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NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, *State Geologist*

Bulletin 37

GLACIAL GEOLOGY OF LOGAN AND McINTOSH COUNTIES NORTH DAKOTA

By

Lee Clayton

GRAND FORKS, NORTH DAKOTA

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ABSTRACT

Logan and McIntosh Counties, in south-central North Dakota, lie within two physiographic districts of the Glaciated Missouri Plateau of the Great Plains. The Coteau Slope district is characterized by integrated, westward-flowing drainage and thin glacial drift, and the Missouri Coteau district is characterized by nonintegrated drainage and thick glacial drift. The Coteau Slope is divided into four distinct subdistricts, the Napoleon and Wishek subdistricts, whose characteristic landform is ground moraine superimposed on preglacial stream-eroded topography, the Beaver Creek subdistrict, which has a stream-dissected topography, and the Zeeland subdistrict, whose dominant landforms are end moraine and ground moraine superimposed on stream-eroded preglacial topography.

The landforms of the Missouri Coteau include several end moraines, a large outwash plain, and numerous features that formed when the last glacier in this area stagnated, leaving bands of drift-covered ice several miles wide. The stagnation landforms include dead-ice moraine; forms composed of collapsed outwash, lake sediment, and subaqueous mudflows; ice-walled outwash and lake plains; and disintegration ridges and trenches.

The bedrock stratigraphic units of Logan and McIntosh Counties include 3,000 feet of flat-lying Paleozoic and Mesozoic formations in the subsurface and the Cretaceous Pierre, Fox Hills, and Hell Creek (?) Formations at the surface. Pleistocene units include the newly named Napoleon, Long Lake, Zeeland, and Burnstad Drifts. Fossil mollusk shells are common in ice-contact deposits of the Burnstad Drift. They have been radiocarbon dated at 9,000, 9,870, 11,070 and 11,650 years old.

The most important economic deposits in Logan and McIntosh Counties are the soil, ground water, sand, and gravel.

INTRODUCTION

Logan and McIntosh Counties comprise about 1996 square miles of south-central North Dakota (fig. 1). In this report the bedrock geology is briefly summarized and the glacial geology is described in detail. No detailed ground water study was made; ground water is discussed in general terms only. In the discussions that follow, landform terminology has been separated from stratigraphic terminology. Mingling of landform, lithologic, time-stratigraphic, lithostratigraphic, and morphostratigraphic nomenclature has probably contributed greatly to the confusion that now exists in Midwest glacial and Pleistocene geology. For this reason an attempt has been made to keep these terminologies independent of each other.

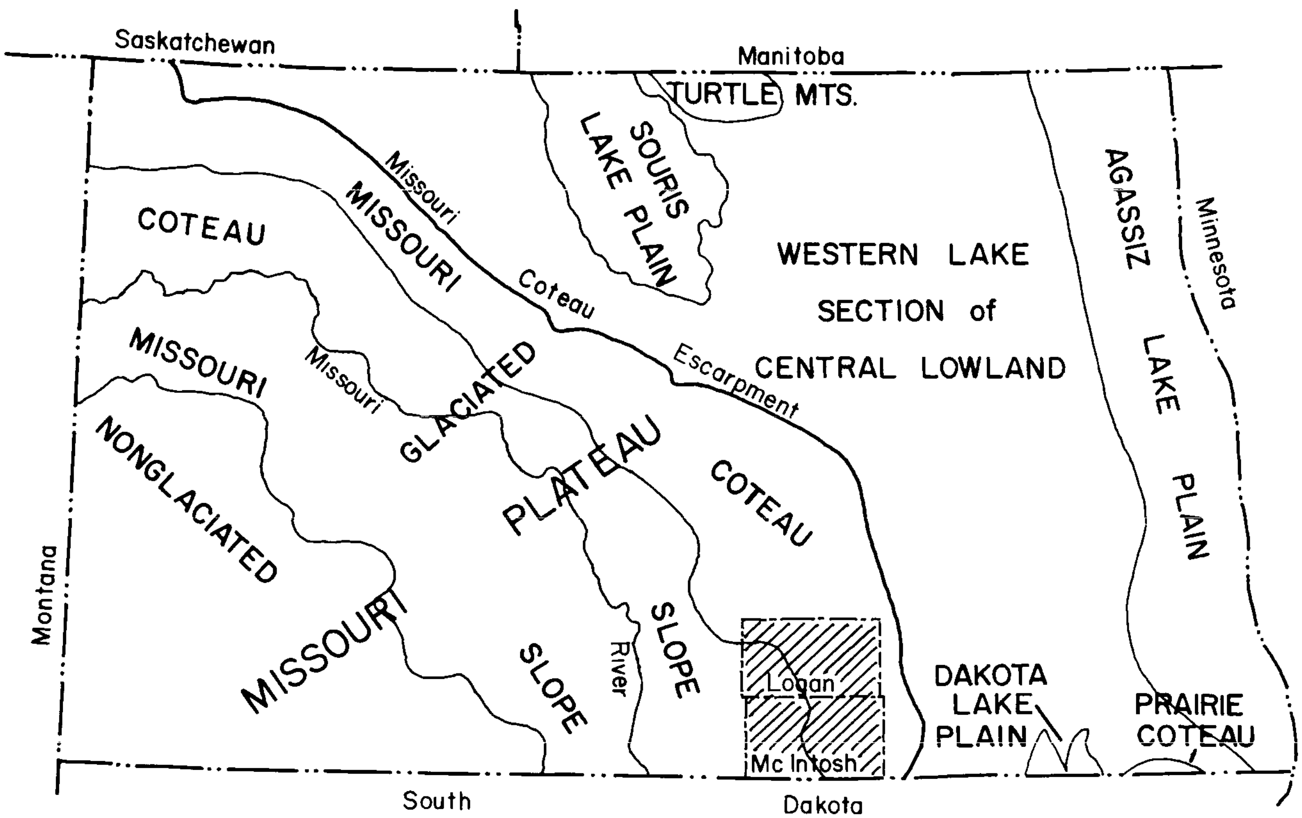


FIGURE 1. Index map of location of Logan and McIntosh Counties and physiographic units of North Dakota. Modified from Lemke and Colton, 1958, fig. 1.

Field work

During the summer of 1960 the southern part of Logan County (see insert on plate 1) was mapped by John W. Bonneville, and the northern part was mapped by Lee Clayton. The mapping of Paulson (1952) in the Streeter area of northern Logan County was rechecked and modified by Clayton. During the summer of 1961 the northern one-fourth of McIntosh County was mapped by Gary G. Thompson, and the rest of the county was mapped by Clayton.

Field information was plotted on the 1958 county highway maps, scale 1:63,360, prepared by the North Dakota Highway Department. Geologic contacts were plotted in the field on 1952 air photo stereopairs, scale 1:63,360, obtained from the U. S. Geological Survey. The only topographic maps of the area are the U. S. Army Map Service Jamestown and Aberdeen quadrangles (scale 1:250,000; contour interval 100 feet). Unpublished soil maps of about one-third of the two counties have been completed by the U. S. Department of Agriculture Soil Conservation Service. They were used to refine some of the geologic contacts.

Nearly every road in Logan and McIntosh Counties, 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 area mapped by Paulson (1952) and the areas immediately adjacent to the two counties. 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

I wish to thank the many people who have contributed to this study. Most of the information from southern Logan County and the northern one-fourth of McIntosh County was obtained by Mr. John W. Bonneville and Mr. Gary G. Thompson, employees of the North Dakota Geological Survey. They also provided the inspiration for many of the ideas presented in this report. Numerous helpful suggestions on the problems of field mapping were given by Dr. Harold A. Winters of Northwest Illinois University and geologist for the North Dakota Geological Survey. Part or all of the manuscript of this report was read and criticized by Dr. F. D. Holland, Jr., Dr. Wilson M. Laird, Dr. John R. Reid, Jr., Dr. Mark Rich, and Mr. S. J. Tuthill, of the University of North Dakota. Tuthill also helped with the identification, interpretation, and photographing of the fossil Pleistocene mollusks. Mr. Denis L. Delorme of the University of Alberta identified the ostracodes. Mr. John P. Knecht and Mr. Clifford E. Jeske, of the U. S. Department of Agriculture Soil Conservation Service in Napoleon and Ashley, permitted the use of unpublished soil maps. Mr. Edward Bradley, District Geologist of the U. S. Geological Survey Ground Water Branch in Grand Forks, provided subsurface lithologic information. Dr. Meyer Rubin, of the U. S. Geological Survey, provided several radiocarbon dates. Clayton's 1960 field work for this study was supported by the National Science Foundation. All phases of this study were guided by Dr. Wilson M. Laird, State Geologist.

Previously published work

Regional studies

Only two regional glacial geology studies have included Logan and McIntosh Counties. The first, by Todd (1896), outlined the glacial geology of the Missouri Coteau from about 25 miles north of Logan County to southern South Dakota. Todd was the first to give a detailed description of some of the glacial landforms of Logan and McIntosh Counties. He described the "Long Lake loop," the "Blue Blanket loop" (Zeeland end moraine), and "Blue Lake loop" (Burnstad end moraine) and "Antelope Valley loop" (Streeter 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. The second regional study, the work of Lemke and Colton (1958), is the most comprehensive summary of North Dakota Pleistocene geology. 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.

A third regional glacial geology study is that of Flint (1955) on the Pleistocene geology of eastern South Dakota. It contains no reference to Logan or McIntosh County, but many of the problems discussed are similar to those encountered in this area.

Local studies

The geology of much of the area adjoining Logan and McIntosh Counties has been mapped at a moderately large scale and with less detail than more recent mapping. The ground water and glacial geology of the Edgeley and La Moure quadrangles, just east of Logan and McIntosh Counties, was mapped by Hard (1929). Much of the dead-ice moraine on the Coteau was mapped by him as "terminal moraine." The geology of Emmons County, on the west, was described by Fisher (1952). He briefly discussed the glacial geology and mapped the glacial deposits of that county. Most of the outwash that he mapped along the eastern edge of Emmons County is instead till or bedrock. The glacial geology of Kidder County, north of western Logan County, was described by Rau and others (in press). Dead-ice moraine was recognized in that report but was not described in any detail. Winters and Huxel (in preparation) have made a detailed study of dead-ice moraine and other stagnation features in Stutsman County.

The geology of several parts of Logan and McIntosh Counties has been studied in detail. The glacial and ground water geology of T. 129 N., R. 73 W., in southwestern McIntosh County was described by Laird (1948). The glacial and ground water geology of the southern part of the Streeter area in Tps. 135-136, N., Rs. 68-70, W., in northern Logan County has been 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. The ground water of the Gackle, Lehr, and Ashley areas was discussed in reports by Adolphson (1961 and 1962) and Randich (1961). The glacial geology of southern Logan County has been discussed in more detail than in the present report in an unpublished master's thesis by Bonneville (1961 b). Bonneville also (1961 a) described an occurrence of possible pre-Wisconsin drift in southwestern Logan County. Clayton (1961) discussed late Wisconsin mollusks from ice-contact drift deposits in the northeastern part of Logan County, and Thompson (1962) described the deposits in a representative slough in northern McIntosh County.

GEOGRAPHY

Location and Size

Logan and McIntosh Counties include about 1996 square miles in Tps. 129-136 N., Rs. 67-73 W., in south-central North Dakota. The area is bordered on the south by McPherson and Campbell Counties in South Dakota, on the west by Emmons County, on the east by Dicky and LaMoure Counties, and on the north by Kidder and Stutsman Counties in North Dakota. The area is 30 miles east of the Missouri River and 30 miles west of the James River.

Population, towns, and roads

In 1960 Logan County had a population of 5,370 and McIntosh County 6,700. The nine towns in the two counties and their populations are as follows: Ashley, the county seat of McIntosh County, (1,420), Fredonia (140), Gackle (550), Lehr (380), Napoleon, the county seat of Logan County, (1,080), Venturia (150), Wishek (1,200), and Zeeland (430). In addition, there are the two unincorporated communities of Burnstad and Danzig (see pl. 1).

Several hard-surfaced highways cross the two counties, and most areas can be reached on all-weather roads. About two-thirds of the section lines have roads or trails that are passable by car in dry weather.

Climate

The climate of Logan and McIntosh Counties has been called dry subhumid and cool mesothermal by Thornthwaite (1948, pl. 1) and humid microthermal continental with a warm summer and no marked wet or dry season by Trewartha (1961, pl. 1). From 1900 to 1940 the area had an average yearly precipitation of about 17 inches, and temperatures varied from -48° F to 120° F, averaging about 8° F in January and 70° F in July. The growing season averaged about 115 days. (Data from U. S. Department of Agriculture, 1941, p. 1046).

Land use and vegetation

Most of Logan and McIntosh 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 the Missouri Coteau part of the two counties 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. They still occur 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 and McIntosh Counties have few trees. Those present occur on steep north-facing slopes and along some lakes with stable water levels; a few trees have been planted in towns and around farm buildings.

Soil

Most of the dark-brown soils of western Logan and McIntosh Counties belong to the Chestnut zonal soil group and the black soils in the eastern part of the area belong to the Chernozem zonal soil group. According to Omodt and others (1961), they include the Morton, Williams, and Verbar soils in the Beaver Creek subdistrict (see section on physiographic units), the Morton and Williams soils in the Napoleon subdistrict, the Williams soils in the Wishek subdistrict, the Raber soils in the Zeeland subdistrict, the Oahe and Sioux soils on outwash plains, the Zahl, Williams, Buse, and Barnes soils on dead-ice moraine and end moraine, and the Barnes and Svea soils on the ground moraine in southeastern Logan County. The soils on the upper Wisconsin tills are leached of carbonates to a depth of only a few inches, whereas the soils on the older drift in the western part of the two counties have a leached zone as much as 3 feet thick.

Nonsorted polygons, as defined by Washburn (1956, p. 831-832), are common in all well drained and uncultivated parts of Logan and McIntosh Counties, as well as much of the rest of North Dakota. They have little or no surface expression but are best seen in freshly graded ditch banks that have a low slope angle (fig. 2). They have been observed in all types of silty or clayey sediments in well drained places, such as hill tops and hill sides. The polygons are 2 to 5 feet in diameter and generally have five or six sides. Their centers are composed of the normal sediment of the area, and their margins consist of wedges of dark, carbonate-leached material that is similar to the surface soil. The marginal wedges of soil extend about 2 feet below the ground surface. The polygons apparently formed by surface soil falling into desiccation or temperature-contraction cracks in the ground. The presence of soil in the margins and the occurrence of open cracks and shallow trenches over some undisturbed polygons indicate that they are not permafrost features but were formed recently. Similar features were observed in Saskatchewan by Christiansen (1959, p. 23-25).

PHYSIOGRAPHIC UNITS AND LANDFORMS

Logan and McIntosh Counties lie within 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 physiographic districts: the Missouri Coteau, on the east side of the Missouri River, and an unnamed district 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 non-integrated drainage (see fig. 6). This restricted Missouri Coteau (fig. 1), which Fenneman (1931, p. 75) called the "Coteau proper," is a more natural physiographic unit because the area of integrated drainage immediately east of the Missouri River (formerly part of the Missouri Coteau) is topographically and geologically more similar to the area west of the river than it is to the Missouri Coteau. The area between the Missouri Coteau and the Missouri River, which Fenneman (1931, p. 75) described as "the slope leading down to the Missouri . . . subject to active erosion," is here named the Coteau Slope district. That part of the Glaciated Missouri Plateau west of the Missouri River is here referred to as the Glaciated Missouri Slope district. (See table 1.) The "Max moraine" of Townsend and Jenke (1951, p. 850-851) is essentially a physiographic unit equivalent to the Missouri Coteau.

Coteau Slope

The Coteau Slope in Logan and McIntosh Counties (fig. 3) is characterized by thin drift and nearly completely integrated drainage that flows westward to the Missouri River (fig. 4). The area is divided into four distinct physiographic subdistricts. Their characteristics are summarized in table 2. Each unit has been given a formal name for ease of discussion in this report;

FIGURE 2. Photo of typical nonsorted polygons. In a shallow roadcut 0.4 mile east of the southwest corner of sec. 16, T. 132 N., R. 69 W.

TABLE 1. Characteristics of the three districts of the Glaciated Missouri Plateau section in North Dakota.

	GLACIATED MISSOURI SLOPE	COTEAU SLOPE	MISSOURI COTEAU
Drainage	Integrated; flows eastward	Mostly integrated; flows westward	Nonintegrated; numerous undrained depressions
Topography	Stream dissected	Stream dissected	Largely high-relief dead-ice moraine
Age of surface drift	Early Wisconsin (??)	Mostly early Wisconsin (?)	Late Wisconsin
Drift thickness	Nonexistent or very thin	Thin or nonexistent	Thick

they should, however, be considered as only tentative physiographic subdivision names because their appropriateness in Emmons County to the west and in McPherson and Campbell Counties to the south is unknown.

Napoleon and Wishek subdistricts

The Napoleon and Wishek subdistricts are similar to each other but are separated by the more dissected Beaver Creek subdistrict (fig. 5). Both areas are characterized by large areas of stream-eroded topography that has a late Wisconsin ground moraine topography superimposed on it. Drainage is mainly westward through Beaver Creek and South Branch Beaver Creek. Other landforms in these two subdistricts are crevasse fillings; kames; eskers; collapsed-outwash topography; outwash plains; strand lines; lake plains; meltwater channels; present-day lakeshore features; ground moraine; and glacially modified, stream-eroded topography (see pl. 1).

Glacial landforms

Moraine.—Moraine is a geomorphic term applied to landforms that are composed mainly of till and have a topography that in detail is primarily the result of direct deposition from glacial ice. Nonmorainic landforms include, among others, those areas of till having a topography that is primarily the result of postglacial stream erosion and areas where the till is too thin to mask the underlying preglacial topography. Of the three types of moraine — end moraine, ground moraine, and dead-ice moraine — only ground moraine is present in the Napoleon and Wishek subdistricts.

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 (Flint, 1955, p. 111; 1957, p. 131). It generally also has a thin cover of ablation till. The undulating ground-moraine topography in the Napoleon and Wishek subdistricts (pl. 1) has a low local relief, but it is super-imposed on a stream-eroded bedrock topography of considerably higher relief. The resulting topography has a local relief of 10 to 30 feet and a regional relief of as much as 150 feet. The ground moraine is composed of a relatively thin blanket of till of the Napoleon Drift (see pl. 2) that is, in most places, 10 or more feet thick. The surface is covered with relatively numerous cobbles and boulders. The drainage is nearly completely integrated, but a few undrained sloughs still remain in the highest parts of the Napoleon and Wishek subdistricts in Logan County. Ground moraine is restricted largely to areas above 2100 feet elevation in the Wishek subdistrict, but is absent from only the northwestern part of the Napoleon subdistrict. On plate 1 ground moraine and glacially modified, stream-eroded topography have not been differentiated.

Collapsed-outwash topography.—Collapsed-outwash topography resulted when stagnant ice melted from beneath superglacial outwash plains or valley trains. Collapsed-outwash topography is here arbitrarily defined as having less than half of its area flat and uncollapsed, to distinguish it from pitted outwash plain, which has more than half its area uncollapsed. The collapsed-outwash topography in the Napoleon subdistrict was identified by its high local relief (as much as 50 feet) and the presence of undrained depressions and ice-contact faces. In most places the collapsed outwash sand and gravel, which is part of the Napoleon Drift (pl. 2), has little apparent relation to the surrounding topography other than being restricted to a northward-sloping

TABLE 2. Characteristics of the four subdistricts of the Coteau Slope in Logan and McIntosh Counties.

	NAPOLEON SUBDISTRICT	BEAVER CREEK SUBDISTRICT	WISHEK SUBDISTRICT	ZEELAND SUBDISTRICT
Drainage	Mostly integrated	Completely integrated	Completely integrated	Well integrated in most of southern 2/3
Undrained depressions	Some Valley-dammed lakes; a few sloughs on drainage-divide areas	None	Very few	Moderate number in southern 2/3; many in northern 1/3
Dominant topography	Ground moraine superimposed on stream-eroded topography	Stream-eroded topography	Ground moraine superimposed on stream-eroded topography	Ground moraine superimposed on stream-eroded topography in southern 2/3; end moraine in northern 1/3
Age of surface drift	Mostly early Wisconsin (?); some late Wisconsin		Mostly early Wisconsin (?); some late Wisconsin	Late Wisconsin
Drift thickness (feet)	0-50 in most of area	0 in most of area	0-50 in most of area	20-150 in southern 2/3; 50-200 in northern 1/3

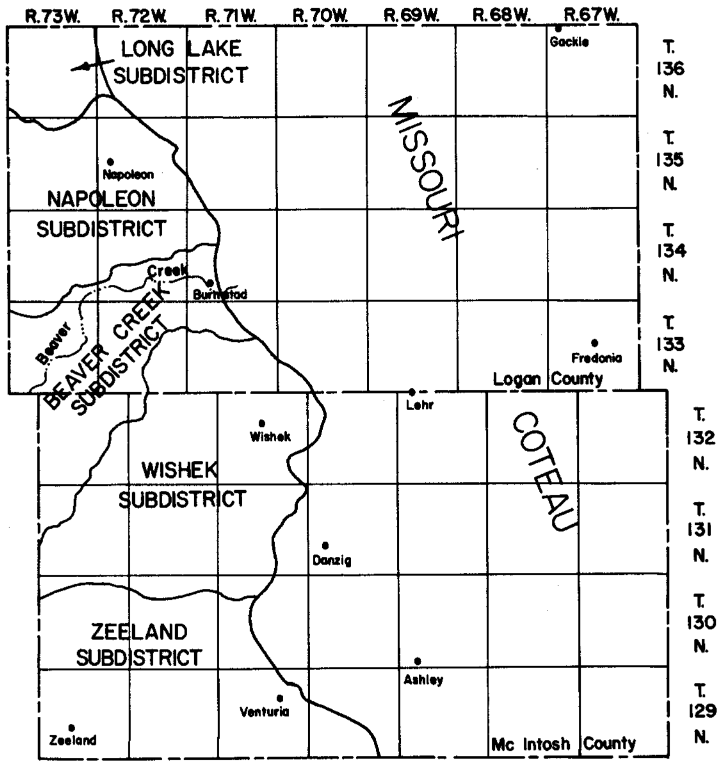


FIGURE 3. Map of physiographic units in Logan and McIntosh Counties. The four subdistricts in the west are part of the Coteau Slope (see fig. 1).

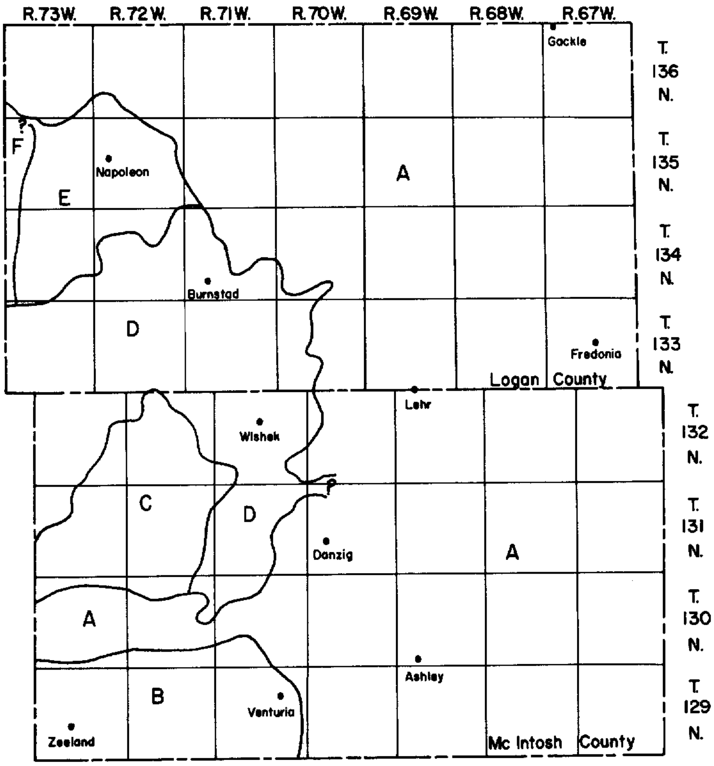


FIGURE 4. Map of drainage basins of Logan and McIntosh Counties. A: Nonintegrated internal drainage. B: Partly integrated drainage tributary to Spring Creek in South Dakota. C: Integrated drainage of South Branch Beaver Creek. D: Integrated drainage of Beaver Creek. E: Integrated internal drainage flowing into lakes west of Napoleon; might overflow in floodtime into F. F: Integrated internal drainage tributary to Long Lake Creek, flows into Long Lake, an internal drainage basin.

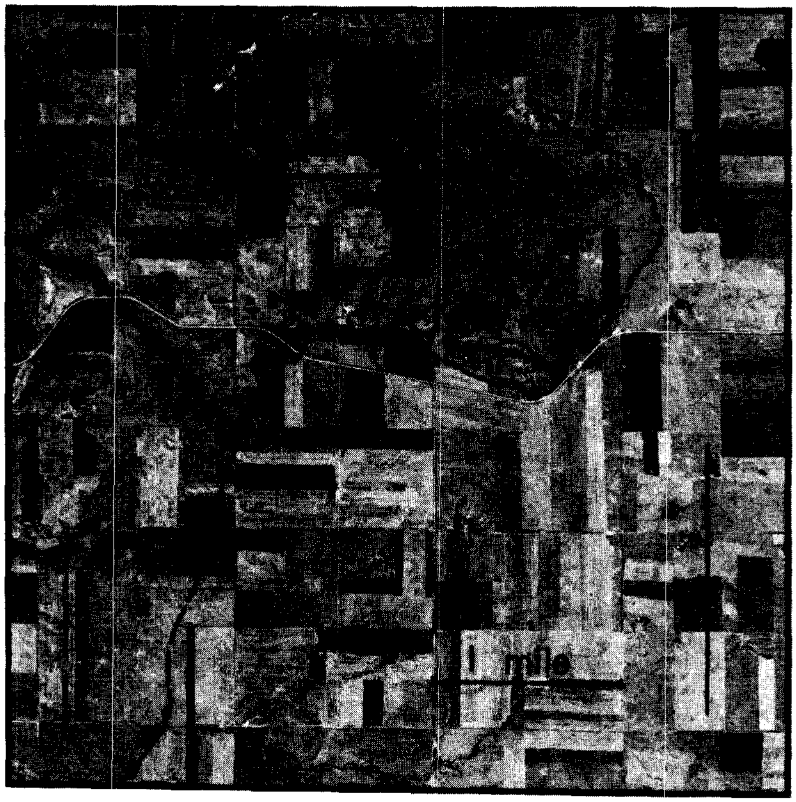


FIGURE 5. Air photo of contact between Wishek (southeast half) and Beaver Creek subdistricts (northwest half); in the northeast part of T. 132 N., R. 73 W., and the northwest part of T. 132 N., R. 72 W.

preglacial valley; at some places it is at considerably higher elevations than adjacent ground moraine.

Kames.—A kame is a conspicuous and prominent hill that is composed of washed drift (mostly gravel and sand) that was deposited against or within glacial ice by meltwater streams. More than 50 small kames occur in the eastern part of the Napoleon subdistrict. Most are 100 to 300 feet across and 10 to 20 feet high. Several more kames are scattered through the rest of the Napoleon and Wishek subdistricts. Similar kames have been reported in drift of about the same age in South Dakota and central North Dakota by Flint (1955, p. 67) and Benson (1952, p. 196).

Crevasse fillings.—A crevasse filling is a relatively straight ridge composed of outwash sand and gravel that was deposited by a meltwater stream in a crevasse in glacial ice. Several crevasse fillings are present in the Wishek subdistrict. They are as much as 50 feet high and one-half mile long and have a dominant northwest-southeast orientation.

Eskers.—An esker is a sinuous ridge of outwash sand and gravel deposited by a meltwater stream flowing in a channel or tunnel it had cut in glacial ice. The eskers in the Napoleon and Wishek subdistricts (pl. 1) are distinguished from crevasse fillings by their greater sinuosity.

Proglacial landforms

Outwash plains and valley trains.—Most of the outwash plains and valley trains in the Napoleon and Wishek subdistricts are flat, having less than 5 feet of local relief. They are composed of sand and gravel belonging to four different drifts – the Napoleon, Long Lake, Zeeland, and Burnstad Drifts (see pl. 2). Boulders and large cobbles are absent on the surface of the outwash.

The southward sloping valley trains in the Wishek subdistrict are composed of Napoleon outwash sand and gravel and, in some places, have a thin cover of dark silty and clayey alluvium of South Branch Beaver Creek. The outwash plain at the southeast edge of the Long Lake end moraine northwest of Napoleon is composed of Long Lake outwash. This elevated plain has as much as 15 feet of local relief and is bounded on the south and east by an outward-facing escarpment that is 30 to 50 feet high. The escarpment may be a foreset delta face that formed in a glacial lake (discussed in next section) that resulted when the late Wisconsin glacial advance that formed the Long Lake end moraine dammed a north-sloping preglacial valley.

The westward-sloping valley train at the north edge of the Zeeland end moraine is composed of Zeeland outwash plus alluvium of the present-day South Branch Beaver Creek. The outwash plains east of Wishek and east and north of Napoleon are composed of Burnstad outwash and have slopes that increase toward the Burnstad end moraine.

Strandline.—A glacial lake that was 10 miles long 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 in the Napoleon subdistrict and once during the late Wisconsin advance that formed the Long Lake end moraine. The position of the highest strandline at about 2000 feet elevation was governed by the elevation of the lowest outlet to the south. The strandline is a vague escarpment marked by many small bodies of outwash, possibly deltas.

Lake plain.—The flat glacial lake plain south of Napoleon is composed of clay that was deposited in the glacial lake discussed in the previous section when its western outlet was blocked during the formation of Long Lake moraine. The lake plain is composed of dark clay, is free of surface boulders, and is about 20 feet above the present high-water level. Southwest of Napoleon it is covered by younger outwash that came from the east.

Adjacent to the valley trains in the Wishek subdistrict are several small lake plains that formed when tributaries were dammed as the bottoms of the main valleys were raised by outwash deposition. Some of these plains are small and difficult to distinguish and have been included with the valley trains in plate 2.

Meltwater channels.—The meltwater channels formed in late Wisconsin time along the outer margins of the Long Lake, Burnstad, and Zeeland moraines are U-shaped or flat-bottomed and have been cut in till, outwash, or bedrock and are floored with outwash or nonglacial alluvium.

Several small meltwater channels that formed in early Wisconsin (?) time are present in the ground moraine of the Napoleon subdistrict. Some of the short channels southeast of Napoleon cross the tops of minor drainage divides, and the meltwater channel in the northeast corner of T. 134 N., R. 72 W., extends about 4 miles along the top of a drainage divide. These channels were probably formed when the divides were exposed by down-melting of stagnant glacial ice.

Nonglacial landforms

Glacially modified, stream-eroded topography.—The surface mapped as glacially modified, stream-eroded topography in the Napoleon and Wishek subdistricts is similar to that of adjacent ground moraine except that till is either thin or absent. The topography is therefore primarily nonglacial; it is in detail primarily the result of stream erosion. Bedrock is at or near the surface over most of the area. The drainage is completely integrated and the local relief is 10 to 40 feet. This landform has not been differentiated from ground moraine in plate 1. It is generally below 2100 feet elevation in the Wishek subdistrict and occurs only in the northwestern part of the Napoleon subdistrict.

Lakes and sloughs.—The intermittent lakes west of Napoleon lie along the bottom of a northward-sloping valley that was dammed by glacial drift during the last part of the Wisconsin Age. The original postglacial lake has been separated into several smaller lakes by well-developed baymouth bars, spits, and connected, opposing cuspate bars. The sand in these spits and bars was derived by wave action and currents from the adjacent outwash plain. A few sloughs (intermittent ponds that may be entirely or in part covered with marsh) are present in the uneroded divide areas in the western and southern part of the Napoleon subdistrict.

Beaver Creek subdistrict

The Beaver Creek subdistrict (fig. 3 and 5) is characterized by a stream-dissected topography and a near lack of drift. Beaver Creek is the only permanent stream in Logan and McIntosh Counties.

Stream-eroded bedrock topography.—Most of the Beaver Creek subdistrict has a stream-eroded bedrock topography. It differs from the glacially modified, stream-eroded topography in the Napoleon and Wishek subdistricts by the near lack of drift, by the complete destruction of any evidence of glacial influence on the topography, and by the much greater dissection. Local relief is nearly 200 feet in some places. In contrast to the topography of the rest of Logan and McIntosh Counties, many slopes are concave and are influenced by local variations on the resistance of the underlying Cretaceous sand, sandstone, siltstone, claystone, and shale. Conspicuous sandstone-capped buttes are present in the northwest corner of T. 131 N., R. 73 W., and in the southeastern corner of T. 133 N., R. 73 W. (Shell Buttes). In some places there are small amounts of eroded till and outwash, and the surface of most of the area has abundant lag cobbles and boulders derived from the eroded drift. Many of the lower areas are blanketed with alluvium or colluvium. The stream-eroded topography of the Beaver Creek subdistrict is separated from the undissected Napoleon subdistrict to the north and the Wishek subdistrict to the south by a sharp escarpment caused by headward erosion by Beaver Creek tributaries. The time and immediate cause of the rejuvenation of Beaver Creek is unknown.

Stream-eroded outwash topography.—Stream-eroded outwash topography in the Beaver Creek subdistrict consists of level-topped remnants of a dissected valley train in McIntosh County and a dissected edge of an outwash plain in the northern part of the subdistrict. The remnants of valley train in McIntosh County are underlain by outwash gravel and have a steeper westward gradient than does the stream that is now dissecting it. This stream now carries much finer alluvium.

Sand and gravel hills.—Some of the hills in the dissected Beaver Creek subdistrict are composed of outwash sand and gravel or are composed of a bedrock core draped with a blanket of outwash sand and gravel. They are generally a few hundred feet across and several tens of feet high. These hills may have been held up by outwash gravel of dissected remnants of former outwash landforms such as outwash plains or meltwater channels, or they may be kames and crevasse fillings. None of them, however, has the conspicuous steep-sided form of kames and crevasse fillings; instead their form is little different from surrounding bedrock hills. If they were originally kames and crevasse fillings, their present shape is due more to stream erosion than it is to the original ice-contact form.

NW-SE drainage lineation and channel fillings.—Throughout much of the Beaver Creek, Napoleon, and Wishek subdistricts the small divides and intermittent streams are parallel and trend about N. 50° W. The lineation is conspicuous on air photos but is seldom noticeable from the ground. Its presence in the more eroded areas suggests that it is unrelated to glacial streamline features or end moraine features but is controlled either by bedrock or wind action.

If the streams have been lineated by bedrock structure, they may be related to the northeast-southwest lineations in northeastern Emmons County that Fisher (1952, p. 14) thought originated in Fox Hills sandstone beds. He said they "probably result from the building of a low sandbar or bank" in Cretaceous time. These lineations in Emmons County are shown on the Glacial Map of the United States (Flint and others, 1959), however, as glacial streamline features (flutings).

More probably the lineation was caused by prevailing northwesterly winds. Throughout much of western South Dakota and the rest of the Great Plains there is a similar conspicuous northwest-southeast drainage lineation that is thought to be related to deflation or deposition of longitudinal dunes (Flint, 1955, p. 155-160). A mechanism by which wind aligns drainage was proposed by White (1961). He suggested (p. 210) that large amounts of wind-blown silt and sand-sized clay aggregates drifted into and filled small stream segments that were aligned in directions other than northwest-southeast, whereas stream erosion was more rapid in streams aligned northwest-southeast because they accumulated little wind-blown sediment. "Any deviation away from the direction of the prevailing winds by the small creeks would be counteracted by the accumulation of eolian material in this segment of the channel."

As in most of western South Dakota (Flint, 1955, p. 159), dune sand is absent in the area of aligned drainage in Logan and McIntosh Counties. In some areas, however, such as in secs. 7 and 8, T. 134 N., R. 73 W., many of the surface boulders have been polished and etched by wind-blown sand or silt. The wind-etched grooves on undisturbed boulders are aligned northwest-southeast.

In the Beaver Creek subdistrict, stream dissection has exposed many small channel fillings that are now well above the bottoms of nearby streams. The channels, which are several feet across, are generally cut in bedrock. They are lined with pebbles and cobbles that were eroded from local glacial drift and are filled with a dark silt that is probably wind blown. These silt-filled channels are probably the abandoned segments of streams that were wind aligned by the mechanism suggested by White.

Zeeland subdistrict

The Zeeland subdistrict has two main landforms: ground moraine with partly integrated drainage tributary to the Missouri River and the Zeeland end moraine with nonintegrated drainage. It might seem more appropriate to include the Zeeland subdistrict in the Missouri Coteau rather than in the Coteau Slope because, like Missouri Coteau, it is underlain by thick, late Wisconsin drift. But because its drainage is at least partly integrated and the streams flow southwestward into the Missouri River, it has been included in the Coteau Slope. This tentative assignment of the Zeeland subdistrict to the Missouri Slope may have to be altered when the physiography of northern South Dakota is studied in detail.

Ground moraine.—The ground moraine in the Zeeland subdistrict consists of about 20 to 150 feet of drift. The Zeeland Drift (see section on stratigraphic units), which makes up much of that thickness, is at the surface in the entire subdistrict in McIntosh County. The drift is not thick enough, however, to obliterate completely the underlying pre-Wisconsin drainage system; broad valleys nearly 200 feet deep are still apparent in most of the area. Along the bases of these valleys present-day streams, which are tributary to the westward flowing Spring Creek in McPherson and Campbell Counties, South Dakota, have been reestablished. The topography is almost identical to that of the ground moraine in the Napoleon and Wishek areas.

In the eastern part of the Zeeland subdistrict subdued circular disintegration ridges (defined in a later section) are abundant. These ridges and the ice-contact lake-sediment topography (see below) suggest that the eastern part of the Zeeland subdistrict is low-relief dead-ice moraine. However, because of the low local relief (less than 15 feet in most places) and the gentle slopes (less than 2°), it has been called ground moraine.

Near the bottom of many of the broad valleys are deposits of intermixed outwash sand and gravel and lake silt and clay, which have been described by Laird (1948, p. 6-7) as kame terraces and eskers. These deposits have no distinct topographic expression, however, and apparently have been overriden by the glacial ice that deposited the Zeeland Drift. The outwash is probably part of the Napoleon Drift, and, before the advance that deposited the Zeeland Drift, it probably underlaid southward extensions of the southward sloping valley trains in the Wishek subdistrict. These buried valley trains may be a good ground-water source. Away from the valley bottoms the ground moraine in the Zeeland subdistrict is underlain by clayey, silty, sandy till with few intermixed gravel deposits.

The end moraines mapped by Laird (1948, p. 4-5, fig. 1) near Zeeland and by Flint (1955, pl. 1) at the southern edge of this area are apparently bedrock drainage divides.

Zeeland end moraine.—End moraine is a type of moraine whose topography is primarily the result of glacial deposition (by thrusting, shove, and dump) 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.

The moraine at the north edge of the Zeeland subdistrict is herein named the Zeeland end moraine. It is equivalent to at least the northern part of Todd's (1896, p. 21-22) "Blue Blanket loop of the First, Outer, or Altamont moraine," but it is unknown whether it is exactly equivalent to the moraine east of Blue Blanket Lake in northern Walworth County, South Dakota. The Zeeland moraine is 3 to 5 miles wide. It was formed by glacial ice that came from the northeast east of the Coteau, moved into South Dakota, swung to the west onto the Coteau, and finally moved northward into North Dakota again. The end moraine differs from the ground moraine to the south in that the drift is thicker and the preglacial drainage system has been completely obliterated — the drainage is nonintegrated and lakes and sloughs are numerous. The local relief is higher than in the ground moraine, generally between 10 to 30 feet, and the slopes are steeper, the steepest in most areas averaging about 4°, in contrast to average steepest slopes of 2° in the ground moraine. Indistinct short ridges oriented east-west are present in some parts of the moraine. The outer (northern) border of the moraine has been accurately located (pl. 1) at the contact of the gray Zeeland Drift and the yellow Napoleon Drift. The inner (southern) edge of the Zeeland end moraine has been only approximately located.

The Zeeland end moraine in most places is composed of clayey, silty, sandy till, but some sand and gravel is present in T. 130 N., R. 72 W., and lake silt and clay is abundant in some places such as at the north margin of the moraine at the McIntosh-Emmons County line. This silt and clay was probably deposited in a lake in a south-sloping, preglacial valley that was dammed by the northward advancing glacier that deposited the Zeeland moraine.

Ice-contact lake-sediment topography.—Two types of ice-contact lake-sediment topography are present in the Zeeland subdistrict in McIntosh County. In the southeastern part of the area is a flat, ice-walled lake plain that has less than 3 feet of local relief and is surrounded by an outward-sloping ice-contact face that is up to 20 feet high. This lake plain is underlain by horizontally stratified lake silt and clay.

A second type of ice-contact lake-sediment topography, in the western part of the Zeeland subdistrict, has higher local relief and has less well defined margins. The higher relief may be in part due to collapse of the lake sediment from stagnant ice and in part the result of failure of the thin lake sediment to obliterate completely the underlying topography.

Collapsed-outwash topography.—The collapsed-outwash topography in T. 130 N., R. 73 W., is composed of the largest surface body of sand and gravel in the Zeeland subdistrict in McIntosh County. It has numerous undrained depressions and is bordered along its southwest edge by a gravel ridge.

Meltwater channels.—The only meltwater channels present in the Zeeland area are several short and fragmented channels near the outer margin of the Zeeland end moraine.

Missouri Coteau

The Missouri Coteau in Logan and McIntosh Counties is characterized by very hilly moraine, completely nonintegrated drainage, numerous small lakes and sloughs, drift that is 50 to 500 feet thick, and numerous landforms resulting from large-scale glacial stagnation. Also present are outwash plains and several end moraines. The Burnstad Drift is at the surface throughout the entire Missouri Coteau part of Logan and McIntosh Counties. (See fig. 6)

The main part of the Coteau in Logan and McIntosh Counties has not been divided into subdistricts because of its relative uniformity. To the northwest, however, two subdistricts may be designated. The Kidder Sand Plain subdistrict includes the large area of outwash in central Kidder County. The Long Lake subdistrict, immediately west of the Kidder Sand Plain, includes the Long Lake moraine and the low- relief moraine behind it. The Long Lake subdistrict has gentler slopes, lower local relief, and thinner drift than the main part of the Missouri Coteau. The northwest township of Logan County is included in the Long Lake subdistrict (fig. 3). The topography of the Kidder Sand Plain and Long Lake subdistricts closely resembles that of some parts of the Coteau Slope, but they have been included in the Missouri Coteau because of their nonintegrated drainage.

In northwestern North Dakota the Missouri Coteau is a bedrock high with a thin drift cover, and the Missouri escarpment is essentially a bedrock erosional escarpment (see Townsend and Jenke, 1951, p. 842-843). In south central North Dakota, however, the Missouri Coteau escarpment is depositional and is formed largely of drift. The buried bedrock escarpment is 20 to 30 miles west of the Missouri Coteau escarpment.

Glacial landforms

End moraine.—Several types of end moraine topography occur in the Missouri Coteau part of Logan and McIntosh Counties (fig. 7). They range from the rolling hills of the Long Lake moraine to the knobs of the Burnstad moraine to the prominent 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 1898 (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. The Long Lake moraine in Emmons and Logan Counties consists of two separate, though probably closely related, inner and outer sections.

The outer, or most southerly section in Logan County, is topographically similar to the ground moraine of the Napoleon subdistrict. It has gentle slopes and a coarse-grained topography and local relief as great as 50 feet, which may in part be a reflection of the preglacial topography. In contrast to the ground moraine to the south, it has a large number of undrained depressions and is part of a larger band of end moraine that has conspicuous small-scale and over-all linearity in areas northwest of Logan County.

The inner or most northern section of the Long Lake moraine in Logan County has steeper slopes and a finer grained topography, and in places it

FIGURE 6. Air photo of contact between Missouri Coteau (east half) and Coteau Slope, Napoleon subdistrict (west half); in southwest part of T. 135 N., R. 71 W., and northwest part of T. 134 N., R. 71 W.

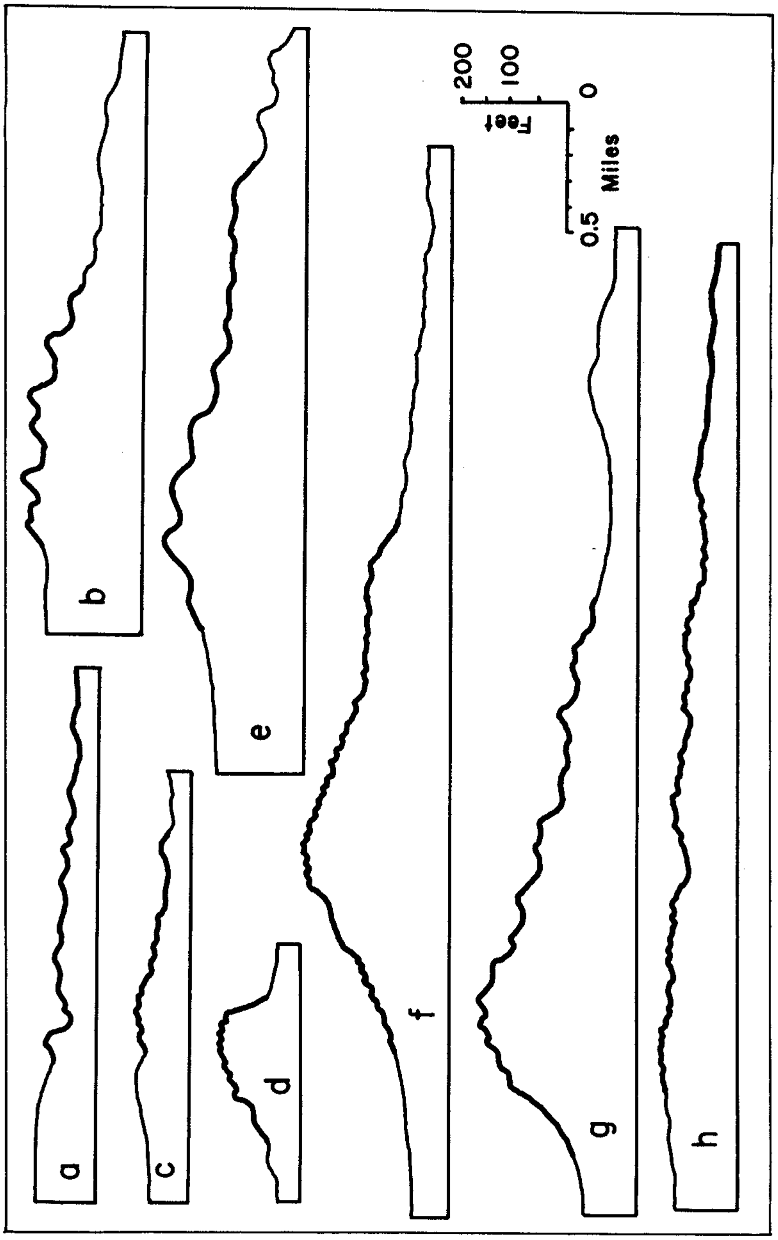


FIGURE 7. Profiles across typical Logan and McIntosh County end moraines. Outer or southwestern edge to left. End moraine represented by heavy line. Locations of lines of profile are indicated on plate 1. a and c: Burnstad moraine. b. and h: Fresh Lake moraine. d: minor moraine in eastern Logan County. e, f, and g: Streeter moraine.

has conspicuous lineations consisting of low arcuate parallel ridges. The entire Long Lake moraine is underlain by till and smaller amounts of outwash of the Long Lake Drift.

The Long Lake moraine has previously been correlated with the Burnstad end moraine (Lemke and Colton, 1958, fig. 5). Evidence that the Burnstad is not equivalent to, but instead overlaps, the Long Lake moraine is presented in the section on the Burnstad moraine.

Venturia moraine.—The end moraine at the western edge of the Missouri Coteau in McIntosh County is herein called the Venturia end moraine for the town of Venturia, at the eastern edge of the Zeeland subdistrict. The Venturia moraine is a ridge that is several tens of feet high, is 1½ mile wide, and has no small-scale, internal lineations. Its relief and slope angles and the detailed texture of its topography differs little from that of the moraine on either side of it; rather, the ground moraine to the west grades eastward into the dead-ice moraine on the east side of the Venturia moraine. To the south, in McPherson County, a large collapsed valley train, extending southwestward across the Coteau from the Streeter moraine, changes to an uncollapsed valley train (in Spring Creek valley) near the outer margin of the Venturia moraine (see pl. 3), indicating that no stagnant ice existed in front of the Venturia moraine at the time that it was formed. This, and the overlapping of the Zeeland moraine at nearly right angles, indicates that the Venturia end moraine represents a significant glacial advance.

Near the Logan-McIntosh County border the Burnstad moraine overlaps the Venturia moraine. To the south, the Venturia may correlate with Flint's (1955, fig. 31, pl. 1) "A-5 Mankato" or possibly with his "A-4 Mankato" end moraine in McPherson County.

Burnstad moraine.—The Burnstad moraine, which extends from northwestern Logan County to central McIntosh County, was first recognized by Todd (1896, p. 13). He called it the "Blue Lake loop" of the "First, Outer, or Atamont moraine." The name "Burnstad," which was given to the moraine by Lemke and Colton (1958, p. 47-49) for the town of Burnstad in 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, and the name "Burnstad" is, at the present time, more widely accepted. The name "Altamont" is not used because so little is now known that correlation 500 miles from McIntosh County to the type area of the Altamont in eastern South Dakota is impossible. Until recently, the outermost late Wisconsin moraines as far northwest as eastern Alberta were called "Altamont."

The Burnstad moraine typically is very knobby (fig. 7), with steep slopes (as great as 15°) and a fine-grained topography. Local relief is from 10 to 50 feet but averages 15 or 20 feet. The moraine is a low, broad ridge that has few small-scale internal lineations. Along much of its outer margin, however, are one or more ridges (push ridges?) which are straight and 10 to 50 feet high (fig. 7). In southern Logan County the form of the moraine is in part controlled by near-surface bedrock.

The Burnstad end moraine has been correlated with the Long Lake moraine by Todd (1895, p. 13) and Lemke and Colton (1958, fig. 5). As suggested by Rau and others (in press), it apparently overlaps the Long Lake moraine, however, and correlates with the Twin Buttes moraine in southern Kidder County (pl. 3). Several reasons for believing this are:

1. There is a greater similarity between the Burnstad and Twin Buttes moraine than there is between them 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 in elevation.

2. If the Burnstad moraine were correlated with the Long Lake moraine, the Twin Buttes moraine would have to be an interlobe 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 interlobe area.

3. The Fresh Lake 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° – the outer edge of the Long Lake is its southern edge and the outer edge of the Fresh Lake is its northern edge (pl. 3).

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. D. E. Hansen (personal communication) has found some evidence that the equivalent of the Burnstad overlaps the Long Lake moraine in northeastern Burleigh County (pl. 3).

It is therefore agreed that the Twin Buttes moraine of Rau and others is part of the Burnstad end moraine.

Farther to the north, in southeastern Kidder County, the Burnstad end moraine (the Twin Buttes part) may be overlapped by the Streeter moraine, as suggested by Rau and others (in press). However, the presence of the collapsed outwash in front of the Streeter end moraine in northern Kidder County (pl. 3) indicates that a mass of stagnant ice several miles wide was present there when the Streeter moraine was being formed. This mass of stagnant glacial ice in northern Kidder County was equivalent to the stagnant ice of the Burnstad advance, which persisted in Logan and McIntosh Counties until after the Streeter moraine was formed. That is, the Burnstad moraine was probably not overlapped by the Streeter in southeastern Kidder County; the dead-ice moraine and collapsed outwash in front of the Streeter moraine in northern Kidder County is equivalent to the dead-ice moraine and collapsed outwash between the Burnstad and Streeter moraines in Logan and McIntosh Counties.

Farther to the northwest, the Burnstad moraine may be equivalent to the moraine of the "post-Tazewell-pre-Two Creeks" advance of Lemke and Colton (1958, fig. 2). To the south, the Burnstad may be equivalent to Flint's (1955, fig. 31) "A6 Mankato" moraine.

Fresh Lake moraine.—The Fresh Lake moraine, a minor recessional of the Burnstad end moraine in northern Logan County, was first recognized by Colton and Lemke (1957). The name "Fresh Lake" was given by Rau and others (in press) to its northermost ridged loop, 2 miles north of Fresh Lake in southeastern Kidder County (pl. 3). The topography of the Fresh Lake moraine is nearly identical to that of the Burnstad moraine. The Fresh Lake moraine is knobby, has steep slopes, and a very fine-grained topography. In addition, at its southern end in Logan County, is a ridged loop consisting of a series of arc-shaped ridges (push ridges?) with a radius of curvature of 1 mile. The ridges are even crested, about 50 feet high, and spaced about 500 feet apart (fig. 7). No attempt has been made to correlate the Fresh Lake moraine with any other moraine to the north or south.

Streeter moraine.—The most prominent end moraine in Logan and McIntosh Counties is the Streeter moraine, 6 to 12 miles east of the Burnstad moraine. It was first recognized by Todd (1896, p. 18 and 34), who called it the "Antelope Valley loop" of the "First, Outer, or Altamont moraine" in McIntosh County and the "Blue Lake loop" of the "Second or Gary moraine" in Logan County. Paulson (1952, p. 17) also called it "Gary." 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, at the present time at least, correlation with the type Altamont or Gary in eastern South Dakota is impossible and because the name "Blue Lake" was given to both the Streeter and Burnstad moraines and apparently has not been used in any other publication since 1896.

The Streeter is a distinctive end moraine that has been recognized for 150 miles from western Dickey County through McIntosh, Logan, Kidder, and Wells Counties to western Sheridan County (pl. 3). It is a prominent ridge that is about 2 miles wide and in many places greater than 200 feet and in a few places as much as 300 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. Superimposed on the ridge are smaller parallel ridges that are 10 to 50 feet high and 200 to 1000 feet apart (fig. 7 and 8). In some places, such as southern Logan County, the Streeter moraine is absent, apparently because it was deposited on top of pre-existing stagnant ice and was collapsed beyond recognition when the ice melted. Part of the northern limb of the McIntosh County loop still retains its overall ridge shape but has been collapsed enough to destroy the superimposed ridges and to form circular disintegration ridges; it is shown on plate 1 as collapsed end moraine.

The interlobe areas between the individual loops of the Streeter moraine were areas of outflowage of large amounts of meltwater. The interlobe between the northern and middle loops in northern Logan County is a low, flat area at about the same elevation as outwash plain to the west. In contrast, the interlobe between the middle and southern loops in northern Logan County is one of the most massive parts of the whole Streeter moraine. It is 600 feet above the lowest area in the dead-ice moraine 3 miles to the north and is covered with an unusually high concentration of boulders.

The outer edge of the southern and southwestern part of the Streeter loop in McIntosh County and the interlobe part of the middle and southern loops in northern Logan County is a steep ice-contact face (fig. 7), indicating that in these areas the Streeter moraine was deposited in contact with large masses of pre-existing stagnant ice. Kame terraces are perched along many parts of this ice-contact face.

The southwestern most part of Streeter moraine in McIntosh County is cut by a gap that is a half mile wide and about 150 feet deep. The gap is floored by lake sediment, and on its south side is a lake-sediment terrace that is about 100 feet high and 1000 feet wide. The gap was first recognized by Todd (1896, p. 19), who called it the "Russian gap" and has been illustrated by Ray (1960, p. 106), who mistakenly said it is in South Dakota. The gap was cut by meltwater from glacial ice behind the Streeter moraine. The absence of flat, uncollapsed outwash or lake sediment beyond the gap and

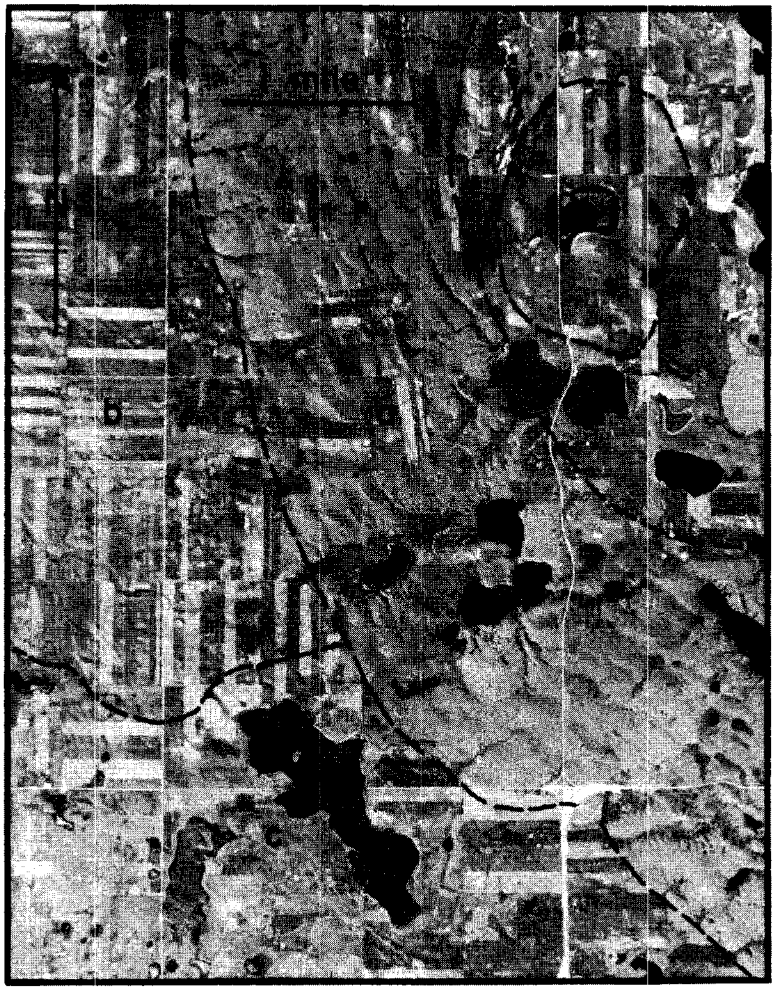


FIGURE 8. Air photo of (a) Streeter end moraine, (b) outwash plain (in northwest part), (c) collapsed outwash topography (in south part), (d) and ice-contact lake sediment topography (in northeast part). In southwest part of T. 136 N., R. 69 W., and the northwest part of T. 135 N., R. 67 W. Compare with plate 1.

the presence of collapsed outwash from the gap westward 17 miles to the western edge of the Missouri Coteau is proof that a more-or-less continuous mass of stagnant ice at least 17 miles wide existed there until after the Streeter moraine was formed.

The Streeter moraine is composed largely of clayey, silty, sandy, stoney till of the Burnstad Drift. In some places it contains large amounts of gravel. The detached outer segment of the north limb of the loop in northeastern McIntosh County is composed largely of folded and contorted lake sediment and outwash, which apparently were associated with the elevated outwash and lake sediment to the west and were pushed into ridges by the advancing glacial ice.

Although the dozen or more loops of the Streeter moraine from Dickey to Sheridan Counties were formed at essentially the same time, there were some minor irregularities in the time of deposition, as indicated by the minor overlapping of the northern loop by the middle loop in northern Logan County. In northwestern Sheridan County, Lemke and Colton (1958, fig. 5) indicate that the Streeter moraine is overlapped by the Martin moraine. To the south, in McPherson County, the Streeter 1) is bent back to the southwest and correlates with Flint's (1955, fig. 31) "B1 Mankato," which does not have the prominent looped-ridge form that is typical of the Streeter, or 2) it is overlapped by Flint's "B1" moraine, or 3) it correlates with another moraine with a different form east of the Missouri Coteau.

Minor end moraines.—The Missouri Coteau in Logan and McIntosh Counties has several other short end moraines, which are of minor importance and are not correlated with any other end moraines. All are recognized and differentiated from adjacent dead-ice moraine by the presence of parallel subarcuate ridges (10 to 30 feet high) and elongated depressions and knobs. The one in T. 135 and 136 N.. R. 67 W., (fig. 7) is a prominent ridge with smaller ridges superimposed on it.

Pitted ground moraine.—Along parts of the eastern edge of the Missouri Coteau where the escarpment is not prominent, the typical dead-ice moraine of the Coteau grades eastward into pitted ground moraine (see pl. 3). This ground moraine extends westward 6 miles into southern Logan County. The moraine is a level area that is pitted with numerous kettles that are 5 to 20 feet deep and 200 feet to one-half mile wide. The convex-inward margins of many of these kettles gives them an angular appearance, and suggests that the till partly flowed back into them after the ice melted.

Dead-ice moraine.—Dead-ice moraine is the characteristic and most widespread landform of the Missouri Coteau; it will be discussed in more detail than the better known landforms. It is a type of moraine whose topography is primarily the result of large-scale glacial stagnation. Townsend and Jenke (1951, p. 857) were 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 related in extent and mode of deposition to ground moraine" and "may have been deposited largely by ablation." It was first called dead-ice moraine by Colton and Lemke (1957).

Terminology.—The term "dead-ice moraine," "dödismorän," or "toteismoräne" has been used in northern Europe for several years (Hoppe, 1952, p. 1-3; Lundqvist, 1959, p. 19, 94-95; Woldstedt, 1954, p. 52). Recently "dead-ice moraine" has been used by several glacial geologists in the Prairie Provinces, including Christiansen (1956, p. 12), Bayrock (1958, p. 6), Gravenor and Kupsch (1959, p. 52), and Bayrock and Gravenor (1961, p. 3).

The term "ablation moraine" has sometime been used in place of "dead-ice moraine." However, as it was used by Tarr (Tarr and Martin, 1914, p. 31), who originated the term, "ablation moraine" referred to moraine that is still on top of the glacial ice.

The descriptive term "hummocky moraine" is preferred by some glacial geologists, including 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 this report because it is thought that these two landforms can be differentiated.

The "collapsed [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). But 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. Similarly, "disintegration moraine," coined by Gravenor and Kupsch (1959, p. 52), is an unneeded synonym for the established name "dead-ice moraine."

Description.—Dead-ice moraine in Logan and McIntosh Counties is characterized by high local relief of as much as 100 feet, a lack of lineation due to active ice, and a medium- to fine-grained topography with large numbers of small, irregular lakes and sloughs (fig. 6 and 8). 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. Various types of disintegration ridges (discussed below) are numerous. The dead-ice moraine in Logan and McIntosh Counties is known to be the result of large-scale glacial stagnation because of its intimate association with the ice-walled outwash plains, ice-walled lake plains, collapsed outwash, and collapsed lake sediment described below.

In the northwest part of T. 136 N., R. 68 W., and northeast part of T. 136 N., R. 69 W., in northern Logan County, are several flat areas in the dead-ice moraine that are similar to some of the "moraine plateaus" of Hoppe (1952, p. 5) and Gravenor and Kupsch (1959, p. 51-52). These roughly circular areas of till are about one-half mile wide and are elevated as much as 50 feet above the surrounding depressions. In contrast to the "moraine plateaux" of Stalker (1960b, p. 31-35), they are not ice-walled lake plains but might be the result of water-saturated till spreading out between the blocks of ice that occupied the present depressions.

In the dead-ice moraine east of the Streeter moraine in northern Logan County are more than a dozen prominent, isolated hills of till. These hills, which were first noted by Todd (1896, p. 34-35), are composed largely of till, though some of the flat-topped ones are capped by lake silt and clay, and some are draped by outwash sand and gravel or contorted lake sediment. Some of the prominent till hills may have been formed by the alteration of earlier glacial features, such as overridden and partly destroyed end moraines. Others, such as the smaller circular ones, may be closely related in origin to the conical "prairie mounds" described by Gravenor (1955) and were formed when superglacial till slid or flowed into sinkholes in stagnant ice.

Other conspicuous local variations in the dead-ice moraine of Logan and McIntosh Counties include: (1) A trench, 2 miles wide and 100 feet deep, behind the Streeter moraine in northeastern McIntosh County. (2) A depression 5 miles wide and 200 feet deep, behind the middle loop of the Streeter moraine in northern Logan County. The lowest part of this depression, which is about 200 feet lower than any other part of Logan and McIntosh Counties, contains a lake that is only about 1000 feet across. Water has never been at a higher level in this depression, suggesting that the water is able to seep away into the postulated buried preglacial valley shown on figure 15. (3) A flat, pitted area, comprising about 7 square miles, in the northwest corner of T. 135 N., R. 70 W., behind the Fresh Lake moraine. It is at the same elevation as the outwash plain to the north and has lake sediment associated with it, indicating that the dead-ice moraine in this area has been modified by a short lived glacial lake which drained through a low area north of Alkaline Lake in southeastern Kidder County.

Origin of relief.—The high local relief of the dead-ice moraine in Logan and McIntosh Counties may have originated in at least three different ways:

1. Reflection of the high relief of the topography existing before the last glaciation was suggested by Flint (1955, p. 111) as the cause of the high relief of the ground moraine and dead-ice moraine (which he called ground moraine) in Campbell and McPherson Counties in South Dakota (see pl. 3). This is probably true in the Zeeland subdistrict, where the preglacial valleys are still apparent; they have not been obliterated by the relatively thin drift. In the Missouri Coteau, however, the drift is as much as 500 feet thick and has completely obliterated the preglacial drainage system. The local relief of the Missouri Coteau seems to be nearly independent of preglacial topography.

2. Squeezing of subglacial till into crevasses and holes in stagnant ice was thought by Hoppe (1952, p. 5-8) and Stalker (1960a) to be the cause of much of the local relief of most dead-ice moraine. No evidence was found for or against this theory in Logan and McIntosh Counties, but it seems unlikely that subglacial squeezing alone could form the topography with 100 feet of local relief that is found in many parts of the Missouri Coteau. Furthermore, Hoppe's proof of subglacial squeezing is based in large part on a questionable interpretation of a large amount of data on the orientation of pebbles and cobbles in disintegration ridges in dead-ice moraine. It seems possible that the orientation he recorded could also be present in disintegration ridges formed by mass movement of superglacial drift off the edge of a gently sloping mass of ice or by spreading out of the ridges into forms much lower and broader than the shape of the crevasses in which they originated.

3. Letting-down of superglacial till from stagnant ice is the most probable origin of the high relief of the dead-ice moraine of 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 super-glacial till is nonexistant or very thin on continental glaciers and was of little importance in the formation of dead-ice moraine. As will be shown in the next section, this apparently was not true on the Missouri Coteau in southern North Dakota in late Wisconsin time; superglacial till was fairly thick on the stagnant ice in Logan and McIntosh Counties. Furthermore, the dead-ice moraine in these two counties has a topography that is nearly identical to the topography of collapsed outwash and lake sediment, which, without doubt, was the result of the letting down of superglacial outwash and lake sediment from melting stagnant ice. It is therefore concluded that the letting down of superglacial till was

largely responsible for the high local relief of the dead-ice moraine in Logan and McIntosh Counties.

Amount of superglacial till.—The presence of abundant fossil mollusk shells in the collapsed and ice-walled lake sediment and outwash (see section on Burnstad Drift) suggests that a thick cover of superglacial drift was present on the stagnant late Wisconsin ice on the Missouri Coteau of southern North Dakota. The assemblage of mollusks found in the ice-contact washed drift is similar to the assemblage existing in lakes and streams of the Upper Midwest today. The water in the lakes and streams that were on top of or walled by stagnant ice in Logan and McIntosh Counties had to be well above freezing during a large part of the summer for these mollusks to thrive, and part of the water was probably unfrozen the entire year for the survival of the fish populations on which the mussel glochidia were parasitic. The relatively high temperature of the water indicates that there was a warm climate and the water was well insulated from the adjacent stagnant ice by a layer of superglacial drift. Ice surrounding the lakes and streams was probably also covered with drift; if the ice had been free of insulating drift, large amounts of cold meltwater would have formed and flowed into the lakes and streams, keeping them near the freezing point.

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. The drift is 5 to 10 feet thick (Tarr and Martin, 1914, p. 205) or only 2 to 3 feet thick (Sharp, 1958, p. 19) where the surface of the ice is stable and undisturbed forest grows on it.

Origin of superglacial till.—The occurrence of superglacial drift over large areas of continental glaciers is apparently unusual. The origin of the superglacial drift that formed dead-ice moraine in south-central North Dakota must have required some special circumstances that were related to an abrupt rise in land elevation; dead-ice moraine is in many places restricted to high, 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, the Prairie Coteau in South Dakota, and the Leaf Hills in Minnesota. There are at least three possible reasons why an abrupt rise in elevation at the east edge of the Missouri Coteau may have been responsible for the superglacial drift:

1. Nonglacial alluvium from east-flowing streams and some glacial outwash and lake sediment may have accumulated on top of the west-sloping glacier. 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. Glacial readvance over thin stagnant masses of ice in low areas and deposition of till on top of the stagnant ice was suggested by Flint (1955, p. 114) as the origin of superglacial drift in South Dakota. Low areas in which stagnant ice could persist would be provided by deep valleys eroded in the steep east edge of the Coteau. If this actually occurred, some plateau-like areas of ground moraine should remain in areas where there was no stagnant ice. None were observed in Logan and McIntosh Counties, 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).

3. Marginal imbricate thrusting in ice less than 200 feet thick, as illustrated by Flint (1957, fig. 5-14), was probably responsible for most of the superglacial drift on the ice. The elevated east edge of the Coteau caused in-

creased thinning of the glacier, which may have been responsible for the increased marginal thrusting.

Extent of Stagnation.—Dead-ice moraine has been defined as being the result of large-scale stagnation. Proof that the stagnation was on a large scale is given by washed-drift features associated with the dead-ice moraine. The completely ice-walled lake plain at Ashley is 5 miles wide, and the ice-walled outwash and lake sediment complex southeast of Lehr is 7 miles long, indicating that masses of stagnant glacial ice at least several miles across existed in these areas. The collapsed valley train in southeastern McIntosh County and northern McPherson County is elevated well above nearby depressions throughout the entire 20 miles of its length, and meltwater channels and uncollapsed outwash and glacial lake sediment are absent throughout this length, indicating that a continuous mass of stagnant ice 20 miles wide existed in this area. Similarly, the collapsed outwash between the gap in the loop of the Streeter moraine and the west edge of the Coteau in central McIntosh County, indicates the stagnant ice there was at least 17 miles wide. These and numerous other examples suggest that a nearly continuous mass of stagnant ice averaging 25 miles wide was present on the Missouri Coteau in southern North Dakota in late Wisconsin time.

The lack of features of large-scale glacial stagnation in most of North Dakota east of the Missouri Coteau is probably not only due to smaller scale stagnation but also to a lack of superglacial till. The end moraine loops in the area of dead-ice moraine on the Coteau have an average radius of curvature of 2 or 3 miles, whereas the loops east of the Coteau average about 20 miles. The ice east of the Coteau was therefore much thicker, had much less marginal thrusting, and had much thinner superglacial drift. For this reason, the ice that did stagnate never formed more than a narrow marginal band because it melted quickly. In contrast, the much thinner ice on the Coteau was covered with an insulating blanket of drift; it took much longer to melt, and a much wider band of stagnant ice was able to accumulate.

Collapsed-outwash topography.—Collapsed-outwash topography is similar to dead-ice moraine, but it is composed of outwash sand and gravel rather than till. It 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 one-half of its area flat and uncollapsed to distinguish it from pitted outwash plain, which has greater than half its area flat and uncollapsed (fig. 8). A characteristic feature of much of the collapsed-outwash topography is the presence of disintegration trenches (described below), which can generally be distinguished on air photos. Collapsed outwash can sometimes be recognized on air photos by its light tone and the presence of stubby postglacial gullies along steeper slopes. Some of the collapsed valley trains also have a series of subparallel disintegration ridges or eskers associated with them. Collapsed-outwash topography is distinguished from outwash plain by its higher local relief, abundant undrained depressions, and numerous gravity faults. The outwash 5 miles southeast of Lehr and 7 miles southeast of Ashley, though it has been collapsed and let down, is still 100 to 175 feet above the nearby ice-block depressions.

The collapsed-outwash topography of Logan and McIntosh Counties is similar to the collapsed-outwash topography described by Flint (1955, p. 106), Tipton (1958), and Steece (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).

Collapsed-lake-sediment topography.—Collapsed-lake-sediment topography is similar in origin to collapsed-outwash topography and dead-ice moraine but has a topography that is slightly more subdued. It formed during the melting of stagnant glacial ice on which silt and clay had been deposited from superglacial lakes. As in dead-ice moraine and collapsed-outwash topography, it has numerous undrained depressions, but in contrast to collapsed outwash, collapsed lake sediment is generally folded and contorted rather than faulted. Its surface is free of cobbles and boulders. The collapsed-lake-sediment topography of Logan and McIntosh Counties is similar to the "superglacial lake" topography of Bayrock and Gravenor (1961, p. 11).

Collapsed-subaqueous-mudflow topography. — Collapsed-mudflow topography has tentatively been recognized in an area of about 3 square miles behind the Streeter moraine in northeastern McIntosh County. It was apparently formed by the collapse of mudflows that had been deposited in a lake on top of stagnant ice.

Relationships between individual mudflows can only be observed in large, freshly-cleaned cuts. Individual mudflows average about 5 feet thick. They are composed of all gradations from clay with no stones to pebbly, sandy, silty, clay (the "flowtill" of Hartshorn, 1958) that is little different from the till in the adjacent dead-ice moraine. Generally there is a complete lack of bedding within the individual flows, but highly contorted bedding and flow lamination are present in some. Where more than one lithology is present within a flow it is generally in the form of irregular lenses and blobs.

In contrast to any bedding that may be present within the individual mudflows, the contacts between separate flows are straight and well defined planes. Between many of the flows are a few inches of evenly stratified lake silt and clay, which was apparently deposited from lake water when mudflows were inactive, or an inch or more of sand, which may have resulted from the washing of the top of the mudflow by the lake water. On the bedding planes between some flows are drumlin-like sole markings similar to those frequently found on graywacke bedding planes. (See Dzulynski and others, 1959, and Kuenen, 1957.) At the north edge of the mudflow area, where the flows are uncollapsed, the long axes sole markings are oriented downslope to the south-southwest.

Except for the northernmost ones, all the mudflows have been collapsed or let down from melting stagnant ice. Dips vary from horizontal to vertical, and in some places the bedding is folded and contorted and the flows are cut by faults with a few inches to several feet of displacement.

The mudflows are on the north side of a 1 mile to 3 mile-wide trench between the Streeter moraine and the plateau-like area in the northeast corner of McIntosh County. Apparently the mudflows originated on stagnant ice on the plateau-like area and flowed to the south-southwest down into a lake on top of stagnant ice in the trench.

Ice-walled outwash plain.—Ice-walled outwash plains are similar to ordinary outwash plains, but are more than half surrounded by an outward-facing ice-contact face that is as much as 100 feet high. Some ice-walled plains are gradational with collapsed outwash topography and have no well defined ice-contact face. This landform is similar to the "perched sand plain" of Farnham (1956, p. 59) and the "perched outwash plains" of Schneider (1961, p. 78) in eastern and central Minnesota.

Ice-walled lake plain.—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 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 plateaux." These features are different from the "moraine plateaus" that were first described by Hoppe (1952, p. 55); the original "moraine plateaus" are composed of till, and evidently 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. One ice-walled lake plain, in the northeast corner of T. 136 N., R. 69 W., was observed by Todd (1896, p. 35), who described it as "presenting the unusual appearance of a flat-topped butte with numerous lake beds around it." Todd (1896, p. 19, 42, and 43) also observed the ice-walled lake plains near Lehr and Ashley and suggested that they are glacial terrace remnants.

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 and McIntosh Counties. The flat lake plains are as much as 12 square miles in area and are surrounded by outward-sloping ice-contact faces that are 15 to 100 feet high. Some of the plains, such as the ones at Lehr and Ashley, are underlain by as much as 50 or 100 feet of lake sediment. Some ice-walled plains, such as the one in T. 134 N., R. 69 W., have a rim of lake sediment, outwash, or till as much as 20 feet high at their margins. The rims, which are a type of disintegration ridge (described below), originated by mass movement of drift from the adjacent ice wall or by the squeezing of drift up from beneath the ice wall. Most of the plains are gently sloping away from the margins toward the center, and a few, such as the one at Ashley, are pitted with kettles. Along some parts of the margins of most of the ice-walled lake plains, at the position of former inlets, are deposits of outwash sand and gravel. The bedding of this outwash and the lake sediment at the margins is generally faulted because of collapse during melting of the ice wall. The contact between ice-walled lake plains and collapsed-lake-sediment topography is generally indistinct and gradational (see fig. 8).

Kames.—A kame is a prominent or 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 of till or outwash is not a kame. The only definite kames in the Missouri Coteau of Logan and McIntosh Counties are the one in T. 136 N., R. 69 W., which may have been a delta at the north edge of an ice-walled lake, and the cluster of six kames at the west edge of the Streeter moraine in northern Logan County, which are cone shaped and about 80 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. Kame terraces are gradational with ice-walled outwash plains, which were more than half ice walled. Kame terraces are present in Logan and McIntosh Counties along the ice-contact face at the outer margin of the Streeter moraine and along the north edge of the interlobe moraine between the middle and southern loops of the Streeter moraine in northern Logan County. Only the most conspicuous kame terraces are shown in plate 1. The one on the north side of the Streeter interlobate moraine is continuous with a 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.

Kettles.—A kettle is a depression in drift that was formed by the melting of a buried block of glacial ice. Few of the depressions in dead-ice moraine or collapsed outwash topography are kettles. Instead, they are random depressions formed by the irregular collapse of drift from a large sheet of stagnant ice. Dead-ice moraine in Logan and McIntosh Counties has many more kettles than does end moraine.

Eskers.—Few good examples of eskers exist in the Missouri Coteau part of Logan and McIntosh Counties. Most of those that are present are less than one-half mile long and are difficult to distinguish from outwash disintegration ridges. The best example of eskers in the two counties are the sinuous ridge in the collapsed valley train in sec. 8, T. 134 N., R. 70 W., and the subdued, northeast-southwest ridge in northeastern McIntosh County.

Disintegration ridges.—The term "disintegration ridge" was first used by Gravenor and Kupsch (1959, p. 52-54) 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, 1955, p. 475-478; Gravenor and Kupsch, 1959, p. 56-60; and Stalker, 1960a):

1. Mass movement of superglacial drift into a crevasse in stagnant glacial ice.
2. Transportation of washed drift by a stream into a crevasse in stagnant glacial ice.
3. Squeezing of subglacial drift up into a crevasse in stagnant glacial ice.
4. Mass movement of superglacial drift from the edge of a single mass of stagnant glacial ice.
5. Squeezing of subglacial drift up from beneath the edge of a single mass of stagnant glacial ice.
6. Mass movement of superglacial drift from the side of a hole in a mass of stagnant glacial ice.
7. Squeezing of subglacial drift up from beneath the side of a hole in a mass of stagnant glacial ice.

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

Circular disintegration ridges are scattered through much of the dead-ice moraine of Logan and McIntosh Counties. These features have also been referred to as "prairie mounds" by Gravenor (1955), "doughnuts" by Gravenor and Kupsch (1959, p. 52) and Stalker (1960a, fig, 3 c), and "rim ridges" of "plains plateaux" by Stalker (1960a, p. 9-11). They average 500 feet in diameter and about 15 feet high. Gravenor (1955, fig. 2) suggested that they formed by mass movement of superglacial drift into a sinkhole in stagnant ice (number 6 above), inversion of topography owing to the insulating effect of the drift, and mass movement off the sides of the ice cone thus formed (number 4 above).

Many circular disintegration ridges are breached in two places on opposite sides of the ring. These have been called "broken rim ridges" by Stalker (1960 a, pl. 10) and have been colloquially referred to as "puckered lips" by glacial geologists in North Dakota. These features originated at the edge of sink holes in stagnant ice in the same way the unbreached circular disintegration ridges formed. The two breaches probably resulted from the melting of ice that had been insulated by the drift accumulating in the two low saddles that, according to Russell (1901, p. 116), are present on opposite sides of many sinkhole lakes in stagnant ice. Russell thought that these sinkholes resulted from local widening of crevasses and the saddles are relics of these crevasses.

Distintegration trenches.—A disintegration trench is here defined as a trench or channel that was formed by the inversion of topography on disintegrating stagnant glacial ice and subsequent burial under outwash; they were not formed by stream erosion. Though they are one of the most characteristic features of collapsed-outwash topography in Logan and McIntosh Counties, they apparently have not been described before. They are seldom conspicuous on the ground but are best identified on air photo stereopairs (fig. 9). The trenches are no more than a few hundred feet wide or no more than one-half mile long. They generally have a parallel or polygonal to random rather than dendritic pattern. Most disintegration trenches are straight and crack-like, though some are sinuous and have a braided pattern. One of their distinguishing characteristics is the lack of control of their position by the present topography; in contrast to channels cut by streams, they are not parallel to the slope of the ground but cross through depressions and over hills. Many of the trenches are closed at both ends.

Disintegration trenches are always found in slightly collapsed outwash that has no till on top of it and has not been overridden during a subsequent glacial advance; the trenches could not have been formed by streams eroding in the bottom of crevasses or channels in the glacial ice. That is, they are not the erosional equivalent of eskers and crevasse fillings. Rather, they were apparently formed in the following way.

1. Superglacial stream channels or crevasses that extended only part way to the base of the stagnant mass of glacial ice were filled with till or outwash (fig. 10a).

2. This till or outwash insulated the underlying ice as the surrounding ice melted, resulting in either straight (under the crevasses) or sinuous (under the stream channels) ice-cored ridges of till or outwash. Many of these "channel deposits [which] have now been converted to ridge cappings by differential melting" have been observed by Sharp (1949, p. 295) near the stagnant terminus of the Wolf Creek Glacier in the Yukon (fig. 10b).

3. The ice-cored ridges of till or outwash were then covered with outwash (fig. 10c).

4. When the ice core melted, the overlying newly deposited outwash collapsed, producing disintegration trenches, the inverted equivalent of the ice-cored ridges (fig. 10d).

Because ice cores are preserved under only some parts of the superglacial channels, the resulting sinuous disintegration trenches consist of disconnected "blind" segments. Disintegration trenches are thus a sort of very long kettle.

Partly buried channels.—Two channels that are partly buried by drift were recognized in northern Logan County. Large amounts of outwash sand and gravel are exposed along much of their lengths, suggesting that they were originally meltwater channels. They might be a significant ground water source. The one in the northwest corner of Logan County (sec. 16, 17, 18, 20, 21, 22, 26, and 27, T. 136 N., R. 73 W.) is a linear depression that is as much as 50 feet deep and is marked by a chain of kettle lakes, one-fourth

FIGURE 9. Air photo of typical disintegration trenches; sec. 21, T. 134 N., R. 69 W.

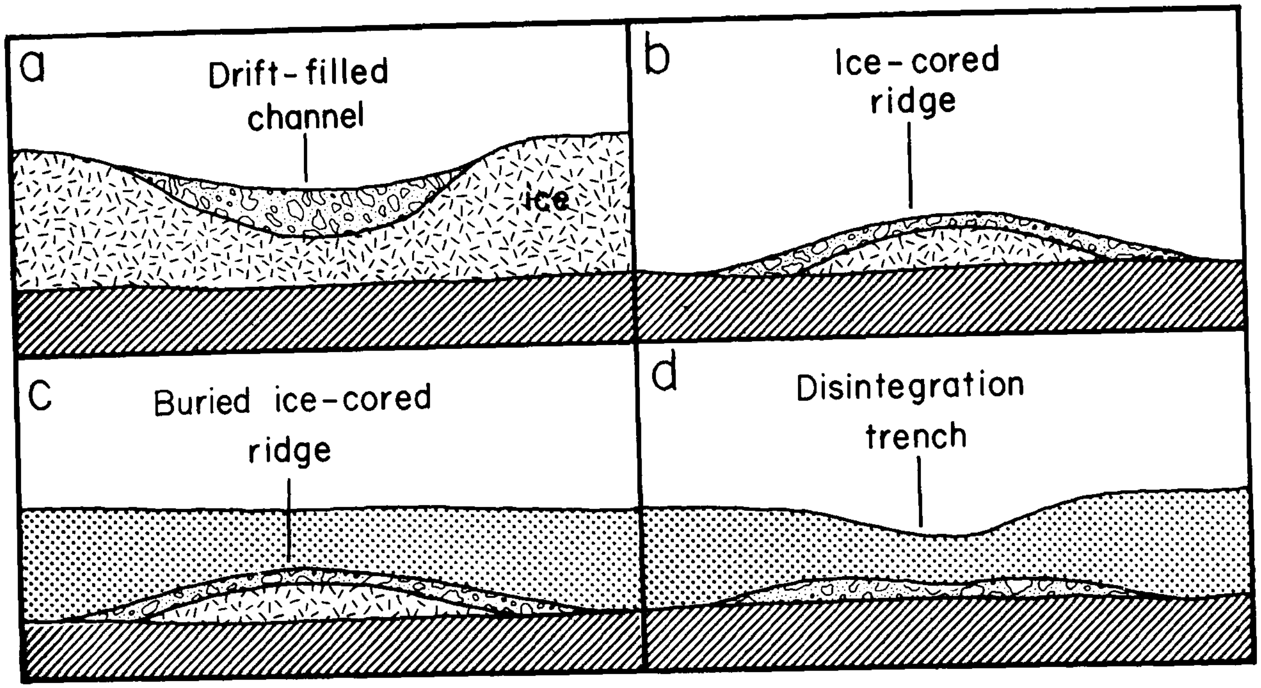


FIGURE 10. Steps in the formation of disintegration trenches.

to one-half mile wide. 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 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 channel may have been buried during a slight readvance of the glacier, or it may have had the same origin as Gravenor and Kupsch's (1959, p. 55-56) "ice-walled channels," which were partly buried by superglacial drift that slid down the bordering ice walls. The westernmost part of the channel, at the northern edge of T. 136 N., R. 72 W., is nonburied.

Proglacial landforms

Outwash plains.—Only one large outwash plain that is nonpitted and was not bounded by stagnant ice is present in the Missouri Coteau of Logan and McIntosh Counties. This outwash plain, which is at the west edge of the Streeter moraine (T. 136 N., R. 70 W.) in Logan County, is very flat, having in most areas less than 2 feet of local relief (fig. 8). The relief that does exist is the result of a braided network of shallow meltwater channels, which are apparent only on air photos. 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 averages about 30 feet thick.

Pitted outwash plain.— A pitted outwash plain, as used in this report, has had less than one-half, but more than 5 percent, of its area collapsed or pitted with kettles. The landform mapped as collapsed-outwash topography has more than one-half of its area collapsed. Only one small area, in the northwest part of T. 135 N., R. 69 W., in northern Logan County, 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. Other areas of pitted outwash plain exist at the contact of outwash plains and collapsed outwash topography in Logan and McIntosh Counties, but they occur as narrow bands and are so insignificant that they have not been mapped.

Meltwater channels.—In dead-ice moraine of the Missouri Coteau part of Logan and McIntosh Counties, meltwater channels that were unrestricted by ice are nearly nonexistant. Instead, most meltwater channels in the Coteau occur in end moraine. Most of the meltwater channels that did exist in the area of dead-ice moraine were cut into stagnant ice, which has since melted.

Meltwater-channel terraces.—Terraces are present along the meltwater channel through the Burnstad moraine in the northwest part of T. 136 N., R. 72 W., in northern Logan County. They are underlain by outwash sand and gravel. This outwash was later entrenched about 30 feet, possibly because the surface of the Burnstad ice was lowered or because base level was suddenly lowered as the meltwater channel west of Napoleon was cut downward through resistant Fox Hills sandstone and into unconsolidated sand.

Non-glacial landforms

Lake plain.—The large ephemeral lake 3 miles northwest of Ashley was about 35 feet higher during part of postglacial-prehistoric time than it is now at its highest level. The 35-foot strandline is best developed in sec. 34, T. 131 N., R. 70 W., at the northwest side of the main body of the former lake, where it is a conspicuous wave-cut, wave-built terrace that is 300 feet wide. Projecting into the former lake were several cuspate bars, which are composed of horizontally bedded gravel. The present lake, which has a high salt concentration, has no surface outlet, though it may have a ground water outlet through the adjacent collapsed outwash. When the lake was at the 35-foot level, the outlet was to the north to Green Lake and the tributary of Beaver Creek 1 mile west of Wishek. Apparently the present lake level is the result of a dryer climate.

Lakes and sloughs.—The Coteau contains large numbers of small lakes and sloughs (intermittent ponds that may be entirely or in part filled with marsh). They are most abundant in dead-ice moraine, where they occupy kettles and other depressions resulting from the irregular deposition of drift. 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 outwash sand and gravel on the Coteau are usually the surface expression of the 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 shores. 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 intermittent. Fewer fish and water birds live in these lakes. The largest lakes with stable water level, Beaver Lake in Logan County and Green Lake and Lake Hoskins in McIntosh Counties, have recreation facilities along their shores.

Gullies.—Postglacial stream erosion has had little effect on the topography of the Missouri Coteau in Logan and McIntosh Counties. The Coteau has almost a complete lack of streams, though a few underfit, intermittent streams flow along some meltwater channels. Only along the edges of deep meltwater channels and along steep ice-contact faces have short gullies modified the original glacial topography.

Bedrock topography

A topographic map of the bedrock surface of Logan and McIntosh Counties has not been made because too little is known about the thickness of drift, especially in the eastern part of the area (fig. 11). However, a few generalizations can be made. In the Beaver Creek, Napoleon, and Wishek subdistricts the bedrock topography is nearly the same as the present topography, except in valley bottoms where the drift may be as much as 100 feet thick. In the southern part of the Zeeland subdistrict the bedrock surface is similar to the present-day surface, but it is buried under 20 to 150 feet of drift. Little is known about the bedrock surface in the Missouri Coteau, but in most areas it is 50 to 500 feet below the present-day surface. A hypothetical drainage pattern on the bedrock surface beneath the Coteau is shown in figure 15.

STRATIGRAPHIC UNITS AND LITHOLOGY

The bedrock of Logan and McIntosh Counties consists of 3000 to 4500 feet of Paleozoic, Mesozoic, and Cenozoic formations lying on the Precambrian basement. Three Cretaceous formations, the Pierre Shale, the Fox Hills

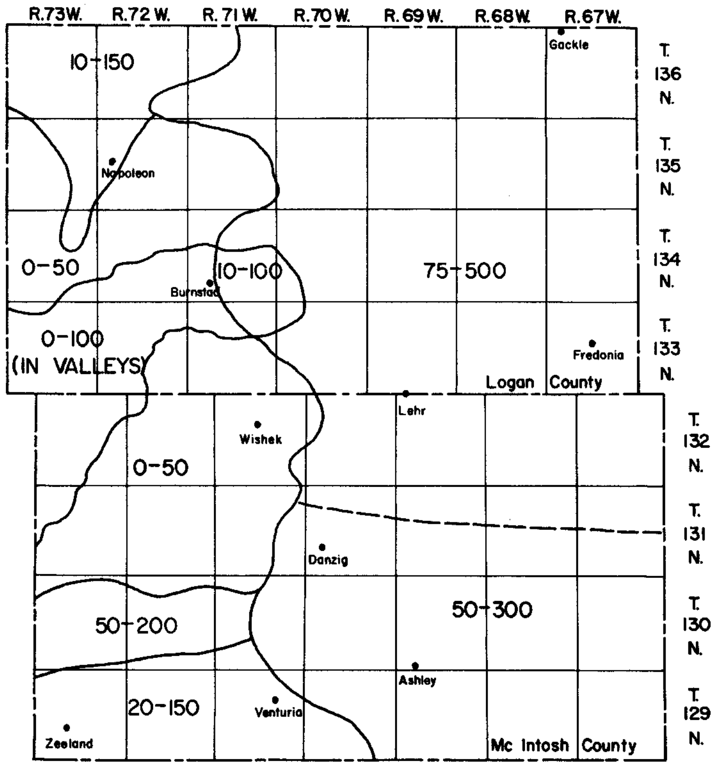


FIGURE 11. Map of drift thickness (in feet) in Logan and McIntosh Counties. Data from several sources, including field observations, North Dakota Geological Survey Circulars, test well logs, and water well inventories, and logs provided by the U. S. Geological Survey office in Grand Forks.

Formation and the Hell Creek (?) Formation, are present at the surface and under the drift cover. Four Pleistocene morphostratigraphic units, the Napoleon, Zeeland, Long Lake, and Burnstad Drifts, cover most of the bedrock. Also present are Upper Cretaceous or Cenozoic residual chert stones, unnamed sub-Wisconsin (?) drift, and undifferentiated Wisconsin and Recent postglacial sediments. The surface stratigraphic units of Logan and McIntosh Counties are shown on plate 2.

Bedrock Beneath the Pierre Formation

From 2500 to 3500 feet of Paleozoic and Mesozoic rocks exist above the complex of Precambrian igneous and metamorphic rocks and beneath the Pierre Shale (fig. 12). All of these sedimentary formations are nearly flat lying, having a dip of several feet in a mile to the northwest into the Williston Basin. The top of the "Dakota" sandstone, an important ground water aquifer in parts of North Dakota, lies at a depth of 2000 to 2500 feet in Logan and McIntosh Counties.

Location of oil test wells in the two counties is shown in plate 2. Depths of some of the formations are shown in table 3.

Upper Cretaceous Series

Pierre Shale.—The Pierre Shale, which underlies all of Logan and McIntosh Counties, is an Upper Cretaceous marine formation that consists of about 1000 feet of dark gray to black shale, which is fissile or has a thin blocky fracture. Its contact with the overlying Fox Hills Formation is conformable and gradational. No outcrops of Pierre were observed in Logan or McIntosh Counties; in the western part of the area it is covered by younger rocks, and in the eastern part it is deeply buried under glacial drift (pl. 2). Small chips of shale from the Pierre are abundant in the drift throughout the entire area.

Fox Hills Formation.—Interbedded sand, sandstone, and mudstone that probably belong, at least in part, to the marine Fox Hills Formation, occur at or near the surface of much of the Beaver Creek, Napoleon, and Wishek subdistricts (pl. 2). According to Fisher (1952, p. 16 and pl. 3) the Fox Hills is 200 feet thick in central Emmons County and has a regional dip of about 15 feet in a mile to the northwest. The bedrock has been glacially deformed at numerous places throughout its outcorp area. The deformation varies from tiny ripples and faults to folds with an amplitude of at least 10 feet. Unconsolidated sand, siltstone, claystone, and shale are the most common lithologies, sandstone being observed in only a few places.

The unconsolidated medium- to fine-grained protoquartzitic sand is gray, yellow, brown, or orange (5Y to 10 YR 5 to 7/2 to 5) when dry. (All sand and sandstone names in this section are defined by Pettijohn, 1957, table 48.) Its grains are subrounded to subangular and are well sorted. The sand is generally noncalcareous.

The sandstone is a fine-grained protoquartzite that has the same lithology as the unconsolidated sand, but it is well consolidated and has a calcareous or silicous cement and 1- to 5-inch bedding. The 10-foot sandstone bed in the northwest quarter of T. 135 N., R. 73 W., is at about 2000 feet elevation and is underlain by unconsolidated sand. The extension of this bed into Emmons County was considered by Fisher (1952, p. 13) to be the uppermost Fox Hills bed and was thought by Benson (1952, p. 32) to be equivalent to the Colgate Member of the Fox Hills.

TABLE 3. Depth to tops of selected formations in four test wells in Logan and McIntosh Counties. From North Dakota Geological Survey Circulars by Garske (1958), Hainer (1955), Anderson (1953), and Carlson (1958).

NDGS WELL NUMBER	89	1835	1355	620
Circular number	19	211	187	117
Location: section township north range west	15 131 73	30 133 72	11 135 72	13 130 69
Surface elevation (feet)	2165	1993	2058	2031
Total depth (feet)	4777	3160	3200	3594
Cretaceous				
Niobrara	1316		1224	1008
Greenhorn	1843	1724	1808	1490
Newcastle ("Muddy")	2260	2133	2220	1920
Fall River ("Dakota")	2466	2333	2402	2130
Jurassic		2462?	2523	
Sundance	2747			
Piper	2820	2654	2778	2285
Mississippian				
Madison				
Charles	2930	2816?		
Mission Canyon	3065		2914	
Lodgepole	3244	3122		2405
Devonian	3612			
Ordovician				
Stony Mountain	3717			
Red River	3817			2797
Winnipeg	4376			3307
Cambrian				3458
Precambrian	4772			3589

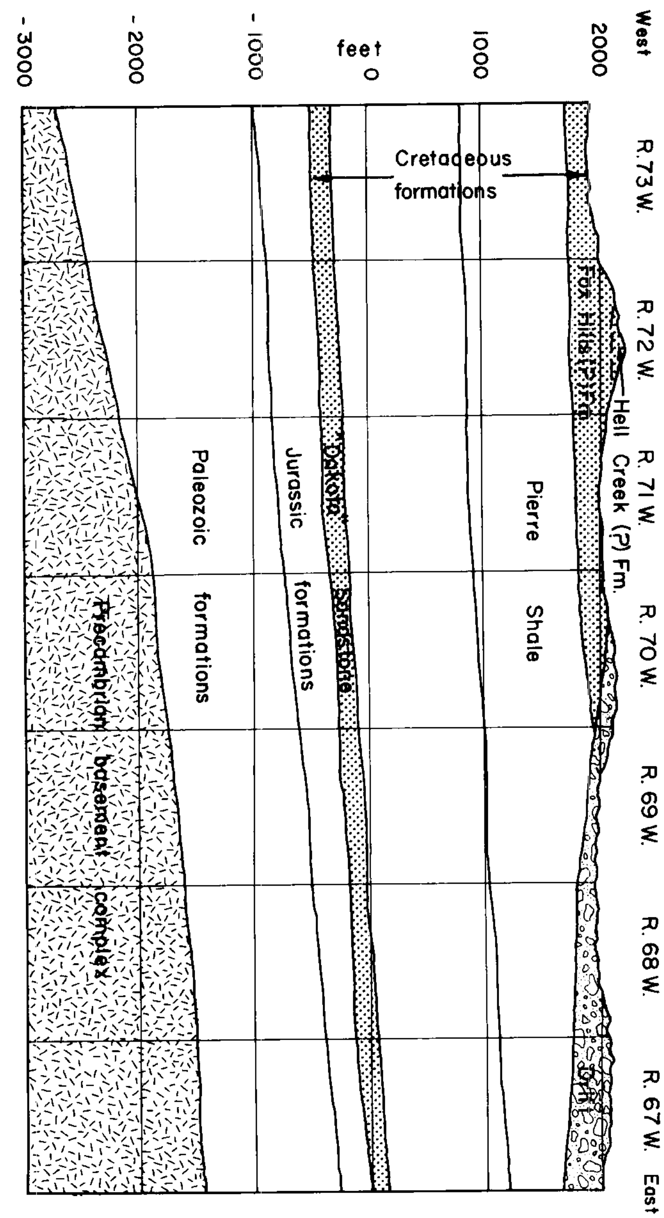


FIGURE 12. Approximate east-west cross section through Logan and McIntosh Counties. Vertical exageration times 25. Data from North Dakota Geological Survey Circulars and test well logs.

An exposure of sandstone of special interest, at an elevation of 2170 feet on top of a butte in sec. 32, T. 131 N., R. 72 W., in the Wishek subdistrict, consists of about 10 feet of medium- to coarse-grained orthoquartzite with subangular grains. The sandstone is gray (5Y6 to 8/2) when dry, has a calcareous cement, and has 1 to 5 inch bedding. Scattered through the sandstone are pebbles of yellowish brown (10YR 4 to 6/2 to 4) chert. The pebbles are subrounded to subangular and are as much as 2½ inches long.

The siltstone, claystone, and shale of the Fox Hills Formation is gray, yellow, or orange (5Y to 10YR 6 to 7/2 to 6) when dry, is noncalcareous, and has 0.05 to 2 inch bedding. The more massive mudstone generally has a blocky fracture.

Fossils are abundant in some parts of the Fox Hills Formation. Fossiliferous concretions occur in a roadcut at the edge of a meltwater channel through the Burnstad moraine near the center of sec. 26, T. 134 N., R. 71 W. The following fossil mollusks were identified in the concretions by Bonneville (1961b, p. 15):

Cephalopods
- Discoscaphites conradi (Morton)

Pelecypods
- Gervillia recta (Meek and Hayden)
- Protocardia subquadrata (Evans and Shumard)
- Tellina scitula (Meek and Hayden)
- Yoldia scitula (Meek and Hayden)

Gastropods
- Unidentified fragments

Scaphapods
- Dentalium sp.

Fossil oysters *(Ostrea)* were found in the Fox Hills Formation in several places in the Beaver Creek subdistrict, including the top of Shell Buttes in sec. 26, T. 133 N., R. 73 W.; 0.5 mile south of the northwest corner of sec. 27, T. 134 N., R. 72 W.; 0.5 mile east of the southwest corner of sec. 27, T. 134 N., R. 72 W.; and in the SW1/4NW1/4 sec. 20, T. 134 N., R. 71 W. The fossil *Halymenites* (a fossil plant?) was observed in a roadcut 0.3 mile south of the northeast corner of sec. 19, T. 133 N., R. 72 W., where they stand upright in the sand and are as much as 5 feet long, and in a roadcut 0.3 mile south of the northwest corner of sec. 17, T. 133 N., R. 72 W. Fossilized wood is also present in some parts of the Fox Hills Formation in Logan and McIntosh Counties. The foraminiferids *Heterohelix, Nonion,* and *Rectogümbelina* were found in the yellowish silt that may be part of the Fox Hills Formation at the base of a road cut in the northwest corner of sec. 20, T. 136 N., R. 72 W., by Kent A. Madenwald (personal communication) of the University of North Dakota.

Fossil plant stem fragments, seed capsules, and cone-like bodies occur in 1 inch beds of feldspathic graywacke within a larger bed of massive, well-cemented protoquartzite 0.5 mile south of the northeast corner of sec. 14, T. 132 N., R. 73 W., at the escarpment between the Beaver Creek and Wishek subdistricts.

Hell Creek (?) Formation.—Rocks of the Hell Creek Formation have not been definitely identified in Logan and McIntosh Counties, but there are four reasons for believing they may be present:

1. Fisher (1952, pl. 2) has indicated that the top of the Fox Hills Formation is at about 2000 feet elevation at the western edge of northern

Logan County and at about 2150 feet near the southwest corner of Logan County. Elevations as much as 100 feet greater than this occur in nearby areas, suggesting that 100 feet of bedrock above the Fox Hills Formation (presumably Hell Creek) are present in the highest areas.

2. Information given in the North Dakota Geological Survey Circular 19 and several unpublished well logs in the Survey files indicate that the Pierre-Fox Hills contact in northwestern McIntosh County is at about 1750 or 1800 feet elevation. The highest elevation in this area (in northwest corner of T. 132 N., R. 72 W.), is 2290 feet. Assuming that the drift on this high area is no thicker than 50 feet and assuming that the Fox Hills Formation is no thicker than 250 feet here, more than 200 feet of bedrock (presumably Hell Creek) above the Fox Hills should occur in the highest part of northwest McIntosh County and southwest Logan County. However, the Fox Hills Formation apparently occurs up to an elevation of 2200 feet in this area, and it might be as much as 400 feet thick.

3. Several feet of dark brown to black claystone and siltstone with numerous fossil leaf fragments is exposed at an elevation of about 2150 feet, 0.2 mile south of the northeast corner of sec. 2, T. 133 N., R. 72 W., 3 miles southwest of Burnstad (Bonneville, 1961b, p. 23, 29-30). This rock is similar to parts of the Hell Creek Formation (Laird and Mitchell, 1942, p. 9-10, and Fisher, 1952, p. 18-19).

4. According to Waage (1961, p. 237), the Hell Creek is lithologically similar to the Fox Hills, but they are distinguished primarily by the presence of lignite in the Hell Creek. No lignite was observed in Logan and McIntosh County, but Todd (1896, p. 56) reported that a lignite bed occurs "south of Napoleon."

The bedrock in the highest parts of the Wishek and Napoleon subdistricts is generally covered with till of the Napoleon Drift. For this reason the contact between the Fox Hills Formation and the overlying Hell Creek (?) Formation or any other younger formations has not been accurately located. The contact is near an elevation of 2000 feet west of Napoleon, is above the top of Shell Butte (2080 feet) in southwestern Logan County, and might be near 2200 feet west of Wishek.

Upper Cretaceous-Cenozoic undifferentiated

Residual sandy chert.—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 and McIntosh Counties. In some parts of the Wishek subdistrict they constitute 95 percent of the surface boulders, cobbles, and pebbles. The chert is light to medium grayish, yellowish, or reddish-brown and has numerous molds of plant stems that were 1 to 10 mm in diameter and had several irregular longitudinal grooves. The stones are subangular and irregularly shaped, but their surface is smooth and highly polished. About 10 to 30 percent of the volume of the rocks is subangular to rounded detrital quartz grains, averaging about 0.2 mm in diameter. The chert matrix and the quartz grains are of equal hardness; fractures cut through the grains rather than around them. The chert (matrix) is microcrystalline quartz with an average grain diameter of about 0.01 mm. No fibrous quartz (chalcedony) or amorphous quartz was seen in thin-sections of the rock. The sandy chert is not an ordinary silica-cemented sandstone; the chert matrix is much more abundant than the detrital quartz grains. Instead the chert is either primary or it replaced an earlier matrix. No evidence of secondary growth or replacement was observed, however.

The residual sandy chert in McIntosh and Logan Counties was probably derived from the Tongue River Formation. Todd (1896, p. 32 and 54) thought it came from layers in the local Fox Hills Formation or from the lower part of the "Loup Fork formation" (the Miocene Arikaree Formation). The chert is similar to some types of residual "pseudo-quartzite" in southwestern North Dakota. Hares (1928, p. 34-36), Tisdale (1941, p. 13-14), Laird and Mitchell (1942, p. 22), and Benson (1954, p. 14) believe that this "pseudo-quartzite" came from the nonmarine Paleocene Tongue River Formation. If the chert in Logan and McIntosh Counties was derived from the Tongue River Formation, it may have been let down more than 700 feet.

Pleistocene Series

Time-stratigraphic terminology

The only divisions of the Pleistocene Series that are applicable in North Dakota at the present time are the Wisconsin and Recent Stages. Sub-Wisconsin drift probably exists, but it is not known to what stage it belongs. Substages of the Wisconsin Stage are not recognized because the age of only a small part of the North Dakota Drift is accurately known. A suggested correlation of Logan and McIntosh County drifts with various systems of time-stratigraphic terminology is shown in figure 13.

Geologic-time terminology directly parallels time-stratigraphic terminology; the only divisions of the Pleistocene Epoch which are applicable in Logan and McIntosh Counties are the Wisconsin and Recent Ages. The American Commission on Stratigraphic Nomenclature's (1961, Art. 39-40) "geologic-climate" units are of little value as a formal substitute for geologic-time units because "geologic-climate" units are time transgressive and result in a complex and awkward terminology.

Lithostratigraphic-morphostratigraphic terminology

None of the formally named drifts described below is a lithostratigraphic unit as defined by the American Commission on Stratigraphic Nomenclature (1961, Art. 4, 4a, 4c, and 4e) because they have been differentiated by their topographic form, geographic position, and inferred geologic history. Stratigraphic subdivision of the surface drifts is desirable, however; a detailed subdivision of the surface drifts will become the basis for later syntheses of geologic history of North Dakota and for the construction of a practical time-stratigraphic terminology. For this purpose, the morphostratigraphic unit of Frye and Willman (1960, p. 7-8; 1962) is the most useful. As used for glacial drifts in Logan and McIntosh Counties, a morphostratigraphic unit is a body of drift that is identified by its surface form and position and consists of all the drift deposited from the glacial ice and associated meltwater of a significant glacial advance, including the till of associated end moraine, dead-ice moraine, and ground moraine, the washed drift of associated lake plains and outwash plains, and associated subsurface drift. The basic unit is a *drift* rather than a *moraine*, as used by Frye and Willman, because "moraine" is considered to be most useful as a landform or geomorphic term rather than as a stratigraphic or lithologic term. If "moraine" were used, confusion would result because the gravel of outwash plains, which are not part of a geomorphic moraine, would have to be considered part of a stratigraphic "moraine," and the till of the Burnstad moraine (a geomorphic unit) would be only a small fraction of the entire "Burnstad Moraine" (a stratigraphic unit).

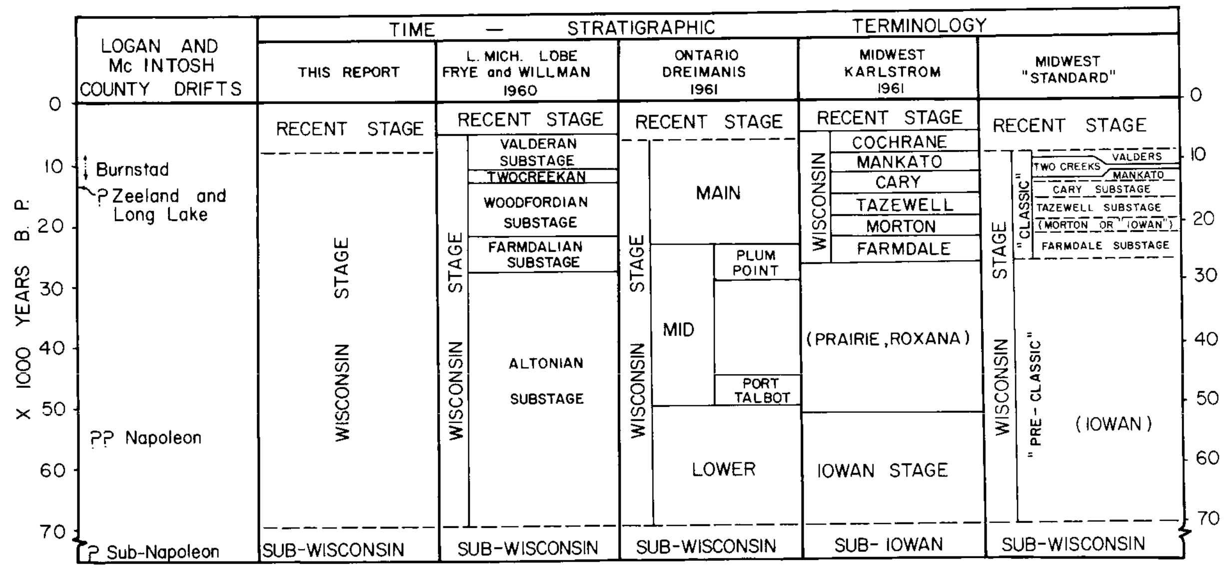


FIGURE 13. Approximate correlation of Logan and McIntosh County drifts with various time-stratigraphic terminologies. The Midwest "Standard" is modified from Leighton, 1960.

Sub-Wisconsin (?) stages

Sub-Napoleon drift.—Jointed till that is thought to be older than the lower Wisconsin (?) Napoleon Drift occurs at several places in western Logan County, including roadcuts in the northwest corner of sec. 20, T. 136 N., R. 72 W., and 0.2 mile south of the northeast corner of sec. 2, T. 133 N., R. 72 W. (see pl. 2). The till is well consolidated and has numerous widely spaced joints that are as much as 10 feet long and are bordered on either side by a zone of iron and manganese oxide. No carbonate leaching was observed, and in all other respects it differs little from the younger tills. In sec. 20., T. 136 N., R. 72 W., it is overlain by a foot of iron oxide-stained gravel and about 20 feet of Napoleon and Burnstad till and outwash. At least 5 feet of jointed till occurs at both localities. The till is thought to be sub-Wisconsin because Flint (1955, p. 31-32) considered joints to be an important distinguishing characteristic of sub-Wisconsin till in South Dakota.

Three occurrences of iron oxide-cemented glacial gravel in the eastern part of the Beaver Creek subdistrict have been described by Bonneville (1961a). In a roadcut 0.2 mile south of the northeast corner of sec. 23, T. 134 N., R. 72 W., the cemented gravel is about 2 feet thick, is overlain by Napoleon Drift, and is underlain by as much as 3 feet of gray to black peaty silt. This peaty silt has been radiocarbon dated by the U. S. Geological Survey at 28,700 ± 800 years B. P. (W-1045). The gravel has the same composition as younger outwash, but the carbonates have been completely leached away, leaving hollow molds in the place of limestone and dolomite pebbles. Contamination with younger organic material might have caused the radiocarbon date to be much too young. The complete leaching of carbonates from the gravel and its complete cementation suggest that it is older than the lower Wisconsin (?) Napoleon Drift, which is not cemented with iron oxide and has little leaching. Other deposits of iron oxide-cemented glacial gravel occur 0.4 mile east of the southwest corner of sec. 19, T. 134 N., R. 71 W., and 0.3 mile east of the southwest corner of sec. 29, T. 134 N., R. 71 W.

Some of the "older drift" reported by Paulson (1952, p. 28-29) in drill holes in the Streeter area may also belong to a sub-Wisconsin stage.

Wisconsin Stage

Lithology. The lithology of the four Wisconsin drifts in Logan and McIntosh Counties are nearly identical. Most of the till is light olive gray (5Y 5/2) and contains approximately equal amounts of clay, silt, and sand and about 5 percent pebbles, cobbles, and boulders. The Zeeland till is slightly grayer and slightly more clayey; the glacial ice that deposited it moved over hundreds of miles of gray Pierre Shale outcrops, but moved over no younger bedrock. The Napoleon till in the Wishek subdistrict is slightly sandier than most of the other till in the two counties and is dusky yellow (5Y 6/4); the ice that deposited it moved over 20 to 40 miles of the yellower and sandier Fox Hills and Hell Creek (?) Formations.

The lithology and source of pebbles in the tills, based on thirty-five 100-pebble samples picked from fresh roadcuts, is shown in table 4. The percentage of shale was determined separately by wet sieving several dozen large samples of till. Fragments of carbonaceous material a fraction of inch across are scattered through the till of the dead-ice moraine in the eastern part of the two counties. They may be carbonized fragments of plants that grew on top of the superglacial till and were incorporated into the till by mass movements. Irregular concentrations of iron oxide and calcium carbonate below the A soil zone gives the till a mottled appearance. It is oxidized to a depth of about 20 feet. In some places the till has numerous gypsum crystals that average about 2 mm across. The surface till is only slightly consolidated and is nonjointed or has very poorly developed irregular joints.

Approximate source and composition of surface boulders and cobbles, based on numerous field estimations, is shown in table 5. The amount of limestone and dolomite is variable. In many places in southwestern McIntosh County less than 1 percent of the surface boulders and cobbles are limestone and dolomite, and in some places in northeastern McIntosh County surface boulders and cobbles are as much as one-fourth limestone and dolomite. 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.

Outwash (in this report used in the broadest sense to mean any washed glacial drift deposited by meltwater streams) of Logan and McIntosh Counties 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 lithology of pebbles in the outwash is similar to the lithology of the pebbles in the surface till, except that shale is generally scarcer, varying from less than 1 percent to nearly 50 percent. The outwash of Logan and McIntosh Counties lacks the large amount of shale found in some outwash near outcrops of Pierre Shale in eastern North Dakota.

Sediments of ice-contact lakes are largely light yellowish 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. Where the lake sediment has collapsed when the supporting stagnant ice melted, it is folded, contorted, and faulted. No varves were identified in any lake sediments in Logan and McIntosh Counties. No loess was recognized in Logan and McIntosh Counties, though it is present as relatively thick surface deposits closer to the Missouri River in Emmons County to the west.

Napoleon Drift.—The Napoleon Drift, which is thought to belong to the Wisconsin Stage, is at the surface of much of the Wishek and Napoleon subdistricts in Logan and McIntosh Counties. The name "Napoleon drift" was first used informally in southern Logan County by Bonneville (1961a, p. 6).

Name and definition.—The Napoleon Drift is here defined as a lithostratigraphic or morphostratigraphic unit consisting of the till of the ground moraine of the Napoleon subdistrict plus 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, and 9, T. 134 N., R. 72 W., is designated as the type area.

Morphostratigraphic recognition.—The Napoleon Drift is distinguished from younger drifts by its topography and location. In the Wishek subdistrict its drainage is completely integrated; in the Napoleon subdistrict the drainage is nearly completely integrated, but a few undrained depressions remain. 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 parts of the Napoleon and Wishek subdistricts and has been completely eroded away in most of the Beaver Creek subdistrict.

Lithostratigraphic recognition.—In the Wishek subdistrict the till of the Napoleon Drift is yellow and is easily distinguishable from the younger gray drifts. It was observed underlying 1 to 15 feet of gray drift in three separate roadcuts in McIntosh County:

TABLE 4. Approximate composition and source of pebbles from till of the Napoleon, Long Lake, Zeeland, and Burnstad Drifts in Logan and McIntosh Counties.

LITHOLOGY	SOURCE	PERCENTAGE
Shale	Pierre, local and eastern N. Dak.	50
Limestone and dolomite	Paleozoic, Manitoba	25
Light-colored, coarse-grained igneous and gneissic rocks	Canadian Shield	10
Dark, fine-grained igneous rocks	Canadian Shield	10
Siliceous rocks	Upper Cretaceous or Cenozoic local residual; Paleozoic, Manitoba; and Canadian Shield	5
Siltstone and claystone	Fox Hills and Pierre concretions, local and eastern, N. Dak.	< 5
Dark, coarse-grained igneous rocks	Canadian Shield	< 5
Sandstone	Fox Hills, western part of Logan and McIntosh Counties	< 1

TABLE 5. Approximate composition and source of surface boulders and cobbles in Logan and McIntosh Counties.

LITHOLOGY	SOURCE	PERCENTAGE
Light-colored, coarse-grained igneous and metamorphic rocks	Canadian Shield	70
Dark, fine-grained igneous rocks	Canadian Shield	10
Dark, Coarse-grained igneous and metamorphic rocks	Canadian Shield	10
Limestone and dolomite	Paleozoic, Manitoba	0-25, average 5
Silicous rocks (chert, quartzite, etc.)	Upper Cretaceous or Cenozoic local residual; Paleozoic, Manitoba; Canadian Shield	< 5
Sandstone	Fox Hills, western Logan and McIntosh Counties	< 1

1. 0.4 mile north of the southwest corner of Sec. 20, T. 131 N., R. 69 W.; 7½ miles north of Ashley.

2. 0.35 mile east of the southwest corner of Sec. 31, T. 131 N., R. 69 W.; 5 miles north of Ashley.

3. 0.1 mile north of the southwest corner of Sec. 18, T. 130 N., R. 72 W.; 8 miles northeast of Zeeland.

At each of these three exposures the gray till is directly in contact with the yellow till along a well defined plane; no interbedded sediment or soil is present. At a few places, the Napoleon Drift lies on an older jointed till or iron oxide-cemented gravel (see section on sub-Napoleon drift), from which it is distinguished by its lack of joints and iron oxide cement, but at most places where its base was observed, the Napoleon Drift rests on bedrock.

Morphostratigraphic correlation.—The Napoleon Drift is equivalent, in part, to the "Tazewell (?)" drift of Lemke and Colton (1958, p. 47) and is probably the surface drift over most of Coteau Slope (excluding the Zeeland subdistrict) in south-central North Dakota (pl. 2 and fig. 14). It correlates with Flint's (1955, p. 94, fig. 27) "Tazewell" drift, which is at the surface from western Campbell County south to Buffalo County, South Dakota, where it is overlapped by younger drift. These correlations are based on the following similarities: thin, unweathered till, integrated drainage, and the presence of end moraines, including, in North Dakota, the Krem moraine in Mercer County (Lemke and Colton, 1958, fig. 5) and the northwest trending moraine in Tps. 130 and 131 N., Rs. 74 and 75 W., in southeastern Emmons County (see pl. 3). In contrast, the older drift to the west is much thinner and has no end moraines.

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). Its age is still unknown. There are, however, four reasons for believing that the Napoleon Drift belongs to the lower part of the Wisconsin Stage (fig. 13):

1. It is only slightly weathered and has none of the characteristics that Flint (1955, p. 31-32) used to identify sub-Wisconsin tills in South Dakota.

2. It has a well integrated drainage pattern, indicating that it is considerably older than the upper Wisconsin Burnstad Drift, which has non-integrated drainage. However, in drainage divide areas of the Napoleon sub-district, the Napoleon Drift is noneroded and has some undrained depressions.

3. It has been radiocarbon dated at older than 38,000 years (W-990) by the U. S. Geological Survey. The dated material consisted of small irregular masses of clayey peat in cross-bedded outwash gravel in a pit in the southwest corner of sec. 32, T. 132 N., R. 72 W., 3 miles south of Napoleon. The outwash is known to be no older than the Napoleon Drift because its upper beds have not been disturbed by a later readvance and no till overlies the outwash. The outwash 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 possiblility that the clayey peat was derived from a deposit that was much older than the Napoleon Drift.

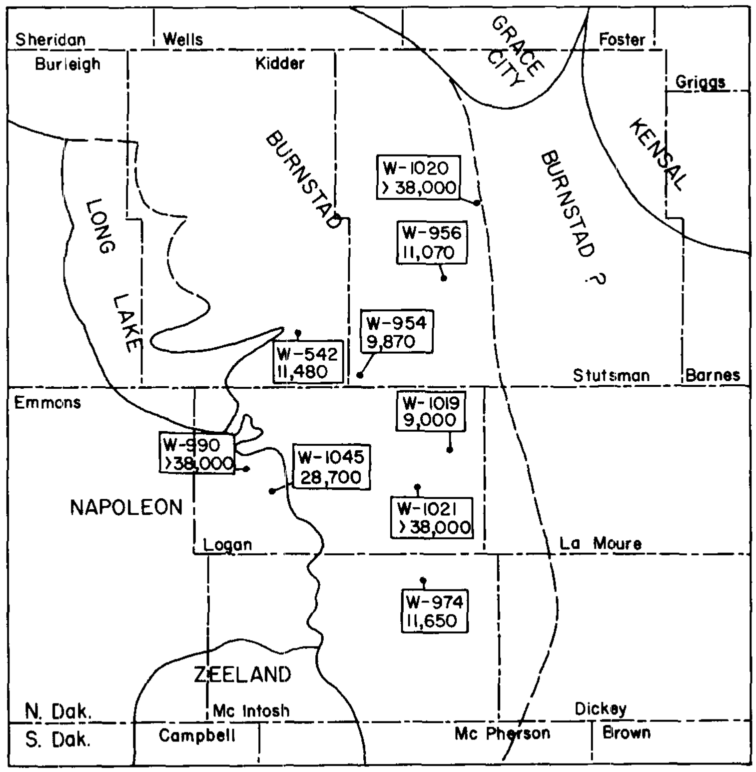


FIGURE 14. Map of surface drift sheets and location of radiocarbon dated material in south-central North Dakota. Figures are U. S. Geological Survey sample numbers and age of drift.

4. It is similar to and laterally correlates with the drift in South Dakota that Flint (1955, fig. 27) called "Tazewell." Flint said (1955, p. 90) that the "Tazewell" and "Iowan" drifts 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 is equivalent to the Tazewell in Illinois. This is improbable, however, because type Tazewell, which is about 18,000 years old, 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 the 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. It can therefore be concluded that the Napoleon Drift is close to the same age as type Iowan or belongs to the lower part of the Wisconsin Stage.

There is evidence, however, that this conclusion may be incorrect. The peat underlying the iron oxide-cemented glacial gravel that underlies Napoleon Drift in a roadcut 0.2 mile south of the northeast corner of sec. 23, T. 134 N., R. 72 W., (fig. 14) has been dated at 28,700 $\pm$ 800 (W-1045) by the U. S. Geological Survey (discussed in section on sub-Napoleon drift). All the carbonate pebbles have been leached from the cemented gravel, suggesting that it is considerably older than the overlying Napoleon Drift, which is only slightly leached and is not cemented with iron oxide. If this is true, the Napoleon Drift belongs to the upper part of the Wisconsin Stage. The 28,700 date could, however, be the result of chemical alteration or contamination with younger organic material.

Other evidence suggests that the Napolen Drift is sub-Wisconsin. A fragment of a horse jaw was found in the Napoleon Drift (?) by D. E. Hansen (oral communication). According to C. W. Hibbard of the University of Michigan (letter to D. E. Hansen dated January 29, 1962), its "dentitional pattern . . . seems to fit best that of *E [quus] hatcheri*," which may be pre-Wisconsin or middle Pleistocene. Several unidentified large mammal bones (probably horse) were also found within outwash of the Napoleon Drift in McIntosh County 0.5 mile west of the northeast corner of sec. 8, T. 131 N., R. 73 W. (University of North Dakota paleontology collection number 6134).

Long Lake Drift.—The upper Wisconsin Long Lake Drift is exposed in the northwest township of Logan County. Although the Long Lake end moraine was named in 1896 by Todd, "Long Lake" has apparently not previously been used as a formal stratigraphic term.

Name and definition.—The Long Lake Drift is here defined as a morphostratigraphic unit consisting of the till of the Long Lake end moraine plus other associated drift that originated from the same glacial ice. The drift is named after Long Lake in Kidder and Burleigh Counties. The type area is designated as secs. 4 through 9, T. 136 N., R. 73 W., in the northwest corner of Logan County, 10 miles southeast of Long Lake.

Recognition.—The Long Lake Drift is d i s t i n g u i s h e d from the older Napoleon Drift by its lack of drainage integration. The Long Lake Drift has been separated from the younger Burnstad Drift because the Burnstad end moraine is thought to overlap the Long Lake moraine and therefore represent a significant readvance. The surface contact between the Long Lake and

Burnstad Drifts is at the outer edge of the Burnstad moraine. The Long Lake Drift has not definitely been recognized beneath the younger drift.

Correlation.—The Long Lake Drift extends northwest into Emmons, Kidder, and Burleigh Counties and is apparently overlapped by the Burnstad Drift in northeastern Burleigh County (pl. 3). The Long Lake Drift is also overlapped by the Burnstad drift in northwestern Logan County. The Long Lake Drift has not been correlated with any other drift, though it might be equivalent to the Zeeland Drift in southern McIntosh County, which is equivalent to drift in South Dakota that Flint (1955, pl. 1) correlated with the Mankato drift in Minnesota.

The age of the Long Lake Drift is unknown. It is older than the Burnstad Drift and is therefore more than 11,500 years old. Its lack of drainage integration suggests that it belongs to the upper part of the Wisconsin Stage.

Zeeland Drift.—The upper Wisconsin Zeeland Drift occurs in the Zeeland subdistrict and southern edge of the Wishek subdistrict in McIntosh County. The Zeeland Drift has previously had no formal lithostratigraphic or morphostratigraphic designation.

Name and definition.—The Zeeland Drift is here defined as a morphostratigraphic unit consisting of the till of the Zeeland end moraine plus till of associated ground moraine and all other associated drift originating from the same glacial ice. It is named for the town of Zeeland in southwestern McIntosh County. The type area is designated as secs. 11, 12, 13, 14, 23, and 24, T. 130 N., R. 73 W., 6 miles northeast of Zeeland.

Recognition.—The Zeeland Drift has a drainage system that is only partly integrated and has a till that is light olive gray, making it easily distinguishable from the underlying and adjacent Napoleon Drift which has a completely integrated drainage and has a dusky yellow till. The Zeeland Drift has been separated from the younger Burnstad Drift because the Venturia end moraine overlaps the Zeeland moraine and probably represents a significant readvance (see section on Venturia moraine). The surface contact between the Burnstad and Zeeland Drifts has been placed at the outer edge of the Venturia end moraine.

Morphostratigraphic correlation.—The Zeeland Drift is equivalent to Flint's (1955, pl. 1 and fig. 31) "A2" and "A3" and probably "A1" and "A4" "Mankato" drifts in northern South Dakota. The Zeeland Drift might be equivalent to the Long Lake Drift.

Time-stratigraphic correlation.—Flint (1955, p. 109) correlated the equivalent of the Zeeland Drift in northern South Dakota with the Mankato drift in Minnesota and Iowa, which has in part been dated at about 11,700 (Ruhe and others, 1957, p. 674). The Zeeland Drift therefore belongs to the upper part of the Wisconsin Stage.

Burnstad Drift.—The Burnstad Drift covers the entire Missouri Coteau part of Logan and McIntosh Counties and some adjacent parts of the Coteau Slope. The name "Burnstad" was first applied to the Burnstad end moraine by Lemke and Colton (1958, fig. 3) but has never been used as a formal stratigraphic name.

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 the Venturia, Fresh Lake, and Streeter end moraines, dead-ice moraine, and ground moraine, and associated outwash and lake sediment. It is named after the town of Burnstad, at the eastern edge of the Beaver Creek subdistrict. The type area is the eastern part of secs. 9 and 16 and secs. 10, 11, 14, and 15, T. 134 N., R. 71 W., northwest of Burnstad.

Recognition.—Inferred geologic history is the main basis for distinguishing the Burnstad Drift from other drifts. The great difference in drainage integration between the Burnstad and Napoleon Drifts indicates that the Napoleon Drift is much older. The Burnstad Drift has been separated from the older Long Lake and Zeeland Drifts because the Venturia and Burnstad end moraines, both of which are composed of Burnstad Drift, overlap the Long Lake and Zeeland end moraines at nearly right angles, indicating that the Burnstad Drift was deposited from the ice of a significant readvance.

The drift between the outer edges of the Venturia and Burnstad end moraines has been included in the Burnstad Drift. The large area of collapsed outwash in front of the Burnstad moraine in central McIntosh County indicates that a large sheet of stagnant glacial ice was present in this area when the Burnstad end moraine was being formed. Therefore, the Burnstad moraine does not represent a significant readvance in central McIntosh County. Furthermore, the drift and topography of both the areas behind the Venturia moraine and behind the Burnstad moraine are nearly identical, and deposition of drift from stagnant ice was contemporaneous in the two areas.

Similarly, the "Burnstad drift" and "Streeter drift" of Clayton (1961, p. 12 and 14) and the "Burnstad Drift" and "Streeter Drift" of Rau and others (in press) have been included in a single morphostratigraphic unit, the Burnstad Drift, because both were deposited by the glacial ice of a single significant advance. Even though the Streeter moraine is the most prominent end moraine in south-central North Dakota, it represents only a minor, insignificant readvance for the following reasons. The Streeter does not overlap any older moraines; it is everywhere parallel to the outer limit of advance of the glacial ice that deposited the Burnstad Drift. A sheet of stagnant glacial ice still existed between the Venturia, Burnstad, and Streeter end moraines at the time the Streeter moraine was formed. This is proven by the presence of collapsed valley trains between the Streeter moraine and the outer edges of the Burnstad and Venturia moraines and by the presence of an ice-contact face at the outer edge of part of the Streeter moraine.

Other, more practical reasons for combining the "Streeter drift" and "Burnstad drift" into a single morphostratigraphic unit are: (1) Both have nearly identical lithology and topography. (2) Where the Streeter moraine is absent, such as in southern Logan County, they canont be differentiated. (3) Washed drift from ice behind the Streeter moraine is intermixed with washed drift from ice in front of the Streeter moraine. For example, the collapsed outwash near Danzig in central McIntosh County was derived from melting stagnant ice behind the Streeter moraine, ice between the Streeter and Burnstad moraines, and ice between the Burnstad and Venturia end moraines.

No younger drift is present in Logan and McIntosh Counties, so the eastern surface limit of the Burnstad Drift is unknown. It may be the outer or western edge of the Kensal end moraine (see pl. 3 and fig. 14), which truncates younger washboard moraines and therefore represents a significant readvance.

Fossils.—Abundant fossil fresh-water snail and mussel shells, ostracode carapaces, and stonewort *(Chara)* zygospore cases occur in at least 20 deposits of ice-contact lake sediment and ice-contact outwash, all of which are part of the Burnstad Drift, in eastern Logan and McIntosh Counties (see Tuthill, 1961; Clayton, 1961):

1. A small body of lake clay in a roadcut 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., 11 miles west of Gackle.

2. A small deposit of lake silt in a roadcut on top of a 50-foot hill in the dead-ice moraine at the northwest corner of sec. 28, T. 135 N., R. 68 W., 11 miles southwest of Gackle.

3. The base of a 1½-foot layer of silty and pebbly outwash sand overlying lake clay in a roadcut in collapsed-lake-sediment topography 0.4 mile south of the northwest corner of sec. 20, T. 135 N., R. 67 W., 9 miles south of Gackle; clam shells dated at 9,000 $\pm$ 300 years (W-1019) by the U. S. Geological Survey.

4. A 4-foot bed of marl overlying lake clay in a roadcut in collapsed-lake-sediment topography 0.3 mile south of the northwest corner of sec. 27, T. 135 N., R. 71 W., 7 miles north of Burnstad.

5. A 6-foot bed of tilted and faulted ice-contact lake silt unconformably overlying intricately folded lake clay in a roadcut at the north edge of collapsed-lake-sediment topography 0.1 mile south of the northwest corner of sec. 14, T. 132 N., R. 69 W., 3 miles southeast of Lehr.

6. More than 4 feet of broadly folded lake silts in a roadcut in collapsed-lake-sediment topography 0.5 mile west of the southeast corner of sec. 16, T. 132 N., R. 69 W., 2¾ miles south of Lehr.

7. A 3-foot bed of outwash 0.3 mile south of the northwest corner of sec. 5, T. 131 N., R. 68 W.

8. A bed of marl, several feet thick, in a roadcut in the Burnstad end moraine 0.1 mile north of the southeast corner of sec. 21, T. 132 N., R. 70 W., at the west end of Clear Lake; could be postglacial.

9. More than 12 feet of outwash sand in a roadcut in a crevasse filling 0.3 mile south of the northeast corner of sec. 6, T. 131 N., R. 68 W., 8 miles southeast of Lehr.

10. More than 3 feet of lake silt in a roadcut at the north edge of collapsed-lake-sediment topography 0.2 mile south of the northwest corner of sec. 15, T. 131 N., R. 67 W., 7½ miles northeast of the gap in the Streeter moraine.

11. More than 4 feet of outwash sand in a roadcut at the north edge of collapsed-mudflow topography 0.4 mile east of the northwest corner of sec. 16, T. 131 N., R. 67 W., 7 miles northeast of the gap in the Streeter moraine.

12. A 3-foot bed of lake silt overlying lake clay in a roadcut in dead-ice moraine 100 feet east of the northwest corner of sec. 30, T. 131 N., R. 67 W., 4 miles northeast of the gap in the Streeter moraine.

13. A 2-inch bed of marl in a 15-foot series of steeply dipping lake clays in a roadcut in dead-ice moraine 0.4 mile north of the southeast corner of sec. 25, T. 131 N., R. 68 W., 3¾ miles northeast of the gap in the Streeter moraine.

14. Several scattered exposures of lake silt and clay in the ice-walled lake plain and collapsed-lake-sediment topography in the north half of sec. 34, T. 131 N., R. 68 W., one-half mile northeast of the gap in the Streeter moraine.

15. More than 2 feet of lake clay in a roadcut at the edge of a gully in collapsed-outwash topography 0.5 mile west and 0.1 mile south of the northeast corner of sec. 27, T. 131 N., R. 68 W., 2 miles northeast of the gap in the Streeter moraine; could be postglacial.

16. More than 8 feet of outwash sand and lake sediment in a roadcut in dead-ice moraine 0.3 mile west of the northeast corner of sec. 36, T. 131 N., R. 68 W., 3 miles east of the gap in the Streeter moraine.

17. Several feet of lake clay and silt in collapsed-outwash topography just west of road 0.1 mile north of the southeast corner of sec. 34, T. 130 N., R. 68 W., 9½ miles east of Ashley.

18. More than 3 feet of lake silt in a roadcut at the north edge of collapsed-outwash topography 200 feet east of the southwest corner of sec. 25, T. 130 N., R. 68 W., 10½ miles east of Ashley.

19. More than 8 feet of outwash sand in a roadcut in collapsed outwash 0.2 mile north of the southeast corner of sec. 36, T. 130 N., R. 68 W., 11½ miles east of Ashley.

20. Several feet of contorted lake sediment intermixed with till and outwash in a roadcut in the western segment of the Streeter end moraine 0.5 mile south of the northwest corner of sec. 20, T. 132 N., R. 68 W., 6 miles southeast of Lehr; not strictly an ice-contact lake sediment deposit, though it probably was before being incorporated into the end moraine ridge; clam shells in the clay dated at 11,650 $\pm$ 310 years (W-974) by the U. S. Geological Survey.

A composite list of the fossils identified from these deposits of ice-contact washed drift is as follows (see pl. 4):

Fresh-water snails
- Amnicola "leightoni"? Baker
- Amnicola limosa (Say)
- Armiger crista (Linnaeus)
- Ferrissia sp.
- Gyraulus parvus (Say)
- Gyraulus sp.
- Helisoma antrosa (Conrad)
- Helisoma campanulata (Say)
- Helisoma trivolvis (Say)
- Lymnaea humilis (Say)
- Lymnaea stagnalis (Linnaeus)
- Physa sp.
- Promenetus exacuous (Say)
- Valvata tricarinata (Say) (tricarinate, bicarinate, and ecarinate)

Fresh-water mussels
- Anodonta grandis Say
- Anodontoides ferussicainus (Lea)
- Lampsilis siliquoidea (Barnes)

Sphaerid clams
- Sphaerium spp.
- Musculium sp.
- Pisidium spp.

Ostracodes
- Cyclocypris cf. C. forbesi Sharpe
- Cyprinotus cf. C. pellucidus Sharpe

Cytherissa lacustris Sars
Eucandona cf. E. caudata (Kaufmann)
Eucandona cf. E. ohioensis (Furtos)
Eucandona swaini (Staplin)
Eucandona sp.
Ilyocypris bradyi Sars
Ilyocypris gibba (Ramdohr)
Limnocythere sp.

Stoneworts
Chara spp.

The mollusk identifications are from Clayton (1961) and S. J. Tuthill (personal communication). The ostracodes were tentatively identified by Denis L. Delorme (written communication May 19, 1962) of the University of Alberta.

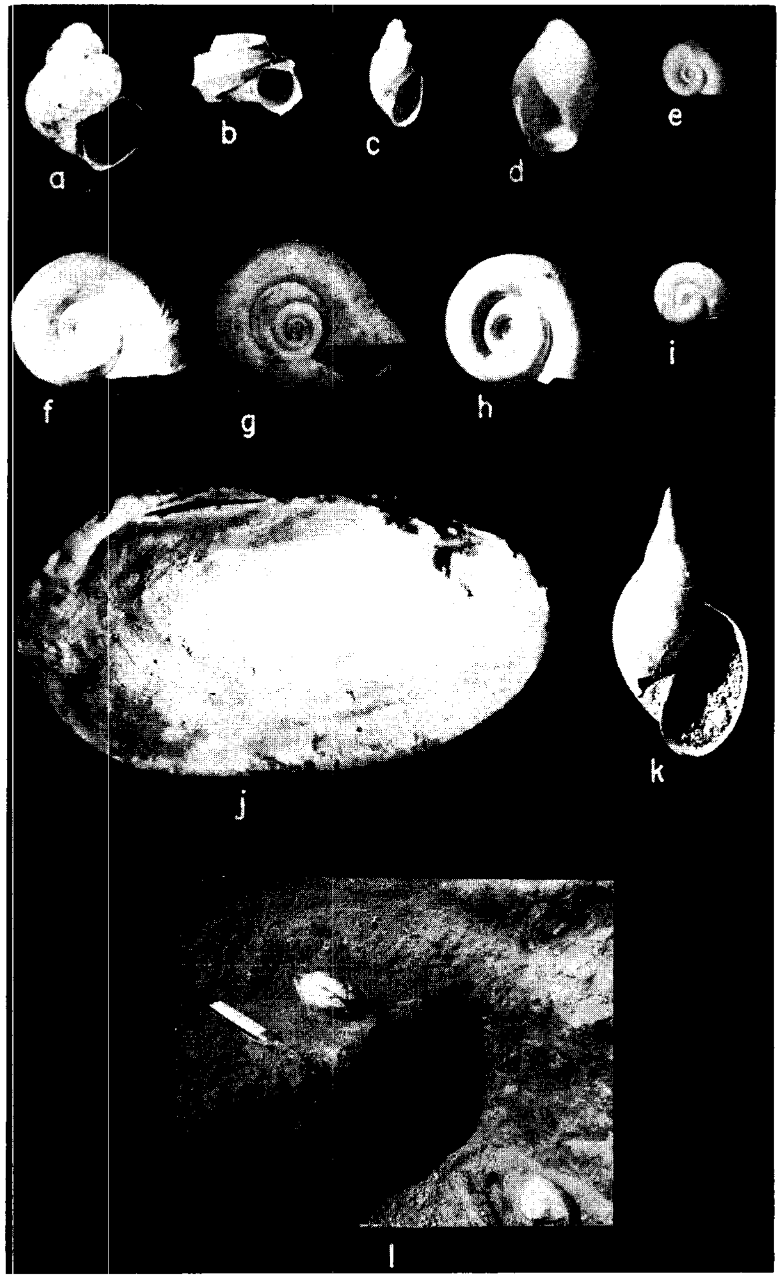
Well preserved, articulated mussel shells are especially abundant at sites 6 and 19, listed above. At site 19, several dozen excellently preserved shells were recovered in a few hours. Some of them still had the ligament preserved. All of the above fossils are known to have lived in streams and lakes that were, in part at least, supported by stagnant glacial ice about 11,500 years ago because they occur in folded and faulted Burnstad outwash and lake sediments on hill sides and hill tops, well above present-day depressions. Their elevated position could not be due to postglacial stream erosion because the drainage of the Coteau is completely nonintegrated and little postglacial erosion has occurred, and it could not be due to glacial shove or erosion (except at site 20) because the outwash and lake sediment have no till on top of them and the upper beds show no evidence of glacial overriding. The fossils were not derived from older deposits but are known to occur in nearly the same place that they lived because most of the shells are unbroken and the mussel shells are generally articulated, some still retaining the ligament.

Fish also occurred in these ice-supported lakes and streams because the parasitic glochidial stage of the mussels require established fish populations. No fish remains have been found, however.

Small fragments of a mammoth or mastodon tusk (University of North Dakota paleontology collection number 6063) were found in a roadcut in a small deposit of ice-contact lake silt 0.45 mile east of the southwest corner of sec. 6, T. 135 N., R. 70 W., 11 miles east of Napoleon. Curvature of the fragments indicates that the tusk had a diameter of at least 2½ inches.

Morphostratigraphic correlation.—The surface extent of the Burnstad Drift is in a 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. It extends northward at least to the northern limit of the Streeter moraine in northern Sheridan County and southward into South Dakota, where it correlates with part of Flint's (1955, pl. 1) "Mankato" drift.

PLATE 4. — Representative fossil mollusks from Burnstad Drift ice-contact deposits. Note varying magnifications. Photos by S. J. Tuthill. a. Amnicola limosa (Say) x4½. b. Valvata tricarinata (Say) x5. c. Lymnaea humilis (Say) x3. d. Physa sp. x5. e. Promenetus exacuous (Say) x6. f. Helisoma antrosa (Conrad) x5. g. Helisoma campanulata (Say) x2½. h. Gyraulus parvus (Say) x10. i. Armiger crista (Linnaeus) x6. j. Lampsilis siliquoidea (Barns) x1. k. Lymnaea stagnalis (Linnaeus) x1. l. 2 Lampsilis siliquoidea in place in excavation at site 19.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Time-stratigraphic correlation.—Five radiocarbon dates (fig. 14) determined by the U. S. Geological Survey indicate that the Burnstad Drift belongs to the upper part of the Wisconsin Stage[1] (see fig. 13):

1. 9,000 ± 300 years B. P. (W-1019) from mussel shells in outwash of the Burnstad Drift at site number 3 discussed in section on fossils; shells from 1½ feet below surface of the ground.

2. 9,870 ± 290 years B. P. (W-954) from mussel shells in lake clay, probably ice contact; though possibly postglacial (Harold A. Winters, personal communication), in the SE1/4SE1/4SE1/4 sec. 29, T. 137 N., R. 69 W., in Stutsman County; shells from 1 foot below the surface of the ground.

3. 11,070 ± 300 years B. P. (W-956) from mussel 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; site discussed by Tuthill (1961); shells from about 6 feet below ground surface.

4. 11,480 ± 300 years B. P. (W-542) from spruce wood in southwestern Kidder County, at base of fine wind-blown sand that was probably derived from newly deposited Burnstad outwash to the north; sand overlies Burnstad Drift of the Twin Buttes loop of the Burnstad end moraine; site discussed by Moir (1958).

5. 11,650 ± 310 years B. P. (W-974) from clam shells in Burnstad lake sediment in a ridge (push ridge?) of the Streeter moraine at site number 20 discussed in section on fossils; shells from about 6 feet below surface of ground.

The 9,000 and 9,870 dates are from shells that were less than 2 feet below the surface; they might have been contaminated or chemically altered. If there has been no contamination or alteration of the shells and the dates are correct, the upper part of the Burnstad Drift was being deposited continuously from before 11,300 years ago until after 9,300 years ago. That is, the stagnant, drift-covered ice from which the upper part of the Burnstad Drift was deposited took more than 2,000 years to melt. This may not be an impossibility because Sharp (1958, p. 19) observed that the stagnant, drift-covered terminus of the Malaspina Glacier in Alaska has an undisturbed forest on top of it that is more than 100 years old; this stagnant ice could take a few hundred years to melt. As was shown in the section on dead-ice moraine, the stagnant ice in Logan and McIntosh Counties was covered with thick superglacial drift, which caused the ice to melt so slowly that the water in the insulated, ice-supported lakes and streams could be kept at a high enough temperature for life to exist in them. If the stagnant late Wisconsin ice on the Coteau in North Dakota had a thicker cover of drift (which seems probable), and if the rainfall were much less than that that falls on the terminus of the Malaspina (which also seems likely), and if the ablation season were shorter in North Dakota than at the Malaspina today (which it probably was), the late Wisconsin ice in the Missouri Coteau may have taken several hundred or even 2,000 years to melt.

During the time that the stagnant ice on the Coteau was melting, the rest of North Dakota to the east and north may have been free of ice. A

1. A sixth date was received as this bulletin was going to press: 9,620 ± 350 years B.P. (W-1149) from mussel shells in outwash of the Burnstad Drift at site 19 discussed in the section on fossils, shells from 3 to 6 feet below the surface of the ground; collected and submitted by S. J. Tuthill. Apparently the three 11,000 to 12,000 dates represent the Two Creeks warm-up when life was beginning to be able to exist on and next to the ice; the 10,000 to 11,000 gap represents the Valders cold interval when no mussels lived on the stagnant ice; and the three 9,000 to 10,000 dates represent a post-Valders warm-up when mussels again were able to live on the stagnant ice.

radiocarbon date of 10,050 ± 300 B. P. (W-1005; determined by the U. S. Geological Survey) from driftwood below 7 feet of gravel of the Ojata beach of Lake Agassiz in the NE1/4SW1/4 sec. 14, T. 150 N., R. 51 W., southeastern Grand Forks County, North Dakota (W. M. Laird, personal communication), indicates that the active-ice margin was considerably north of the North Dakota-Manitoba border at that time because the outlet of Lake Agassiz was to the east through Ontario at the time the Ojata beach was formed. The northeast part of the state was also free of ice for the length of time before 10,000 B. P. that was required to form the upper, well-developed beaches above the Ojata.

The four youngest of these radiocarbon determinations date the upper part of the Burnstad Drift, which was deposited after the glacier stagnated; only the fifth or oldest determination (11,650 ± 310) dates the lower and older part of the Burnstad, which was deposited while the glacier was still active. This date is in agreement with dates of about 11,500 to 12,000 (Karlstrom, 1961, p. 314; Karlstrom, 1960, p. B331; Ruhe and others, 1957, p. 687; and Wright and Rubin, 1956) from roughly equivalent (Flint, 1955, p. 109) James lobe drift in South Dakota and Des Moines lobe Mankato drifts of Minnesota and Iowa. The clay containing the mussel shells could possibly have been derived from a drift older than the Burnstad. If so, the 11,650 date represents a maximum age for the Burnstad Drift.

It is therefore concluded that, if the above five radiocarbon dates are correct, the Burnstad Drift belongs to the upper part of the Wisconsin Stage, or to the Mankato, Two Creeks, and Valders Substages, and possibly even the Recent Stage of Leighton (1960) or the Twocreekan and possibly the Valderan Substages of Frye and Willman (1960). (The Burnstad is not part of Frye and Willman's Woodfordian Substage because they placed the boundary between the Woodfordian and Twocreekan Subages at 12,500 B. P.). The lower part of the Burnstad Drift was probably deposited about 11,650 years ago. The upper part was deposited from slowly melting stagnant glacial ice during the Two Creeks warm-up, about 11,400 years ago, when spruce were growing in southeastern Kidder County and other life was abundant in stagnant ice-supported streams and lakes, and possibly during the cooler Valders time and during the post-Valders or Recent warm-up, when life may again have been present in the ice-supported lakes and streams. More dates are needed, however, to prove that the 9,000 and 9,870 dates are not too young because of contamination or alteration of the shallow buried shells.

Two other dates (U. S. Geological Survey number W-1020 and W-1021) from wood and peat in the Burnstad Drift of Logan and Stutsman Counties are > 38,000 B. P. They obviously are from material derived from older deposits.

Wisconsin-Recent Stages undifferentiated

Postglacial sediments in Logan and McIntosh Counties belong to both the Wisconsin and Recent Stages. Most abundant are the deposits of lakes, sloughs, and other undrained depressions and low areas. The slough deposits consist of several feet of dark organic clay and silt, which contain abundant fossil ostracode carapaces, terrestrial snail shells, slug internal plates, and fresh-water snail and small clam shells. Beneath this clay and silt is generally about one-half foot of fresh-water limestone with fossil snails, ostracodes, stoneworts and fresh-water sponge spicules. In at least one place (SW1/4 SW1/4 sec. 24, T. 132 N., R. 69 W.) this limestone is underlain by about one-half foot of peat composed of the aquatic moss *Calliergon giganteum* with fragments of coniferous wood, needles, and cones. (See Thompson, in press.)

Other postglacial sediments include beach and bar sand along the large intermittent lakes west of Napoleon and northwest of Ashley; dark, silty, alluvium along Beaver Creek, South Branch Beaver Creek, and other intermittent streams; minor amounts of wind-blown silt and sand; and colluvium at the base of steep slopes.

SYNTHESIS OF PLEISTOCENE HISTORY

Pre-Wisconsin (?) ages

Phase 1. Little is known about Logan and McIntosh County pre-Wisconsin glaciations, but it is probable that at least one occurred.

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. 15).

Wisconsin Age

Phase 3. More than 38,000 years ago a glacier advanced over the area and deposited a thin blanket of Napoleon Drift.

Phase 4. As the ice front retreated, outwash plains, valley trains, and a proglacial lake were formed (fig. 16).

Phase 5. Following the glaciation that deposited the Napoleon Drift, there was a time of nonglaciation, probably totaling over 25,000 years. Drainage was again integrated into a pattern similar to that of pre-Wisconsin time, and the Napoleon Drift was completely eroded away from the Beaver Creek subdistrict.

Phase 6. About 12,000 or 13,000 years ago, glacial ice advanced into the Zeeland subdistrict from the southeast. The Zeeland end moraine and an ice-marginal channel, the westward-flowing part of South Branch Beaver Creek, were formed at this time (fig. 17). The ice stagnated and the ice-walled lake plains in the southern part of the Zeeland subdistrict in McIntosh County were formed.

At approximately the same time the glacial ice advanced into northern Logan County, forming the Long Lake end moraine and again forming the proglacial lake of phase 4. A delta-like mass of outwash was built into this lake and an ice-marginal spillway to the west was formed (fig. 17).

Phase 7. After the glacial advance that formed the Zeeland end moraine there followed a period of perhaps a few hundred years during which there probably was no glacial ice in Logan and McIntosh Counties. Only minor stream erosion took place during this time.

Phase 8. About 12,000 years ago the ice that deposited the Burnstad Drift advanced from the east halfway into Logan and McIntosh Counties and formed the Venturia end moraine and the meltwater channel and outwash plains at the east edge of the Wishek subdistricts (fig. 18).

Phase 9. The ice then stagnated and the outer margin of active ice retreated about 9 miles in McIntosh County and advanced a few miles in Logan County and formed the Burnstad end moraine. Meltwater flowed over the till-covered stagnant ice behind the Venturia moraine, depositing a superglacial outwash plain, and ice-walled lakes filled up openings in the stagnant ice. Outwash plains were formed in the northern part of the Napoleon subdistrict (fig. 19).

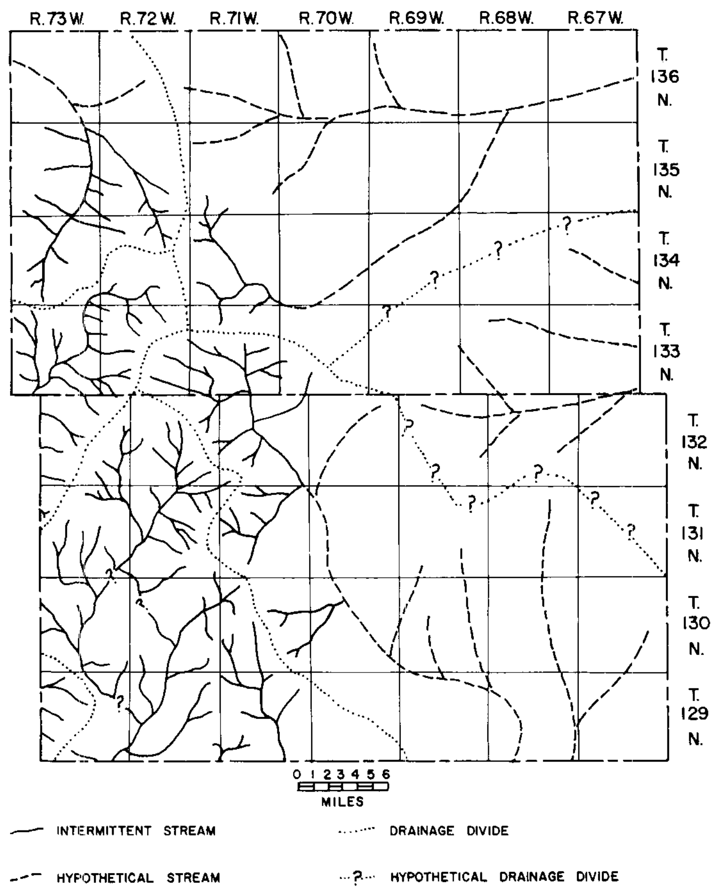

FIGURE 15. Phase 2 of Pleistocene history – pre-Wisconsin drainage.

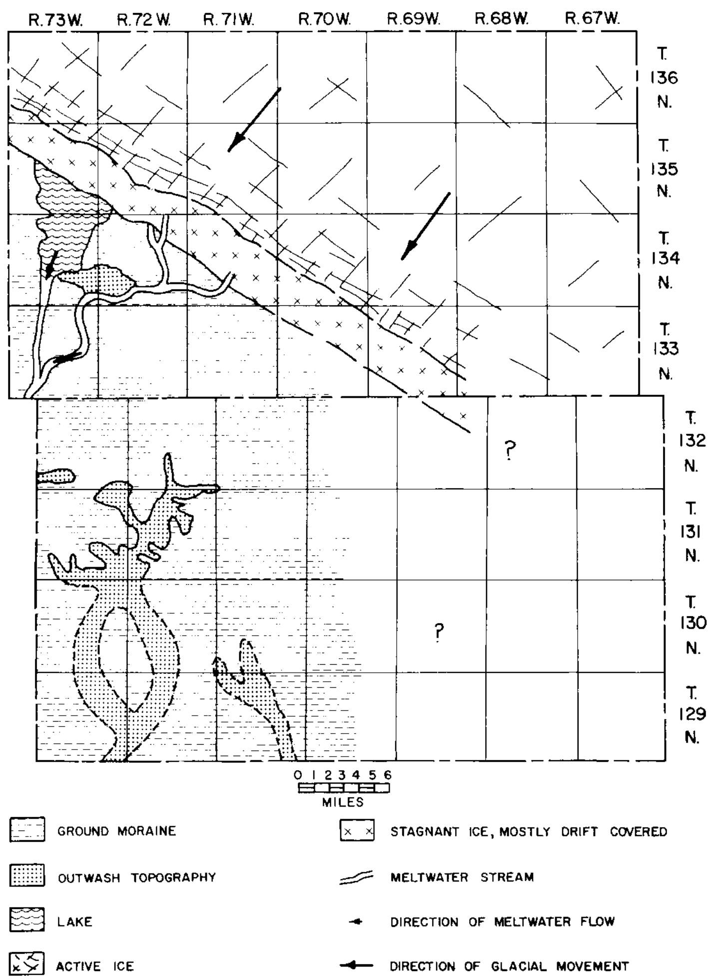

FIGURE 16. Phase 4 of Pleistocene history – early Wisconsin (?) retreat.

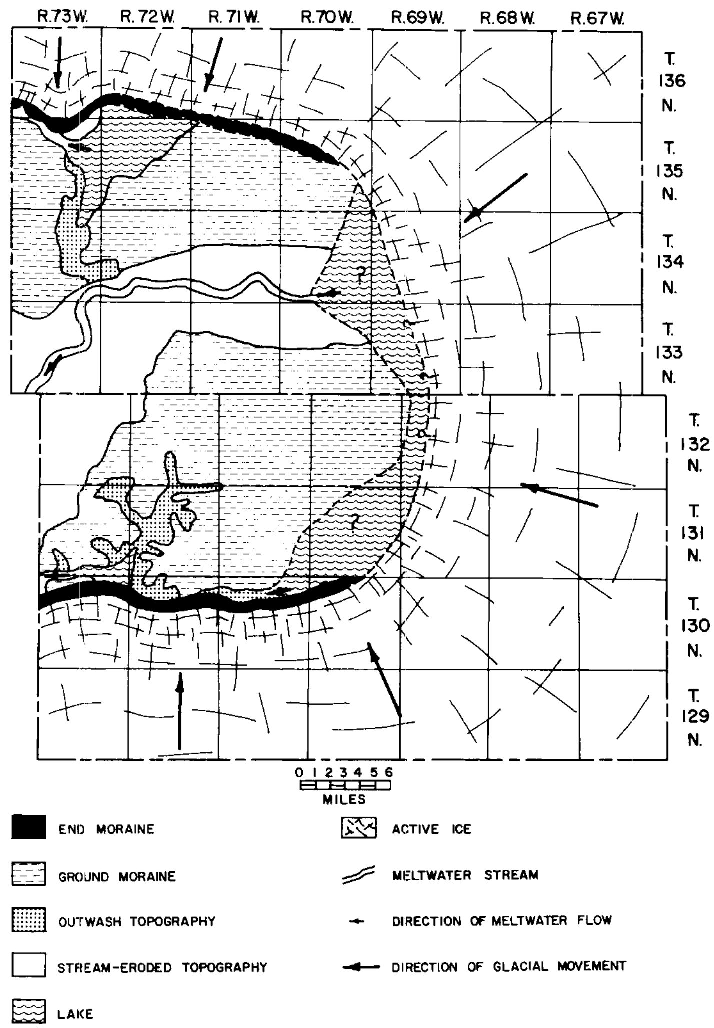

FIGURE 17. Phase 6 of Pleistocene history – formation of Long Lake end moraine may not have been contemporaneous with formation of Zeeland end moraine.

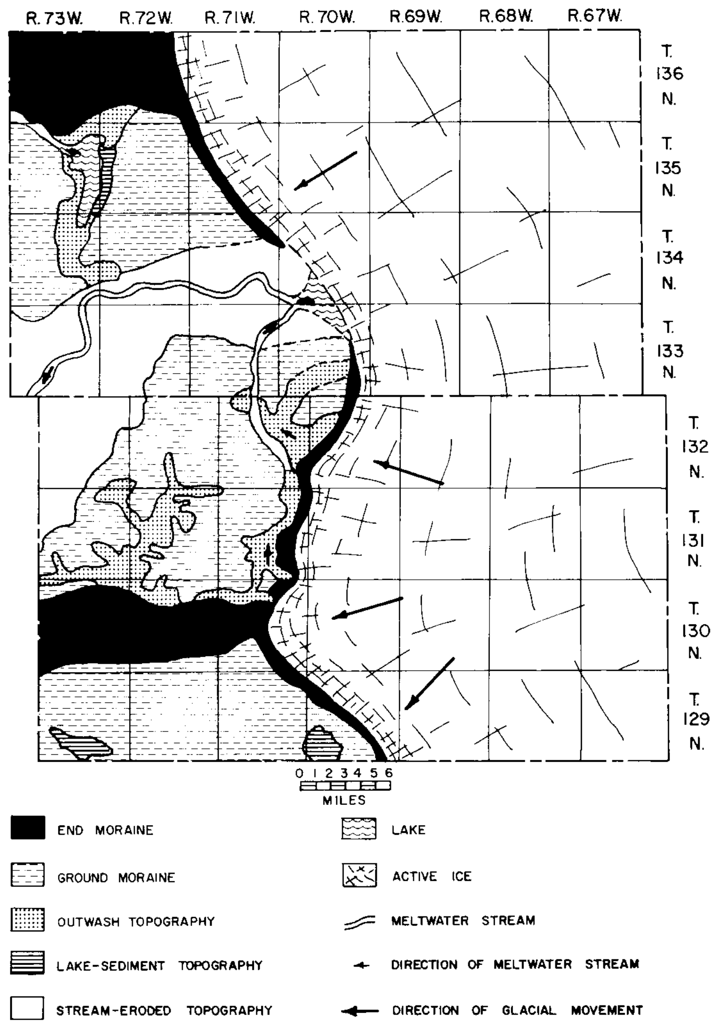

FIGURE 18. Phase 8 of Pleistocene history – formation of Venturia end moraine.

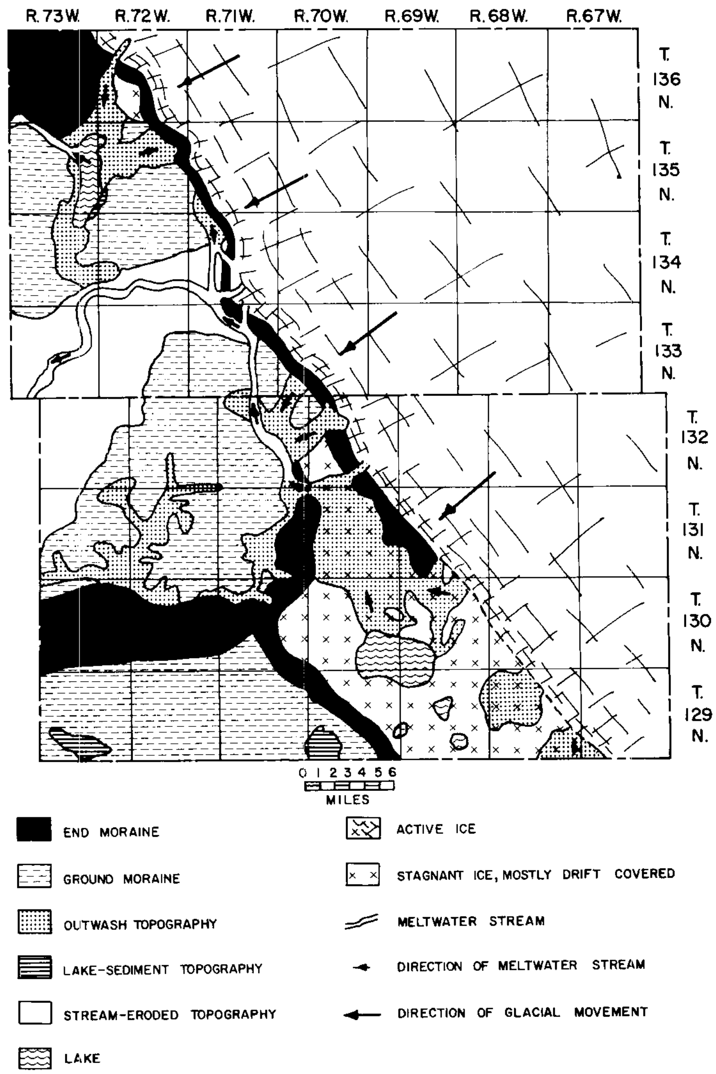

FIGURE 19. Phase 9 of Pleistocene history – formation of Burnstad end moraine.

Phase 10. The active-ice margin retreated more than 12 miles, again leaving behind a sheet of stagnant ice. During retreat, minor standstills or slight readvances formed the Fresh Lake end moraine and several other minor end moraine segments. The stagnant ice was covered with till that had probably been thrust up from beneath, lakes formed on and within the stagnant ice, and meltwater streams flowed over it, depositing valley trains and outwash plains on the stagnant glacier.

Phase 11. A slight readvance occurred and the Streeter end moraine was formed (fig. 20). By this time much of the stagnant ice behind the Fresh Lake moraine at the north edge of Logan County had melted and a large flat outwash plain was built in front of the Streeter moraine. To the south, however, much stagnant ice still remained. The active ice abutted against this stagnant ice, forming the ice-contact face at the outer edge of the Streeter moraine, and, in places, such as southern Logan County, active ice may have overridden the stagnant ice.

Phase 12. The western edge of the active ice mass then retreated from the area, leaving the eastern half of the two counties covered with a nearly continuous mass of stagnant ice more than 20 miles wide. During retreat, locally more active parts of the glacier formed the two minor end moraines in northeastern Logan County.

The stagnant 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 and lakes were formed.

As melting continued, the superglacial drift became thicker, causing the ice to melt more slowly. The climate was relatively mild. Fish swam up Beaver Creek and other tributaries of the Missouri River, entered the superglacial drainage system, and swam up 10 or 15 miles of superglacial streams to reach ice-walled lakes on either side of the Streeter moraine. These fish carried with them the parasitic glochidia of mussels, which became established and thrived in the ice-supported lakes and streams. Water birds came into the 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 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 (including spruce) and animals (including mammoths or mastodons) were probably also common on the superglacial drift and on adjacent ground from which all ice had melted.

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 melting. Later, after much of the ice had melted, the superglacial drift was much thicker, causing the remaining ice to melt even slower and the environment to be 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 and ice-walled outwash plains were left perched above the surrounding dead-ice moraine. It may have taken more than 2,000 years, or until less than 9,000 years ago, for all the glacial ice in Logan and McIntosh Counties to melt.

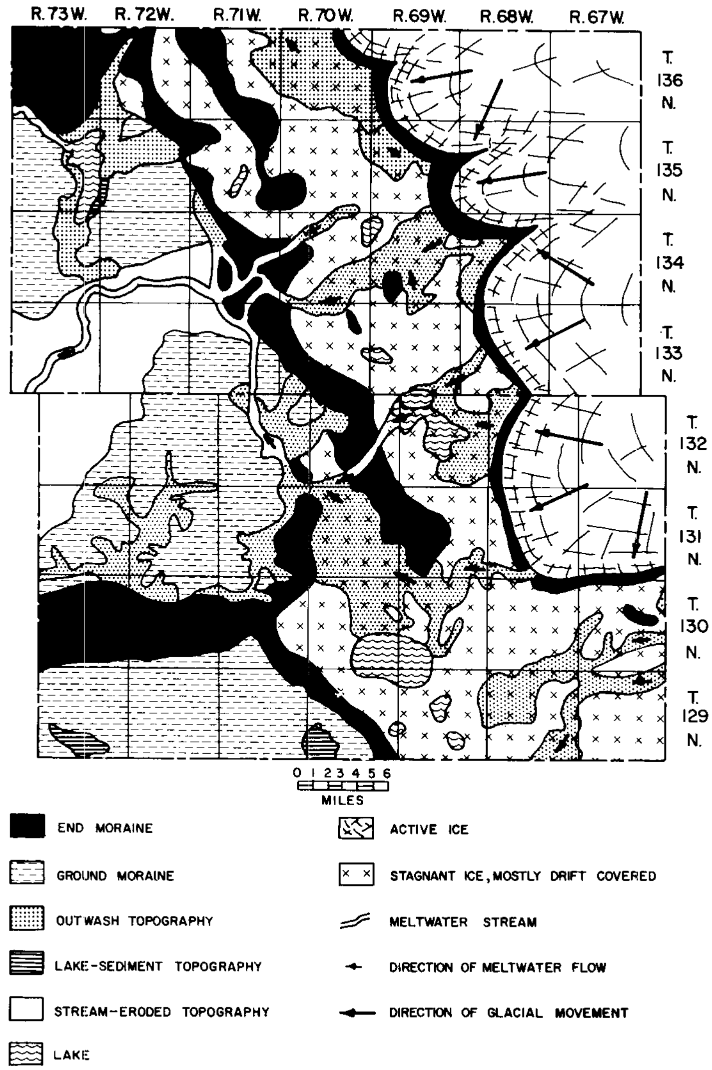

FIGURE 20. Phase 11 of Pleistocene history — formation of Streeter end moraine.

Recent Age

Phase 13. Only minor changes have taken place in Logan and McIntosh Counties since the last Burnstad ice melted. Several feet of erosion has occurred in some gullies on the steepest slopes, but in most places erosion has removed only a few inches or a few feet of the Burnstad Drift. Most of the eroded drift has been deposited in nearby sloughs and other low areas.

ECONOMIC GEOLOGY

Agriculture

The basic occupation in Logan and McIntosh Counties is agriculture. Land use is closely related to several geologic factors, including slope of the ground, abundance of cobbles and boulders on the surface, fertility of the soil, permeability of the soil, amount of surface drainage, and amount of ground water available. The geological factors affecting land use for each landform are summarized in table 6. In general, all soils derived from glacial drifts in Logan and McIntosh Counties are relatively fertile. The largest areas of nearly level land are in the Napoleon and Wishek subdistricts and in southeastern Logan County.

The areas best suited for irrigation are the outwash plains, valley trains, and ice-walled lake plains because they are flat and have permeable soils. According to Paulson (1952, p. 43-44), the large outwash plain west of the Streeter end moraine in north-central Logan County has enough ground water at shallow depths for extensive irrigation. Other outwash plains and valley trains and parts of Beaver Creek bottomlands may also have enough ground water for irrigation. Few of the ice-walled lake plains can be easily irrigated, however, because of a lack of a good water supply.

Ground Water

The ground water in most of the wells in the Napoleon, Beaver Creek, and Wishek subdistricts, and the westernmost part of the Missouri Coteau in Logan County comes from sand and sandstone of the Fox Hills Formation, though the water in many shallow wells comes from gravel of the outwash plains and valley trains in the area.

Most of the surface deposits of outwash sand and gravel in Missouri Coteau have enough water at shallow depths for local use. According to Paulson (1952, p. 43), the large outwash plain in north-central Logan County has an average thickness of about 20 feet of water saturated sand and gravel. The collapsed-outwash topography between Ashley and Wishek is also underlain by sand and gravel containing large amounts of ground water.

In the Zeeland subdistrict and most of Missouri Coteau that has no surface outwash, ground water is derived largely from numerous scattered deposits of outwash sand and gravel buried a few tens to a few hundred feet below the surface. Buried valley trains in the preglacial valleys extending from the Wishek subdistrict southward beneath the Zeeland Drift may be an important source of ground water in the Zeeland subdistrict (see fig. 16). The locations of the buried Missouri Coteau preglacial valleys, shown in figure 15, are inferred; they may, however, also be a good ground-water source, but their positions will have to be more precisely located by an extensive test drilling program.

According to Simpson (1929), Abbott and Voedisch (1938), Laird (1948), Paulson (1952), Randich (1961), and Adolphson (1961 and 1962),

TABLE 6. Geologic influence on land use in Logan and McIntosh Counties.

LANDFORMS	GEOLOGIC FACTORS				DOMINANT LAND USE
	Slope of ground	Abundance of surface cobbles and boulders	Permiability of soil	Completness of drainage	
Stream-eroded bedrock topography	High to medium 0° - 30°	Medium	High to medium; sandy to clayey	Well drained	Cultivation, grazing, and haying
Glacially modified stream-eroded topography	Medium to high 0° - 10°	Medium	High to medium; clayey to sandy	Well drained	Cultivation, grazing, and haying
Ground moraine of Wishek, Napoleon, and Zeeland subdistricts	Gentle 0° - 2°	Medium	Low; clayey	Generally well drained	Cultivation
Outwash plains and valley trains	Flat 0°	None	High; sandy	Good subsurface drainage	Cultivation
Collapsed-outwash topography	Medium 0°- 8°	None	High; sandy	Good subsurface drainage	Cultivation, grazing, and haying
Collapsed-lake-sediment topography	Medium 0°- 5°	None	Medium; silty	Fair subsurface drainage	Cultivation
Ice-walled lake plain	Flat 0°	None	Medium; silty	Generally well drained	Cultivation
Ground moraine in southeastern Logan County	Nearly flat 0° - 1°	Low to medium	Low; clayey	Many undrained depressions	Cultivation
Dead-ice moraine and collapsed mudflow topography	Medium 0° - 8°	Medium	Low; clayey	Many undrained depressions	Cultivation, grazing, and haying
End moraine	Medium to high 0° - 15°	High to medium	Low; clayey	Many undrained depressions	Grazing and haying

the total dissolved solids in the ground water of Logan and McIntosh Counties varies from less than 300 to more than 4000 ppm, averaging about 1200 ppm, and the total hardness (as $CaCO_3$) varies from less than 100 to more than 1600 ppm, averaging about 600 ppm.

Surface Water

Cattle watering is the most important use of surface water in Logan and McIntosh Counties. The numerous small lakes and sloughs in the Missouri Coteau provide adequate water in wet years, and dugouts have been made in the lowest areas to collect surface run off and near-surface seepage for dryer periods. Lakes that are fed by ground water seepage from outwash provide a permanent source of water.

The only permanent stream in the Coteau Slope part of the area is Beaver Creek. Other sources of surface water for cattle are ponds behind small dams across intermittent streams (where till, lake clay, or bedrock clay is present to prevent draining of the ponds by seepage) and dugouts in flat bottomlands.

Sand and Gravel

Logan and McIntosh Counties have nearly unlimited supplies of sand and gravel for use as road surfacing material. All of the outwash plains and valley trains, collapsed-outwash topography, kames, eskers, and crevasse fillings, and many of the meltwater channels are underlain by gravel and sand of varying size and sorting. Many small unmapped sand and gravel deposits also occur in much of the area; some of these are marked on plate 1 as sand and gravel pits. Pierre Shale fragments are the only significant fraction of the gravel that makes it detrimental for concrete aggregate. Shale constitutes 1 to 50 percent of the pebbles but is much less abundant than it commonly is in gravel near Pierre Shale outcrops east of the Missouri Coteau.

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