R. 74 W. The marl bed was exposed in a portion of a slough that had been excavated to provide additional water for cattle. A list of the fossils identified from this deposit are as follows:

Fossil Specimen	Number
Helisoma sp. H. cf. H. anceps	11
Promenetus exacuous	11
Pisidium sp.	34 (valves)
Lymnaea humilis	37
Valvata tricarinata	24
Spaerium sp.	1 (valve)
Gyraulus sp.	15
Gyraulus parvis	67
Vallonia gracilicosta	1
Armiger crista	3
Ostracoda	25
Chara	25.

SYNTHESIS OF PLEISTOCENE HISTORY

INTRODUCTION

Throughout the description of morphology of the glacial and proglacial landforms in the physiographic units of eastern Sheridan County detailed discussions of most of the sequences and mechanics of development were presented. Conflicting or alternate interpretations were discussed if they had been published or reported previously. The following interpretation of the phases of glacial history summarizes the ideas presented previously and includes several alternate possibilities for certain of the phases.

Three morphostratigraphic units, the Streeter, Grace City and Martin drifts, are present in eastern Sheridan County and each of these drift sheets has portions of end moraine present within the county. Some glacial geologists might consider that these particular end moraines were formed by three distinctly separated ice sheets. There has been some tendency in the past to imply that every significant end moraine was the product of an ice sheet that advanced an undeterminable distance from the north and then ablated some distance before the next ice sheet advanced to form the next end moraine.

Since most of the radiocarbon dates reported in North Dakota are less than 13,000 years B.P., much of the drift has been classified as post-Tazwell (Clayton, 1962, p. 54; Lemke and Colton, 1958, Fig. 5). Most of these dates give an approximate indication of the actual age of the drift. They are minimum age dates because, for the most part, they were obtained from material found in stratified drift deposits formed during retreat of the ice front. Thus, the time that it took for the ice sheets of North Dakota and Canada to advance and then to ablate was only a few thousand years, making it difficult to envision each end moraine as the result of a significant ice advance.

The end moraines of eastern Sheridan County, with the possible exception of the Martin end moraine, are the product of one more or less continuous ice sheet. These end moraines represent either stages in the retreatal phase of the active ice behind a stagnant peripheral zone or minor advances. The Martin end moraine has incorporated into its southern margin a large portion of uncollapsed outwash derived from the Grace City drift or from the advancing ice that deposited the Martin drift. If the outwash is part of the Grace City drift, then a significant time break occurred between ablation of the Grace City drift and advance of the Souris Lobe during which the stratified drift was deposited.

PHASES OF GLACIAL HISTORY

Pre-Wisconsinan Stage

No information is available concerning the importance of Pre-Wisconsin glaciation in eastern Sheridan County. An iron cemented, jointed till in Logan County is considered to be pre-Wisconsinan by Clayton (1962). Well logs in Sheridan County (Figs. 19-20) show other tills present below the Grace City drift and, although it is not probable, these drifts may be pre-Wisconsinan.

Wisconsinan Stage

Phase 1

According to Clayton (1963, p. 70) a glacier advanced over North

Dakota more than 38,000 thousand years ago and deposited the Napoleon drift of Logan and McIntosh Counties.

Phase 2

About 13,000 years ago glacial ice re-entered North Dakota and deposited the Zeeland drift in McIntosh and Logan Counties (Clayton, 1963, p. 70).

Phase 3

A third major advance occurred about 12,000 years ago, (Clayton, 1963, p. 70) and deposited the Burnstad drift in Burleigh County.

Phase 4

The Burnstad ice sheet stagnated along its periphery, uncovering lodgement till and depositing ablation till and outwash. The ice sheet then regained its equilibrium and formed the Streeter end moraine and the Jones Lake "shear" moraines (Fig. 28).

Alternate Phase 4

Although it is simpler and probably more correct to assume that the Jones Lake "shear" moraines were developed by shearing well back from the active ice front, it is possible to interpret them as end moraines formed by the reactivation of the Streeter ice sheet.

Phase 5

While the Streeter ice sheet stagnated along its periphery and while its associated outwash and lacustrine deposits were being laid down, the ice sheet again reached a position of equilibrium and formed the Lincoln Valley end moraine and the associated Grace City ground

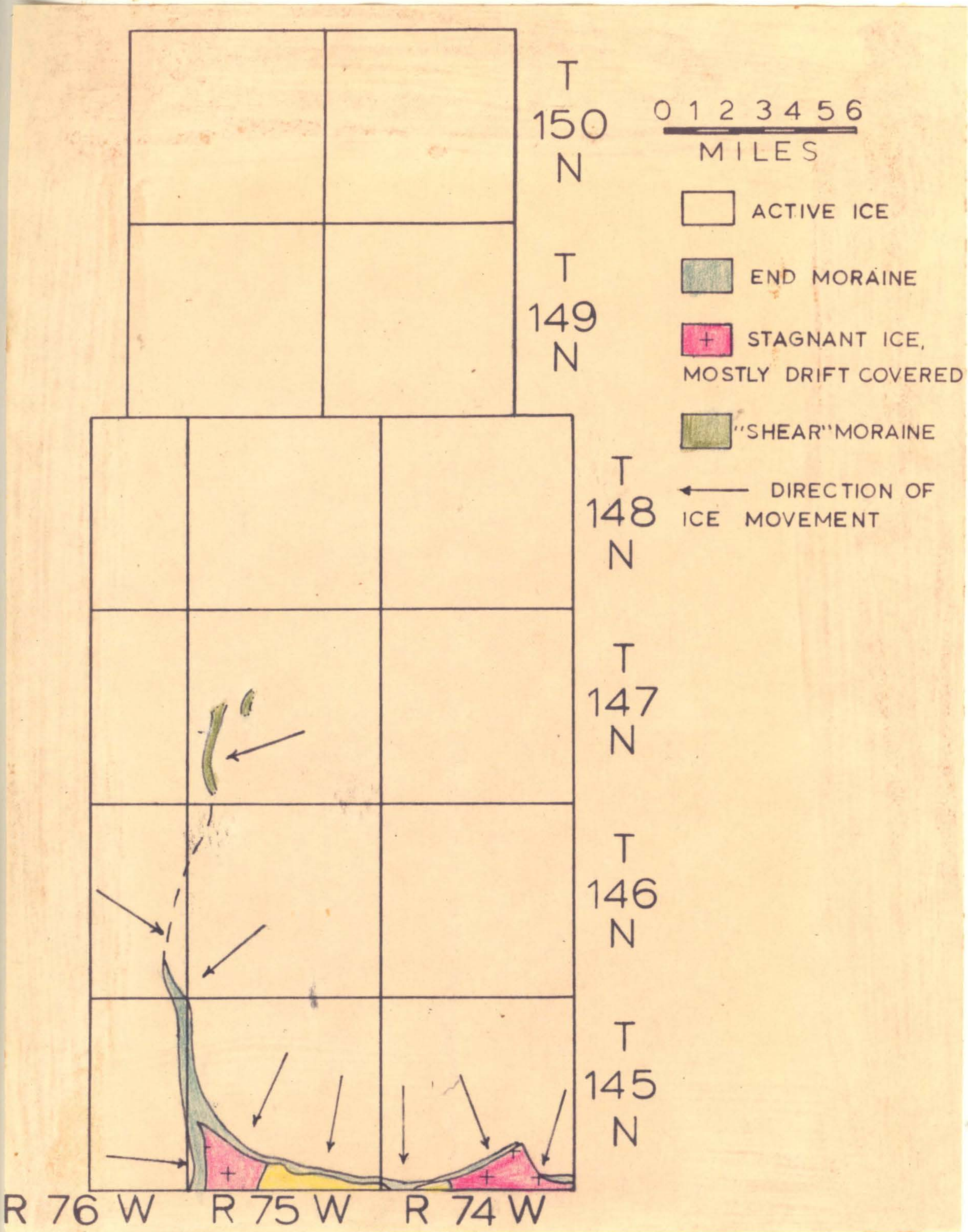


Figure 28.--Phase 4 of Pleistocene history - formation of Streeter end moraine.

moraine (Fig. 29).

Alternate Phase 5

The Lincoln Valley end moraine may well be the result of shearing of the Streeter ice sheet as it moved over the Missouri Coteau escarpment. The difference in the type of landform found in the Streeter drift and in the Grace City drift could be due to the differing amounts of debris present in and on the ice to either side of the escarpment. By this reasoning, the Grace City and Streeter drifts are contemporaneous.

Phase 6

The Grace City ice sheet began to ablate and the Sheyenne River was formed as an ice-marginal stream. A large stratified drift deposit was formed from the debris provided by the Grace City ice sheet. The Sheyenne Lake moraines were uncovered as ablation of the Grace City ice sheet continued.

Phase 7

Due to thinning of the ice in the vicinity of the Turtle Mountains, two ice lobes were formed, the Souris Lobe to the west and the Leeds Lobe to the east. The Souris Lobe advanced slightly to form the Martin end moraine and its associated "shear" moraines (Fig. 30).

Phase 8

The periphery of the Souris Lobe stagnated and formed the Martin ground moraine and a small area of dead-ice moraine. With continued ablation, waters were ponded behind the Martin end moraine. The waters eventually cut through the end moraine and formed a large meltwater

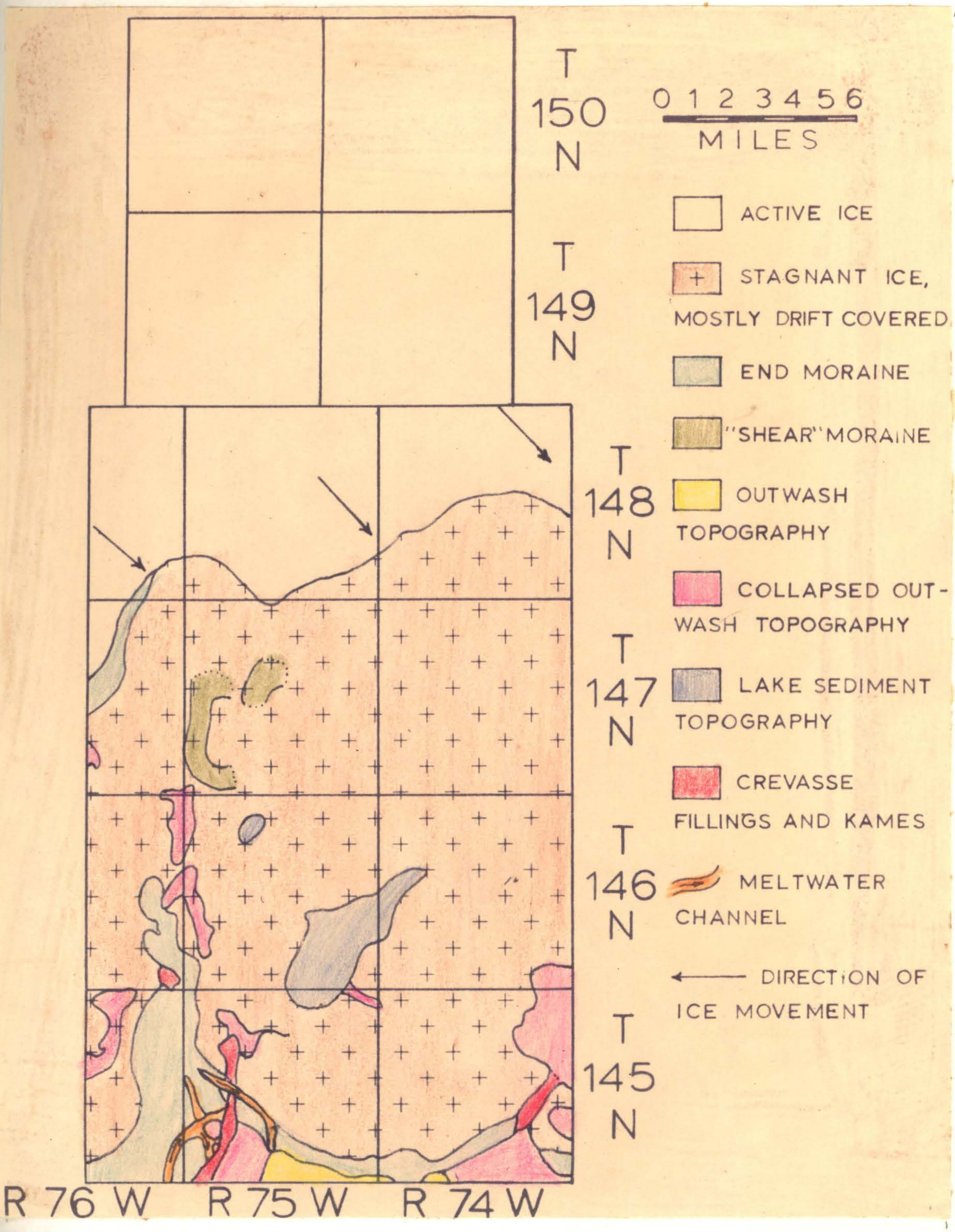


Figure 29.--Phase 5 of Pleisocene history - formation of Lincoln Valley end moraine.

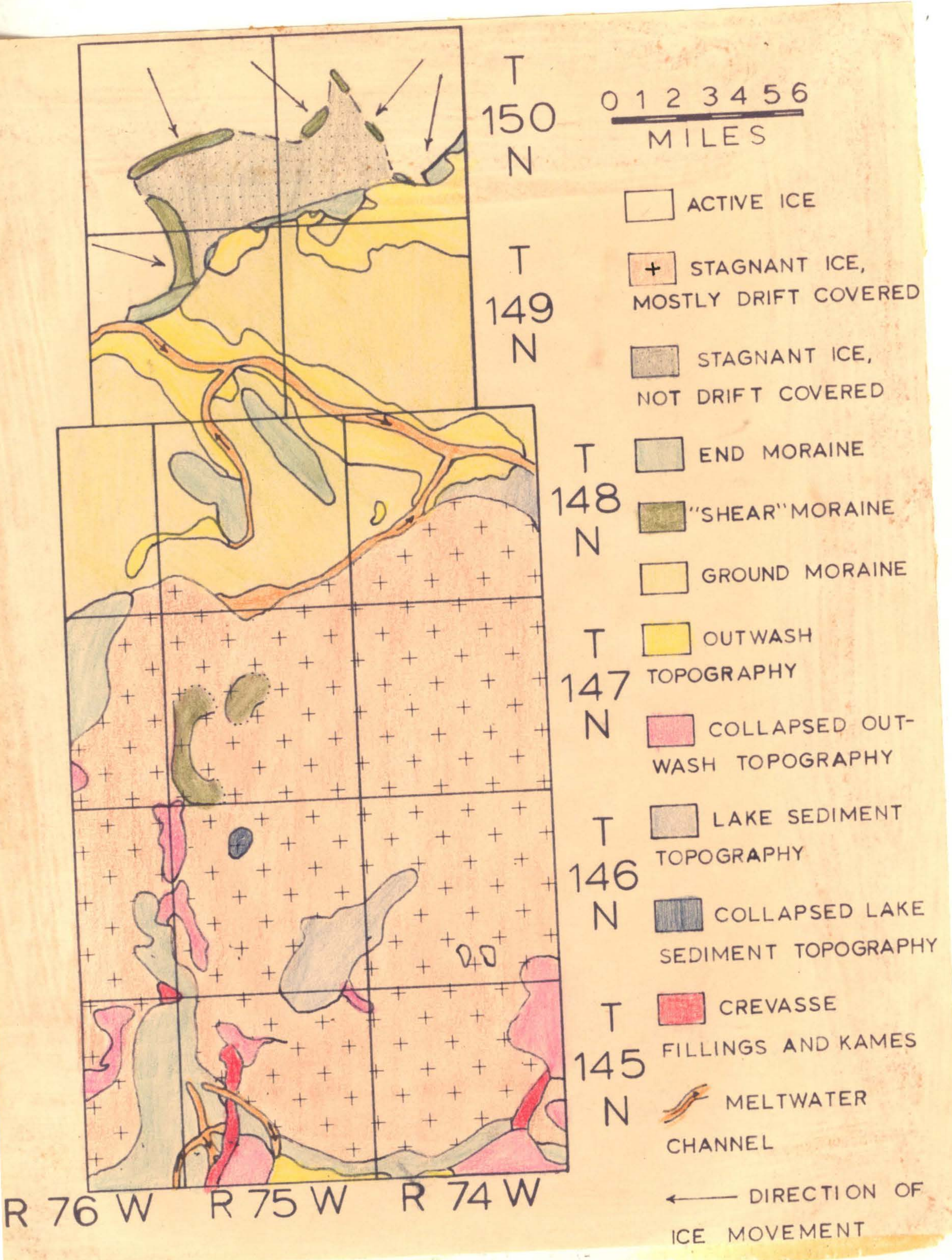


Figure 30.--Phase 7 of Pleistocene history - formation of Martin end moraine.

channel. Continued ablation of the ice sheet caused outwash to be transported south from Lake Souris resulting in the formation of extensive outwash deposits in front of the Martin end moraine and along the Sheyenne River.

Post-Wisconsinan History

Since complete ablation of the ice sheets and drainage of their meltwaters, little change has occurred in eastern Sheridan County. A very poorly integrated drainage system and low precipitation have resulted in only minor amounts of erosion. Most of the small amount of sediment that has been removed from the high areas has been immediately deposited in undrained depressions. Minor eolian silts, the sediment in some of the undrained depressions in the bed of present-day Sheyenne River are the only Post-Wisconsinan deposits in the report area (Fig. 31).

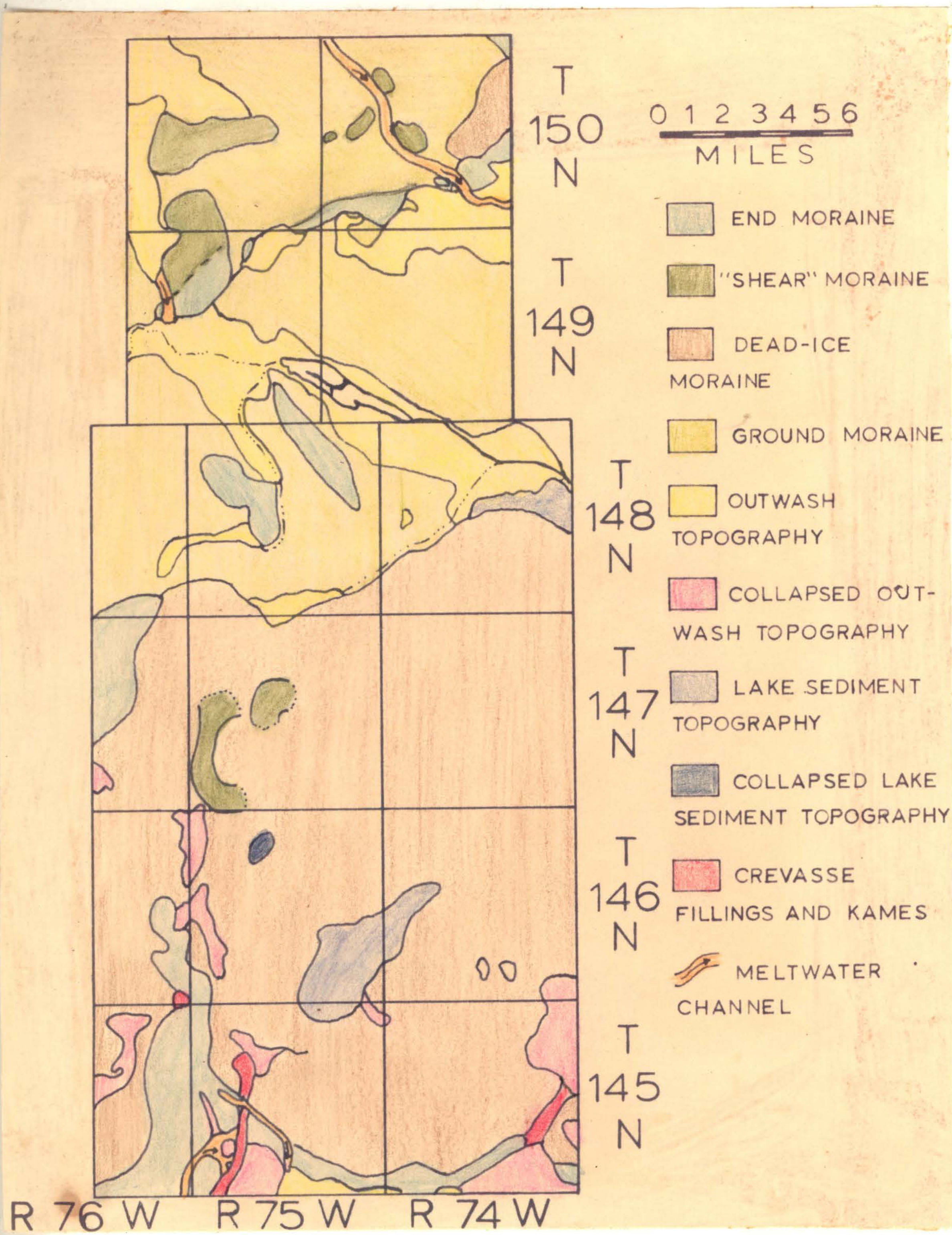


Figure 31.--Post Wisconsinan - complete ablation of the ice.

ECONOMIC GEOLOGY

AGRICULTURE

Many of the landforms mapped in eastern Sheridan County have characteristic soil types which restrict certain types of farming practices. High relief dead-ice moraine and ground moraine, and end moraine are best suited for grazing because the topography and soil type (Buse Barnes) preclude effective use of the land by cultimation. Lacustrine deposits, low relief dead-ice moraine, and ground moraine are best suited for cultivation. Outwash deposits should be cultivated or grazed with great care because of the shallow depth of the soil. In many places soils developed on outwash plains have been nearly destroyed by cultivating too deeply or by overgrazing. Where the soil cover has been lost, wind erosion becomes excessive and causes blowouts which result in the inundation of the surrounding areas by sand and silt.

Most of the larger outwash plains have considerable ground water in shallow depths and they therefore could be irrigated

SURFACE WATER

There are two primary types of surface water, that which collects in till-floored depressions and that which is found in association with sand and gravel deposits. The area covered by undrained till-floored depressions in the report area is larger, but the dimensions have not been mapped sufficiently to estimate total acreage.

The minimal permeability of the till precludes much mixing of the waters of the till-floored depressions with ground water. The lack of circulation with ground water means that the percentage of total dissolved salts remains high and is not reduced by ground water dilution. Evaporation is the only means by which water leaves the basin and the salts that are carried into the basin in solution remain in the basin to increase the salinity. The fluctuation in water content and high total dissolved salt content make the waters of till-floored depressions undesirable.

The salt content is often so high that locally white salt accumulations surround the ponds. In these extreme cases, neither plant nor animal life can survive in the pond and the waters are avoided by livestock.

Water that collects in depressions in outwash or in streams is best for livestock watering and can usually be used for human consumption. This water is a surface expression of the water table and does not have the high salt concentration that waters in the till-floored depressions have. Good sources of surface water are the Sheyenne River, Coal Mine Lake, Sheyenne Lake, Guyes Lake and Wolf Lake. North Lake and Jones Lake are typical examples of permanent till-floored lakes.

SAND AND GRAVEL

There are approximately seventy miles of outwash deposits in eastern Sheridan County. Much of this material is several tens of feet deep. At present, it is not known if the sand and gravels contain enough deleterious material to make them unfit for the use as concrete aggregate. Nevertheless, the material is still usable as fill and road base. The availability of this material is attested to by the fact that most of the unpaved roads in the area are surfaced with sand and gravel. If in the future a larger market develops for this material, it will have a greater commericial value. At present, the supply far exceeds the demand for this material and thus it has little commericial value, except when small amounts are purchased to surface section line roads. All the outwash deposits some of the crevasse fillings and some of the meltwater channels have large amounts of sand and gravel.

GROUND WATER

The major part of the ground water of eastern Sheridan County is derived from outwash deposits. The surficial deposits of outwash will in many cases yield ground water at a shallow depth. The lakes and sloughs in the outwash deposits reflect the intersection of the surface with the ground water table. In many areas buried lenses of outwash waters have a high salt content (Simpson, 1929) as well as total dissolved solids, but they may suffice for the use of livestock. Unfortunately, there is no inexpensive way of predicting the occurrence, extent or water quality of these buried sand lenses.

The most important potential sources of ground water are buried or abandoned channels, but it is not known to what extent these water sources are now being utilized in Sheridan County. One of the channels, the ancient Knife River, extends through the Missouri Coteau in central Sheridan County. Lemke (1960, p. 109) reports that a drill hole situated about eleven miles north of the Lincoln Sag in Sec. 6, T 148 N., R. 75 W. penetrated 240 feet of surficial deposits before reaching bedrock. Lemke states that this great thickness suggests that a buried valley extends northward from the Lincoln Valley Sag. The possibility of ground water in this buried channel should be investigated.

The Bently Lake-Guyes Lake Spillway, the ancient Sheyenne River channel and the channel occupied in part by Wolf Lake are all abandoned channels that may yield significant amounts of ground water.

The quality of the water is in a general way dependent on circulation of the ground water. According to Abbott and Voedisch (1938) and Simpson (1929), waters derived from undrained till-floored depressions contain as much as 6,000 ppm. total dissolved silids. These depressions act as evaporating pans, since the floors are so impermeable and there is essentially no contact or dilution of these waters by ground water. Similar conditions probably exist for waters in buried outwash lenses. In surficial outwash deposits, the waters are free to circulate and materials in solution are not appreciably concentrated by evaporation. Their waters have an average of about 500 ppm. total dissolved solids and are generally suitable for human consumption. In any case, waters which contain too much salts or dissolved solids to be used for human consumption usually can be used for stock watering or for irrigation.

SUMMARY AND CONCLUSIONS

Sheridan County has been divided into two physiographic units 1) the Missouri Coteau to the south, and 2) the Western Lake Section to the north. The Western Lake Section has been subdivided into the Martin area and the Sheyenne River area.

In eastern Sheridan County, the Missouri Coteau is covered by the Streeter drift which was probably deposited during a recessional phase of the Burnstad ice sheet found farther to the south. Dead-ice landforms, well developed end moraines and a lack of integrated drainage are characteristic of the Streeter drift.

The Grace City drift which occurs in the Sheyenne area is characterized by relatively low relief ground moraine and by a poorly integrated drainage system and is lithologically very similar to the Streeter drift. An arbitrary boundary between the two drifts, wherever the Lincoln Valley end moraine is not present, has been placed at the Missouri Coteau escarpment. The chief difference between the two drifts is the type of landform development. The Streeter drift has dead-ice features and the Grace City drift does not. The two drifts were deposited by the same ice sheet and there was little or no time break between them. The name, Grace City, should be retained until the full extent of the Grace City drift is known.

The Martin drift, which occupies all of the Martin area and a small portion of the Sheyenne area, is found in the northern quarter of the county. The Martin drift in eastern Sheridan County is characterized by high relief ground moraine and by a total lack of integrated drainage. The Martin drift is similar to the Grace City and the Streeter drifts in appearance, but it is somewhat sandier.

There is a significant time break between the deposition of the Grace City drift and the deposition of the Martin drift. The ice sheet that deposited the Grace City drift was completely ablated in the vicinity of the Martin end moraine, north of Lincoln Valley, and it had provided material for a large outwash plain to the south before the Souris Lobe advanced which is suggested by the blocks of outwash sands and gravels that were incorporated into the Martin end moraine.

At approximately the same time that the Martin end moraine was being formed a large "shear" moraine was constructed a few miles to the north. Locally, this shearing moved enough debris into and onto the ice to result in the formation of dead-ice moraine upon ablation.

The economic consequences of this study are twofold: 1) sand and gravel, and 2) ground water. A nearly unlimited amount of sand and gravel is available for use in eastern Sheridan County. Unfortunately, the general abundance of shale in the sediments restricts its use in concrete, but it could certainly be used for fill and road construction. Several potentially important ground water aquifers are also present in the report area. These are the buried channel of the pre-glacial Knife River, the abandoned channels of the Sheyenne River, the Guyes Lake-Bently Lake Spillway, the channel occupied in part of Wolf Lake, and the large outwash plains associated with end moraines. The future of this area may be dependent on the development of these aquifers. Detailed investigation of the ground water in this area is strongly recommended.

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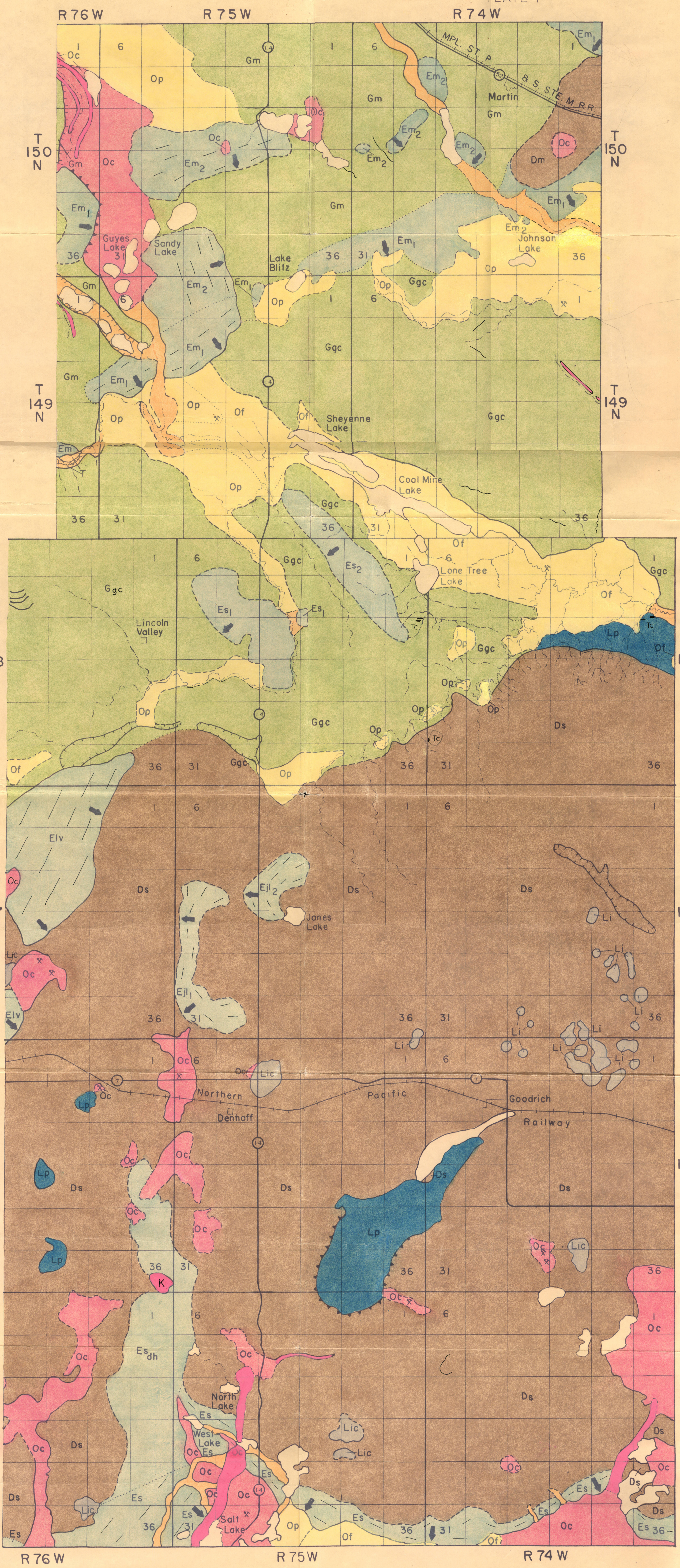
PLATE 1



GLACIAL LANDFORMS

E — END MORAINE and "SHEAR" MORAINE: Composed of till; lines represent crests of morainal ridges.

Es: STREETER end moraine: A series of linear ridges; less than 1/3 mile to 2 miles in width; relief 50 to 130 feet; lobate in form.

Es_{dh}: DENHOFF interlobate moraine: Coarse textured topography; less than 2 miles in width; relief up to 270 feet.

Ejl_1 and $_2$: JONES LAKE "shear" moraines: Two groups of linear ridges less than ½ mile to one mile in width; relief up to 80 feet.

Elv: LINCOLN VALLEY end moraine: A series of elongate linear ridges; less than ½ mile to more than 3 miles wide; relief up to 60 feet.

Es_1 and $_2$: SHEYENNE LAKE end moraines: Two morainal segments; surface without linear features; relief up to 80 feet.

Em_1: MARTIN end moraine: Irregularly shaped groups of hills; less than 2 miles in width; relief up to 175 feet; some segments without linear features.

Em_2: MARTIN "shear" moraine: A series of elongate hills, some with linear ridges; less than 2 miles in width; relief up to 60 feet.

G — GROUND MORAINE: Composed of till; relief up to 70 feet.

Ggc: GRACE CITY ground moraine: Proximal side of the Lincoln Valley end moraine; ground moraine topography with less than 30 feet of relief; covered locally by a thin layer of sandy ablation or water washed till.

Gm: MARTIN ground moraine: Proximal side of the Martin end moraine; ground moraine topography with up to 70 feet of relief; ablation till, water washed till and eolian sediments are present locally.

D — DEAD-ICE MORAINE: Composed of till and smaller amounts of stratified drift; non-linear knob and kettle topography with numerous lakes and sloughs; non-integrated drainage; relief up to 100 feet. Ds: Streeter; Dm: Martin moraine.

Oc — COLLAPSED OUTWASH TOPOGRAPHY: Composed of stratified sand and gravel; stratification usually disturbed; disintegration usually present; up to 70 feet of local relief.

Lic — COLLAPSED-LAKE-PLAIN TOPOGRAPHY: Composed of lacustrine silts and clays; medium local relief; formerly ice walled.

Li — ICE-WALLED-LAKE PLAIN: Composed of lacustrine silts and clays; flat; surrounded by outward facing ice-contact slopes.

K — KAMES: Prominent hills composed of outwash sand and gravel.

ESKERS and CREVASSE FILLINGS: Straight to sinuous ridges composed of outwash sand and gravel and smaller amounts of till.

DISINTEGRATION RIDGES and CREVASSE FILLINGS: Very narrow elongate ridges composed of outwash sand and gravel and till; straight to sinuous in form; relief generally less than 20 feet.

REMNANT ICE-WALLED CHANNELS: Linear to sinuous depressions floored with tillor outwash sand and gravel; channel walls are ice-contact slopes.

KETTLE CHAINS: A linear series of kettles floored with till; walls are ice-contact slopes.

ICE-CONTACT SLOPES: A steep slope formed in contact with stagnant ice; only the most prominent shown; arrowheads point downslope.

PROGLACIAL LANDFORMS

Of — OUTWASH PLAIN: Composed of sand and gravel; flat to gently undulating topography with less than 15 feet of relief.

Op — PITTED OUTWASH PLAIN: Similar to outwash plain but pitted with kettles; has greater than 5 percent and less than 50 percent of its area collapsed or pitted with kettles; relief up to 30 feet.

Lp — LAKE PLAIN: Composed of laminated silt and clay; flat.

MELTWATER CHANNELS: Channels formed by glacial meltwaters; underlain by outwash sand and gravel, till, lacustrine clay and silt, or nonglacial alluvium.

T — MELTWATER CHANNEL TERRACES: Terraces formed in meltwater channels; composed of sand and gravel.

NONGLACIAL LANDFORMS

BEDROCK OUTCROP: Tc: Tertiary Cannonball Formation.

PERMANENT LAKES, EPHEMERAL LAKES, and LARGE SLOUGHS.

PERMANENT STREAMS.

EPHEMERAL STREAMS.

7 14 — STATE HIGHWAYS.

52 — FEDERAL HIGHWAY.

SAND AND GRAVEL PIT.

CONTACTS:

- Accuracy generally greater than 0.1 mile.
- Accuracy may be less than 0.1 mile.
- Accuracy may be less than 0.3 mile.

Arrows indicate position and direction of ice movement at the time of end moraine deposition.

N

GLACIAL GEOLOGY

EASTERN SHERIDAN COUNTY

NORTH DAKOTA

SCALE

1 0 1 2 3 4 5 6

MILES