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Glacial geology of northern Logan County, south-central North Dakota

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GLACIAL GEOLOGY OF NORTHERN LOGAN COUNTY, SOUTH-CENTRAL NORTH DAKOTA

by

Lee Clayton

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1962

This thesis submitted by Lee Clayton 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.

Wilson M. Laird
Chairman

F. D. Holland Jr.

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Dean of the Graduate School

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GLACIAL GEOLOGY OF NORTHERN LOGAN COUNTY, SOUTH-CENTRAL NORTH DAKOTA

Lee Clayton

ABSTRACT

Northern Logan County, in south-central North Dakota, is included in two physiographic divisions: the southwest fifth is part of the glaciated Missouri Plateau that has integrated drainage and thin drift, and the rest is part of the Missouri Coteau, which has thick drift and nonintegrated drainage. Logan County is underlain by the Cretaceous Pierre Shale, undifferentiated Cretaceous sand, sandstone, and mudstone, and by three surface drifts, the Napoleon (lower part of the Wisconsin Stage?), the Long Lake, and the Burnstad (upper part of the Wisconsin Stage) Drifts.

Landforms of the area southwest of the Coteau include ground moraine, outwash plains, outwash topography of high relief, small kames, meltwater channels, and glacial Lake Napoleon strandlines and clay plain. Landforms in the Missouri Coteau part of northern Logan County are dead-ice moraine, Long Lake, Burnstad, and Streeter end moraines, outwash plains, ice-walled lake plains, collapsed outwash topography, disintegration ridges, and several other minor features.

The thin glacier that deposited the Burnstad Drift stagnated in a zone that was at least 6 miles and possibly over 20 miles wide. Radiocarbon dates indicate that it might have taken over 2000 years to melt. The presence of numerous fossil mollusk shells in ice-contact lake sediments indicates that superglacial till was present in large enough amounts to insulate the lakes from the ice and was probably abundant enough to be an important factor in the formation of dead-ice moraine.

INTRODUCTION

Northern Logan County, which is 588 square miles in area, lies within Tps. 136, 135, and the northern third of 134 N., Rs. 67-73 W., in south-central North Dakota (fig. 1). The area is 34 miles north of the South Dakota border and 30 miles east of the Missouri River. Two towns, Napoleon and Gackle, are present in northern Logan County. Napoleon, in the western part of the area, is the county seat and has a population of 978 (1960 census), and Gackle, in the northeastern part of the area, has a population of 523. All-weather roads cross much of the area, and about two-thirds of the section lines have roads or trails that are passable by car in dry weather.

In this report the surface bedrock geology is briefly summarized, and the glacial geology is described in detail. Special emphasis has been placed on the problem of glacial stagnation in northern Logan County.

Field methods

Field work was done during 2 months of the summer of 1960. Field information was plotted on the 1958 General Highway Map of Logan County, scale 1:63,360, prepared by the North Dakota Department of State Highways. Geologic contacts were plotted in the field on air photo stereopairs, scale 1:63,360, supplied by the U. S. Geological Survey. The only topographic map of the area is the U. S. Army Map Service Jamestown quadrangle (scale 1:250,000; contour interval 100 feet). Unpublished soil maps of about one-third of the area have

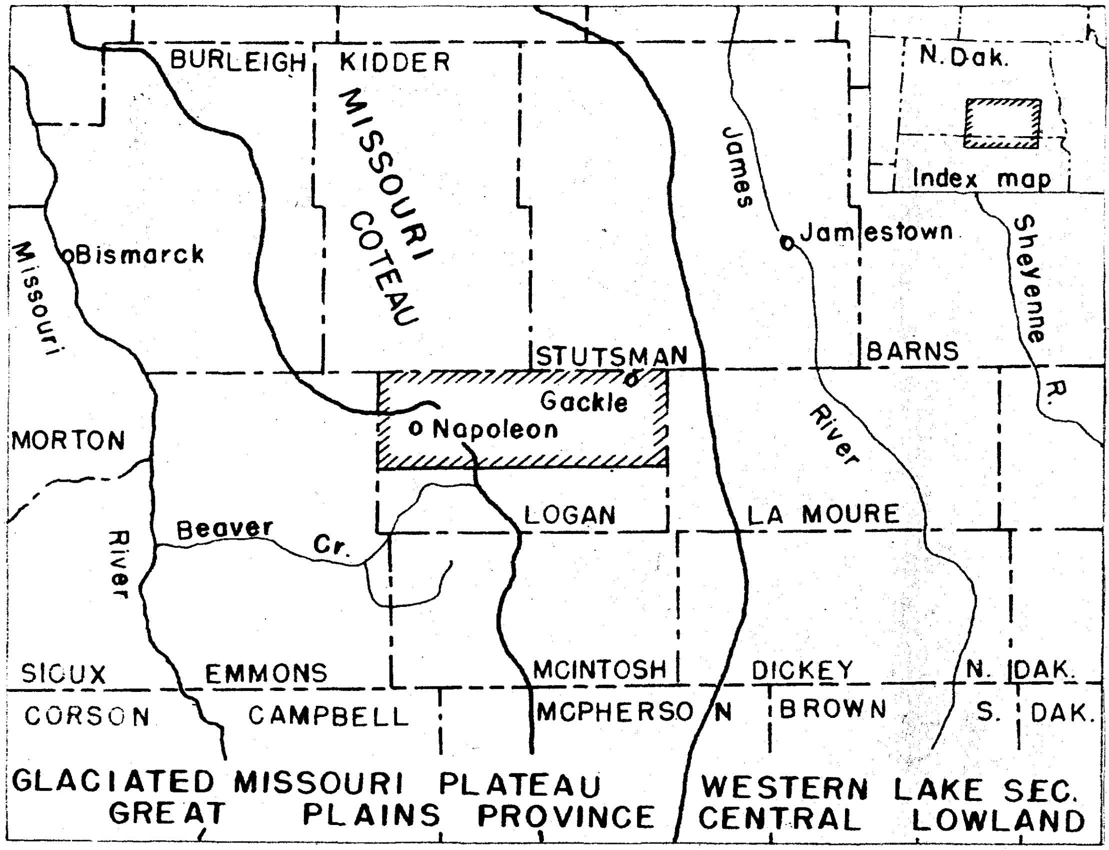


FIGURE 1.--Location of northern Logan County and physiographic units of the surrounding area. From Lemke and Colton, 1958, fig. 1.

been completed by the U. S. Department of Agriculture Soil Conservation Service. They were used to refine some of the geologic contacts.

This study was considered to be a detailed reconnaissance. Every road in the northern part of the county, except in the area mapped by Paulson (1952), was traversed by car at least once, and some less accessible areas were covered on foot. A less detailed reconnaissance was made of the areas immediately adjacent to northern Logan County. The part of northern Logan County that has been described by Paulson (1952) was also studied in less detail. Most lithologic information was obtained from road cuts and shallow holes dug with shovel and hand auger. Colors of sediments were determined by comparison with the Rock Color Chart (Goddard and others, 1948). Topographic profiles were constructed with the aid of a Paulin altimeter.

Acknowledgments

The field work for this study was supported mainly by a National Science Foundation Cooperative Graduate Fellowship. I wish to thank the many people who have helped me with this study. Dr. Wilson M. Laird, State Geologist and Chairman of the University of North Dakota Department of Geology, provided field equipment, gave help in the field, and critically read the manuscript of this report. John W. Bonneville, fellow graduate student who mapped southern Logan County, contributed many discussions of the problems encountered in the field. Dr. Harold A. Winters, of Northern Illinois University and part-time geologist for the North Dakota Geological Survey, gave numerous helpful suggestions on the problems of field mapping. John P. Knecht of the U. S. Department

of Agriculture Soil Conservation Service in Napoleon permitted the use of unpublished soil maps. Dr. F. D. Holland, Jr., Dr. Mark Rich, and Dr. John R. Reid, of the University of North Dakota, made many helpful suggestions and critically read the manuscript of this report. To these people I give thanks for help they gave me with this study.

Previous published work

Regional studies

Three regional studies are frequently cited in this report. Those of Todd (1896) and Lemke and Colton (1958) contain some detailed information on Logan County. The one by Flint (1955) deals with an area entirely south of Logan County.

Todd's (1896) paper gives an outline of the glacial geology of the Missouri Coteau from about 25 miles north of Logan County to southern South Dakota. His study was the first to give a detailed description of some of the glacial landforms of Logan County. Todd described the "Long Lake loop" and "Blue Lake loop" (Burnstad end moraine) of the "First, Outer, or Altamont moraine," the "Blue Lake loop" (Streeter end moraine) of the "Second or Gary moraine," and the moraine of high relief behind these end moraines. A summary of his interpretation of the glacial geology of south-central North Dakota is shown in figure 2.

The most comprehensive summary of North Dakota Pleistocene geology is the work of Lemke and Colton (1958). It is the result of (1) an analysis of previous studies by other workers in North Dakota and adjacent areas, (2) detailed and reconnaissance mapping

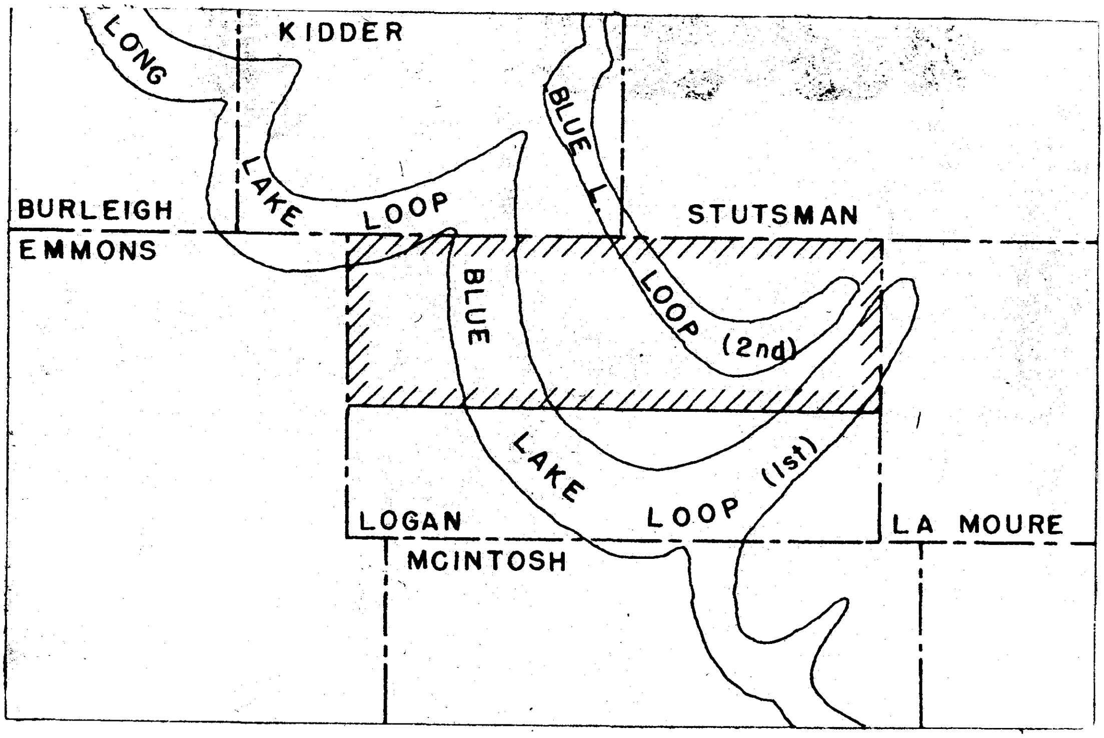


FIGURE 2.--Todd's (1896) interpretation of the glacial geology of south-central North Dakota.

of part of the state by Lemke and Colton, (3) an analysis of radiocarbon dates, and (4) a study of large-scale air photo stereopairs of the entire glaciated part of the state. Their interpretation of the state's glacial geology is shown on the unpublished Glacial Map of North Dakota (Colton and Lemke, 1957). They were the first to map the moraine with high relief and no lineations on the Missouri Coteau as dead-ice moraine or stagnation moraine, rather than end moraine, as it had generally been called. Lemke and Colton's interpretation of the Pleistocene geology of south-central North Dakota is shown in figure 3.

The report by Flint (1955) on the Pleistocene geology of eastern South Dakota contains no reference to Logan County. Many of the problems discussed, however, are similar to those encountered in Logan County. Flint's report is one of the most useful guides for glacial geologists working in South Dakota and adjacent areas.

Local studies

The geology of much of the area adjoining the northern part of Logan County has been mapped at a moderately large scale. The ground water geology and glacial geology of the Edgeley and La Moure quadrangles, immediately east of Logan County, were mapped by Hard (1929). Much of the dead-ice moraine of the Coteau was mapped by him as "terminal moraine." The geology of Emmons County, to the west of Logan County, was described by Fisher (1952). He briefly discussed the glacial geology and mapped the glacial deposits of that county. Most of the large areas of outwash that he mapped along the Logan County border are nonexistent.

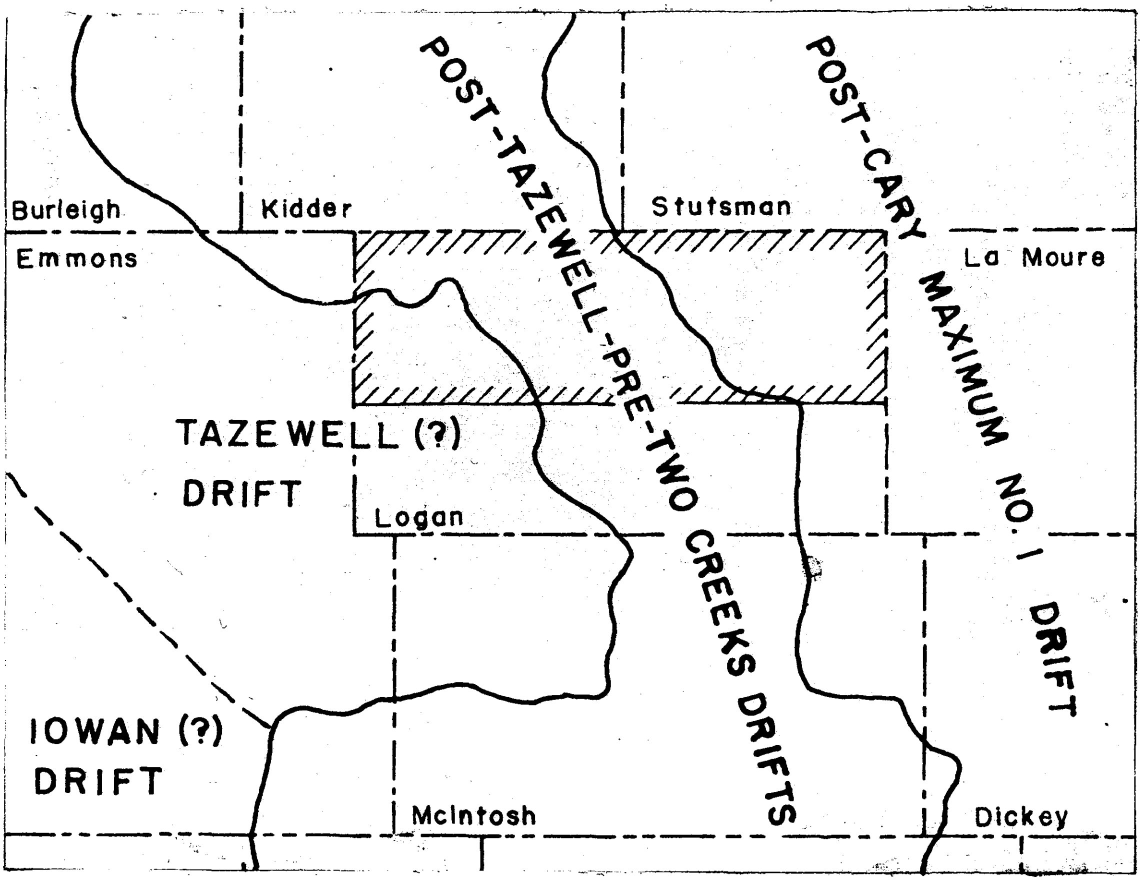


FIGURE 3.--Lemke and Colton's (1958, fig. 4) interpretation of the Pleistocene geology of south-central North Dakota.

The glacial geology of Kidder County, north of western Logan County, was described by Rau and others (in press). Dead-ice moraine was recognized but was not described in any detail. The glacial geology of southern Logan County was described by Bonneville (1961a and 1961b). He discussed the problem of glacial stagnation and described some pre-Wisconsin (?) glacial deposits.

The only part of northern Logan County that has previously received detailed geologic study is the southern part of the Streeter area in Tps. 135-136 N., Rs. 68-70 W. The ground water geology and glacial geology of this area of 120 square miles was mapped by Paulson (1952). In the present report, several changes have been made in Paulson's interpretations, the most important of which are the altering of his unridged "end moraine" to dead-ice moraine and changing his "ground moraine" to ice-contact lake sediment topography.

Glacial stagnation studies

The most comprehensive discussion of the terminology and origin of till landforms resulting from glacial stagnation in central North America is that of Gravenor and Kupsch (1959). Many of the features that they observed in Alberta and Saskatchewan are similar to those found on the Missouri Coteau in south-central North Dakota. Much of their terminology, however, has not gained general acceptance (for instance, see Bayrock and Gravenor, 1961).

The publications of Christiansen (1956, 1959, 1960, and 1961) were found to be some of the most useful guides to practical field glacial geology. Many of the landforms and stratigraphic problems that Christiansen encountered in Saskatchewan are similar to those dealt with in Logan County.

Two glacial geologists who have discussed at length the subglacial origin of stagnation landforms are Hoppe (1952), in Sweden, and Stalker (1960a and 1960b), in Alberta. Some of their ideas will be discussed in a later section of this report.

Climate

Logan County has a dry subhumid first (cool) mesothermal climate (Thornthwaite, 1948, pl. 1). From 1900 to 1940 (U. S. Department of Agriculture, 1941) precipitation at Napoleon averaged 17 inches a year; much of it fell as rain during the spring and summer. Temperatures varied from -48°F to 115° and averaged 7° during January and 70° during July. Prevailing winter winds are from the northwest.

Land use and vegetation

Most of the county is farmland. About one-half of the dry land is cultivated and the other half is either grazed or used as hay land. About one-tenth of northern Logan County is covered by small lakes and sloughs, many of which are grazed in dry years. Native vegetation, other than that in marshes, is dominantly mixed prairie grasses. It is preserved along many unimproved section-line roads and on much of the grazing and hay land. Wolfberry (*Symphoricarpos occidentalis*) is the dominant low shrub on permanent pasture land. Logan County has but few trees. Those present occur on steep north-facing slopes such as the gullys in the kame terrace on the north side of the Streeter interlobe moraine and along some lakes with stable water levels; a few trees have been planted in towns and around farm buildings.

Soil

The county lies within the Chestnut and Chernozem soil zones. The Chernozem soils in the east part of the county are dark and usually have only the upper few inches leached of carbonates. The Chestnut soils in the western part of the county are browner and in a few places have a carbonate leached zone up to 3 feet deep.

Surface water

The area southwest of the Missouri Coteau (fig. 1) in northern Logan County has a large number of ephemeral streams but has no perennial streams. The only undrained depressions in this area are the large ephemeral lakes west of Napoleon and a few small sloughs, especially in the southwest corner of the area (pl. 1). The lakes west of Napoleon are in the bottom of a northward sloping valley that was dammed by glacial drift during the last part of the Wisconsin Age. Shore processes have greatly altered the shape of these lakes. Spits, cuspate bars, and baymouth bars have separated the original lake into several smaller basins. Most of the sloughs (intermittent ponds that may be entirely or in part covered with marsh) in the area southwest of the Coteau are confined to the uneroded ground moraine of broad drainage divide areas.

The Missouri Coteau has almost a complete lack of streams but has a large number of small lakes and sloughs. Lakes and sloughs are most abundant in dead-ice moraine, where they occupy kettles and other depressions resulting from the irregular deposition of drift from the melting stagnant glacial ice. In parts of the dead-ice moraine there may be as many as 75 small lakes and sloughs in a square mile. Lakes in depressions in collapsed outwash sand and gravel are usually the surface expression of a larger ground water reservoir. As a result of the smaller amount of evaporation at the surface of the underground part of the reservoir, these lakes have fresh water and have a stable water level; large numbers of fish, pelicans, ducks, and gulls frequently occupy these lakes, and trees and shrubs grow along many of their margins. In contrast, lakes floored entirely by impermeable till or lake clay usually have a high salt concentration and a rapidly fluctuating water level, and many are ephemeral; fewer fish and water birds live in these lakes.

PHYSIOGRAPHIC UNITS AND LANDFORMS

Logan County is part of the Glaciated Missouri Plateau section of the Great Plains province of the Interior Plains major division (Fenneman, 1946). The Glaciated Missouri Plateau in North Dakota has generally been divided (Fenneman, 1931, p. 73-75; Howard, 1960, p. 9) into two units: the Missouri Coteau, on the east side of the Missouri River, and an unnamed unit west of the Missouri River. Recently, however, Lemke and Colton (1958, fig. 1) have relocated the western boundary of the Missouri Coteau at the contact between integrated and nonintegrated drainage. This restricted Missouri Coteau (fig. 1) is a more natural physiographic unit because the area of integrated drainage immediately east of the Missouri Coteau (formerly included in the Coteau) is topographically and geologically more similar to the area west of the river. (See table 1.)

In the discussions that follow, landform terminology has been separated from stratigraphic terminology. Mingling of landform, lithologic, time-stratigraphic, and lithostratigraphic nomenclatures have probably contributed greatly to the state of confusion that now exists in Mid-West glacial and Pleistocene geology. For this reason an attempt has been made to keep these terminologies entirely independent of each other.

Table 1.--Characteristics of the three districts of the Glaciated Missouri Plateau in south-central North Dakota.

Physiographic unit Characteristic	Unnamed district west of Missouri River	Unnamed district between Missouri Coteau and Missouri River	Missouri Coteau district
Drainage integration	Complete	Nearly complete	Lacking
Topography	Rolling and dissected	Rolling and dissected	Hilly with many undrained depressions
Surface drift age	Early Wisconsin(??)	Early Wisconsin(?)	Late Wisconsin
Drift thickness	Non-existent or very thin	Thin or non-existent	Thick

Area southwest of Missouri Coteau

The area within Logan County southwest of the Missouri Coteau is characterized by an integrated drainage system and thin drift. The individual landforms of this area consist of ground moraine, small kames and eskers, outwash topography with low to high relief, strand lines, lake plain, and meltwater channels.

Glacial landforms

Moraine.--Moraine is a landform or geomorphic term applied to areas that are underlain mainly by till and have a topography that, in detail, is primarily the result of deposition from glacial ice (see Flint, 1955, p. 111-112; 1957, p. 130-131). Of the three main types of moraine--ground moraine, dead-ice moraine, and end moraine--only ground moraine exists in the area southwest of the Coteau.

Ground moraine.--Ground moraine is relatively low-relief, undulating (swell and swale) moraine that lacks transverse linear trends and has a topography that is dominantly the result of subglacial lodgement of till on the ground (Flint, 1955, p. 111; 1957, p. 131). It may also include thin cover of ablation till. The undulating ground moraine topography in the area southwest of the Coteau is underlain by a thin blanket of lower Wisconsin (?) till and is superimposed on a stream-eroded bedrock topography with a local relief of up to 100 feet. In most places bedrock outcrops are few and the till averages 10 or more feet thick, but near the western border of the county, bedrock outcrops are numerous and the till is very thin. Here the till only slightly modifies the pre-existing bedrock topography;

it therefore may not be true ground moraine.

Most of the ground moraine has well-integrated drainage. The integration is, however, no indication of any great amount of postglacial stream erosion or any great length of time since the drift was deposited. This is best explained by a comparison of "external erosion" and "internal erosion"--concepts that apparently have not previously been emphasized. "External erosion" can be defined as headward extension into an area of the headwaters of an established drainage system. It would remove the till from the lower areas first, leaving the till on higher divide areas uneroded. External erosion in southern Logan County (Bonneville, 1961b) has completely removed the till from an area a few miles wide on either side of Beaver Creek. The escarpment of headward erosion is about a mile south of the area of this report. External erosion has been inactive in most parts of the ground moraine southwest of the Coteau in northern Logan County; till in the lower parts of main valleys is as thick as, or thicker than, till along the better developed tributaries.

"Internal erosion," which can be defined as erosion that was initiated within an area rather than by the headward extension into the area of headwaters of another drainage system, probably was responsible for integrating the drainage of the ground moraine southwest of the Coteau in northern Logan County. In this area, in contrast to the Beaver Creek area in southern Logan County, drainage was integrated after glaciation by quick re-establishment of the preglacial drainage without the aid of external erosion. Till had merely mantled the preglacial stream-eroded topography; it did not obliterate it.

Undrained depressions on this thin till veneer were originally shallow and were easily filled with rain water, spring runoff, and glacial meltwater. The depressions overflowed, an outlet was cut, the water was concentrated in the valleys, and the preglacial drainage system was quickly re-established.

If, however, the drfit had been thicker, the undrained depressions had been deeper, and the preglacial drainage system had been completely obliterated, as on the Coteau, the water would have flowed only a short distance into the depressions and stayed there. If the amount of precipitation were not excessive this type of topography would require external erosion from an outside drainage system to establish an integrated drainage pattern. Thus, the difference in drainage integration between the Coteau and the area southwest of the Coteau is a function, not only of time, but also of original drift thickness and the degree of obliteration of the preglacial drainage system.

Small kames.--Small kames are common on the ground moraine on high drainage divide areas southeast of Napoleon. Most are 100 to 300 feet in diameter and 10 to 20 feet high. They are noticeable only because their relatively steep slopes contrast with the gently undulating ground moraine. The kames are composed of coarse gravel and smaller amounts of sand, silt, and clay. They are similar to the "Iowan" and "Tazewell" kames in South Dakota described by Flint (1955, p. 67).

Eskers.--Two small eskers are present in the southwest corner of the area mapped. They are distinct, slightly sinuous ridges that are 1500 and 1000 feet long and are composed of coarse gravel that is over 10 feet thick.

Proglacial landforms

Outwash topography.--Three types of proglacial outwash topography are present in the vicinity of Napoleon. They are outwash topography of high relief, outwash plain of high elevation, and outwash plain of low elevation.

Outwash topography of high relief.--The outwash topography of high relief north and southwest of Napoleon is a series of gently rolling hills and as great as 40 feet of local relief. These are hills composed of lower Wisconsin (?) sand and gravel. Except for its being restricted to the lower part of the northward sloping preglacial valley, the outwash has little apparent relation to the surrounding topography.

The high relief of the outwash topography could have originated in one or more of at least five different ways: glacial erosion, meltwater erosion, postglacial stream erosion, collapse from stagnant ice, or deposition controlled by a fluctuating baselevel. Glacial erosion was probably not the cause of the high relief, because no distortion of the outwash bedding and no till on top of the outwash were observed. Nor is it likely that meltwater or postglacial stream erosion was a major cause of the relief, because a definite system of meltwater or postglacial stream channels is absent.

Collapse of outwash that was deposited against or on top of melting stagnant ice might have been a partial cause of the high relief. There are, however, no definite kettles in the area. Two possible ice-contact faces are the steep west shore of the lake southwest of Napoleon and the irregular, northward-facing escarpment 1 mile north of Napoleon. A fifth explanation of the origin of the high relief is fluctuation of the local baselevel of outwash deposition. As the terminus of the early Wisconsin (?) glacier retreated northward down the valley, several different outlets on the east or west side of the lake may have been formed, causing the fluctuation of the lake surface, the local baselevel. No evidence was observed, however, that indicates this is the correct explanation; multiple outlets or levels of deposition are absent. A combination of the above suggested causes may have been responsible for the origin of the outwash of high relief in the vicinity of Napoleon.

Elevated outwash plain.--The elevated outwash plain northwest of Napoleon apparently was deposited when the late Wisconsin glacier that formed the Long Lake moraine again dammed up a lake in the valley west of Napoleon. The outwash plain has several feet of local relief and is bounded on the south and east by an outward-facing, escarpment that is 30 to 50 feet high. This escarpment may be a foreset delta face that formed before the lake was drained by a meltwater channel to the west.

Outwash plain of low elevation.--The outwash plain north of Napoleon has only a few feet of local relief and is composed of upper Wisconsin outwash that was deposited by meltwater from the southwest-sloping channel through the Burnstad end moraine. The water table is near the surface under most of the plain.

The flat outwash plain east of Napoleon is underlain by well sorted sand and gravel. The slope of the plain increases up to the Burnstad end moraine where the plain becomes a series of coalesced gravel fans with an east-facing ice-contact face at the outer edge of the moraine.

Strand lines of glacial Lake Napoleon.--The name "Glacial Lake Napoleon" is herein applied to the lake that was 10 miles long and formed when the north-sloping valley west of Napoleon was dammed by glacial ice. This occurred at least twice: once during the early Wisconsin (?) advance that formed the ground moraine southwest of the Coteau and once during the late Wisconsin advance that formed the Long Lake moraine. The position of the highest strand line at about the 2000-foot contour was governed by the elevation of the lowest outlet to the south. The strand line is a vague escarpment marked by many small bodies of outwash (not shown on plate 1 because they have no definite topographic expression). A pit in one of these bodies of outwash in the southwest corner of sec. 32, T. 132 N., R. 72 W., exposes 8 feet of sand and gravel with steep cross-beds that are 2 feet high. Within the cross-bedded gravel are irregular masses and lenses of clay and peaty material that were probably derived from a short distance away. These gravel deposits may be small deltas formed of outwash from near-by stagnant ice on divide areas on either side of the valley. Several more obscure strandlines may exist below the 2000 foot contour.

Glacial Lake Napoleon plain.--The flat lake plain south of Napoleon is underlain by clay that was probably deposited when the western outlet of Lake Napoleon was blocked for the last time, that is, during the time that the Long Lake moraine was formed. The lake plain is about 20 feet above the present high-water level. Southwest of Napoleon the lake plain is covered by younger outwash from the east.

__Meltwater channels.__--Most of the meltwater channels along the west side of the Burnstad moraine are small U-shaped or flat-bottomed channels cut in till or outwash and floored with outwash or nonglacial alluvium. The channel northwest of Napoleon, however, is cut 50 feet through Fox hills sandstone, and has a flat bottom that is covered with lake clay.

Several short meltwater channels southeast of Napoleon cross the tops of drainage divides. The meltwater channel in the northeast corner of T. 134 N., R. 72 W., extends for about 4 miles along the top of a drainage divide. These channels may have been formed when the divides were exposed by downmelting stagnant glacial ice.

NW-SE Lineations

Northwest-southeast trending drainage lineation is visible on air photos of the ground moraine southeast of Napoleon. The lineation is not noticeable on the ground. It is unknown whether the lineations originate in the drift or the underlying bedrock. If in the drift, they could be glacial flow or end moraine lineations. If they are in the bedrock, on the other hand, they may be similar to the northeast-southwest trending lineations in Emmons County that Fisher (1952, p. 14) described as Fox Hills "sandbar" features.

Bedrock topography

The bedrock topography of the area southwest of the Coteau is nearly the same as the surface topography. Only in the bottom of the valley west of Napoleon and the bottom of the valley southeast of Napoleon is the drift thick enough to modify greatly the bedrock topography.

Missouri Coteau

The Missouri Coteau part of Logan County is characterized by a nonintegrated drainage system, large areas of dead-ice moraine, and thick drift of the upper part of the Wisconsin Stage. Also present are end moraines, collapsed outwash topography, ice-contact lake plains, outwash plains, and several other smaller features.

Glacial landforms

Moraine

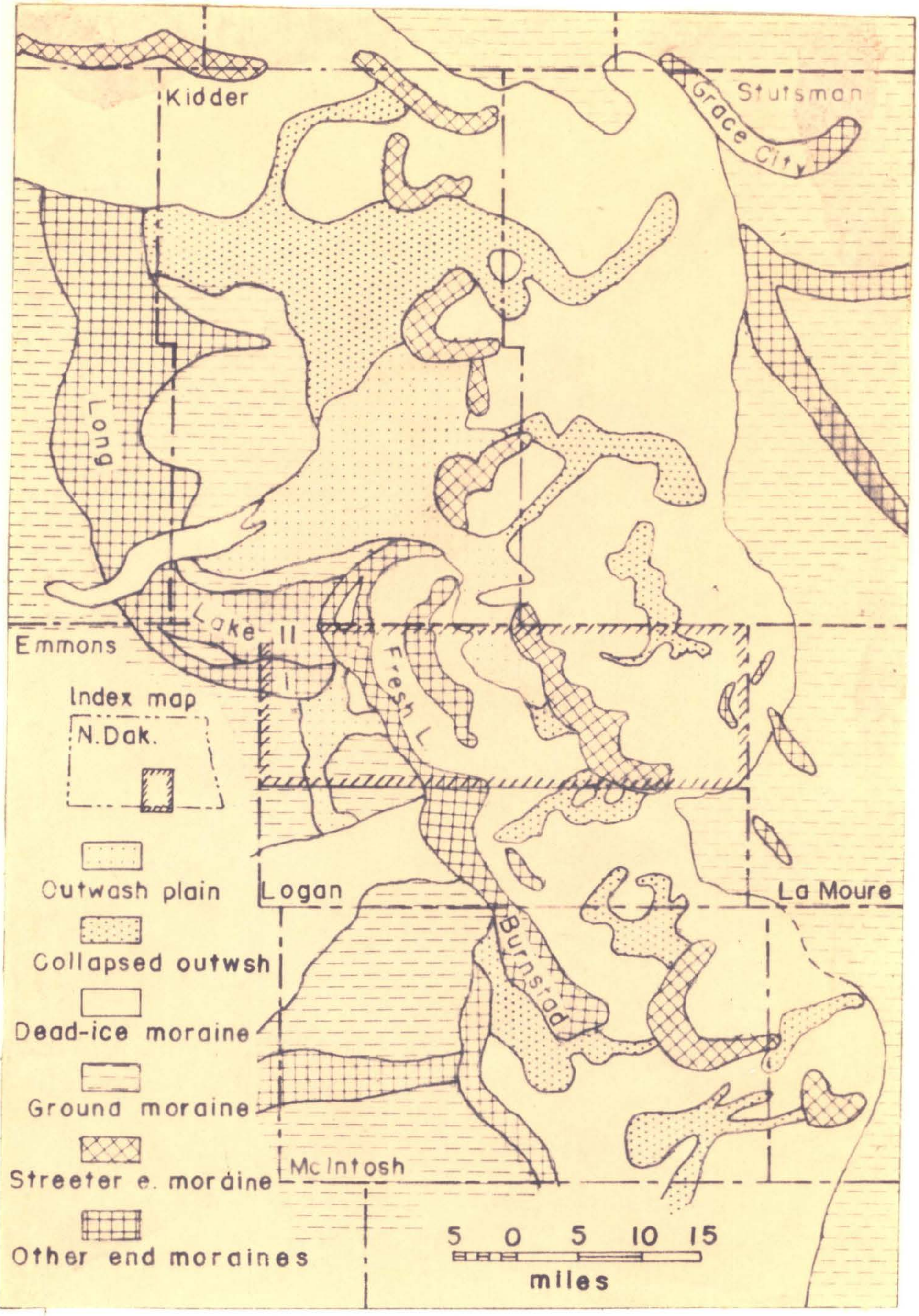
Three types of moraine were mapped in the Missouri Coteau part of northern Logan County: end moraine, pitted ground moraine, and dead-ice moraine.

End moraine.--The topography of end moraine is primarily the result of glacial deposition or shove at the margin of an active glacier. The most important criterion for recognition of its origin at an active glacier margin is linearity--either overall linearity of the end moraine or small-scale linearity of depressions, hills, and ridges within the end moraine.

There are several types of end moraine topography in northern Logan County. They range from rolling hills of the Long Lake moraine to the knobs of the Burnstad and Fresh Lake moraines to the ridges of the Streeter moraine.

Long Lake moraine.--The Long Lake end moraine, in the northwest corner of Logan County, was named by Todd in 1896 (p. 13). He applied the name "Long Lake loop of the First, Outer, or Altamont moraine" to two broad loops in Kidder, Burleigh, Emmons, and Logan Counties (fig. 4). The southern loop is breached in Burleigh and Kidder Counties by Long Lake. In Emmons and Logan Counties the southern loop is composed of two separate, though probably closely related, end moraines; they are herein referred to as Long Lake I moraine and Long Lake II moraine.

Long Lake I end moraine, the older and most southern of the two, is topographically similar to the ground moraine to the south. It has moderate to high local relief (as great as 50 feet) that may in part be a reflection of preglacial topography. Long Lake I moraine has gentle slopes and low topographic density (small number of depressions or hills in a given area). In contrast to the ground moraine to the south, it has numerous small undrained depressions. To the west, in Emmons County, it has a more typically ridged and hummocky end moraine topography. If the segment of Long Lake I end moraine in Logan County had been considered separately from the rest of the moraine, it would probably have been called ground moraine. But because it is part of a larger band of moraine that has conspicuous small-scale and over-all lineation, it has been mapped as end moraine.



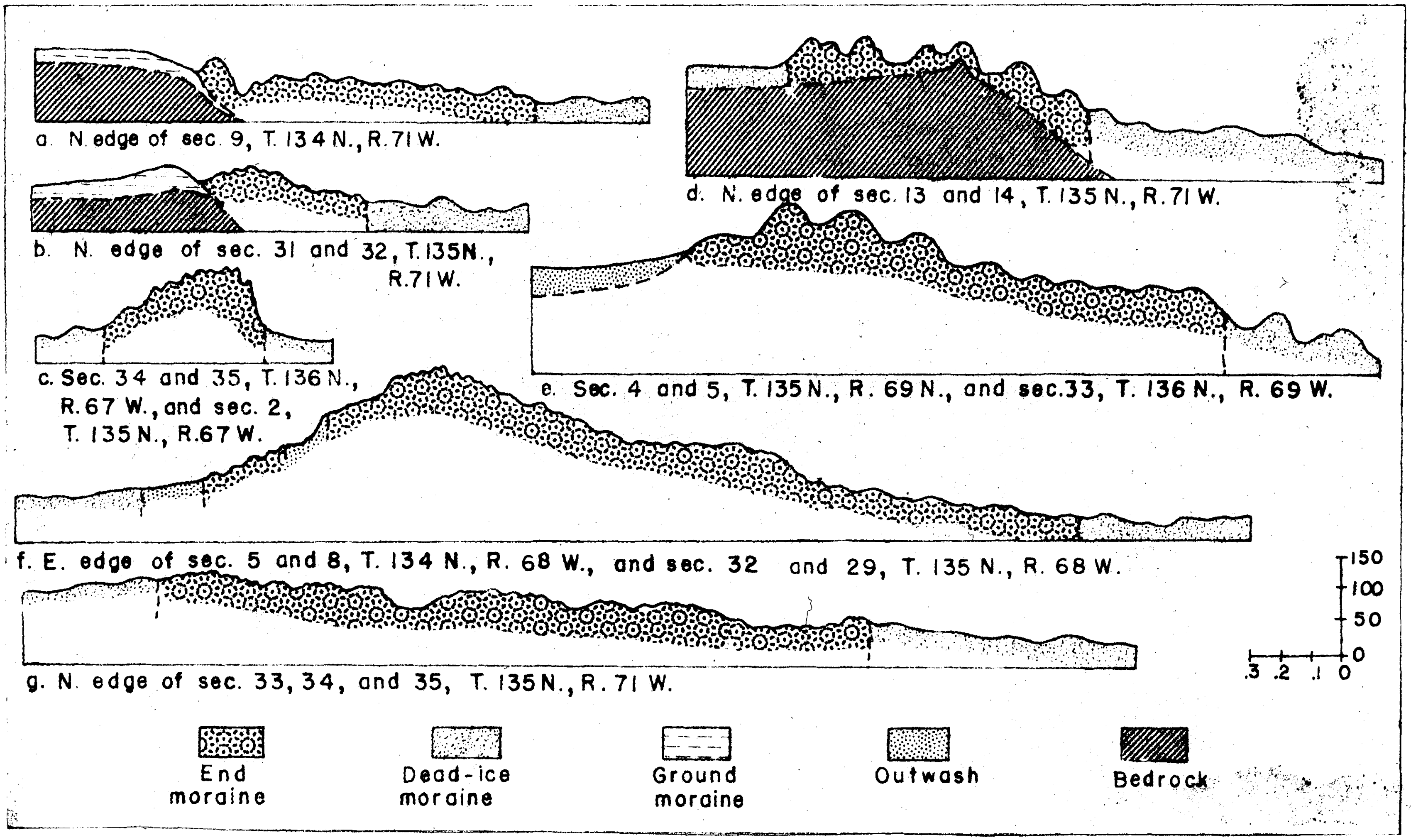
URE 4.--Regional landform map. In part from Colton and Lemke (1957), Flint (1955, pl. 1), Winters and Huxel (in preparation), and Bonneville (1961b, pl. 1).

Long Lake II end moraine has steeper slopes and a higher topographic density than Long Lake I moraine. West of Logan County and in the east part of T. 136 N., R. 73 W., it has conspicuous lineations consisting of low arcuate to slightly sinuous parallel ridges.

The Long Lake end moraine has previously been correlated with the Burnstad end moraine. Evidence that the Burnstad moraine is not equivalent to, but instead overlaps, the Long Lake moraine is presented in the next section.

Burnstad moraine.--The Burnstad end moraine, in western Logan County, was first recognized by Todd (1896, p. 13). He called it the "Blue Lake loop of the First, Outer, or Altamont moraine." The name "Burnstad," which was given to the moraine by Lemke and Colton (1958, p. 47-49) for the town of Burnstad in southern Logan County, is used in this report rather than "Blue Lake" because "Blue Lake" was applied by Todd (1896, p. 16 and 34) to both the Burnstad and Streeter moraines. There is only a slight possibility that it correlates with the Altamont moraine in eastern South Dakota.

The Burnstad moraine typically has a very knobby topography (fig. 5a and b). Slopes are very steep and the topographic density is very high. Local relief averages about 15 feet. The moraine is a low, broad ridge that has few internal lineations. Along much of its outer margin are one or more push (?) ridges, which are straight and 10 to 30 high. In several places the end moraine is lower than the older ground moraine to the west of it. This higher ground in front of the Burnstad might have acted as a buttress and caused the formation of the terminal push (?) ridges.



a. N. edge of sec. 9, T. 134 N., R. 71 W.

b. N. edge of sec. 31 and 32, T. 135 N., R. 71 W.

c. Sec. 34 and 35, T. 136 N., R. 67 W., and sec. 2, T. 135 N., R. 67 W.

d. N. edge of sec. 13 and 14, T. 135 N., R. 71 W.

e. Sec. 4 and 5, T. 135 N., R. 69 N., and sec. 33, T. 136 N., R. 69 W.

f. E. edge of sec. 5 and 8, T. 134 N., R. 68 W., and sec. 32 and 29, T. 135 N., R. 68 W.

g. N. edge of sec. 33, 34, and 35, T. 135 N., R. 71 W.

FIGURE 5.--Cross sections through northern Logan County end moraines. Outer or western side to left. a and b: Burnstad end moraine. c: minor recessional moraine behind Streeter moraine. d: southern ridged loop of Fresh Lake moraine. e: middle loop of Streeter moraine. f: southern loop of Streeter moraine. g: unridged part of Fresh Lake moraine.

The Burnstad has previously been correlated with the Long Lake moraine. It apparently overlaps the Long Lake, however, and correlates with the Twin Buttes moraine of Rau and others (in press) in southern Kidder County (fig. 4). There are several reasons for believing this:

1. There is a greater similarity between the Burnstad moraine and Twin Buttes moraine than there is between either the Burnstad or Twin Buttes moraines and the Long Lake moraine. In northern Logan County and southern Kidder County, the Burnstad and Twin Buttes moraines are 1 or 2 miles wide, have a knobby topography with few small-scale internal lineations, and have a maximum elevation of 2100 or 2200 feet, whereas the Long Lake moraine is 6 to 10 miles wide, has numerous low parallel ridges (especially northwest of Logan County), and is about 300 feet lower.

2. If the Burnstad moraine were correlated with the Long Lake moraine, the Twin Buttes moraine would have to be an interlobate moraine, as first suggested by Todd (1896, p. 13). This is unlikely because all of the meltwater channels are directed to the north through the prominent outer edge of the Twin Buttes moraine rather than to the southwest through the supposed interlobate area.

3. The Fresh Lake recessional end moraine (discussed in the following section) closely parallels both the Twin Buttes and the Burnstad end moraines, whereas the orientation of the Long Lake moraine and the northern part of the Twin Buttes moraine differ by nearly 180° (see fig. 4).

4. The lineations at the margin of the Burnstad moraine in secs. 7, 17, and 18, T. 136 N., R. 72 W., are at right angles to those 2 miles

to the southwest at the margin of the inner part of the Long Lake moraine, indicating that the Burnstad, at least locally, overlaps the Long Lake moraine.

5. Hansen and Kume (in preparation) have found some evidence that the equivalent of the Burnstad overlaps the Long Lake moraine in northeastern Burleigh County (fig. 4).

These five points seem to justify the correlation of the Burnstad with the Twin Buttes moraine rather than with the Long Lake moraine. The Twin Buttes moraine will hereafter be referred to as the Twin Buttes loop of the Burnstad end moraine.

Farther to the north, in southeastern Kidder County, the Twin Buttes loop may be overlapped by the Streeter moraine, as suggested by Bau and others (in press). There is evidence, however, that the outer limit of the Burnstad advance was several miles in front of the outer limit of the Streeter advance in northern Kidder County. The dead-ice moraine and collapsed outwash in front of the Streeter moraine in northern Kidder County probably correlates with the dead-ice moraine and collapsed outwash in front of the Streeter moraine in Logan County. That is, the collapsed outwash in both areas was probably deposited on top of the same stagnant ice which persisted until after the Streeter moraine was formed.

To the south, the Burnstad may correlate with one of Flint's (1955, fig. 31) "A series Mankato" end moraines.

Fresh Lake moraine.--The Fresh Lake end moraine, a minor recessional of the Burnstad moraine, was first recognized by Colton and Lemke

(1957). The name "Fresh Lake" was applied by Rau and others (in press) to a small but prominent ridged loop 2 miles north of Fresh Lake in southern Kidder County (fig. 4). Rau and others did not recognize an unridged part that extends south into Logan County.

The name "Fresh Lake moraine" as used here includes the original northern loop of Rau and others, the band of unridged end moraine extending south into Logan County, and another prominent ridged loop at the south end of the same moraine.

Except for the southern and northern loops, the Fresh Lake end moraine has few ridges. It has, instead, a knobby topography with steep slopes and high topographic density very similar to that of the Burnstad end moraine (fig. 5g). Like the Burnstad, its outer margin in places is marked by a few low, straight push (?) ridges. The ridged loop at the south end of the moraine is very similar to the one in Kidder County. They consist of a series of symmetrical, arc-shaped push (?) ridges with a radius of curvature of about 1 mile. The ridges are even crested, about 30 feet high, and spaced about 500 feet apart (fig. 5d).

No attempt has been made to correlate the Fresh Lake moraine with any other end moraines to the north or south.

At the south end of the Fresh Lake moraine is an area of high moraine whose relation to the Fresh Lake is unknown. Its ridges are convex to the north and at right angles to the regional north-south end moraine trends.

Streeter moraine.--The most conspicuous end moraine in northern Logan County is the Streeter moraine, about 12 miles east of the Burnstad moraine. It was first recognized by Todd (1896, p. 34), who called it the "Blue Lake loop of the Second or Gary moraine." It was also referred to as "Gary" by Paulson (1952, p. 17). The name "Streeter" was first applied to this moraine by Lemke and Colton (1958, p. 49, fig. 5). The name "Streeter" is used in this report because there is only a small possibility that it correlates with the Gary moraine in eastern South Dakota and because the name "Blue Lake," which was given to both the Burnstad and the Streeter moraines, has not been used in any other publication since 1896.

The Streeter is a distinctive end moraine that can be recognized considerable distances north and south (fig. 4). It is a high ridge that is about 2 miles wide and in many places is over 200 feet high. The ridge is in the form of a series of disconnected semicircular loops that have a radius of curvature of 2 to 4 miles. Rau and others (in press) traced the Streeter moraine from its type area in northern Logan County and southwestern Stutsman County northward through Kidder County. No detailed work has yet been done on that part of the Streeter moraine northwest of Kidder County, but the reconnaissance work of Lemke and Colton (1958, fig. 4) shows that it is overlapped by the Martin moraine in northwestern Sheridan County. The Streeter is absent in southern Logan County (Bonneville, 1961, p. 69) but is again prominent in McIntosh County. Lemke and Colton (1958, fig. 4) have suggested that it correlates with Flint's (1955, fig. 31) "B-1 Mankato" end moraine in northern South Dakota.

In northern Logan County the Streeter consists of three well developed loops. The north and middle loops are composed of a series of parallel push (?) ridges that are about 50 feet high and about

1000 feet apart (fig. 5e). The middle loop slightly overlaps the northern loop. Apparently the disconnected segment of end moraine east of the north interlobe area (secs. 3, 4, 9, 10, T. 136 N., R. 69 W.) is part of the north limb of the middle loop. The moraine between the two segments may have been end moraine that was deposited on stagnant ice and collapsed beyond recognition when the ice melted.

Part of the southern limb of the middle loop has been mapped as collapsed end moraine. (It is not called dead-ice moraine because it still has end moraine lineations.) This part of the Streeter may have also been deposited on stagnant ice and later let down and collapsed as the ice melted. Its ridges are poorly defined and have a disrupted appearance. On the ground its topography more closely resembles that of the adjacent dead-ice moraine than it does that of the rest of the middle loop.

The south loop differs from the other two loops in its greater height and smaller push (?) ridges (fig. 5f). The two interlobe areas between the three loops differ greatly. The north interlobe area is lower than the moraine and served as a broad meltwater outlet. It is at about the same elevation as the outwash plain in front of the Streeter. In contrast, the interlobe area between the middle and south loops is the most massive part of the whole Streeter moraine in Logan County. It is nearly 300 feet above the distal margin of the moraine 3 miles north of the interlobe area. The steep and rugged flanks of the interlobe are covered with an unusually high concentration of boulders.

Minor moraines.--The Missouri Coteau in northern Logan County contains four other minor end moraines. The one in the northeast corner of T. 135 N., R. 70 W., is a series of straight parallel ridges that have uneven crests and are about 15 feet high and about 250 feet apart. Their relation to the surrounding glacial features is unknown, though their northwest-southeast orientation and uneven crests suggest that they are transverse end moraine ridges rather than longitudinal streamline flow ridges. The areal pattern of the ridges is similar to that of washboard end moraines, but the individual ridges are much higher than those of typical washboard moraine.

In T. 134 N., R. 69 W., is another small area of end moraine. It consists of several low, broad ridges that trend north-northeast.

A minor recessional of the Streeter moraine in T. 135 and 136 N., R. 68 W., has a very knobby topography. It has 10-25 feet of local relief, has steep slopes (especially where it is composed of gravel), has a high topographic density, and has a high concentration of surface boulders. The arcuate pattern of lineations shown on plate I is visible only on air photos and is the result of the elongation of knobs and depressions. In many places, especially in the southwest part, the moraine has a very high gravel content. A roadcut through a knob 0.1 mile north of the southwest corner of sec. 2, T. 135 N., R. 68 W., exposes a gravel composed of nearly 100 per cent boulders.

Another minor recessional of the Streeter is the prominent ridge in T. 135 and 136 N., R. 67 W. (fig. 3c). It has smaller push (?) ridges superimposed on it.

There is no known evidence that suggests a correlation of these minor recessionals with any other known moraines.

Pitted ground moraine.--Only one small patch of ground moraine is present in the Missouri Coteau part of northern Logan County. This 1½ square miles of pitted ground moraine, in the southeast corner of the area shown on plate 1, is the northwest edge of a much larger area of ground moraine in La Moure County and southern Logan County (fig. 4). It is a level area that is pitted with abundant kettles that are 2 to 20 feet deep and 200 feet to one-half mile wide.

The kettles may have formed when ice blocks became separated from the retreating ice front and sank into the water-saturated till. Kettles of this type would likely have till rims squeezed up around their margins. The lack on any such rims in the pitted ground moraine of eastern Logan County could have been caused by the complete leveling out of the saturated till between the ice blocks or by flowing of the till back into the kettle as the ice melted. The convex inward margins of some of the kettles suggest that the till actually did start to flow back into these depressions.

A more probable explanation of the kettles is deposition of till in the form of ground moraine on top of pre-existing isolated blocks of stagnant ice. The resulting partly collapsed or pitted ground moraine grades westward into completely collapsed ground moraine or dead-ice moraine.

Dead-ice moraine.--Dead-ice moraine is a type of moraine whose topography is dominantly the result of large scale glacial stagnation.

The term "dead-ice moraine" has been used for many years in northern Europe (Hoppe, 1952, p. 1-3) and is considered to be the most important type of moraine in northern Sweden (Lundquist, 1959, p. 19, 94-95). In the past 5 years the term has been used by several glacial geologists in the Prairie Provinces (for example, Christiansen, 1956, p. 12; Bayrock, 1958, p. 6; Gravenor and Kupsch, 1959, p. 32; and Bayrock and Gravenor, 1961, p. 3).

The descriptive term "hummocky moraine" is preferred by many writers (for example, Hoppe, 1952, p. 3; Stalker, 1960b, p. 27; and Christiansen, 1961, p. 15). It is a general term that includes both dead-ice moraine and unridged end moraine. "Hummocky moraine" is not used in the present study because it is thought that these two landforms can be differentiated.

The "collapse till topography" of Flint (1955, p. 114) is the same as dead-ice moraine.

The term "stagnation moraine," another synonym for dead-ice moraine, has been used by several North Dakota and Montana geologists, including Lemke and Colton (1957), Bakken (1960, p. 51), Chmelik (1960, p. 30), Williams (1960, p. 72), Clayton (1960, p. 26), Bonneville (1961b, p. 56), and Colton and others (1961). Because "stagnant ice" and "dead ice" are usually used synonymously and because "stagnation moraine" has been used only locally, the term "dead-ice moraine" is to be preferred.

Townsend and Jenke (1951, p. 857) were probably the first to realize that much of the high-relief moraine on the Missouri Coteau in North Dakota is probably not end moraine, but may be "more nearly related in extent and mode of deposition to ground moraine." It was first recognized as dead-ice moraine by Colton and Lemke (1957).

Dead-ice moraine is identified by its association with numerous features that indicate large-scale stagnation, such as disintegration ridges, ice-contact faces, ice-contact meltwater channels, and ice-walled and collapsed outwash and lake sediment features. It lacks the small scale lineations of ridged end moraine and the monotonous knobby topography (steep slopes and high topographic density) and over-all linearity of unridged end moraine. In south-central North Dakota, dead-ice moraine usually has much higher local relief than ground moraine.

Dead-ice moraine is highly variable. Local relief varies from a few to 100 feet, and topographic density varies from 200 to 2000 depressions in a square mile. Small irregular lakes in kettles and other depressions are abundant. In many places, numerous ice-contact faces give the dead-ice moraine a terraced appearance. Meltwater channels and eskers are absent or short and fragmental.

The high local relief of dead-ice moraine may have originated in at least three different ways:

1. Reflecting of the high relief of the topography that existed before the last glaciation may in part be a cause of the high relief. Evaluation of the effects of pre-late Wisconsin relief on the present topography is difficult because little subsurface information is available; but, though no definite evidence can be given, it is thought to be of only slight importance.

2. Squeezing of subglacial till into crevasses and holes in stagnant ice was thought by Stalker (1960a) and Hoppe (1952, p. 5-6) to be the cause of the high local relief of most dead-ice moraine. No evidence was found in Logan County for or against this theory, but it seems unlikely that it could form the topography with over 100 feet of local relief that is found in parts of northern Logan County.

3. Letting down of superglacial till from stagnant ice is the most probable origin of the high relief of the dead-ice moraine in Logan and McIntosh Counties. Any drift on top of the stagnant ice was probably originally irregularly distributed and later became further redistributed by mass movement and stream action. When the stagnant ice melted, the superglacial till was let down to form the irregular, high-relief topography of dead-ice moraine. Stalker (1960b, p. 34) and Hoppe (1952, p. 26) state, however, that superglacial till was nonexistent or very thin on continental glaciers and was of little importance in the formation of dead-ice moraine. This, apparently, was not true in Logan County in late Wisconsin time. As is shown in a later section, superglacial till was probably fairly thick on the stagnant ice of Logan County. Furthermore, the dead-ice moraine of Logan County has a topography that is nearly identical to the topography of collapsed outwash, which without doubt was the result of the letting down of superglacial outwash. It is therefore thought that the letting down of irregularly distributed superglacial till was largely responsible for the high local relief of the dead-ice moraine in Logan County.

Partly buried channels

Two channels that are partly buried by drift were recognized in northern Logan County. They might be an important source of ground water. One in the northwest corner of the county is a broad linear depression that is as much as 30 feet deep. It is marked by a chain of kettle lakes that are one-fourth to one-half mile wide. Large quantities of outwash gravel are exposed along much of its length, suggesting that it originally was a meltwater channel. The channel was buried by the glacial advance that formed the Long Lake end moraine.

A second partly buried channel, at the north edge of T. 136 N., Rs. 71 and 72 W., is about one-third mile wide and nearly a hundred feet deep. It is partly filled with hummocky till and outwash. A small postglacial ephemeral stream flows along its bottom and into Fresh Lake. Contrary to what is shown on the Glacial Map of the United States (Flint and others, 1959), the channel slopes to the east and is not part of the meltwater channel that slopes southwestward through the Burnstad moraine. The western-most part of the channel, in the Burnstad end moraine, is unburied. The channel may have been buried by a minor readvance of the glacier, or it may have had the same origin as the similar "ice-walled channels" described by Gravenor and Kupsch (1959, p. 55-56). These channels were partly buried by superglacial drift that slid down the ice walls.

Till stagnation features

Till stagnation features in the Coteau section of northern Logan County include prominent till hills, moraine plateaus, rimmed saucers, till, disintegration ridges, and kettles.

Prominent till hills.--Prominent, isolated hills of till are abundant in the dead-ice moraine in the eastern part of Logan County. These hills, which were first noted by Todd (1896, p. 34-35), are composed largely of till, though many of the flat-topped ones are capped by lake silt and clay. One immediately east of Gackle is nearly completely covered with lake sediment, which has been highly contorted by postglacial mass wasting or by collapse during melting of the stagnant ice. The large till hill in the northeast corner of T. 135 N., R. 67 W., has large amounts of sand and gravel on its sides.

Some of these hills may have been formed by the disruption of earlier glacial features. For example, the elongated hills in the northeast corner and along the south edge of T. 135 N., R. 67 W., may be an overriden and partly destroyed end moraine. Others, such as the smaller, circular ones, may be closely related in origin to the conical "prairie mounds" described by Gravenor (1955). They were probably formed when superglacial till slid into sinkholes in stagnant ice. The silt and clay on top of some of the till hills settled out of ponds in these sinkholes.

Moraine plateaus.--In the northwest part of T. 136 N., R. 68 W., and northeast part of T. 136 N., R. 69 W., are several flat areas of till in the dead-ice moraine that have the appearance of very low buttes. These roughly circular areas are about one-half mile wide and are elevated up to 50 feet above the near-by depressions. These features are similar to the "moraine plateaus" first described by Hoppe (1952, p. 5) and first recognized in North America by glacial geologists (Gravenor and Ellwood, 1957, p. 12; Gravenor and Kupsch, 1959, p. 51-52) working in Alberta and Saskatchewan. The "moraine plateau" of Stalker (1960b, p. 31-35), are more similar to the ice-walled lake plains described below, but there are probably all gradations between ice-walled lake plains and the "moraine plateaus" of Hoppe. The origin of "moraine plateaus" is unknown, though they may be the result of water-saturated till spreading out between the blocks of ice that occupied the near-by depressions.

Rimmed saucers.--In sec. 10, T. 134 N., R. 70 W., are two features that are here referred to as "rimmed saucers." They are depressions that are shaped like half saucers and have a 10 foot rim around half their circumferences. The surrounding dead-ice moraine is more hummocky than the smooth surface of the saucers. The east edge of the one in the southeast quarter of sec. 10 is composed of till; presumably both rimmed saucers are made entirely of till.

These rimmed saucers are somewhat similar to Christiansen's (1961, p. 19-20) "rimmed depressions," which were thought to be ice-walled lake basins. The rimmed saucers are smaller, however, and there is no known evidence that suggests that they were lake basins. The greater steepness of the outside edge of the rims suggests that they are disintegration ridges that were formed by mass wasting of superglacial till from stagnant ice that surrounded the saucers as shown in figure 6.

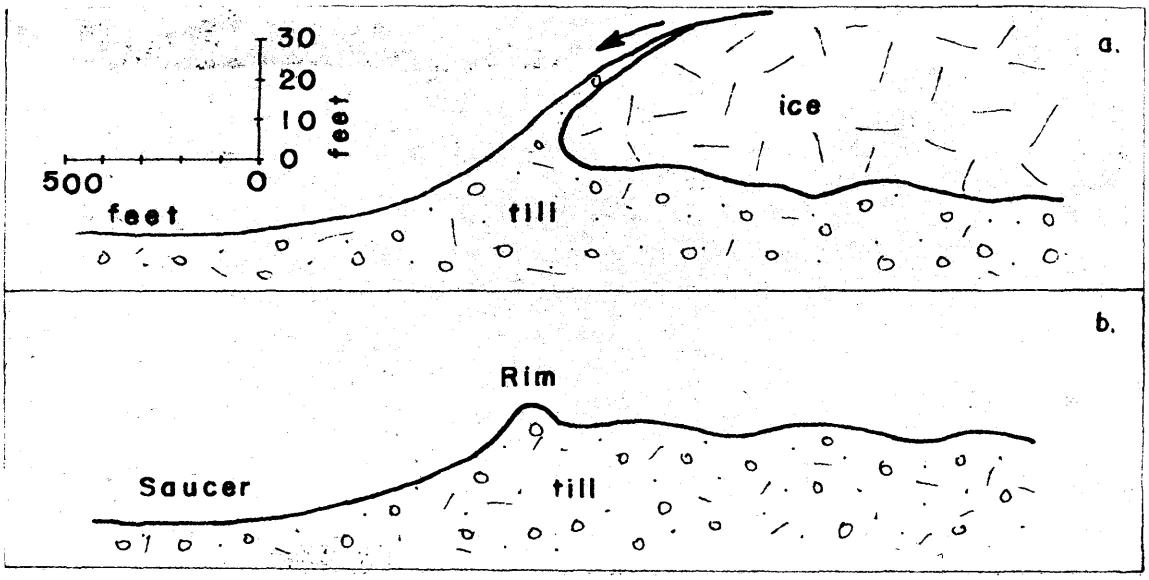


FIGURE 6.--Suggested origin of rimmed saucer. a. Superglacial drift of sliding off stagnant ice. b. After ice melts.

Disintegration ridges.--The term "disintegration ridge" was first used by Gravenor and Kupsch (1959, p. 32-34) to designate ridges formed by disintegrating stagnant ice. It is a useful general term that includes circular and linear ridges which are composed of till or washed drift and formed in the following ways (Hoppe, 1952, p. 5-6; Gravenor and Kupsch, 1959, p. 56-60; and Stalker, 1960a):

1. Filling of crevasses from above by mass movement of superglacial drift.

2. Filling of crevasses from below by squeezing up of subglacial drift.

3. Mass movement of drift from the edge of a single mass of ice.

4. Squeezing of drift up from beneath the edge of a single mass of ice.

5. Mass movement of drift from the side of a hole in a mass of ice.

6. Squeezing of drift up from beneath the side of a hole in a mass of ice.

Disintegration ridges are not as abundant in the dead-ice moraine of Logan County as they are in the Missouri Coteau in northwestern North Dakota and in parts of Alberta and Saskatchewan. Linear disintegration ridges composed of till are, however, present in many parts of the dead-ice moraine in Logan County. They are sinuous to straight ridges that average about 15 feet high and less than one-half mile long.

Poorly- to well-developed circular disintegration ridges are scattered through much of the dead-ice moraine in northern Logan County. These features have also been referred to as "doughnuts" by Gravenor and Kupsch (1959, p. 52) and Stalker (1960a, fig. 3c) and "rim ridges" of "plains plateau" by Stalker (1960a, p. 9-11). They average 500 feet in diameter and about 15 feet high (fig. 7). Many circular disintegration ridges are breached in two places on opposite sides of the circle. These have been called "broken rim ridges" by Stalker (1960a, pl. 10) and have been colloquially referred to as "puckered lips" by workers here in North Dakota.

In Logan County, no evidence was found for or against Hoppe's (1952) and Stalker's (1960a) subglacial "ice pressing" theory for the origin of disintegration ridges. One of Stalker's arguments against a superglacial origin of the drift in the ridges is the "small amount of material within the upper zones" of ice sheets. As will be shown in the section on superglacial till, however, there is definite evidence that large amounts of till were present on top of the stagnant late Wisconsin ice in Logan County.

Gravenor's (1955, p. 475-478) theory on the origin of circular disintegration ridges ("doughnuts") is dependent on the presence of fairly abundant superglacial drift. First, large holes form in the ice by the collapse of "solution" cavities (forming sinkholes) or by the irregular insulation or irregularly distributed superglacial drift (fig. 8a and b). This drift then slides into the holes (fig. 8c), and, as melting continues, the topography is inverted (fig. 8d). This is caused by the greater insulating affect of the thicker drift in the bottoms of the holes. Finally, the cones of ice under the former bottoms of the sinkholes melt, leaving the depressions in the center

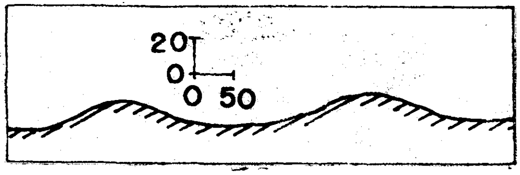


FIGURE 7.--Profile across typical circular disintegration ridge. Scale in feet. 0.5 mile south of the northeast corner of sec. 18, T. 135 N., R. 67 W.

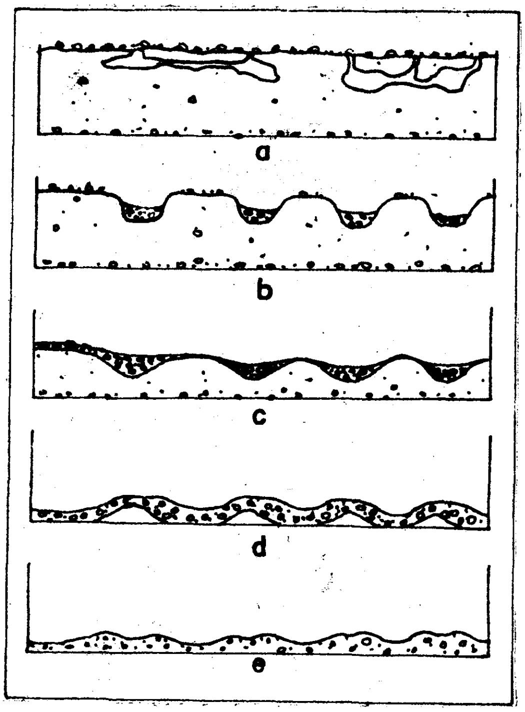


FIGURE 8.--Origin of circular disintegration ridges. Modified from Gravenor, 1955, fig. 2.

of the circular disintegration ridges (fig. 8c). In 1901, Russell (p. 115-116) observed circular ridges being formed by this same process on the stagnant part of Malaspina Glacier in Alaska. These circular ridges are apparently identical to the circular disintegration ridges of Alberta, Saskatchewan, and North Dakota. Thus, it seems more probable that the circular disintegration ridges of Logan County were formed from superglacial drift rather than subglacial drift.

Kettles.--A kettle is a depression that was formed by the melting of a buried block of glacial ice. Few of the depressions in dead-ice moraine are kettles. Instead, they are random depressions formed by the irregular collapse of drift from a single large mass of stagnant ice. Dead-ice moraine in Logan County, however, contains many more kettles than end moraine.

Ice-contact outwash landforms

The ice-contact outwash landforms in the Missouri Coteau part of the county include collapsed outwash topography, ice-walled outwash plains, outwash disintegration ridges, eskers, kames, kame terraces, and kettles.

Collapsed outwash topography.--Collapsed outwash topography was formed during the melting of stagnant ice on which a superglacial outwash plain or valley train had been deposited. Collapsed outwash topography is here defined as having less than 50 percent of its area flat and uncollapsed. This landform is similar to the collapsed outwash topography described by Flint (1955, p. 106), Tipton (1958), and Stoece (1957); the "dead-ice kame moraine" described by Bayrock (1958, p. 6); the "pitted outwash of . . . extreme type" described by Thwaites (1959, p. 47); and the "kame complex" described by Christiansen (1959; p. 16). Some of the collapsed valley trains in Logan County resemble some of the Irish "eskers" described by Flint (1930).

Collapsed outwash and dead-ice moraine have nearly identical topography. They are differentiated by their lithology. Collapsed outwash topography can sometimes be distinguished on air photos by its light tone and the presence of stubby postglacial gullies along the steeper slopes. Some collapsed valley trains also have a series of subparallel disintegration ridges and eskers associated with them. Collapsed outwash topography is distinguished from outwash plain by its higher local relief and numerous undrained depressions. Gravity faults are common in collapsed outwash and absent in uncollapsed outwash.

A well-developed example of a collapsed valley train is present in T. 134 N., R. 70 W. It consists of a series of short irregular disintegration ridges, which have a pattern that suggests that they are let-down braided channel deposits. Associated eskers were probably formed by subglacial streams flowing beneath the superglacial valley train. These ridges and eskers converge on a southwest sloping meltwater channel at the contact between the dead-ice moraine and the Burnstad end moraine.

Ice-contact outwash plain.--At the east edge of the south loop of the Streeter moraine is a small, fairly flat outwash plain that is elevated above the dead-ice moraine to the south, east, and north. The plain was apparently deposited in contact with stagnant ice.

Disintegration ridges.--Outwash disintegration ridges differ from till disintegration ridges only in composition. The most common type of outwash disintegration ridge is crevasse filling (Flint, 1957, p. 150). Outwash disintegration ridges are distinguished from eskers by their lesser sinuosity.

Eskers.--An esker is a sinuous ridge of outwash sand and gravel that was deposited by a meltwater stream flowing in a subglacial, englacial, or superglacial channel that was largely cut by the stream itself. Thus, a crevasse filling is not an esker because the channel was not largely stream cut; the stream that deposited a crevasse filling flowed in a relatively straight rather than a sinuous channel.

Few good examples of eskers exist in the Missouri Coteau part of northern Logan County. Most of those that are present are less than a half mile long and are not easily distinguished from outwash disintegration ridges. The best example in the area mapped is the sinuous ridge in the collapsed valley train in sec. 8, T. 134 N., R. 70 W.

Kames.--A kame is a prominent and conspicuous hill of ice-contact outwash sand and gravel. Thus, in dead-ice moraine or collapsed outwash topography, any hill of outwash that is about the same size and shape as adjacent hills is not a kame.

Only a few hills of sand and gravel in the Missouri Coteau part of northern Logan County were considered prominent enough to be called kames. The one in T. 136 N., R. 69 W., may have been a delta at the north edge of an ice-walled lake. The six kames on the west edge of the south loop of the Streeter moraine are cone shaped and about 30 feet high.

Kame terraces.--A kame terrace is a terrace of ice-contact outwash sand and gravel that was deposited between stagnant ice and the side of a hill or valley. The kame terrace on the north side of the interlobate moraine between the middle and south loops of the Streeter moraine is continuous with the floor of the meltwater channel immediately to the west, indicating that the terrace was the floor of a meltwater channel that had stagnant ice as its north wall. This terrace is dissected by several postglacial gullies which contain one of the largest stands of native trees in the county.

Kame terraces on the distal slope of the interlobe part of the Streeter are less prominent than those on the north side of the interlobe. They indicate that this steeper part of the distal margin of the Streeter was formed in direct contact with a mass of stagnant Burnstad ice.

Kettles.--Kettles in the pitted and collapsed outwash in northern Logan County are nearly identical to those in till, except that they usually have steeper sides, probably because water-saturated till flows easier than outwash.

Ice-contact lake sediment landforms

Ice-walled lake plains.--Ice-walled lake plains are elevated areas of smooth and nearly flat topography underlain by horizontally bedded silt and clay that were deposited in a glacial lake that was more than half walled by stagnant glacial ice. The only known previous descriptions of similar features in North America are those of Stalker (1960a, p. 5, pl. 12; 1960b, p. 31-35), who called them "moraine plateaus."

These features are different from the "moraine plateaus" that were first described by Hoppe (1952, p. 5); the original "moraine plateaus" are composed of till and evidentally have no associated lake sediment. The "moraine plateaus" described by Gravenor and Kupsch (1959, p. 50-51) are composed of till, but some have a thin cover (2 to 10 feet) of lake sediment.

Though they are variable, ice-walled lake plains are a distinctive landform that is one of the most characteristic stagnation features of the Missouri Coteau in Logan County. They are 15 to 90 feet above the low areas in the surrounding dead-ice moraine, and have margins that are outward sloping ice-contact faces. Some have a rim of lake sediment, outwash, or till around their margins. The rims which are a type of disintegration ridge, may have been originated by mass movements of drift from the adjacent ice wall or by the squeezing of drift up from beneath the ice wall (see number 5 and 6 in the section on the origin of disintegration ridges). Most of the plains are gently sloping away from the margins toward the center, and a few are pitted with kettles. Some have sand and gravel along parts of their margins, probably near former inlets. The bedding at the margins is generally faulted because of collapse during melting of the ice wall. Examples of well developed ice-walled lake plains are shown in figure 9. The highest ice-walled lake plain in northern Logan County is in the northeast corner of T. 136 N., R. 69 W. It is a butte-shaped hill, the top of which is more than 90 feet above adjacent depressions; the hill has at least 75 feet of horizontally stratified clay exposed in the road cut down its south side. Deposits of stratified sand,

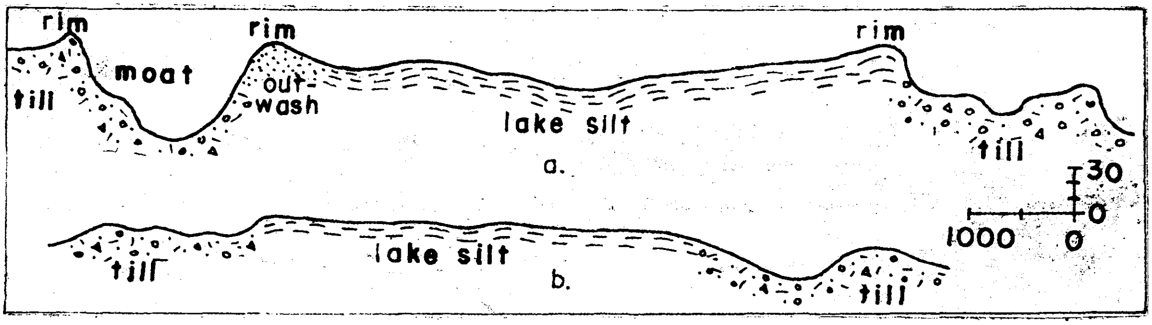


FIGURE 9.--Cross sections through ice-walled lake plains. a. Along the north edge of sec. 12, T. 134 N., R. 70 W., and sec. 7, T. 134 N., R. 69 W. b. Along the north edge of sec. 15 and 16, T. 135 N., R. 71 W. Scale in feet.

gravel, and lake clay and silt exposed in a pit on the north side of this hill are cut by numerous gravity faults. This is probably the same hill which Todd (1896, p. 35) described as "presenting the unusual appearance of a flat-topped butte with numerous lake beds around it."

The ice-walled lake plains of northern Logan County are proof of the existence of masses of stagnant ice that were at least 2 miles across. The elevated position of the plains could not have been caused by erosion of surrounding drift because the nonintegrated drainage indicates that postglacial erosion on the Coteau has been very slight.

The origin of the holes in the stagnant ice that held these lakes is unknown. No evidence was observed, however, that would suggest that they were the result of any process other than random irregular melting caused by an irregular concentration of crevasses and drift on the surface of the ice.

Lake-sediment topography of high relief.--The features mapped as lake-sediment topography of high relief are similar to and gradational with ice-walled lake plains; they are, however, less smooth, have more undrained depressions, have higher local relief (as much as 75 feet), and have less well-developed bordering ice-contact faces. Their origin is similar to that of the ice-walled lake plains except that they are underlain by lake sediment that was deposited on top of stagnant ice and was let down and collapsed when the ice melted or else are underlain by lake sediment that is so thin that it fails to mask the underlying moraine topography completely.

Ice-walled meltwater channels

The best example of ice-walled channels in northern Logan County are those in sec. 11, T. 135 N., R. 67 W. These channels are about 100 feet wide, about 10 feet deep, and have a polygonal pattern. This pattern may be the result of streams flowing at the base of crevasses in stagnant ice. An example of a much larger channel that might also have been ice-walled was previously discussed in the section on partly buried channels. Ice-walled channels are a less important stagnation feature in Logan County than they are in some parts of the Prairie Provinces (Gravenor and Kupsch, 1959, p. 55-56).

Proglacial landforms

Proglacial landforms recognized in the Coteau part of northern Logan County are outwash plains, pitted outwash plain, lake-modified till topography, unrestricted meltwater channels, and meltwater channel terraces.

Outwash plain.--There is only one large unpitted outwash plain in the Coteau part of northern Logan County. This outwash plain, which is west of the north and middle loops of the Streeter moraine, is very flat, having in most areas less than 2 feet of local relief. The relief that does exist is the result of a braided network of shallow meltwater channels which is obvious only on air photos. These channels may have been partly filled with wind-blown sediment. Local relief increases to several feet at the edge of the Streeter moraine. The plain is underlain by outwash that varies from coarse gravel adjacent to the moraine to very fine sand and silt at the northwest edge. According to Paulson (1952,

p. 22 and 43), the outwash is at least 65 feet thick and probably averages over 30 feet thick.

Pitted outwash plain.--A pitted outwash plain is here defined as one that has had less than 50 percent, but more than 5 percent, of its area collapsed or pitted with kettles. In contrast, the feature mapped as collapsed outwash topography has more than 50 percent of its area collapsed. Only one small area, west of the Streeter moraine, has been mapped as pitted outwash plain. It is contemporaneous and gradational with the unpitted outwash plain to the north and the collapsed outwash topography to the southeast. It is pitted with kettles that are several feet deep and up to a thousand feet across.

Lake-modified till topography.--About 10 square miles of the north-central part of the county has been mapped as lake-modified till topography. It differs from the adjacent dead-ice moraine in having only about 10 feet of local relief and in being at, or slightly below, 1900 feet elevation. The dead-ice moraine has much higher relief and is above 1900 feet. The lake-modified topography is underlain by till and lesser amounts of lake sediment, sand, and gravel. In many places these sediments are contorted and intermixed.

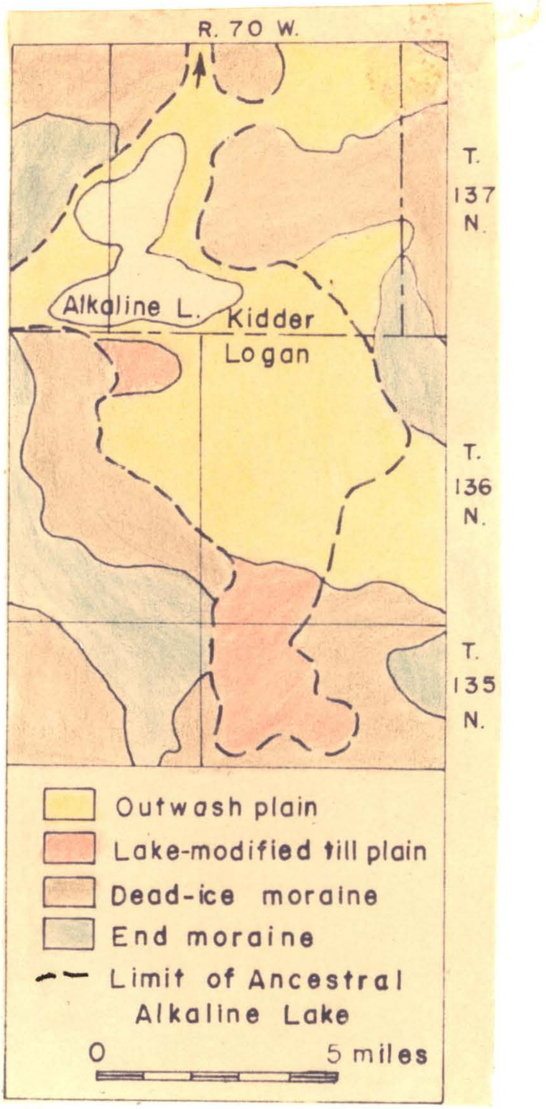
Although this area is underlain by more till than any other sediment, it is not believed to be moraine. Rather, its topography is probably the result of wave action by a lake, herein referred to as ancestral Alkaline Lake. This lake is named after modern Alkaline Lake, just north of the Logan County border in southeastern Kidder County. Ancestral Alkaline Lake, which was probably at or slightly below 1900 feet in elevation, covered about 40 square miles and had its outlet near the north end of present-day Alkaline Lake (fig. 10).

The southern part of the area that was modified by ancestral Alkaline Lake is pitted by numerous shallow kettles. None have been filled in with lake sediment, indicating that ancestral Alkaline Lake was drained before all the blocks of stagnant ice in its southern end had melted. The lake was drained when the outlet was cut by escaping meltwater or when the last ice melted from the area north of present day Alkaline Lake. After the lake disappeared, the outwash plain west of the Streeter moraine was built out over the former lake bottom.

The relative scarcity of lake sediment underlying the lake-modified topography and the absence of any strand lines indicates that the lake was short-lived. It therefore seems probable that wave erosion and lake sediment deposition are not the only causes of the flatness of the topography. Leveling by flowage of water-saturated superglacial till from blocks of ice in and surrounding the lake might have been an important factor.

Unrestricted meltwater channels.--In the dead-ice moraine of the Missouri Coteau part of northern Logan County meltwater channels that were unrestricted by ice are nearly nonexistent; instead, most meltwater channels in the Coteau are cut through end moraine. Most of the meltwater channels that did exist in the area of dead-ice were cut into ice, which has since melted.

Meltwater channel terraces.--Terraces are present along the meltwater channel through the Burnstad moraine north of Napoleon. They



E 10.--Location of ancestral Alkaline Lake.

are underlain by outwash sand and gravel deposited by a meltwater stream that was about 2000 feet wide. This outwash was later entrenched about 30 feet by a smaller meltwater stream. The terraces and meltwater channel are terminated upstream near minor recessional ridges in the Burnstad end moraine; apparently the channel and terraces were formed when the active ice front was at this position. The cause of the entrenching is unknown, though it may have been related to lowering of the Burnstad ice surface or a sudden downcutting of the meltwater channel west of Napoleon as the meltwater cut through resistent Fox Hills sandstone and into unconsolidated sand.

Bedrock topography

In the Coteau part of northern Logan County too little information is available on which to reconstruct the bedrock topography. East of the Fresh Lake moraine the bedrock surface is buried under an average of about 300 feet of drift, and in most places west of the Fresh Lake moraine it is probably less than 100 feet below the present surface.

Nonsorted polygons

Nonsorted polygons as defined by Washburn (1956, p. 831-832), are common in uncultivated parts of Logan County. They have little or no surface expression and are best seen in freshly graded ditch banks that have a low slope angle (fig. 11). They have been observed in till and lake silt, in well drained areas, such as hill sides or on hill tops. The polygons are 2 to 5 feet in diameter and generally form a well defined net. The material in the center of the polygons is the normal

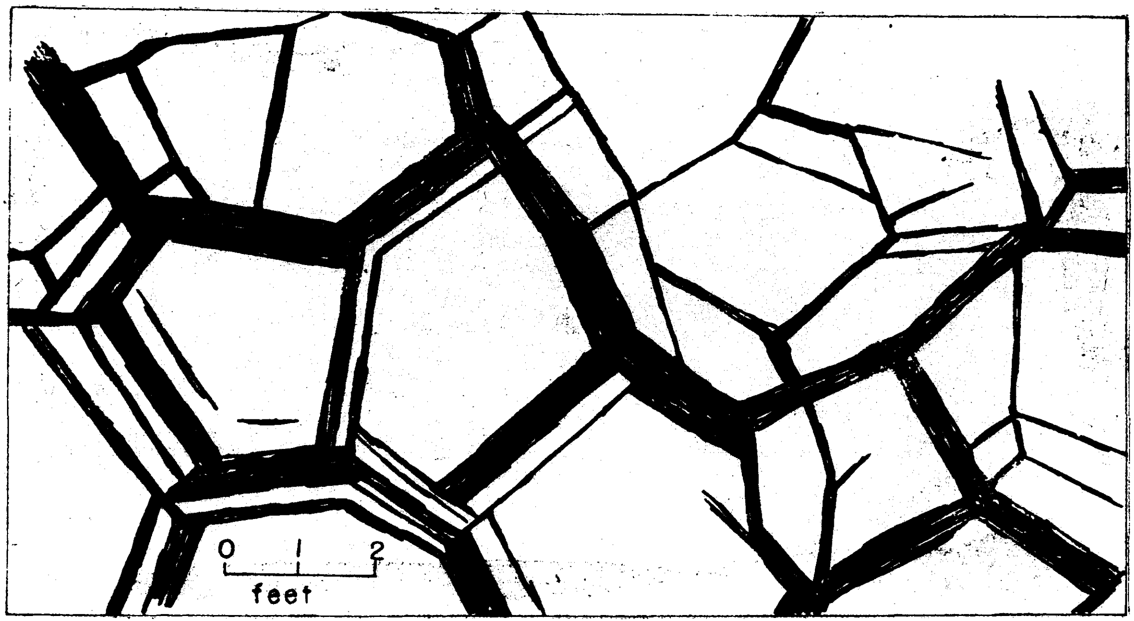


FIGURE 11.--Field sketch of nonsorted polygons in map view. 0.7 mile north of the southeast corner of sec. 9, T. 135 N., R. 71 W.

drift of the area, and their margins are composed of wedges of a dark, leached material that is apparently the same as the surface soil. This wedge of marginal material extends about 2 feet below the surface.

The polygons probably formed by surface soil falling into desiccation or possibly temperature-contraction cracks in the ground. The presence of soil in the margins indicates that they are not frigid-climate features, but formed in a relatively mild climate, probably in relatively recent time. Similar features were observed in Saskatchewan by Christiansen (1959, p. 23-25).

STRATIGRAPHIC UNITS

The formally named surface stratigraphic units of northern Logan County include the Upper Cretaceous Pierre Shale, the Napoleon Drift of the lower part of the Wisconsin Stage (?) and the Long Lake and Burnstad Drifts of the upper part of the Wisconsin Stage. Also present are undifferentiated Upper Cretaceous sand, sandstone, and mudstone, Upper Cretaceous or Cenozoic residual chert stones, an unnamed sub-Wisconsin (?) drift, and Wisconsin and Recent postglacial sediments. (See fig. 12.)

Upper Cretaceous Series

Pierre Shale

The Pierre Shale, which underlies the entire county, is an Upper Cretaceous marine formation that is composed of about 1000 feet of dark gray to black shale, which is fissile or has a thin blocky fracture. Its contact with the overlying formation is conformable and gradational. No outcrops of Pierre were observed in Logan County; in the western half of the county it is covered by younger rocks, and in the eastern half it is deeply buried under glacial drift. Small chips of shale from the Pierre are common in the drift in all of Logan County.

Undifferentiated sand, sandstone, and mudstone

The interbedded sand, sandstone, and mudstone in the western part of Logan County have been assigned to the Fox Hills Formation by Hansen

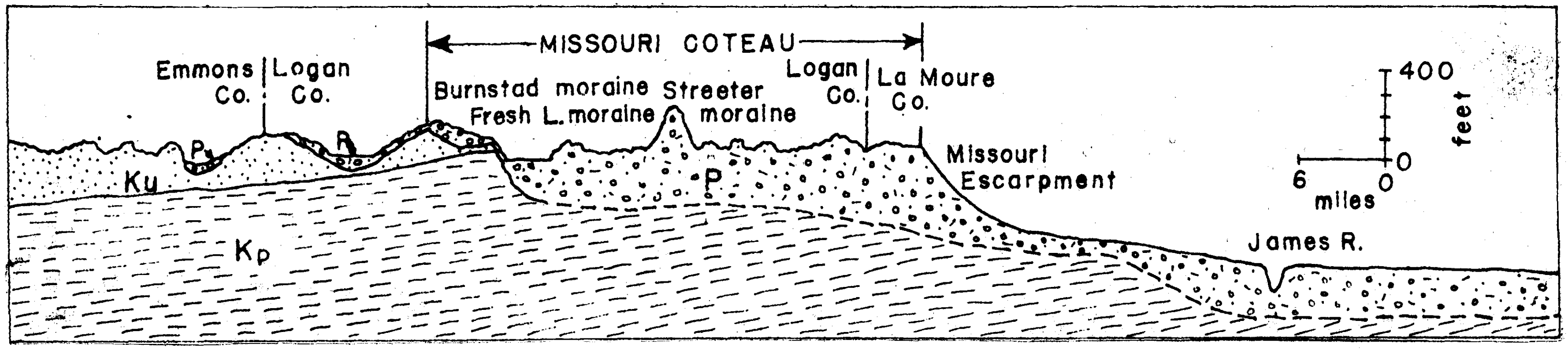


FIGURE 12.--Stratigraphic cross section from eastern Emmons County to eastern La Moure County. Kp: Pierre Shale. Ku: undifferentiated upper Cretaceous rocks. P: Pleistocene drift.

(1956). However, the validity of this assignment and even the validity of Fox Hills as a rock-stratigraphic unit in this area is questionable. The contact of the Fox Hills with any overlying formation (possible the Hell Creek) is difficult to place because of the lack of abundant outcrops. Apparently rocks above the Fox Hills do exist in Logan County because bedrock occurs at higher elevations than the sandstone bed (in the northwest quarter of T. 135 N., R. 73 W.) that Fisher (1952, p. 13-14) thought is at the top of the Fox Hills Formation, and because lignite, which apparently is absent in the Fox Hills Formation (Fisher, 1952, p. 10 and 18), has been reported "south of Napoleon" by Todd (1896, p. 56).

The unconsolidated medium- to fine-grained protoquartzitic (Pettijohn, 1957, table 48) sand in the western part of northern Logan County is yellow, brown, or orange (5Y to 10YR 5 to 7/4 to 5) when dry. Its grains are subrounded to subangular and are well sorted. In places it contains reddish sandstone concretions.

The fine-grained sandstone of northwestern Logan County is gray, brown, or orange (5Y to 10YR 5 to 6/2 to 6) when dry. The grains are subrounded. Most of this sandstone is calcite cemented and has 1 to 2 inch bedding. Nearly all of the sandstone observed is in the northwest quarter of T. 135 N., R. 73 W. It is part of a resistent 10-foot bed, which is at about 2000 feet elevation and is underlain by unconsolidated sand. This sandstone bed is considered by Fisher (1952, p. 13) to be the top of the "Fox Hills" Formation. Benson (1952, p. 32) thought it is equivalent to the Colgate Member of the Fox Hills.

The mudstone in the northwestern part of Logan County is gray, yellow, or orange (5Y to 10YR 6 to 7/2 to 6) when dry, is noncalcareous, and has 0.1 to 2 inch bedding. The more massive mudstone generally has a blocky fracture.

No bedrock macro-fossils have been found in place in northern Logan County. Fossil wood at many outcrops and fragments of oyster shells in till above mudstone in the NE¼NE¼ sec. 14, T. 135 N., R. 71 W., however, are probably not far from their source. The foraminiferids *Heterohelix* sp., *Rectogumbolina* sp., and *Nonion* sp. were found in the yellowish silt at the base of the road cut in the northwest corner of sec. 20, T. 136 N., R. 72 W., by Kent A Madenwald (personal communication).

Upper Cretaceous or Cenozoic

Residual sand chert stones

Boulders, cobbles, and pebbles of a distinctive sandy chert make up 1 to 10 percent of the stones in and on the drift in the western half of Logan County. According to Bonneville (1961b, p. 45), they constitute 95 percent of the erratics in T. 133 N., R. 71 W., in southwestern Logan County.

In hand-specimens the rock is a light to medium grayish, yellowish, or reddish-brown chert with inconspicuous but abundant grains of detrital quartz and numerous molds of plant stems. The stems were 1 to 10 mm in diameter and appear to have had several irregular longitudinal grooves. One chert specimen contains a mold of the interior of a small limpet-shaped gastropod. The surface of the rock is usually smooth and highly polished. The matrix and detrical grains are of equal hardness; fractures cut through the grains rather than around them.

In thin-section the detrital quartz grains are more conspicuous. They are generally subangular, though a few are rounded, and they vary from 0.01 to 0.3 mm but average about 0.1 mm in diameter (very fine sand). Most of the grains consist of a single, clear quartz crystal, but a few are composed of an aggregate of smaller quartz crystals. The quartz grains comprise about 20 to 60 percent of the thin-section area and are floating in the matrix. A small percentage of zircon grains is also present.

The matrix of the sandy chert is microcrystalline quartz with an average grain diameter of about 0.01 mm. It has a cloudy or dusty appearance, which is due to many minute inclusions, and has an undulose extinction. No fibrous (chalcedony) or amorphous quartz was seen in thin-section, nor was any evidence of secondary growth (such as quartz crystals projecting into cavities) or replacement observed.

The origin of the sandy chert is unknown. The chert seems to be identical to some types of "pseudo-quartzite" described by Russom and others (1954, p. 30), "quartzitic sandstone" described by Laird and Mitchell (1942, p. 22), and "silicified sandstone" described by Benson (1952, p. 55-58; 1954, p. 14). These rocks have generally been thought to be of secondary origin. Russom and others (1954, p. 39) thought that "pseudo-quartzite" is a surface phenomenon caused by the deposition of silica at the surface by evaporation of upward moving silica-bearing ground water. He pointed out that "pseudo-quartzite" has never been reported from any wells in the area. Benson (1952, p. 57-58), however, said that it has been penetrated by some water wells in many parts of western North Dakota and believed that silicification occurred shortly after deposition.

The presence of detrital quartz sand floating in a finer microcrystalline quartz matrix indicates that the sandy chert in Logan County is not an ordinary silica-cemented sandstone; instead, the silica either replaced an earlier matrix or is primary. However, no evidence for replacement was found, and the presence of plant stem molds with a complete absence of any secondary fillings in them suggests that primary silica was deposited around the plant stems and was at least partly lithified before the stems decomposed.

The stratigraphic source of the sandy chert stones in Logan County is also unknown. Todd (1896, p. 32 and 54) thought that they came from layers in the local "Fox Hills" sandstone. In a footnote (p. 32), however, he stated that the rock came from beds that, "as has now been discovered, belong to the Tertiary, probably to the lower portion of the Loup Fork formation." The "lower portion of the Loup Fork formation" is the present Arikaree Formation (Miocene) of South Dakota. "Pseudo-quartzite" in southwestern North Dakota has been thought to come from the Paleocene Tongue River Formation by Tisdale (1941, p. 13-14), Laird and Mitchel (1942, p. 22), and Benson (1954, p. 14), from the Eocene Golden Valley Formation by Benson (1954, p. 14), and Russom and others (1954, p. 41), and from the Oligocene White River Formation by Russom (1954, p. 36) and C. G. Carlson (personal communication). All of these formations are nonmarine. The rock seems seldom to have been seen in place.

Three possible stratigraphic sources of the chert in Logan County are: (1) glacial erratics from beds below the "Fox Hills" to the north and east, (2) float from the local bedrock, and (3) residual stones from previously existing beds above the "Fox Hills" Formation. The first can be excluded because no sandy chert has been found in the areas of outcrop on beds below the "Fox Hills" in Stutsman County (H. A. Winters, personal communication) or eastern Logan County. The second possibility is strongly supported by the near coincidence of the eastern limit of chert stones and the eastern limit of "Fox Hills" outcrops. This, however, may not be significant; it seems unlikely that such an uncommon lithology as sandy chert with numerous plant stem impressions would be found in both the marine Cretaceous formations and the continental lower Cenozoic formations of North Dakota. Nevertheless, float from local beds is the most likely source of the chert in areas such as parts of southern Logan County where it makes up most of the surface stones.

The last suggested possibility, residual stones from previously existing beds, seems the most probable source of the chert stones in northern Logan County; all of the formations may have thinned to the east, and only a few tens or hundreds of feet of rock need to have been eroded to let down the chert from pre-existing nonmarine beds.

Pleistocene Series

Time-stratigraphic terminology

The only established divisions of the Pleistocene Series that are applicable in Logan County are the Wisconsin and Recent Stages. Sub-

Wisconsin drift probably exists, but it is not known to what stage it belongs. The "classic" divisions of the Wisconsin Stage are inapplicable in North Dakota because they are in part based on local lithostratigraphic and morphostratigraphic units that are useful only within a single glacial lobe.

Wisconsin Stage divisions similar to those proposed by Frye and Willman (1960) or Dreimanis (1960) are not as detailed and may be more useable. More radiocarbon dates are needed in North Dakota, however, before it can be determined to which substage many of the drifts near the substage boundaries belong. An alternative to Frye and Willman's and Dreimanis' classifications is Karlstrom's (1961, p. 296) suggested return to the use of Iowan and Wisconsin as stages of equal rank. None of these Wisconsin classifications is used in this report, however, because none of them is in general usage at the present time and the age of only a small part of the drift in North Dakota is accurately known. (See fig. 13.)

Geologic-time terminology

Geologic-time terminology directly parallels time-stratigraphic terminology. Therefore, the only divisions of the Pleistocene Epoch which are applicable in Logan County are the Wisconsin and Recent Ages.

Geologic-climate terminology

The American Commission on Stratigraphic Nomenclature (1961, art. 39-40) has suggested that in areas of continental glaciation the Pleistocene Epoch be divided into geologic-climate units, which are

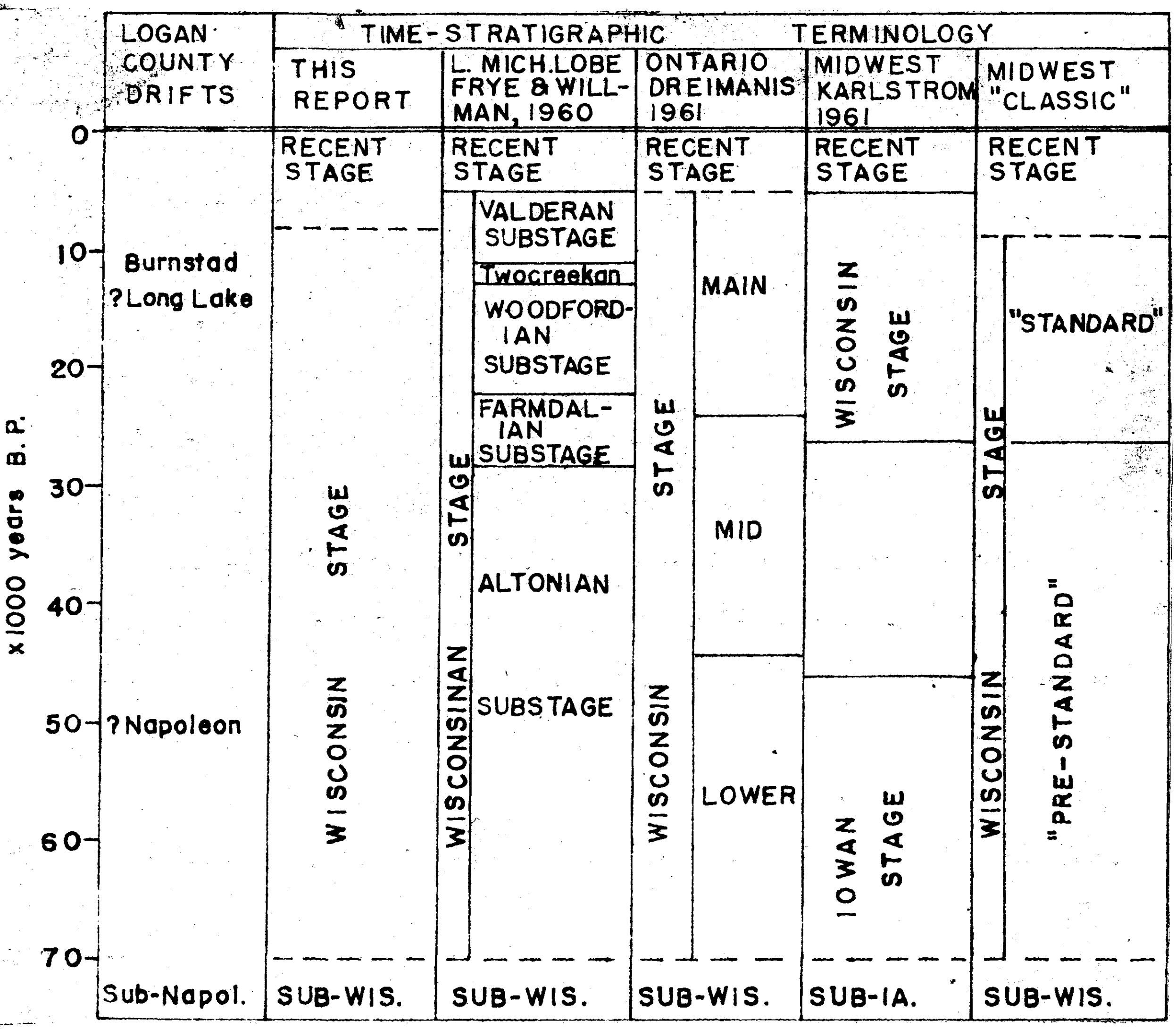


FIGURE 13.--Correlation of drifts of Logan County with various time-stratigraphic terminologies.

time transgressive, rather than into geologic-time units, which are isochronous. This would solve some nomenclature problems. For instance, it might not be known whether a drift was deposited at the end of the Two Creeks Subage or at the beginning of the Valders Subage. If geologic-climate nomenclature were used, the drift would be assigned to the Valders Stage.

Difficulties are encountered, however, when an attempt is made to put geologic-climate terminology into practical use. Time is isochronous; time-transgressive time is not a useful concept. A hypothetical example of a geologic-climate classification diagram is given in figure 14. "A" and "C" are glaciations, and "B" is an interglaciation. Sediment deposited at time and place "x" would be considered to have been deposited during interstade "e" whereas the sediment deposited at the same time but at place "y" would be considered to have been deposited during interglaciation "B" because it is between drifts deposited during glaciations "A" and "C." During this time, however, drift was being deposited in areas to the north and in higher areas to the south during glaciation "C." It can therefore be seen that variations in local climate conditions in a north-south direction can result in a complex shaped geologic-climate diagram. Complex variations in climate and resulting variations in depositional conditions also occur in an east-west direction and in a vertical direction, resulting in the necessity for much more complex three-dimensional and four-dimensional geologic-climate diagrams and very impractical stratigraphic nomenclature. The simpler time-stratigraphic nomenclature, which has been successfully used in pre-Pleistocene stratigraphy and has only one dimension--time, is much more useful.

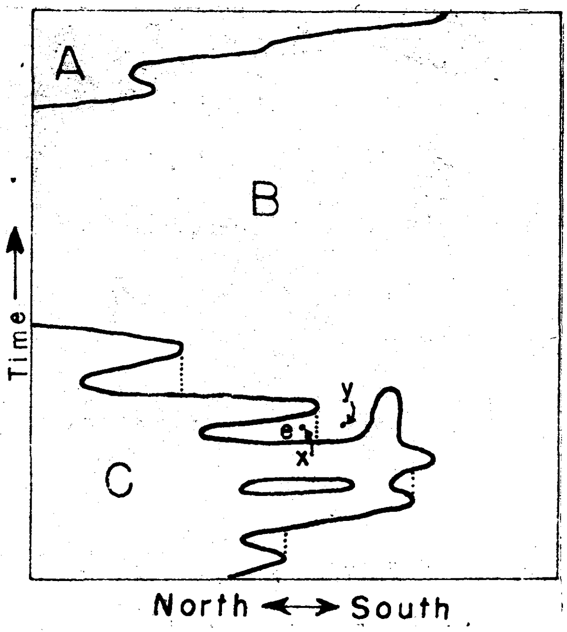


FIGURE 14.--Hypothetical geologic climate diagram. A and C are glaciations. B is an interglaciation. e is an interstadial. x and y are specific locations.

Furthermore, so little is yet known about North Dakota glacial stratigraphy that a formal geologic climate classification of the Wisconsin Glaciation (or Stage) would have little value at the present time. Before a more detailed time-stratigraphic or geologic-climate terminology will be useful in North Dakota, it is necessary that a system of lithostratigraphic or morphostratigraphic terminology be established; this terminology will be the basis for later syntheses of regional geologic history and for the construction of a practical time-stratigraphic terminology.

Lithostratigraphic-morphostratigraphic terminology

None of the drifts described below is a lithostratigraphic unit as defined by the American Commission on Stratigraphic Nomenclature (1961, art. 4). The sub-Napoleon drift is too local to be any kind of formal stratigraphic unit. Nor are the Napoleon, Long Lake, and Burnstad Drifts lithostratigraphic units because they have been recognized solely by their topographic form and geographic position. According to the Commission (art. 4e), "primary surface form . . . may be a factor in the definition of a lithostratigraphic unit, but should be subsidiary to the character of the rock itself." The Napoleon, Long Lake, and Burnstad Drifts are more nearly morphostratigraphic units as defined by Frye and Willman (1960, p. 7-8). According to them, a morphostratigraphic unit is a "body of rock that is identified primarily from the surface form it displays," and "consists of the end moraine, ground moraine, and the continuation of the natural unit in subsurface where recognisable."

This definition, however, must be modified for use in the present study. "Moraine" is best used as a geomorphic term rather than as a stratigraphic or lithologic term; a morphostratigraphic unit should therefore contain "till of moraine" rather than "moraine." Furthermore, Frye and Willman's definition excludes all associated washed drift and the till of associated minor recessional moraines and dead-ice moraine. A morphostratigraphic unit is therefore redefined for use in this report as a body of sediment that is identified by its surface form and position and consists of the till of the end moraine, associated minor recessionals, ground moraine, dead-ice moraine, associated lake sediment and outwash, and associated subsurface drift. Thus, the outwash in front of the Burnstad moraine and derived from the glacial ice that deposited the Burnstad moraine is considered part of the Burnstad Drift.

Sub-Wisconsin (?) Stages

Sub-Napoleon drift.--Till believed to be older than the lower Wisconsin Napoleon Drift was found at only one place in the northern part of Logan County. It is in a 25 foot road cut in the northwest corner of sec. 20, T. 136 N., R. 72 W., 5 miles north of Napoleon. Because the road cut is partly covered with fill, relationships between the materials in the exposure are incompletely known. The till at the base of the exposure is yellowish gray (5Y 7/2) when dry, is fairly well consolidated, and has numerous widely spaced joints that are as much as 10 feet long and are bordered on either side by a 1 inch iron and manganese oxide stained zone. This till is 5 feet or more thick. It rests on a yellowish silt that is believed to be part of the Fox Hills Formation. The till, in turn, is overlain by about a foot of coarse gravel that is stained with iron oxide. This gravel is overlain by about 20 feet of Napoleon and Burnstad till and outwash.

The till at the base of the exposure is thought to be sub-Wisconsin because it differs greatly from all other till in northern Logan County in being consolidated and having long joints with iron and manganese oxide-stained zones. Flint (1955, p. 31-32) thought that these joints are important distinguishing characteristics of sub-Wisconsin tills in South Dakota. Other drifts that may belong to a sub-Wisconsin stage are the jointed till and iron oxide-cemented outwash in southern Logan County (Bonneville, 1961, p. 27-38) and the "older drift" observed in drill holes in the Streeter area (Paulson, 1952, p. 28-29).

Wisconsin Stage

Lithology

The lithologies of the three Wisconsin Stage drifts, the Napoleon, Long Lake, and Burnstad, are very similar. The till is light olive gray (5Y 5/2) when dry and contains about equal amounts of clay, silt, and sand, and about 5 percent pebbles, cobbles, and boulders. Pebble lithology and source, based on twenty five 100 pebble samples, is shown in table 2. Winters (1960, p. 52) observed that dark igneous rocks are about half as abundant in the surface till in the Jamestown area in Stutsman County as they are in Logan County. He also indicated that shale is less abundant there, but he may have used different methods of estimating its amount. Shale content of northern Logan County till was determined

Table 2.--Approximate composition and source of pebbles from till of the Napoleon, Long Lake, and Burnstad Drifts, in northern Logan County.

Lithology	Source	Percentage
Shale	Pierre, local and eastern North Dakota	50
Limestone and dolomite	Paleozoic, Manitoba	25
Dark, fine-grained igneous rocks	Canadian Shield	10
Light-colored, coarse-grained igneous and gneissic rocks	Canadian Shield	10
Siliceous rocks	Local; Paleozoic, Manitoba; and Canadian Shield	5
Mudstone	Fox Hills and Pierre concretions, local and eastern North Dakota	5
Dark, coarse-grained igneous rocks	Canadian Shield	5
Sandstone	Fox Hills, western part of Logan County	1
Lignite (?)	Northeast or north of Logan County	1

by wet sieving all pebbles from samples of till; pebble counts made at clean till exposures in the field usually result in too low values for fissile shale.

Irregular concentration of iron oxide and calcium carbonate below the A soil zone gives the till a mottled appearance. In some places the till has numerous gypsum crystals that average about 0.05 inches across. The surface till is poorly consolidated and is unjointed or has very poorly developed irregular joints.

Approximate surface boulder and cobble lithology and source, based on several field estimations, is shown in table 3.

Many of the dark, fine-grained igneous rocks have 1 to 2 inch vesicles. Limestone and dolomite cobbles and boulders are over four times more abundant in the Jamestown area of Stutsman County than they are in Logan County (Winters, 1960, p. 55). This might be partly the result of Logan County's greater distance from the source area in Manitoba. In some areas, such as sec. 7, and 8, T. 134 N., R. 73 W., many of the boulders have been polished and etched by wind-blown sand. Boulders more than 5 feet in diameter are rare. Most of the largest ones have their sides polished about 3 feet above the ground and are surrounded by 1 to 3 foot depressions; they were used by bison as rubbing stones (see Stalker, 1956, p. 12).

Outwash (used in this report to mean washed glacial drift deposited by meltwater streams) underlying the flat outwash plains varies from coarse, poorly-sorted gravel adjacent to the end moraines to well-sorted fine sand a few miles away from the end moraines. The high relief outwash

Table 3.--Approximate composition and source of surface boulders and cobbles in northern Logan County.

Lithology	Source	Percentage
Light-colored, coarse-grained igneous and gneissic rocks	Canadian Shield	75
Dark, fine-grained igneous rocks	Canadian Shield	20
Limestone and dolomite	Paleozoic, Manitoba	5
Dark, coarse-grained igneous rocks	Canadian Shield	5
Silicous rocks	Local; Paleozoic, Manitoba; Canadian Shield	5
Sandstone	Fox Hills, western Logan County	1

near Napoleon and the collapsed outwash of the Coteau has more variation within shorter distances. The lithology of outwash pebbles is similar to that of the surface till, except that shale varies from less than 1 percent to nearly 30 percent. The outwash of northern Logan County seldom contains the large amount of shale that is so common in the outwash east of the Coteau.

Sediments of ice-contact lakes are largely light yellowish brown silt. Darker clay and fine sand are less abundant. Most of the lake sediments are horizontally stratified, with individual beds a fraction of an inch thick, but near ice-contact faces the bedding is folded, distorted, and faulted. Lake Napoleon sediment is dark, poorly stratified clay. No varves were identified in any of the lake sediments in northern Logan County.

Napoleon Drift

The Napoleon Drift, which is thought to belong to the lower part of the Wisconsin Stage, was observed only in that part of Logan County west of the Missouri Coteau. The name "Napoleon drift" was first used informally in southern Logan County by Bonneville (1961a, p. 6; 1961b, p. 26).

Name and definition.--The Napoleon Drift is here defined as a morphostratigraphic unit consisting of the till of the ground moraine in the area southwest of the Coteau in northern Logan County and all other associated drift that originated from the same glacial ice. The area south of Napoleon in secs. 32 and 33, T. 135 N., R. 72 W., and secs. 4, 5, 8, 9, T. 134 N., R. 72 W., is designated as the type area.

The Napoleon Drift is distinguished from younger drifts by its topography and position. Its drainage is nearly completely integrated, and it has few undrained depressions; the drainage on the younger drifts is nonintegrated. The Napoleon is thinner than younger drifts; it probably averages more than 10 feet thick in much of the area, but it is represented by only a few stones lying on bedrock in many places along the western border of the county, and it has been completely eroded away from the Beaver Creek area in southern Logan County. The Napoleon was nowhere definitely recognized beneath younger drift. At only one place (described in the section on sub-Napoleon drift) it is thought to rest on older drift, and at all other places where its base was observed it rests on bedrock.

Morphostratigraphic correlation.--The Napoleon Drift is probably equivalent to the "Tazewell (?)" drift of Lemke and Colton (1958, p. 47) and is probably the surface drift over most of the northern two-thirds of Emmons County, the western two-thirds of Burleigh County, the northwestern quarter of McIntosh County, and the southwestern quarter of Logan County (fig. 15). There is no definite evidence that it correlates with any stratigraphic unit in South Dakota, although Lemke and Colton's suggested correlation with Flint's (1955, p. 91-92) "Tazewell" drift in central South Dakota may be correct. A gross correlation between the Napoleon Drift and the drifts of Flint's "Tazewell" and "Iowan" Substages in South Dakota is suggested by their similar drainage integration, thinness, abundance of small kames, and lack of any great amount of weathering. Similarily, the "Tazewell (?)" drift of Lemke and Colton

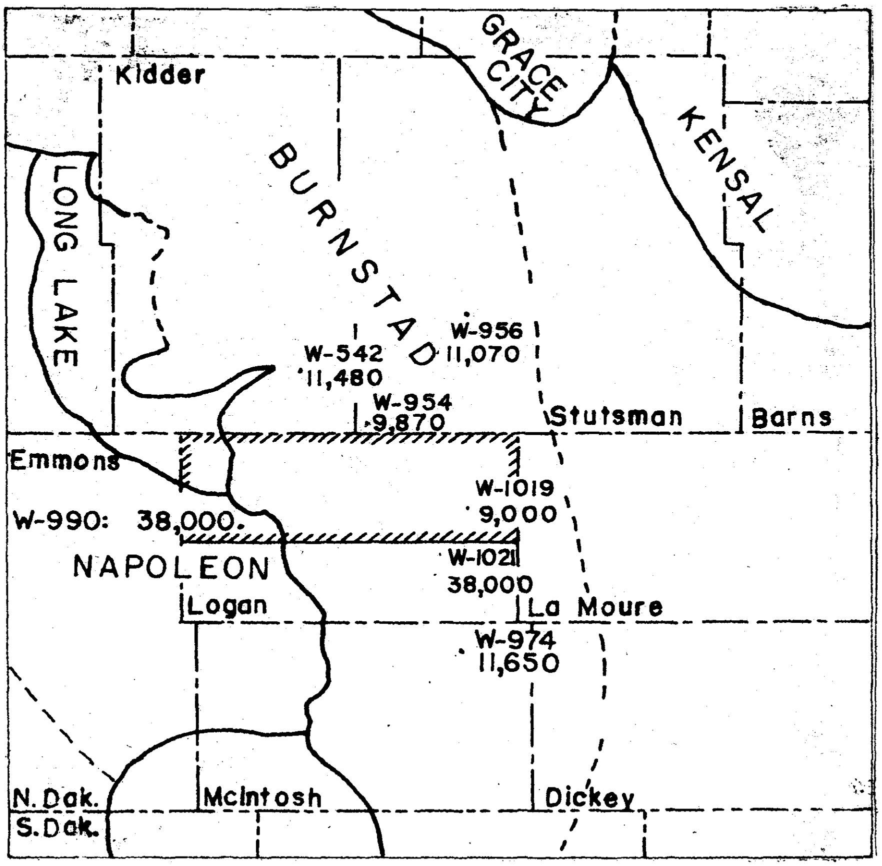


FIGURE 13.--Radiocarbon dates and regional distribution of surface drifts in south-central North Dakota.

(1958) in northern Mercer County in west-central North Dakota may be equivalent to the Napoleon Drift because it also has numerous small kames, whereas the "Iowan (?)" drift of Lemke and Colton (1958) in southern Mercer County is older and has few kames (Benson, 1952, p. 196).

Time-stratigraphic correlation.--The Napoleon Drift has been correlated with the "Mankato" by Benson (1952, p. 194; see Lemke, 1960, p. 38), the "Tazewell (?)" by Lemke and Colton (1958, fig. 3), the "Early Wisconsin" by Leonard (1916, p. 532), the "Iowan or Illinoian" by Alden (1932, p. 75-79), the "Illinoian or Iowan" by Leverett (1917, p. 144), and the "Kansan or Nebraskan" by Todd (1914, p. 58). There are five reasons for believing that the Napoleon Drift belongs to the lower part of the Wisconsin Stage:

1. It is younger than the sub-Wisconsin stages because it is only slightly weathered and has none of the characteristics of sub-Wisconsin tills in South Dakota as described by Flint (1955, p. 31-32).

2. It is probably older than the upper part of the Wisconsin Stage because it has a well integrated drainage pattern developed on it.

3. It is probably older than the upper part of the Wisconsin Stage because it has been radiocarbon dated by the U. S. Geological Survey (W-990) at greater than 38,000 years old. The dated material was a clayey peat collected from the gravel pit discussed above in the section on Lake Napoleon strandlines. The gravel is known to be no older than the Napoleon Drift because the upper beds have not been disturbed by a later readvance and the gravel has no till on top of it. The gravel is

known to be no younger than the Napoleon Drift because it is in a high position, separated from the outer limit of the next glacial advance by a drainage divide and an interdivide area to the east and a broad valley to the north. The only stratigraphic uncertainty involved is the possibility that the clayey peat was derived from a much older deposit.

4. Lloyd L. Joos, soil scientist for the U. S. Department of Agriculture Soil Conservation Service, suggested (written communication, March 13, 1961) that the soils on the Napoleon Drift are not "a great deal older" than the soils on the Long Lake and Burnstad Drifts, because soils on the Napoleon Drifts have little accumulation of clay in the B horizon. He did not think they are the same age, however, and suggested that the soil on the Napoleon Drift "is probably about 3 times as old" as the soil on the Long Lake and Burnstad Drifts, although he could not substantiate this "with any concrete evidence." If the Napoleon Drift is three times as old as the Long Lake and Burnstad Drifts, it is greater than 30,000 years old; that is, it belongs to the lower part of the Wisconsin Stage.

5. The Napoleon is similar to and laterally correlates with the drift in South Dakota that Flint (1955, pl. I) called "Tazewell" and "Iowan" (Lemke and Colton, 1958, fig. 3). Flint said (1955, p. 90) that the "Tazewell" and "Iowan" are lower Wisconsin and are much older than the upper Wisconsin "Cary" and "Mankato" drifts. Flint presented evidence (1955, p. 83-84) that the "Iowan" of South Dakota correlates with "Iowan" in Iowa, and therefore assumed that the drift between the

"Iowan" and "Cary" in South Dakota could be equivalent to only the Tazewell in Illinois. This is improbable, however, because type Tazewell, which is about 18,000 years old (Frye and Willman, 1960 fig. 1), is nearer in age to the type Cary, which is about 14,000 years old (Frye and Willman, 1960, fig. 1), than it is to type Iowan, which is now known to be older than 38,000 years (Ruhe and Scholtes, 1959, p. 589). It is therefore likely that the drift in South Dakota that Flint called "Tazewell" is much older than type Tazewell in Illinois. It is likewise probable that the drift in North Dakota that Lemke and Colton (1958, fig. 3) called "Tazewell (?)," which is, at least in part, equivalent to the Napoleon Drift, is much older than type Tazewell. The "Tazewell" in South Dakota, the "Tazewell (?)" in North Dakota, and the Napoleon Drift are probably about the same age as the type "Iowan;" that is, they belong to the lower part of the Wisconsin Stage.

Long Lake Drift

The Long Lake Drift of northwestern Logan County consists of the till of the Long Lake end moraine and associated outwash and lake sediment. The type area is near Long Lake in southeastern Burleigh County (Hansen and Kume, in preparation). The Long Lake Drift is overlapped in Logan County by the Burnstad Drift and extends northwest into Kidder, Emmons, and Burleigh Counties (fig. 15). The Long Lake Drift is distinguished from the younger Burnstad Drift by its topography and position (see discussion in section on Burnstad end moraine).

The Long Lake Drift has not been radiocarbon dated and has not been correlated with any drift of known age. Because it underlies the Burnstad

Drift, yet has a nearly noneroded topography, the Long Lake Drift probably belongs to the upper part of the Wisconsin Stage.

Burnstad Drift

The Burnstad Drift, which belongs to the upper part of the Wisconsin Stage, covers the eastern three-fourths of northern Logan County. The name "Burnstad" was first applied to the Burnstad end moraine by Lemke and Colton (1958, fig. 3) and was first used in an informal morphostratigraphic sense by Bonneville (1960b, p. 49).

Name and definition.--The Burnstad Drift is here defined as a morphostratigraphic unit consisting of the till of the Burnstad end moraine and other associated drift that was deposited from the same glacial ice, including the till of other associated end moraines, dead-ice moraine, and ground moraine, and associated outwash and lake sediment. The type area is designated as the eastern part of secs. 9 and 16, and secs. 10-15, T. 134 N., R. 71 W., northwest of the town of Burnstad in southern Logan County.

Fossils in ice-contact deposits.--Numerous fossil fresh-water pelecypod and gastropod shells, ostracode carapaces, and charophyte zygospore cases were found in the following four deposits of Burnstad ice-contact washed drift (see Clayton, 1961, and Tuchill, 1961):

1. A 4-foot bed of marl overlying lake clay from an ice-contact lake 0.3 mile south of the northwest corner of sec. 27, T. 135 N., R. 71 W., between the Burnstad and Fresh Lake end moraine.

2. A small deposit of ice-contact lake silt capping a 50-foot hill at the northwest corner of sec. 28, T. 135 N., R. 68 W., east of the south loop of the Streeter moraine.

3. The base of a 1½-foot layer of silty and pebbly outwash sand lying on lake clay of an ice-contact lake, 0.4 mile south of the northwest corner of sec. 20, T. 135 N., R. 67 W., 9 miles south of Gackle.

4. A small body of ice-contact lake clay at the south edge of collapsed outwash topography, 0.4 mile north of the southwest corner of sec. 9, T. 136 N., R. 69 W., east of the north interlobe area of the Streeter moraine.

A composite list of the mollusks found in these deposits is as follows:

Amnicola cf. A. leightoni Baker

Armiger crista (Linnaeus)

Gyraulus cf. G. parvus (Say)

Gyraulus sp.

Helisoma anceps (Menke)

Helisoma campanulata (Say)

Helisoma trivolvis (Say)

Unidentified small lymnaeids

Physa sp.

Pisidium sp.

Promenetus cf. P. exacuous (Say)

Sphaerium sp.

Unidentified naiads

Valvata tricarinata (Say)

Valvata sp.

Because these mollusks are similar to those found today in relatively warm and permanent bodies of water with submerged vegetation in the Upper Midwest, it is assumed that the late Wisconsin ice-contact environments represented by the fossils from Logan County were similar to present day Upper Midwest fresh-water environments.

In their larval form, naiads are parasitic on fish, indicating that fish were present in the lakes and streams on and walled by stagnant Burnstad ice; fish could have migrated to these environments from the nonglacial drainage system to the west by swimming up several miles of superglacial streams.

Small fragments of a mammoth or mastodon tusk (UND paleontology collection no. 6063) were found in a roadcut in lake silt 0.45 mile east of the southwest corner of sec. 6, T. 135 N., R. 70 W., east of the Fresh Lake moraine. Curvature of the fragments indicates that the tusk had a diameter of at least a 2½ inches.

Morphostratigraphic correlation.--The surface extent of the Burnstad Drift is in large part the same as that of Lemke and Colton's (1958, fig. 4) "post-Tazewell - pre-Two Creeks" and "post-Cary maximum advance no. 1" drifts (fig. 15). It extends northward at least to the northern limit of the Streeter moraine in northern Sheridan County and southward at least to South Dakota, where it correlates with part of Flint's (1955, pl. 1) "Mankato" drift. Its eastern surface limit is unknown but may be the outer edge of the Grace City and Kensal-Oaks moraines.

The "Burnstad Drift" and "Streeter Drift" of Rau and others (in press) and the "post-Tazewell - pre-Two Creeks" drift and "post-Cary maximum no. 1" drift of Lemke and Colton (1958, fig. 4) are combined into a single morphostratigraphic unit, the Burnstad Drift, for four reasons:

1. Both were deposited from essentially the same ice sheet at essentially the same time.

2. Both are nearly identical topographically and lithologically.

3. The Streeter moraine probably represents an advance of, at most, only a few miles.

4. In many places the two cannot be differentiated. Where the Streeter moraine is absent, as in southern Logan County (Bonneville, 1961, p. 70-73), the "Burnstad" and "Streeter" tills cannot be distinguished, and collapsed outwash in front of the Streeter moraine probably was derived from both the ice behind the Streeter end moraine and ice between the Streeter and Burnstad end moraines.

Time-stratigraphic correlation.--Five radiocarbon dates determined by the U. S. Geological Survey (fig. 16) indicate that the Burnstad Drift belongs to the upper part of the Wisconsin Stage:

1. 11,070 ± 300 years B. P. (W-956). The date is from clam shells in several feet of Burnstad ice-contact outwash behind the Streeter end moraine in sec. 17, T. 139 N., R. 67 W., in Stutsman County.

2. 9,870 ± 290 years B. P. (W-954). The date is from clam shells in Burnstad (?) ice-contact (?) lake sediment in sec. 29, T. 137 N., R. 67 W., in Stutsman County. The shells were 1 foot below the surface.

3. 11,480 ± 300 years B. P. (W-542). The date is from spruce wood from southeast Kidder County (Moir, 1958). The wood came from near the base of a deposit of wind-blown fine sand that was probably derived

from newly deposited Burnstad outwash. The sand overlies Burnstad Drift of the Twin Buttes loop.

4. 11,650 ± 310 years B. P. (W-974). The date is from clam shells from 0.5 mile south of the northwest corner of sec. 20, T. 132 N., R. 68 W., in McIntosh County. The shells came from several feet of Burnstad lake sediment in a Streeter end moraine push ridge.

5. 9,000 ± 300 years B. P. (W-1019). The date is from clam shells from site number 3 discussed in the section on Burnstad Drift fossils. The shells were 1½ feet below the surface.

The 9,000 and 9,870 dates are from shells that were less than 2 feet below the surface and may have been contaminated or chemically altered. If there has been no contamination or alteration of the shells and the dates are correct, the Burnstad Drift was being deposited from before 11,300 years ago until after 9,300 years ago.

Recent Stage

Most of the observed postglacial sediments in northern Logan County are part of the Recent Stage. They consist mainly of black organic clay and silt that have accumulated in lakes, sloughs, and other undrained depressions and low areas. The only observed cuts in these deposits are the numerous cattle watering dugouts. Mollusk shells, ostracodes, and other organic remains are abundant in these sediments. Other postglacial sediments include minor amounts of alluvium along ephemeral streams, minor amounts of wind-blown silt and sand, and colluvium at the base of steep slopes.

WISCONSIN GLACIER CONDITIONS

Ice thickness

The small radii of curvature of the loops of the Fresh Lake and Streeter end moraines indicates that the glacier that deposited the Burnstad Drift was thin. Flint (1955, p. 135-136) estimated that the James lobe of the same glacier in South Dakota was about 1000 feet thick. He remarked that the glaciers of northeastern North America were much thicker, probably because the climate there was wetter than in the Dakotas. Flint also showed (1955, p. 134-135) that the glacier that deposited the equivalent of the Napoleon Drift was thicker than the glacier that deposited the equivalent of the Burnstad Drift. It might seem that the thick glacier would deposit thicker drift than the thin glacier. The opposite is true in South Dakota and south-central North Dakota; the Burnstad Drift is much thicker than the Napoleon Drift. Flint (1955, p. 136) stated that this is probably the result of a much shorter time during which the thicker glacier occupied the area.

Extent of glacial stagnation

Late Wisconsin glacial stagnation in Logan County was not restricted to a narrow terminal part of the glacier but occurred over relatively broad areas. The ice-walled lakes, which were at least 2 miles long, indicate that stagnant masses of ice were at least 2 miles across. The collapsed valley train west of Gackle is throughout its length elevated above adjacent dead-ice moraine depressions, indicating that the zone of stagnant ice here was at least 6 miles wide. Areas of dead-ice moraine that are over 15 miles wide and have no uncollapsed outwash plains or continuous meltwater channels suggest that a nearly continuous mass of stagnant ice over 15 miles wide occupied this area at one time. The presence of kame terraces on the outer slope of the Streeter end moraine and collapsed outwash in front of it indicate that the Streeter was in part formed in contact with a large amount of stagnant ice on the west side of the moraine. This suggests that discontinuous stagnant ice might have occupied an area over 20 miles wide on the Coteau. It is concluded that stagnant glacial ice occupied areas at least 10 miles wide and probably, at least in discontinuous masses, areas over 20 miles wide on the Missouri Coteau in late Wisconsin time.

Superglacial till

Amount

Stalker (1960b, p. 34) and Hoppe (1952, p. 26) stated that superglacial till is usually insignificant on continental glaciers. The presence of mollusks in ice-contact drift, described in a previous section, however, indicate that superglacial drift was present on the stagnant late Wisconsin ice in Logan County. The assemblage of mollusks found in ice-contact washed drift in Logan County is similar to the assemblage existing in lakes and streams of North Dakota and Minnesota today. These Logan County mollusks lived in lakes and streams that were on top of or walled by stagnant ice. Water temperature had to be well above freezing during a large part of the summer for these mollusks to thrive, and part of the water had to remain unfrozen the entire year for the survival of the fish populations on which the naiad larvae were parasitic.

The relatively high temperature of the water indicates that there was a warm climate during the time that the Burnstad ice stagnated and that the water was well insulated from the adjacent stagnant ice by a layer of drift. Ice surrounding the lakes and streams was probably also covered with drift; if it had been free of insulating drift, large amounts of meltwater would have formed and flowed into the bodies of water, keeping them cool.

Mollusk shells were found in only four bodies of ice-contact washed drift in Logan County. But because of the few exposures only a very small fraction of it was observed, it is probable that there are many more occurrences of mollusks in the ice-contact washed drift of Logan County. It is therefore probable that most of the stagnant late Wisconsin ice in Logan County was covered with superglacial till.

The average thickness of the superglacial drift is unknown, but it may have been similar to the thickness of the drift on the stagnant terminus of the Malaspina Glacier in Alaska. Where the drift is 2 or 3 feet thick on the Malaspina, there is frequent mass movement, but where the drift averages 5 to 10 feet thick, surface is stable and undisturbed forest grows on it (Tarr and Martin, 1914, p. 205).

Origin

The occurrence of superglacial drift over large areas of nunatak-free continental glaciers is apparently unusual. The origin of this drift must have required some special circumstances. These circumstances seem to have been related to an abrupt rise in elevation because dead-ice moraine is in many places restricted to high-elevation, plateau-like areas (Gravenor and Kupsch, 1959, p. 50) such as the Missouri Coteau in North Dakota and Saskatchewan, the Turtle Mountains in North Dakota and Manitoba, Moose Mountain in Saskatchewan, and the Leaf Hills in Minnesota. There are at least three possible reasons why abrupt rises in elevation are responsible for superglacial drift:

1. Nonglacial alluvium from northeast-flowing streams and some glacial outwash and lake sediment may have accumulated on top of the ice between the northeastward sloping land and the southwestward sloping ice (fig. 16a). Probably this was of little importance, however, because most of the dead-ice moraine is composed of till rather than collapsed inwash and washed drift.

2. Marginal thrusting in that part of the glacier that is less than 200 feet thick, as illustrated by Flint (1957, fig. 5-14), may have brought large amounts of subglacial till to the surface of the ice. The elevated east edge of the Coteau caused increased thinning of the glacier and may have caused increased marginal thrusting (fig. 16b).

3. A mechanism suggested by Flint (1955, p. 114) is glacial readvance over thin stagnant masses of ice in low areas and deposition of ground moraine till on top of the stagnant ice. Low areas in which stagnant ice could persist would be provided by deep valleys eroded in the steep east edge of the Coteau (fig. 16c). If this actually occurred, some plateau-like areas of ground moraine should remain in areas where

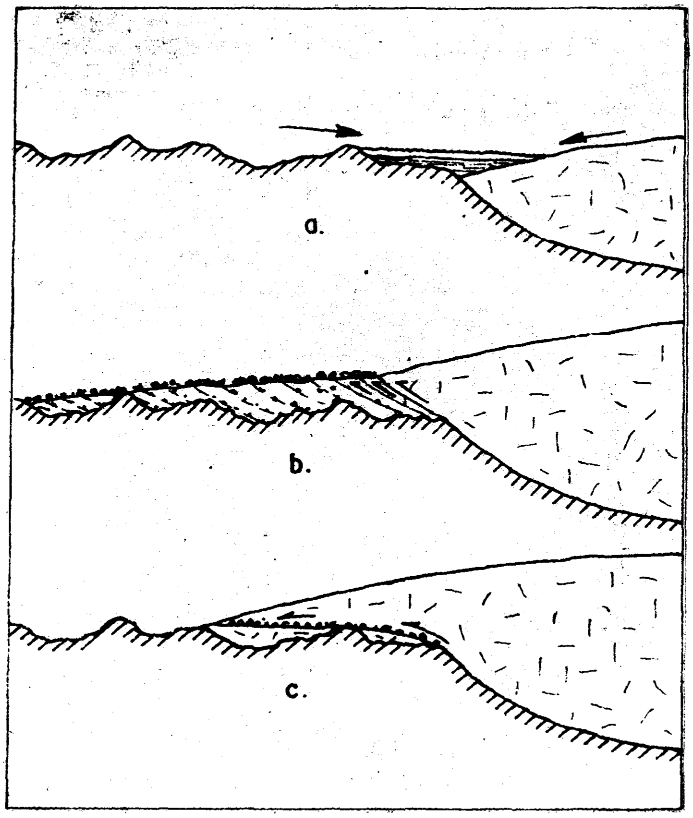


FIGURE 16.--Origin of superglacial drift on late Wisconsin ice on the Missouri Coteau. a. Inwash on top of terminus. b. Marginal thrusting. c. Overriding of stagnant ice.

there was no stagnant ice. None were observed in Logan County, although this could have been the origin of some of the moraine plateaus of Hoppe (1952, p. 5) and Gravenor and Kupsch (1959, p. 51-52).

It seems probable that the late Wisconsin superglacial drift in Logan County originated by either or both the second and third methods.

Rate of melting of stagnant ice

The drift-covered stagnant ice on the Missouri Coteau probably melted very slowly. This is indicated by the presence of the snails *Valvata* and *Amnicola* in the superglacial lakes. These snails have gills and require relatively silt-free water, indicating that the meltwater was formed slowly enough for the silt to settle out of it (and slowly enough for the sun to warm it).

A second evidence for slow melting is the radiocarbon dates that were discussed in the section on the time-stratigraphic correlation of the Burnstad Drift. If it is assumed that the dated material had undergone no chemical alteration and was uncontaminated, the stagnant ice that deposited the Burnstad Drift was present on the Coteau from at least 11,300 years ago until at least 9,300 years ago, or for over 2000 years.

It is not impossible that it took 2000 years for the late Wisconsin ice on the coteau to melt. The drift-covered terminal part of the Malaspina Glacier in southern Alaska is covered with trees that are nearly 100 years old (Tarr and Martin, 1914, p. 205). These trees are straight and upright, indicating that the underlying stagnant ice has undergone little change in the last 100 years. It therefore seems possible that it will take a few hundred years for the stagnant Malaspina ice to melt.

The Malaspina area presently has shorter and milder winters and much more rain than Logan County has now and probably had in later Wisconsin time. The average January temperature at Cordova, 175 miles west of Malaspina Glacier, is 27°F and the mean yearly precipitation is 145 inches, as compared with 7°F and 17 inches at Napoleon (U. S. Department of Agriculture, 1941). Because large amounts of rain would greatly accelerate melting of the drift-covered ice, it is likely that the stagnant late Wisconsin glacier on the Coteau melted slower than the stagnant part of the Malaspina Glacier. It is therefore concluded that it is possible that the previously mentioned radiocarbon dates are correct; and if so, it took over 2000 years for the drift-covered stagnant ice on the Missouri Coteau to melt.

If this is true, glacial ice persisted on the Missouri Coteau for over a thousand years after the glacial ice had melted in the rest of North Dakota. A radiocarbon date of 10,050 ± 300 years B. P., determined by the U. S. Geological Survey (W-1005) from driftwood under 7 feet of gravel of one of the lower beaches of Lake Agassiz in sec. 14, T. 150 N., R. 51 W., in Grand Forks County, North Dakota, indicates that the glacial ice that deposited the Edinburg end moraine (Lemke and Colton, 1958, fig. 5) had melted and the upper Lake Agassiz beaches (formed when the River Warren outlet was in use) were formed over 10,000 years ago.

Cause of stagnation

Large scale stagnation such as existed in Logan County did not occur in most of North Dakota east of the Missouri Coteau. This is indicated by the lack of dead-ice moraine and the presence of many active-ice features, such as ground moraine, washboard moraine, and streamline flow features. It is therefore probable that glacial stagnation was also related to the abrupt rise in elevation of the Coteau and was related to the same mechanism that produced the large amounts of superglacial drift. High relief caused by erosion on the eastern slope of the Coteau may have furnished low areas in which ice could be caught and become stagnant. The abrupt rise in elevation at the east edge of the Coteau may also have been the cause of increased marginal thinning of the ice, thus increasing the likelihood of stagnation. Another possible cause of stagnation is overloading of the ice with englacial till (Flint, 1942, p. 122).

SYNTHESIS OF PLEISTOCENE HISTORY

Pre-Wisconsin (?) ages

Phase 1. Little is known about Logan County pre-Wisconsin glaciations other than that at least one probably existed.

Phase 2. During the interglacial time that followed, most of the sub-Wisconsin (?) drift was eroded away, and an integrated drainage system was established (fig. 17).

Wisconsin Age, early part (?)

Phase 3. More than 38,000 years ago a glacier advanced completely over Logan County and deposited a thin blanket of Napoleon till.

Phase 4. As the ice front retreated, glacial Lake Napoleon was formed. It drained first to the south at a low point in the divide. Small outwash deltas were formed along the shoreline. As the ice melted from the north end of the valley, glacial Lake Napoleon drained to the northwest, possibly through the partly buried channel in the northwest corner of the county (fig. 18).

Phase 5. Following the glaciation that deposited the Napoleon Drift, there was a time of nonglaciation, totaling over 25,000 years. Drainage was reintegrated into a pattern similar to that of pre-Wisconsin time. Probably only a few feet of Napoleon till was eroded away from northern Logan County (fig. 19). In other areas, such as a few miles on either side of Beaver Creek in southern Logan County, all Napoleon till was eroded away.

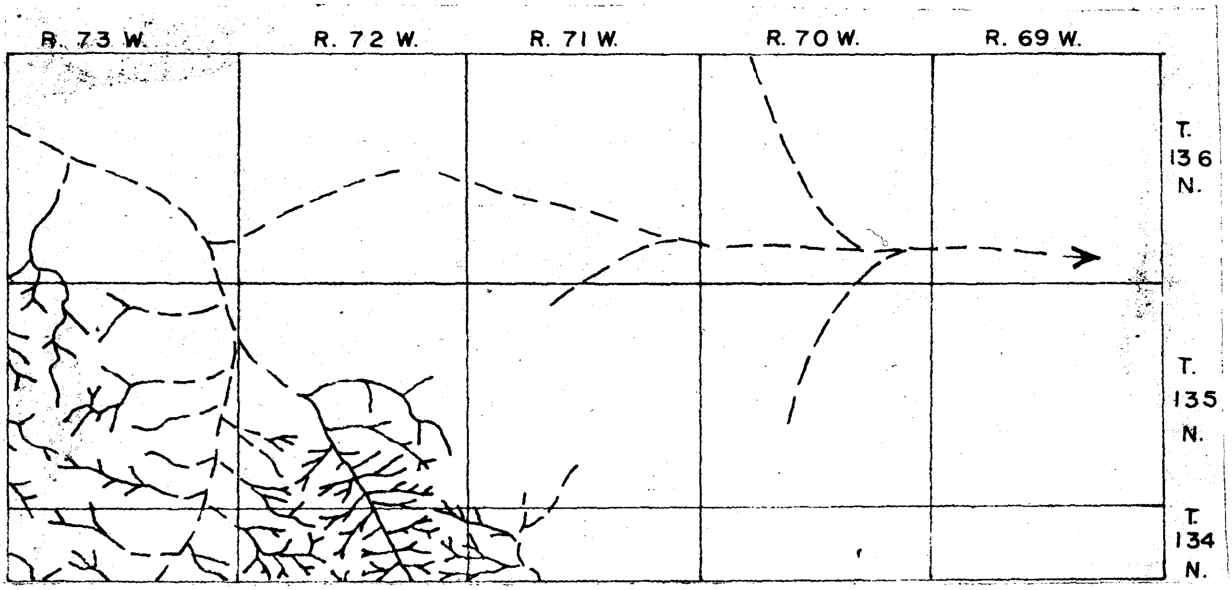


FIGURE 17.--Pleistocene history phase 2--preglacial drainage.

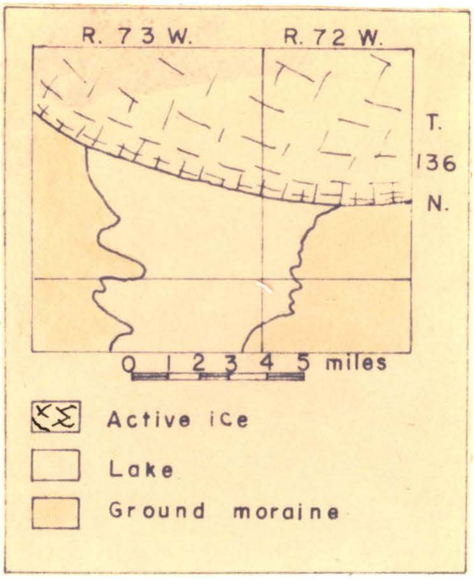


FIGURE 18.--Pleistocene history phase 4. Formation of Napoleon ground moraine and Glacial Lake Napoleon.

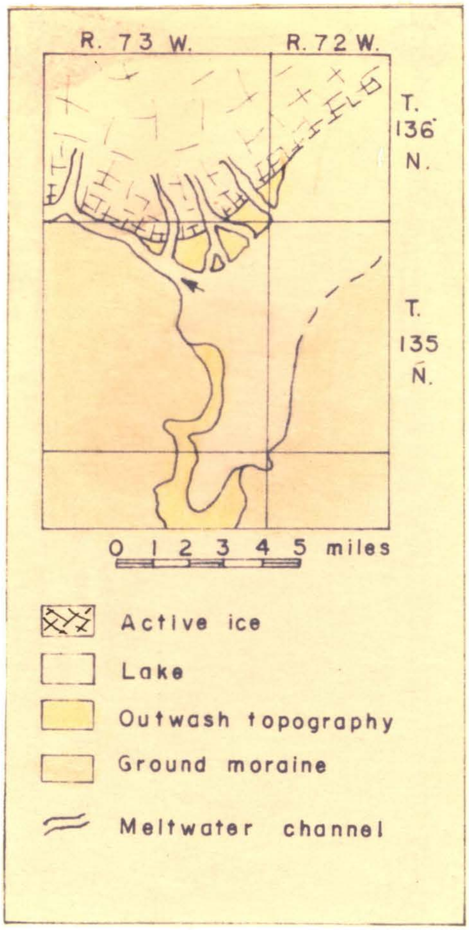


FIGURE 19.--Pleistocene history phase 5. Interglacial interval.

Wisconsin Age, late part

Phase 6. The Long Lake advance occurred during the late part of the Wisconsin Age. The Long Lake ice moved about 6 miles into the northwest corner of Logan County, and again blocked the north end of the valley west of Napoleon, again forming Lake Napoleon. A delta-like elevated outwash plain was built out into the lake at the ice front, and a westward flowing ice-marginal meltwater stream eroded a spillway into bedrock (fig. 20).

Phase 7. The Long Lake ice margin retreated to the north, perhaps pausing a short time at the position marked by the north end of the meltwater channel in the southwest corner of T. 136 N., R. 73 W. A longer pause or a slight readvance occurred when Long Lake II moraine was formed.

Phase 8. After the Long Lake advance, there followed a period of perhaps hundreds to a few thousands years length, during which there probably was no glacial ice in Logan County. Only minor erosion took place during this time.

Phase 9. About 12,000 years ago the ice of the Burnstad advance covered the eastern three-fourths of northern Logan County. It formed the Burnstad end moraine and proglacial outwash plains and meltwater channels. The patch of dead-ice moraine in front of the Burnstad end moraine was probably deposited by a slightly earlier minor fluctuation of the Burnstad ice (fig. 21).

Phase 10a. During the eastward retreat of the Burnstad ice front, there was a standstill or slight readvance at the position marked by

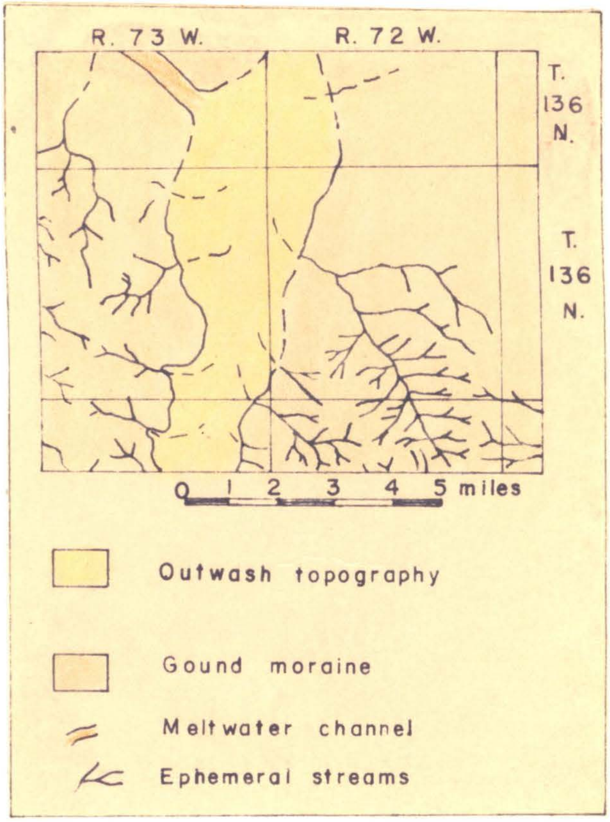


FIGURE 20.--Pleistocene history phase 6. Formation of Long Lake moraine and Glacial Lake Napoleon.

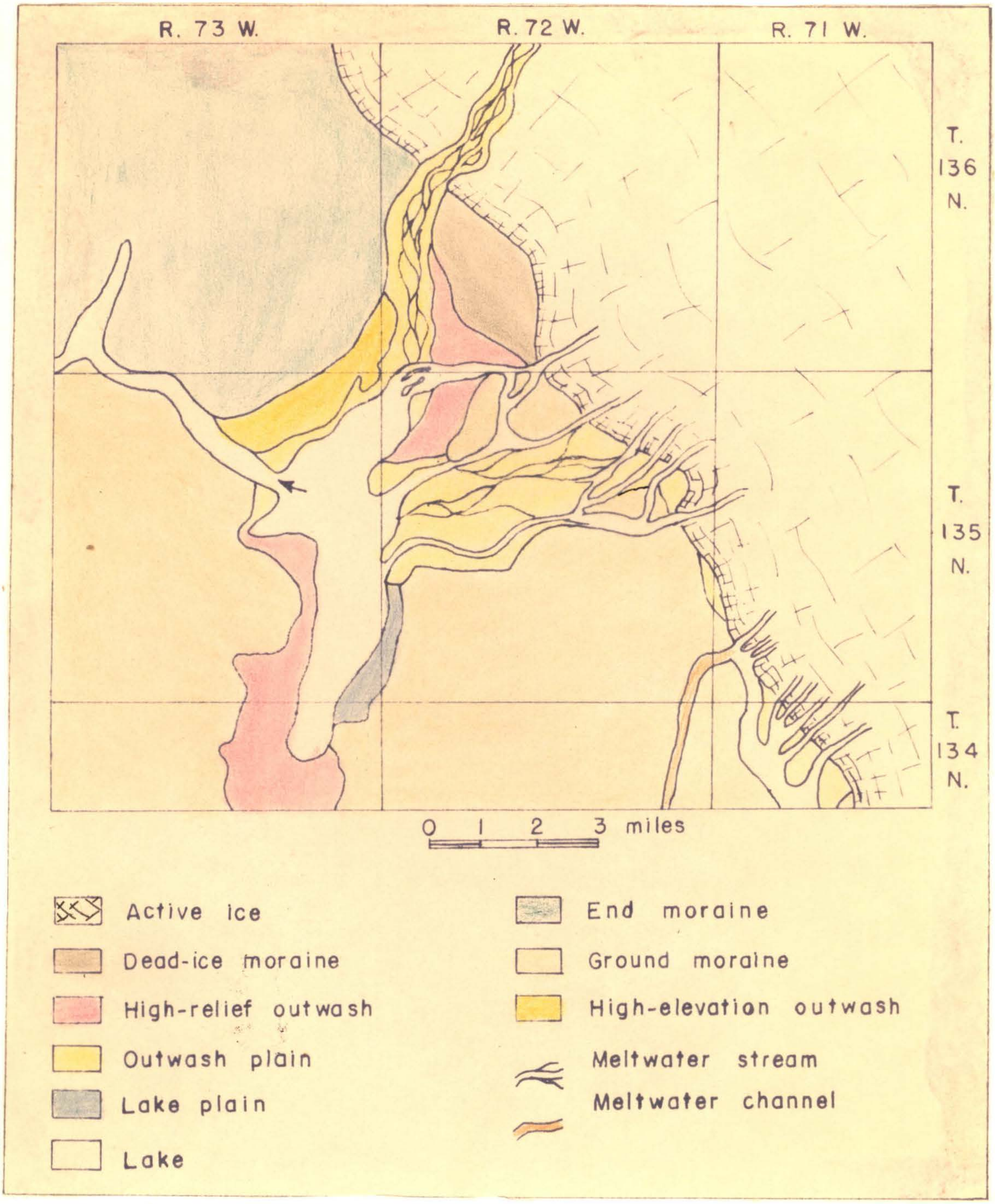


FIGURE 21.--Pleistocene history phase 9. Formation of Burnstad moraine.

recessional ridges and the terminated meltwater channel in sec. 4, T. 136 N., R. 72 W.

Phase 10b. During further retreat of the front of the active Burnstad ice, a zone of stagnant ice 3 miles wide separated from the main ice mass. This ice was covered with superglacial till that had been thrust up from beneath the ice. Lakes formed on top of the ice and in open holes in the ice (fig. 22).

Phase 10c. The Fresh Lake end moraine was formed during a standstill or slight readvance of the thinning Burnstad ice (fig. 22).

Phase 10d. The Burnstad active-ice front then retreated and left behind an 8 mile wide zone of debris-covered stagnant ice. Lakes were formed on and within the stagnant ice and meltwater streams flowed over it, depositing valley trains of outwash in the valleys on the stagnant ice mass. The ice between the Burnstad and Fresh Lake moraines continued to melt.

Phase 11. The active-ice front retreated eastward an unknown but probably short distance, and then, a slight readvance occurred, and the Streeter end moraine was formed. By this time much of the stagnant ice behind the Fresh Lake moraine at the northern edge of Logan County had melted; ancestral Alkaline Lake formed in this area. To the south, however, much still remained. The ice abutted against and overrode this stagnant ice at the outer edge of the Streeter moraine. Meltwater from behind the Streeter moraine deposited outwash plains and valley trains on top of Burnstad ice in front of the Streeter. The last of the ice between the Burnstad and Fresh Lake moraines may have been melt-

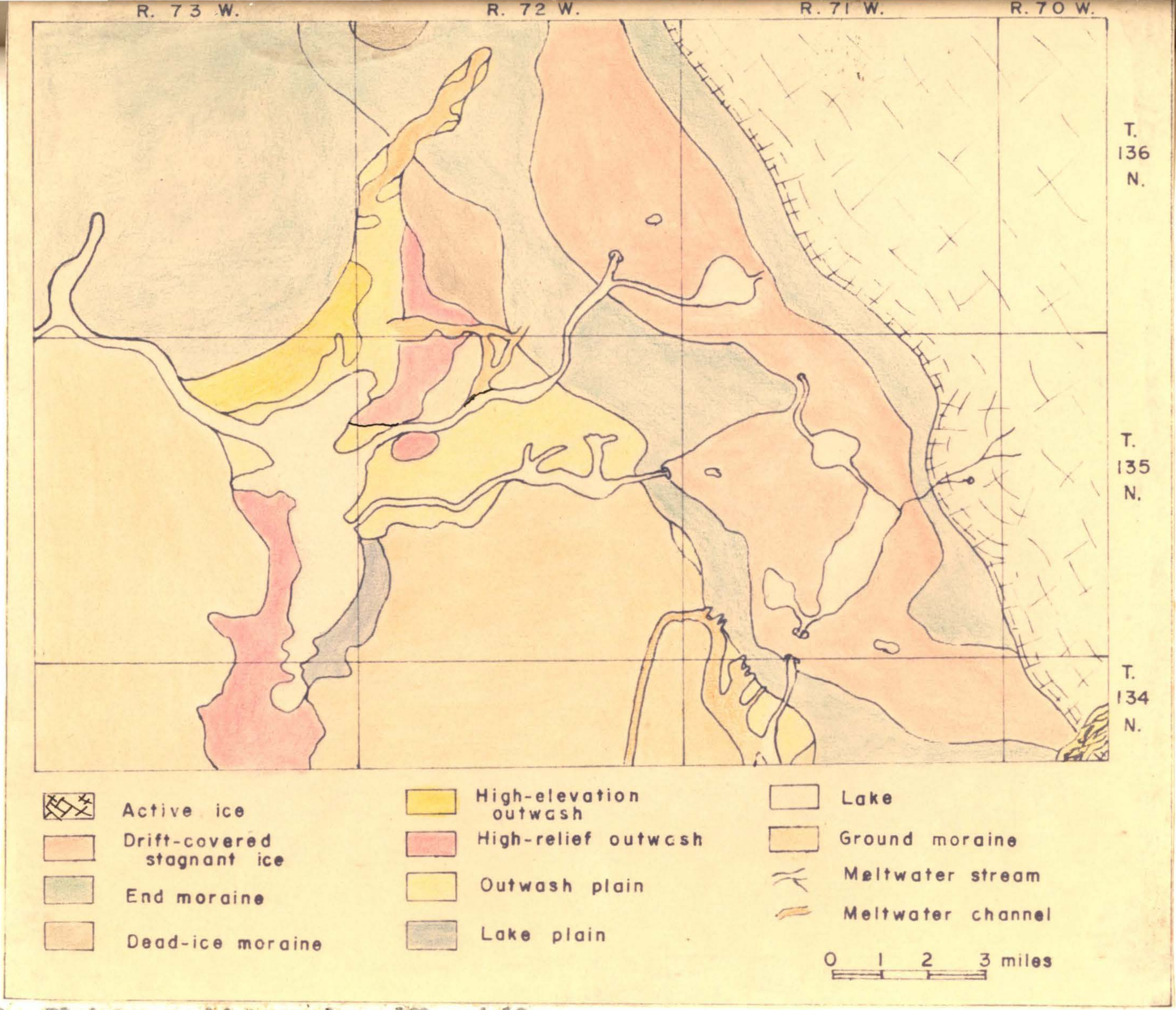


FIGURE 22.--Pleistocene history phase 10b and 10c.

ing at this time. The northern outlet of ancestral Alkaline Lake (in Kidder County) was further eroded, the lake level dropped, and the outwash plain west of the Streeter moraine was built out over the former lake bottom. Meltwater from the northern two Streeter lobes flowed northwestward to the Long Lake valley in Kidder County, and meltwater from the southern lobes flowed over stagnant Burnstad ice, through the Burnstad end moraine, and entered the Beaver Creek drainage system at Beaver Lake in southern Logan County (fig. 23).

Phase 12. The western edge of the Burnstad active ice mass then retreated from the county, leaving the eastern third of northern Logan County covered by a mass of stagnant ice. During the retreat, locally more active parts of the glacier formed the two minor recessional end moraines in the eastern part of the area.

The stagnant Burnstad ice was covered with superglacial till. In valleys on the irregular surface of the ice, meltwater from the melting ice deposited outwash in the form of superglacial valley trains. In other low areas on the ice, small outwash plains were deposited and lakes were formed.

As melting continued, the superglacial drift became thicker, causing the ice to melt more slowly. The superglacial drainage system became more sluggish, and the meltwater became warmer. The climate was relatively mild. Fish swam up the Missouri River tributary in Long Lake valley in Kidder County and entered the superglacial drainage system at the outlet at the north end of the north loop in Stutsman County. They swam up at least 12 miles of superglacial streams to reach the superglacial lake

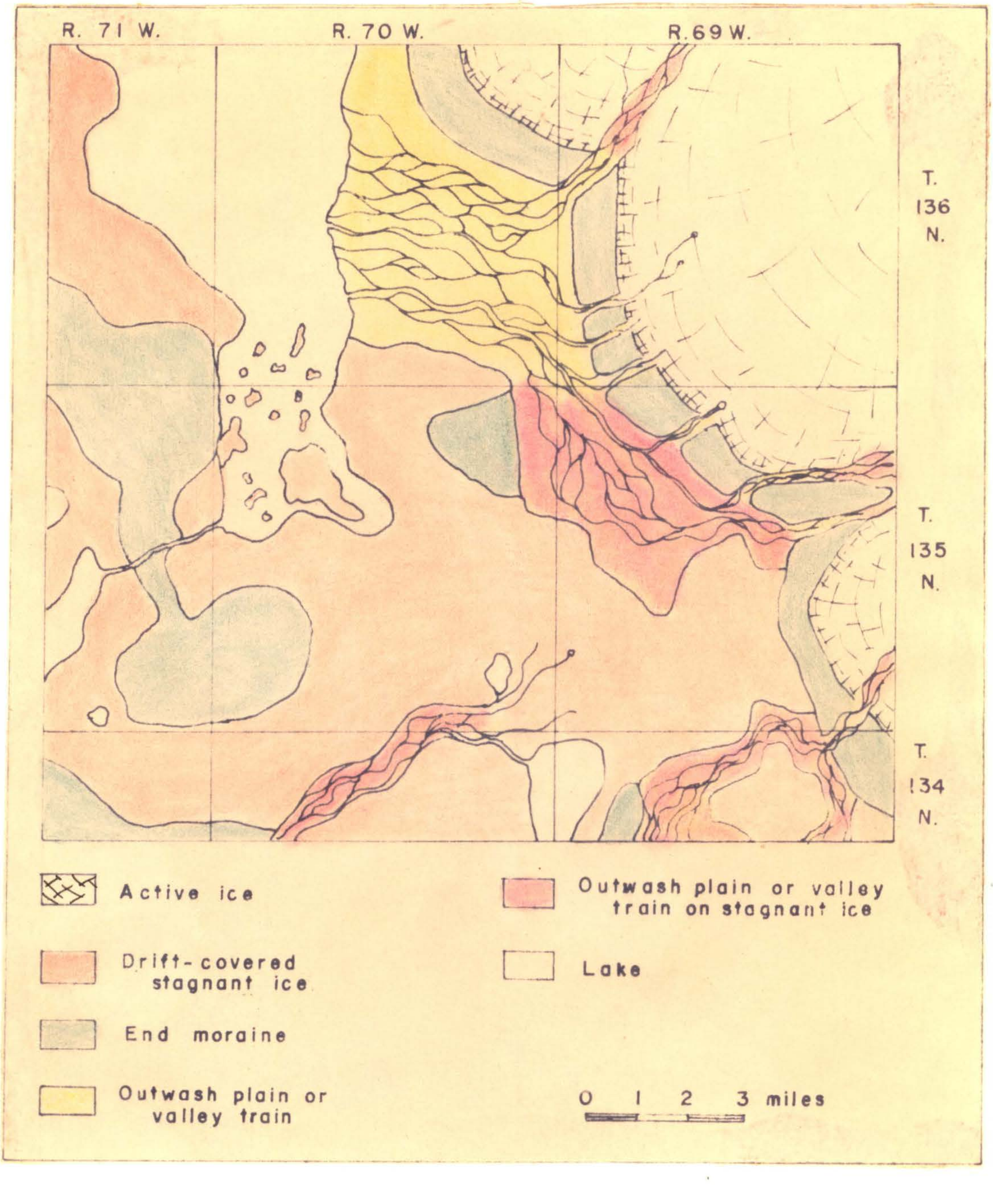


FIGURE 23.--Pleistocene history phase 11. Formation of the Streeter moraine.

in sec. 19, T. 135 N., R. 67 W. These fish carried with them the parasitic larvae of naiade clams, which became established in this and other ice-contact lakes. Water birds probably came to these superglacial lakes and streams, carrying several species of fresh-water snails in the mud on their feet and feathers; these snails, too, became established in the lakes, some of which were by now floored by solid ground but were still enclosed by stagnant ice. Also present in the streams and lakes were abundant ostracodes, stoneworts, and probably many other kinds of organisms. Plants and animals (including mammoths or mastodons) were probably also common on the till on top of the ice.

The superglacial environment was probably at first a very dynamic environment. Lakes and streams were continually being formed and drained as the ice melted at varying rates. Drift slid into crevasses, holes, and other low areas, exposing new ice to renewed downmelting. Later, after much of the ice had melted, the superglacial till was much thicker, and the environment was more stable.

As the last of the ice melted the superglacial till, outwash, and lake sediment were let down, forming a hummocky dead-ice topography, and the ice-walled lake plains were left perched above the surrounding dead-ice moraine. It may have taken more than 2000 years, or until less than 9000 years ago, for all the stagnant glacial ice in Logan County to melt.

Recent Age

Phase 13. Only minor changes have taken place in northern Logan County since the last Burnstad ice melted. There has been several feet of erosion in some gullys on the steepest slopes. In most places, however, erosion has probably been only a few inches or a few feet. Most of the eroded drift has been deposited in nearby sloughs and other low areas.

ECONOMIC GEOLOGY

Agriculture

The basic occupation of Logan County is agriculture. Land use is closely related to the glacial geology of the county. The ground moraine southwest of the Coteau is largely cultivated. It has gentle slopes, a medium number of surface stones, and is in most places well drained and free of sloughs.

End moraine generally has such steep slopes and large numbers of surface cobbles and boulders that it is permanently pastured instead of cultivated, but the Long Lake moraine has gentle slopes and is largely cultivated.

A large percentage of the dead-ice moraine is cultivated, though many areas are grazed and used for hayland. Dead-ice moraine has gentler slopes and fewer cobbles and boulders on the surface than end moraine and has a heavy clayey soil. It has large numbers of sloughs, which are usually left undrained.

Collapsed outwash topography has about the same land use as dead-ice moraine, but has few surface cobbles and boulders and has a sandy to gravely soil. Nearly all the outwash plains are cultivated. They are flat, free of boulders, and have a light sandy soil.

The ice-walled lake plains are flat, well drained, free of stones, and covered with a thick fertile silty soil. Nearly all are cultivated.

Surface water

Surface water is of little economic importance in northern Logan County. Small lakes and sloughs are used to water cattle. Many cattle-watering dugouts have been made in sloughs and other low areas to collect surface water and near-surface seepage, and in the area southwest of the Coteau small dams have been built across many ephemeral streams. Beaver Creek is the only permanent stream in the area.

Ground water

Next to the soil, the most important natural resource in the county is ground water. Except for the outwash plain around Napoleon, most ground water west of the Fresh Lake moraine is derived from bedrock sand and sandstone. Nearly all of the wells east of the Fresh Lake moraine are in drift. The surface outwash usually provides enough water for local use, and in addition, the outwash plain west of the Streeter moraine probably has enough ground water for extensive irrigation. It is underlain by a minimum average thickness of about 20 feet of saturated sand and gravel (Paulson, 1952, p. 43). The surface of the outwash plain is flat and is in most places well drained and is probably suitable for irrigation. The dead-ice moraine has many minor surface deposits containing water supplies adequate for local use. The Coteau is also underlain by many buried bodies of sand and gravel. Their size and the amount of water they contain would have to be determined by a detailed test drilling program.

Sand and gravel

Logan County contains nearly unlimited supplies of sand and gravel for use as road surfacing material and concrete aggregate. All of the outwash plains, collapsed and high-relief outwash topography, kames, and eskers, and many of the meltwater channels are underlain by gravel and sand of varying size and sorting. There are also many unmapped sand and gravel deposits in the dead-ice and end moraine; some of these deposits are marked as sand and gravel pits on plate 2. Pebbles in the gravel in northern Logan County are 1 to 30 percent shale.

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GLACIAL LANDFORMS
NORTHERN LOGAN COUNTY
NORTH DAKOTA

Scale: 1:63,360

PLATE I

E	End moraine Ei: Long Lake I Eii: Long Lake II Eb: Burnstad Ef: Fresh Lake Es: Streeter
G	Ground moraine Gi: with integrated drainage Gp: pitted with kettles
D	Dead-ice moraine
t	Prominent till hills
C	Collapsed outwash topography
k	Kame
kt	Kame terrace
e	Esker or outwash disintegration ridge
Li	Ice-walled lake plain
Lh	Lake sediment topography of high relief
O	Outwash plain
On	Outwash topography of high relief
M	Lake-modified till topography
L	Proglacial lake plain
ct	Meltwater channel terrace
	Meltwater channel
	Partly buried channel
	Glacial Lake Napoleon strandline
	Permanent lake, intermittent lake, or large slough
	Intermittent stream
	Sand and gravel pit
	Geologic contact, generally more accurate than 0.1 mile
	Geologic contact, may have accuracy of less than 0.1 mile
	Geologic contact, may have accuracy of less than 0.3 mile
—③—	Numbered state highways
——	Improved roads
- - -	Unimproved roads
——	Section lines

PLATE 2

STRATIGRAPHIC UNITS

NORTHERN LOGAN COUNTY

NORTH DAKOTA