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QUATERNARY GEOLOGY OF
SARGENT COUNTY, NORTH DAKOTA

by
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A Dissertation

Submitted to the Graduate Faculty

of the

University of North Dakota

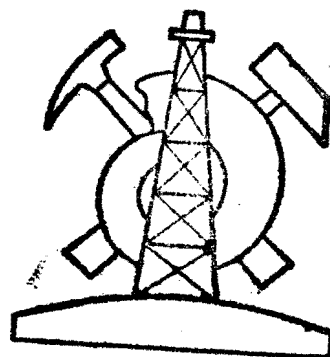
in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Grand Forks, North Dakota

December
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ABSTRACT

Sargent County, in southeastern North Dakota, was glaciated during the Pleistocene Epoch. Objectives of a study of Sargent County were to (1) describe the surface sediment and interpret its origin, (2) correlate, where possible, this sediment with that of adjacent areas, and (3) reconstruct the general geologic history of the county for the Quaternary Period.

A geologic map of the county was prepared using field data, topographic maps, aerial stereopairs, and soil maps. A map showing surface sediment origin was subsequently made using the available field and laboratory information.

Most of Sargent County is typical rolling prairie underlain by Quaternary sediment resting unconformably on Mesozoic rocks. The Quaternary sediment is primarily nonindurated sediment belonging to the Coleharbor and Walsh Formations. The Mesozoic rocks are mostly well-indurated sediment belonging to the Pierre, Niobrara, Carlile, Greenhorn, Belle Fourche, Mowry, Newcastle, and Skull Creek Formations.

The Coleharbor Formation comprises about 95 percent of the county surface area and is primarily glacial sediment. The Formation includes five facies: diamicton (glacial sediment); sand and gravel (fluvial channel sediment); silt (lacustrine sediment); silty clay (lacustrine

sediment); and silt, sand, silty sand, and clay (turbidity-current sediment).

The Walsh Formation comprises the remaining 5 percent of the county and includes four facies: clay (lacustrine sediment), sandy silt (slope-wash sediment), clayey silt (fluvial overbank sediment), and silty sand (eolian sediment).

Evidence of previous glacier advances includes: (1) the occurrence of two different drift units exposed in a roadcut on the Prairie Coteau, (2) the morphology and structure of the Whitestone Hills, and (3) the morphology and stratigraphy of the Lake Oakes Hills.

Two glacial diamicton beds are exposed in a Prairie Coteau roadcut; the upper bed, Drift A, is noticeably rich in shale fragments whereas the lower bed, Drift B, is shale-poor. Drift A correlates with the upper member of the Red Lake Falls Formation on the upper Red River Valley and the New Ulm Till of southwestern Minnesota. The shale fragments in Drift A were eroded by a glacier that moved down the valleys on the Red and Minnesota Rivers. The small percentage of shale fragments in Drift B indicates that it was deposited by a glacier that moved southward along the axis of the Red Lakes lowland, where there is little shale bedrock to erode. Drift B correlates with the lower member of the Red Lake Falls Formation of the upper Red River Valley and the Granite Falls Till of southwestern Minnesota.

The Whitestone Hills are streamlined and probably represent an overridden landform from a previous glacier advance, as evidenced by oxidized

diamicton occurring beneath unoxidized diamicton, separated by fluvial sand and gravel.

The Lake Oakes Hills in western Sargent County were found to be primarily composed of turbidity-current sediment that was deposited in an ice-marginal lake called Lake Oakes. Lake Oakes predates the last advance of ice because the hills are veneered with glacial diamicton deposited during overriding of the hills by the last glacier advance. The Lake Oakes sediment overlies another glacial diamicton evidently deposited by an earlier glacial advance.

The geologic events of the last glacial advance and ensuing deglaciation can be subdivided into three phases. During Phase 1, ice moved southward along the lowland of the Red and Minnesota Rivers. The Prairie Coteau caused the glacier to split into the James and Des Moines Lobes. Climatic warming caused the glacier to thin and retreat.

The presence of stagnant ice in Sargent County marks the beginning of Phase 2. Melt water from the James River in Dickey County and other streams in Sargent County and adjacent areas drained southward into South Dakota where it was eventually ponded by an end-moraine complex, resulting in the formation of glacial Lake Dakota. The lake eventually reached to several miles north of Cogswell in Sargent County.

Glacier ice was no longer active in Sargent County by the beginning of Phase 3. Superglacial debris covered stagnant ice over most of the county, however, insulating it from rapid melting. Melt water discharged into glacial Lake Agassiz in the Red River Valley during this phase. Lake

silt was deposited on stagnant ice above the Herman Beach level in Sargent County during the Milnor subphase. The lake dropped to the Herman level (1,060 feet) during the Herman subphase and overflow from the Sheyenne River cut across northeastern Sargent County during the subsequent Milnor Channel subphase.

All glacier ice in Sargent County was gone by 10,000 B.P. The climate continued to warm resulting in a vegetative succession from forest to prairie. The increased dryness resulted in increased stream and wind erosion. Between 7,000 and 8,000 years B.P. maximum dryness was reached; resulting eolian activity produced dunes in some sandy and silty parts of the county. From 7,000 until 4,000 years B.P. the climate gradually cooled. Since 4,000 years B.P. the climate of Sargent County has been relatively uniform.

INTRODUCTION

The purpose of this report is to describe the Quaternary geology of Sargent County, to identify and briefly describe the surface sediment and interpret its origin, to correlate, where possible, the sediment with that in adjacent areas, and to reconstruct the general geologic history of Sargent County during the Quaternary Period.

Location

Sargent County with an area of 855 square miles (townships 129 through 132 north, ranges 53 through 58 west) is in southeastern North Dakota (Figure 1). Forman, the county seat, is in the geographical center of the county.

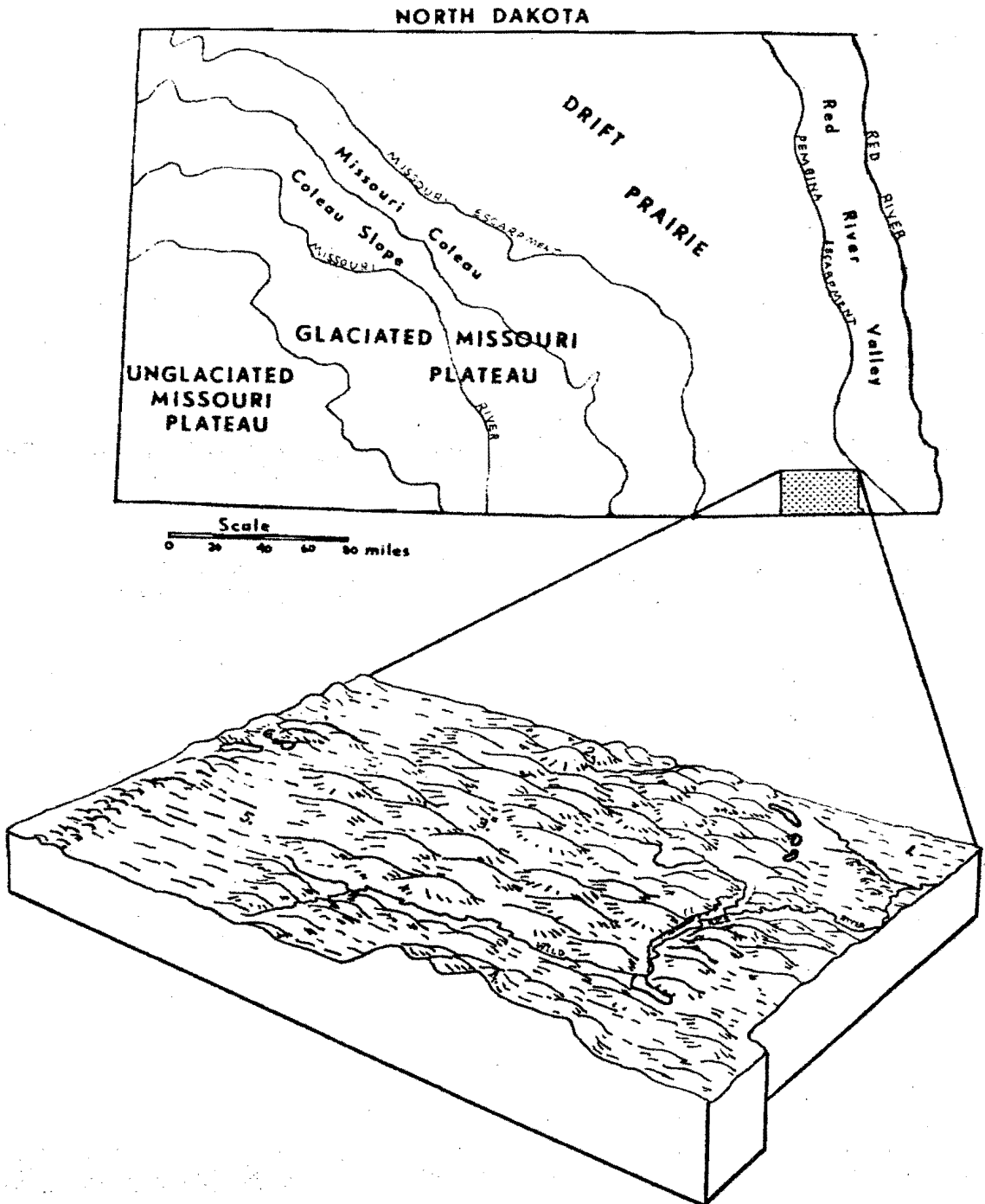


Fig. 1.--Index map showing the location of Sargent County and its physiographic position in North Dakota and adjacent states. The physiographic areas include (1) Lake Agassiz Plain, (2) Whitestone Hills, (3) Drift Hills, (4) Prairie Coteau, (5) Lake Dakota Plain, and (6) Sand Hills (modified from Larsen and others, 1964, p. 3).

BASIC GEOLOGIC DATA

Methods of Study

During the summer field seasons of 1969 and 1970 the surface lithology of all twenty-four townships in Sargent County was mapped at a scale of 4 inches to 1 mile and later reduced to a scale of $\frac{1}{4}$ inch to 1 mile. Aerial stereopairs (scale 1:20000) and county soil-map photos (scale 1:24000) were used to give a preliminary interpretation of the surface lithology. Field checking and sampling with shovel and hand auger were carried out along all passable roads. In addition, about fifty holes were augered by the North Dakota Geological Survey truck-mounted auger.

Topographic maps ($7\frac{1}{2}$ minute quadrangles; scale 1:24000; contour interval 5 or 10 feet) are available for all of Sargent County. A topographic map of Sargent County (Plate 1) with a 20-foot contour interval and a scale of 1:31680 was prepared. Detailed topographic information is available on 1960 aerial stereopairs (scale 1:20000) obtained from the Soil Conservation Service of the United States Department of Agriculture and from aerial soil photographs (scale 1:15840) contained in the Sargent County Soil Survey report (Larsen and others, 1964).

Sediment textures were estimated in the field. Forty-three samples were collected to check estimates and were subjected to sieve and pipette analysis (listed in Appendix A). The county soil report and East Oakes

Garrison Diversion Project drill-hole logs (on file at the Bureau of Reclamation office in Oakes, North Dakota) provided additional textural and stratigraphic information.

Topography

Most of Sargent County is typical rolling prairie, 1,100 to 1,300 feet above sea level. The Prairie Coteau, in the southeastern part of the county, rises 400 to 700 feet higher. Along the western border of the county are a group of hills locally known as the "Sand Hills" that rise from 100 to 200 feet above the rolling prairie.

Quaternary Sediment

Several geologic maps of North Dakota including Sargent County have been published (Flint, Colton, Goldthwait, and Willman, 1959 and Colton, Lemke, and Lindval, 1963). The maps have been basically genetic or landform maps and have not directly included lithologic data although some lithologic information can be inferred from them.

Two separate maps were prepared for Sargent County. Plate 2, "Geologic Map of Sargent County," is basically descriptive, whereas Plate 3, "Origin of Surface Sediment in Sargent County," is interpretive. Plate 2 shows the surface extent of the lithologic units of the Coleharbor Formation and the Walsh Formation (discussed separately below).

Coleharbor Formation

The Coleharbor Formation was named by Bluemle (1971c, p. 16-24) for exposures along the shore of Lake Sakakawea near Coleharbor in McLean

County, North Dakota. He defined it (p. 17) to include "all bouldery, cobbly, pebbly, sandy, silty clay (diamicton of this report), sand and gravel, and silt and clay exposed in the type section and all comparable sections." The formation consists of three distinct facies: diamicton, sand and gravel, and silt and clay. The complex interbedding and interfingering of the different facies produces a distinctive lithostratigraphic unit.

Distribution

The Coleharbor Formation covers most of the northeastern two-thirds of North Dakota, eastern South Dakota, Saskatchewan, Manitoba, northern Montana, and western and southern Minnesota (Bluemler, 1971c, p. 21). The formation covers about 95 percent of the surface of Sargent County (Plate 2).

The formation ranges in thickness from about 200 to 300 feet (Figure 2) in Sargent County; it overlies older rocks of all ages and is overlain in some parts of the county by sediments of Holocene age.

Lithologic Units

The Coleharbor Formation has not yet been formally subdivided into members. Informal lithologic units will be used in this report as subdivisions, or facies, of the Coleharbor Formation (Plate 2).

Diamicton

About 70 percent of the surface area of Sargent County (Plate 2) is diamicton (bouldery, cobbly, pebbly, sandy, silty clay). The diamicton,

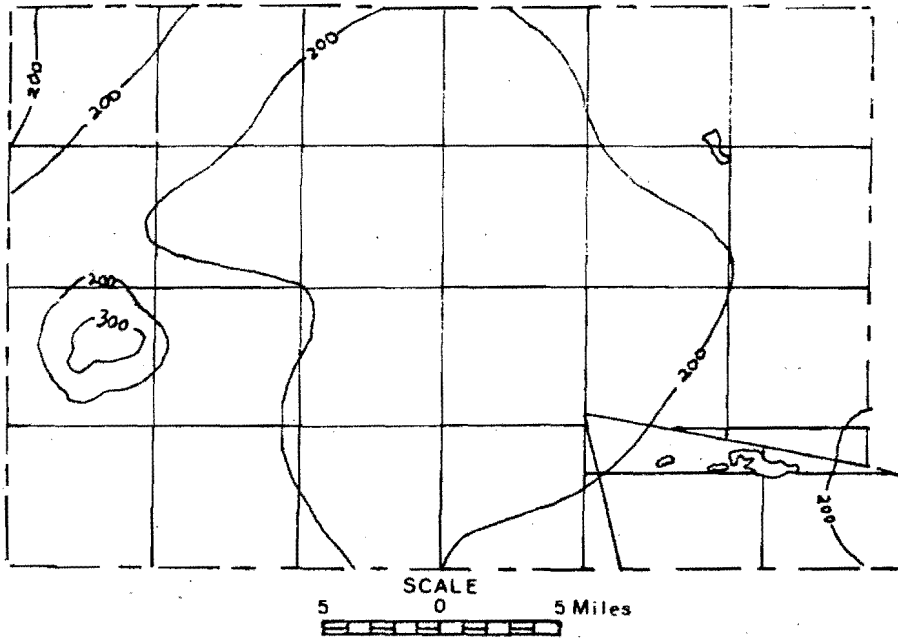


Fig. 2.--Thickness of Quaternary sediment of Sargent County, North Dakota (modified from Bluemle, 1971a).

when oxidized, has a color ranging from pale yellow (2.5Y 8/4--dry) to a light olive brown (2.5Y 5/4--moist). In one roadcut exposure, however, a light gray (2.5Y 7/2--dry) to light brownish gray (2.5Y 5/2--moist) bed of diamicton occurs below diamicton having the previously described color (Figure 3). The lower diamicton was observed at the surface only at the Coteau section.

Texture.--The diamicton is a relatively uniform, nonbedded mixture of approximately equal parts of sand-size, silty-size, and clay-size grains along with small amounts of pebbles, cobbles, and boulders. Sieve and pipette analyses were made on twenty-seven surface samples of diamicton and the results are plotted in Figure 4. The samples have a mean sand, silt, and clay ratio of 36:41:23. An additional ten samples were taken from the lower diamicton bed exposed in the Coteau section (Figure 3). The size distributions of the additional samples are also plotted in Figure 4. The mean sand, silt, and clay ratio of the ten samples is 32:40:28.

Mineralogy.--Petrologic examination of the coarse-sand fraction of some samples used for texture analysis indicates that Canadian Shield igneous and metamorphic rock fragments and carbonate rock from southern Manitoba predominate (Table 1). The presence of soft gray or black Cretaceous shale fragments is discernible in all samples except those from the lower diamicton bed in the Coteau section (sample numbers 27, 19, 35, 28, 30).

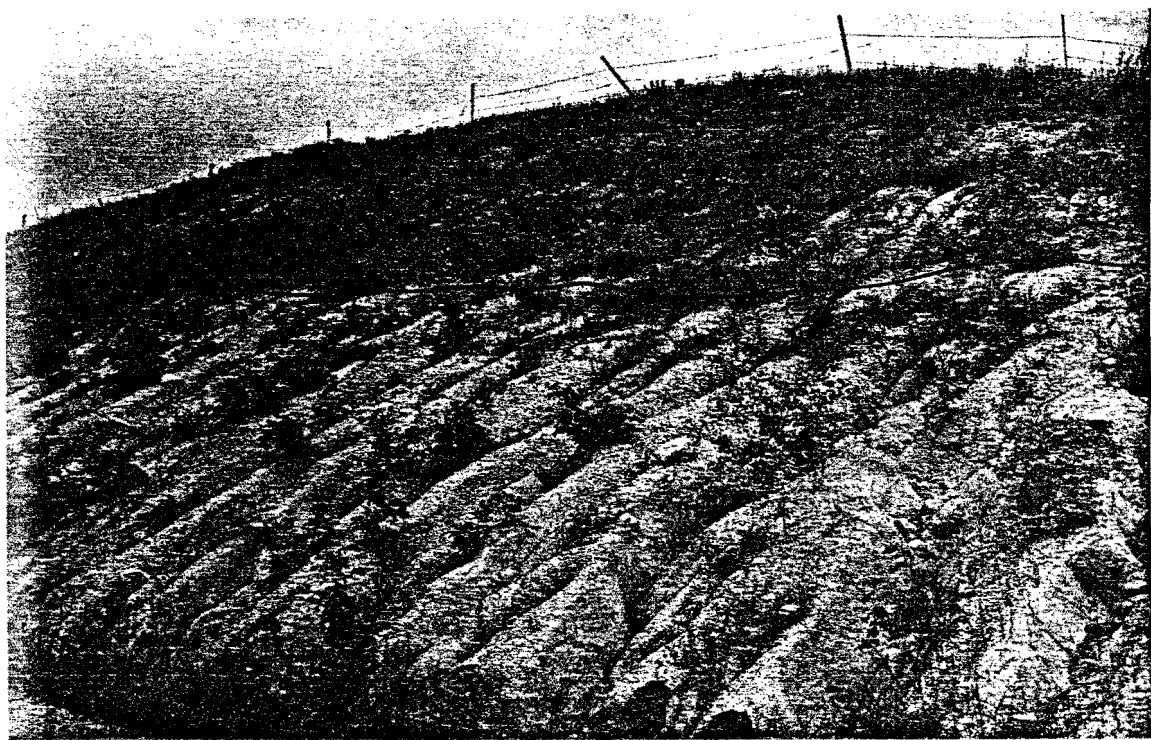


Fig. 3.--Two diamicton beds exposed in a roadcut on the Prairie Coteau in Sargent County ($NE\frac{1}{4}$ $NE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.). The line shows the contact between the two beds.

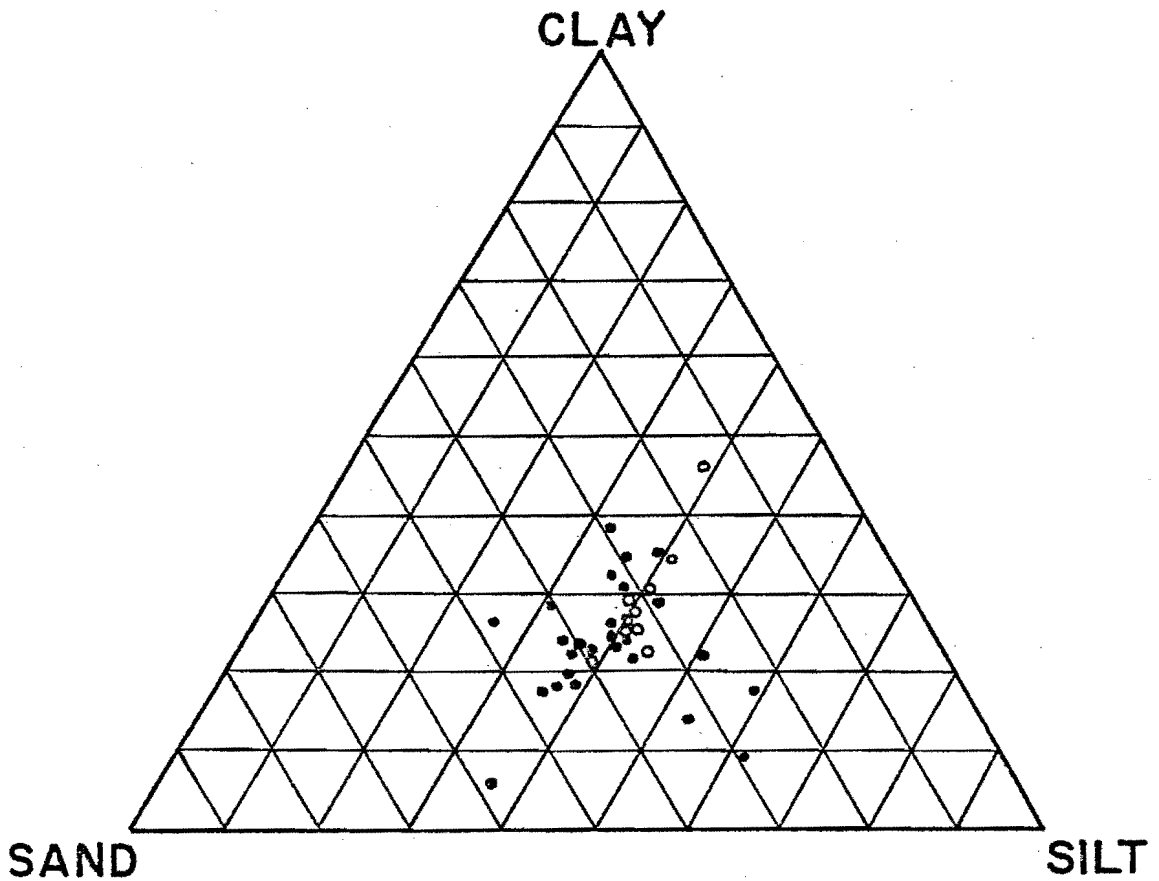


Fig. 4.--Size distribution of selected diamicton samples (gravel size omitted), Sargent County, North Dakota. The open circles represent samples from the lower diamicton bed (shown in Figure 3). The location and texture of each sample is in Appendix A.

TABLE 1

LITHOLOGY OF COARSE-SAND FRACTION OF DIAMICTON
 SAMPLES FROM THE COLEHARBOR FORMATION OF
 SARGENT COUNTY (MINIMUM OF 250 GRAINS)

Sample Number ^a	Ign. and Met. Crystallines	Carbonate	Shale	Other
10	39%	20%	39%	2%
1	40	36	23	1
24	36	41	21	2
15	47	28	22	3
17	27	20	35	18
12	36	30	28	6
9	43	35	19	3
11	24	53	17	6
5	27	52	16	5
27	30	66	0	4
19	48	37	5	10
35	57	38	4	1
28	38	57	1	4
30	51	45	1	3

^aLocation of each sample is listed in Appendix A.

Sand and Gravel

About 8 percent of the surface area of Sargent County is sand and gravel (Plate 2). The sediment typically has ripple and dune cross-bedding but also includes some lenses of flat-bedded sandy gravel. The sediment is generally horizontally layered except in the hilly areas of east-central Sargent County, where the layering is commonly tilted, contorted, or faulted.

In general, the best sorted deposits of sand and gravel occur in the flat areas of northeastern and northwestern Sargent County. Most of the sandy gravel in irregularly-shaped ridges and hills in the east-central part of the county is poorly sorted and coarse-grained. It typically contains some diamicton and boulders of all sizes.

Field observations indicate that the sand and gravel has a mineralogic composition similar to the diamicton; the grains were derived from the north and northeast in Manitoba and Ontario. The sand and gravel fractions typically contain granitic and metamorphic rock types, dolomite, limestone, and shale.

The deposits occur both as thin layers and lenses within the diamicton and as thick, continuous deposits independent of the diamicton. The sediment ranges in thickness from a few feet to several tens of feet (based on hand-augered and power-augered test holes).

Silt

About 13 percent of the surface area of Sargent County is silt (Plate 2). The silt usually contains some fine-sand-size and clay-size

grains in amounts up to 35 percent by weight. The sediment typically is laminated. The laminations range in thickness from 0.1 to 0.5 inches.

The silt is generally horizontally laminated except in the undulating area (slopes ranging from 1 to 4 percent) in northeastern Sargent County where the laminations are commonly tilted, contorted, or faulted.

The silt generally occupies basins or valleys in the diamicton. It ranges in thickness from several feet to nearly 100 feet in southwestern Sargent County.

Silty Clay

About 1 percent of the Sargent County surface area is silty clay (Plate 2). The sediment consists dominantly of clay-size grains but as much as 40 percent silt-size material may be present. The sediment is typically laminated. The laminations are rarely more than several tenths of an inch thick.

The sediment occurs only in the northeastern corner of Sargent County where the surface is flat (slopes 0 to 1 percent). The thickness is less than 5 feet and usually overlies sand and gravel.

Silt, Sand, Silty Sand, Clay, Gravel, and Diamicton

This lithologic unit is primarily composed of interbedded silt and sand but contains some thin beds of gravel, silty sand, and diamicton. The individual beds are commonly thin and in many cases discontinuous, making them difficult to map in the field. For this reason they are all considered to be part of the same lithologic unit within the Coleharbor Formation.

Twenty-eight holes were drilled as deep as 225 feet in the Lake Oakes Hills (see the Quaternary History section) by the Bureau of Reclamation using a rotary drill. The holes were completed as part of the Taayer Reservoir Project in Sargent County. Detailed lithologic drill-hole logs (on file at the Bureau of Reclamation office, Bismarck, North Dakota) were used in preparing a cross section through the Lake Oakes Hills (Figure 5). The lithologic data from each drill-hole are described in Appendix B.

The drill-hole logs indicate that the silt generally contains very fine sand and is clayey in zones. Varves were tentatively identified in several of the holes by Bureau of Reclamation personnel.

Walsh Formation

The Walsh Formation was named by Bluemle (1973, p. 33-36) for exposures in Walsh County, North Dakota, where it is particularly widespread. He defined it (p. 33) to include "a variety of clay, sand, silt, and gravel deposits that overlie the Coleharbor Formation and all other formations." Bluemle states that the sediments of the Walsh Formation have a "dirty" appearance due to the presence of organic material.

Bluemle (1973, p. 33) suggests that the contact between the Walsh Formation and the Coleharbor Formation corresponds in most places to the Pleistocene-Holocene boundary, about 10,000 years B.P. A climatic warming occurred about this time in North Dakota, causing prairie grassland to replace woodland (see the Holocene History section). The prairie soils, with thick A1 soil horizons, were more susceptible to wind erosion

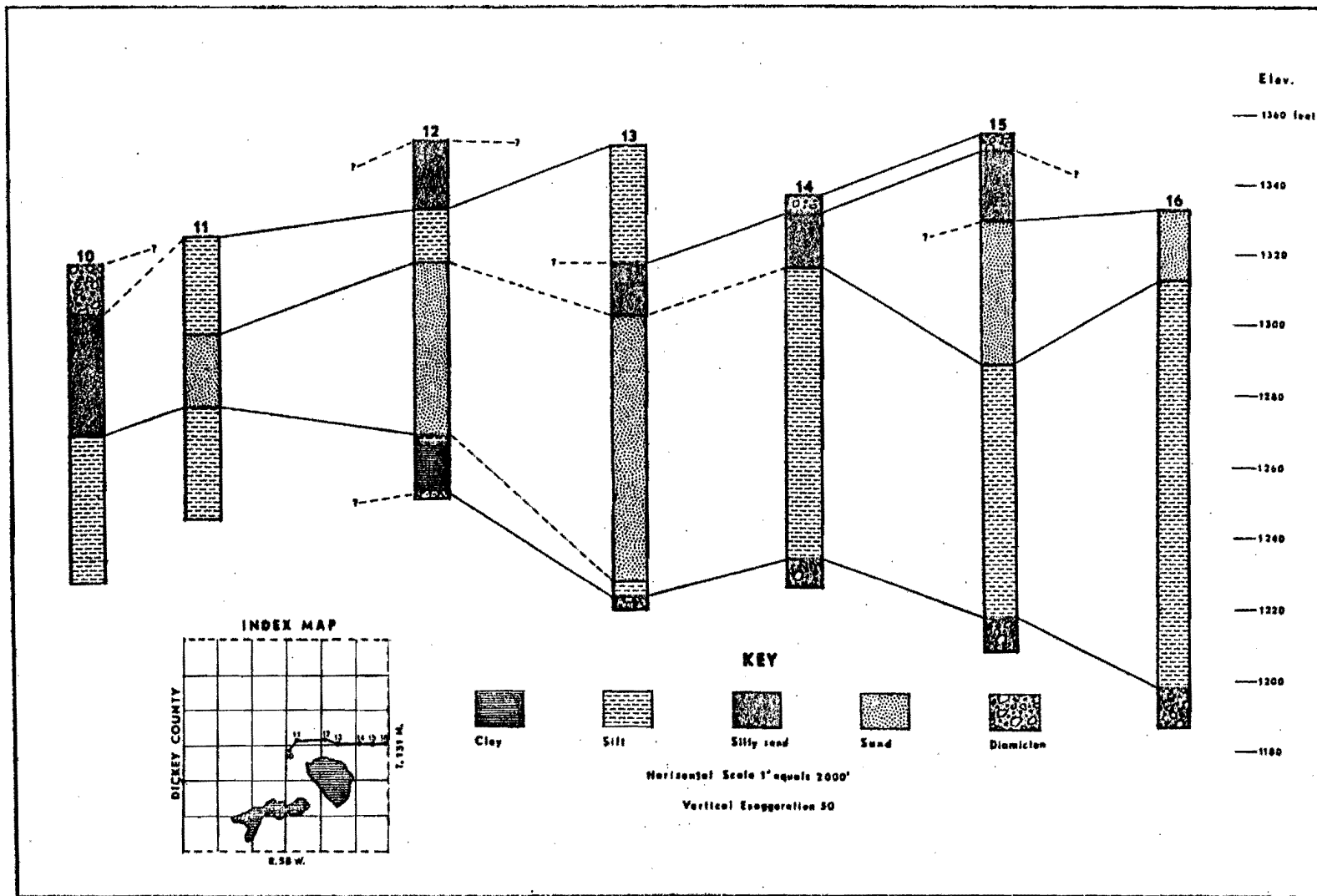


Fig. 5.--Cross section through the Lake Oakes Hills; based on Bureau of Reclamation drill-hole logs (on file at the Bureau of Reclamation office, Bismarck, North Dakota).

than the former forest soils. The result was that some of the black Al soil particles were eroded by wind and distributed over large areas.

Distribution

Bluemle (1973, p. 33-34) suggests that for practical purposes it is best to limit the Walsh Formation to areas where typical dark-colored prairie soils such as Chernozems and Chestnuts predominate. Sargent County is in such an area. The Walsh Formation covers about 5 percent of the county (Plate 2) and is usually less than 10 feet thick, except in a few places in western and eastern Sargent County where it is about 20 feet thick (Bureau of Reclamation drill-hole logs).

Lithologic Units

Bluemle (1973, p. 35-36) divided the Walsh Formation into three main facies: clay, sand and silt, and gravel. In Sargent County, four main facies occur: clay, sandy silt, clayey silt, and sand.

Clay

The clay facies consists of very well sorted gray to black clay and silty clay. The clay is commonly fine-bedded (0.1 to 0.3 inches), and is generally less than 4 feet thick (Bureau of Reclamation drill-hole logs). In some deposits the bedding has been destroyed by organisms. Terrestrial fossils (shells and pollen) are common.

The clay is generally found in sloughs and small lakes throughout Sargent County. Most of the clay areas are too small to be shown on Plate 2.

Sandy Silt

Most of this unit consists of sandy silt but commonly includes up to 30 percent clay (field estimate). The sediment is generally gray to black due to the presence of finely disseminated organic matter. Typically the sediment is poorly sorted and has very indistinct bedding. This sediment is usually found at the base of slopes and is up to 5 feet thick along the base of the Prairie Coteau (North Dakota Geological Survey auger hole, NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 33, T. 129 N., R. 55 W.).

Clayey Silt

This unit contains mostly clayey silt but commonly includes some well-sorted sand beds. The clayey silt generally has indistinct horizontal bedding and is generally dark brown, gray, or black due to the presence of finely disseminated organic matter. Terrestrial and aquatic fossils such as shells, wood fragments, and bones are common.

The sediments of this unit are generally found in flat areas adjacent to the Wild Rice River.

Silty Sand

This unit consists primarily of fine sand and silt. The sediment is very well sorted and typically has indistinct cross-stratification. Black organic silt is discernible in most of the sediment. Fossils are generally absent although some small rodent bones and teeth were found in some deposits (SE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 13, T. 131 N., R. 53 W.).

The sediment contained in this unit generally occurs in hills less than 20 feet high (Plates 1 and 2). The sediment generally overlies

the sand and silt facies of the Coleharbor Formation. Numerous small deposits of this sediment occur throughout Sargent County but were too small to map.

BEDROCK TOPOGRAPHY

All of Sargent County is mantled with Quaternary sediment. Bluemle (1971b) compiled a topographic map of the bedrock surface of North Dakota from exploratory oil well data and Works Progress Administration well schedules. The Sargent County part of his map is shown in Figure 6.

Elevations of the bedrock surface are about 800 feet in the northeast corner of the county and gradually increase southwestward to about 1,200 feet. A bedrock high is shown in the southeastern corner of the county corresponding to the surface feature known as the Prairie Coteau. The Prairie Coteau is a linear upland area between the Minnesota River lowland and James River lowland. It occupies most of eastern South Dakota and southwestern Minnesota and is a flatiron-shaped upland area about 200 miles in length trending north-south.

The Prairie Coteau is only one part of a much more extensive upland, known as the Pembina Slope or Escarpment, which continues northward through North Dakota into Manitoba and Saskatchewan. For more than 40 miles northward from the tip of the Coteau in Sargent County, the escarpment is absent. North of the present Sheyenne River the escarpment reappears and has a surface elevation of 1,400 to 1,500 feet, 500 to 600 feet higher than the floor of the Red River valley to the east.

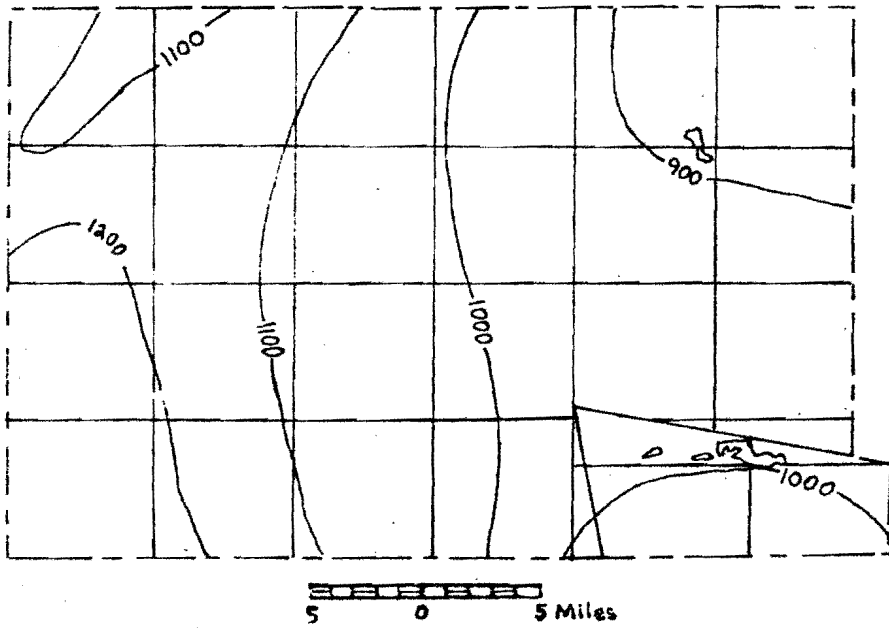


Fig. 6.--Bedrock topography map of Sargent County, North Dakota (modified from Bluemle, 1971b).

Leverett (1932, p. 11) said that the northern part of the Coteau is cored with Cretaceous shale overlain by as much as 400 to 500 feet of drift. Tipton and Leap (1969, p. 50) mention one hole drilled in the southeastern corner of Marshall County which penetrated 805 feet of drift before reaching bedrock.

Cretaceous sedimentary rocks underlie all Quaternary sediment in Sargent County. The rocks include, from oldest to youngest, the Skull Creek, Newcastle, Mowry, Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations (Carlson, 1969). These formations are predominantly soft, easily eroded limestone, sandstone, and shale. Shale is the most abundant rock type. There are no exposures of Cretaceous rocks in Sargent County. The bedrock map is shown in Figure 7.

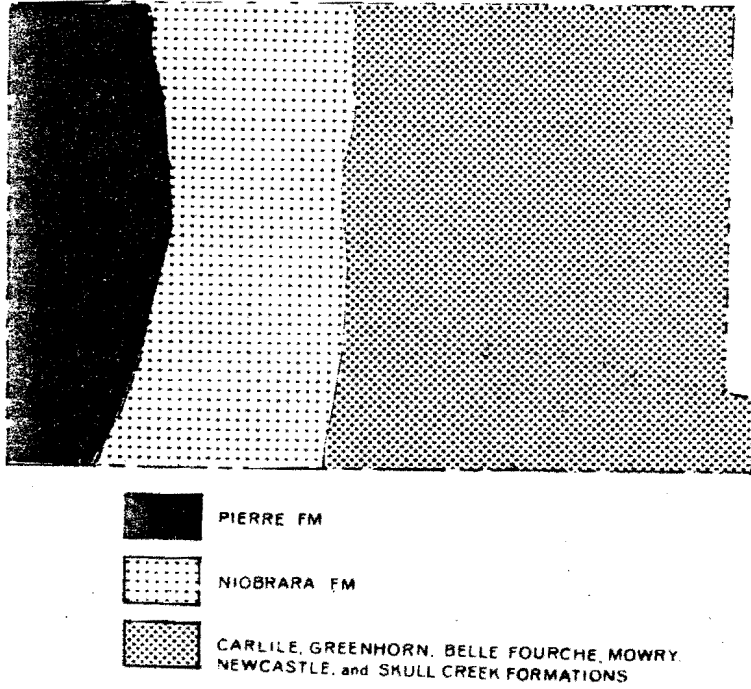


Fig. 7.--Subcrop map of the bedrock formations that underlie the Quaternary sediment in Sargent County (modified from Carlson, 1969).

ORIGIN OF QUATERNARY SEDIMENT

Plate 3 is a map of Sargent County showing the origin of the Quaternary surface sediment. The map is interpretive and is based on surface morphology (Plate 1) and lithology (Plate 2). Each map unit is identified with a number and in some cases a letter. Each number represents a major kind of sediment (for example, unit 1, fluvial channel sediment). A letter may accompany the number if the numerical unit is subdivided (for example, 1-A, lower-flow-regime fluvial channel sediment).

The map units can be classified under two major headings, sorted and nonsorted sediment. The former is divided into bed-load and suspended-load sediment, whereas the latter has only one subdivision, glacial.

Sorted Sediment

The sorting of sedimentary materials begins with the entrainment so the only sizes that are moved are those available in the source area and capable of being moved by the transporting agent (Jackson, 1970, p. 143). To a large extent the transporting agent and the original grain size control the sorting of sediments according to size. Clastic particles can be transported either as bed load or as suspended load.

Bed-Load Sediment

Bed-load sediment can be transported by water or air but in either medium the grains move more slowly than the medium itself. The particles move in traction by rolling, sliding, or saltation, and in general, are supported by the bed rather than by the transporting medium. The particles may move individually along the bottom or they may travel in groups. Bed-load sediment can be subdivided into four different genetic types including (1) fluvial channel sediment, (2) eolian sediment, (3) shoreline sediment, and (4) slope-wash sediment.

Fluvial Channel Sediment (map unit 1)

Most stream sediment in Sargent County was deposited during deglaciation. Except for the Wild Rice River, Holocene streams are intermittent or ephemeral and have not deposited enough sediment to be included on Plate 3.

The water flowing in streams during the last deglaciation came from two sources, melting ice and precipitation. Melting ice provided most of the water until late stages of deglaciation, when glacier ice melted slowly under a blanket of sediment (see the section Quaternary History), reducing the relative amount of water released by melting. During deglaciation most streams in Sargent County flowed under lower-flow-regime conditions in low-sinuosity streams.

Unit 1-A.--Most of this unit consists of lower-flow-regime fluvial sediment deposited in channels on solid ground and generally in contact with stagnant ice along the channel margins. Gravel-pit exposures, drill-

hole logs (Bureau of Reclamation), and hand-auger samples, generally show the presence of poorly-sorted, cross-bedded gravelly sand occurring in linear channels in Sargent County. Some upper-flow-regime channel sediment was usually found in the channels but was less abundant than the lower-flow-regime channel sediment.

This unit includes large areas of western and eastern Sargent County (Plate 3). The streams in these areas were confined by either stagnant or active ice. Evidence of stagnant ice includes fluvial channel sediment overlain by diamicton along the channel margins (Figure 8) and the presence of low-relief and medium-relief diamicton adjacent to the margins of the channel. The diamicton overlying the channel sediment is generally less than 5 feet thick and has no significant lateral extent. This suggests that it was probably deposited by mass wasting rather than by glacier overriding. The low-relief and medium-relief diamicton adjacent to the channels indicates the presence of stagnant ice covered by superglacial debris (see the section Nonsorted Sediment). This unit contains sediment that has been variously called "outwash" or "proglacial alluvium."

Wind has reworked the fluvial sediments in some areas of western and eastern Sargent County. Small dunes and blow-outs are common. The fluvial sediment is protected from deflation in areas where the water table intersects the surface, forming sloughs.

Unit 1-B.---This unit consists primarily of lower-flow-regime fluvial sediment and some upper-flow-regime fluvial sediment deposited on or within stagnant ice. As the sediment settled onto the subglacial surface, gravity faulting displaced the sediment (Figure 9). Mudflows from adjacent ice



Fig. 8.--Gravel pit exposure of upper-flow-regime sand and gravel overlain by diamicton (SW $\frac{1}{4}$ sec. 34, T. 132 N., R. 58 W.).



Fig. 9.--Poorly sorted sand and gravel exposed in a small gravel pit in Sargent County (SE $\frac{1}{4}$ sec. 36, T. 131 N., R. 54 W.).

covered some parts of the fluvial sediment with a discontinuous veneer of diamicton.

In some areas of Sargent County the sediment occurs as sinuous, linear deposits (eskers) and some isolated, nonlinear deposits (kames). A group of hills, about 4 miles northeast of Havana, is composed of poorly sorted fluvial sandy gravel. The fluvial sediments were deposited on stagnant ice and were later collapsed during melting of the underlying ice (collapsed outwash). The hills have about the same relief as those adjacent hills composed of diamicton.

Eolian Sediment (map unit 2)

Eolian activity during the following deglaciation was important in modifying the Sargent County landscape. Sandy sediment is subject to wind erosion if the sediment is not stabilized by vegetation or moisture. During dry climatic periods the vegetation and moisture are reduced permitting deflation of surface sediments.

Evidence of eolian origin of this sediment in Sargent County includes (1) very well sorted coarse silt and fine sand with no gravel and (2) indistinct dune cross-bedding. The sediment is blown into dunes up to 20 feet high in some parts of the county and generally is covered by vegetation (Figure 10). The dunes were evidently more active during past dry periods and most are stabilized today. A few blowouts occur on high ground where moisture is less.

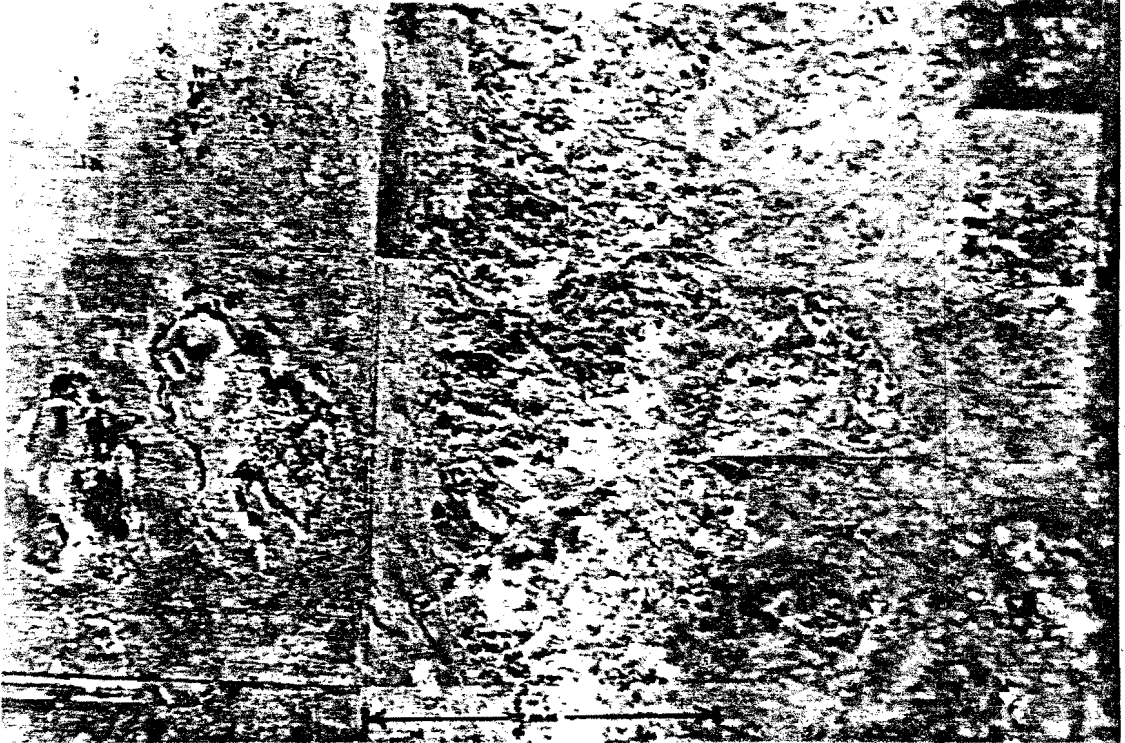


Fig. 10.--Dunes on the plain of glacial Lake Dakota (sections 29 and 30, T. 129 N., R. 58 W.).

Slope-Wash Sediment (map unit 3)

Most slope-wash sediment in Sargent County is too limited in area to be included in Plate 3. The Prairie Coteau, however, is high enough and has steep enough slopes to form large amounts of slope wash. The sediment forms an apron around the Coteau and generally overlies diamicton. Augering and topographic evidence indicate the apron is basically triangular in cross-section. The sediment was primarily derived from diamicton higher on the Coteau slope.

The slope-wash sediment is indistinctly bedded and poorly sorted, indicating that it was probably transported by sheet wash during periods of high surface runoff. The black color of the sediment indicates that most of the slope wash occurred during Holocene time after prairie soils succeeded forest soils (see the section Holocene History).

Suspended-Load Sediment

Suspended-load sediment is composed of finer particles than bed-load sediment and involves those grains supported by the fluid until the settling velocities of the grains exceed the upward fluid forces. The suspended load consists primarily of silt-size and clay-size grains. Suspended-load sediment is associated with fluvial and lacustrine depositional environments in Sargent County.

Fluvial Overbank Sediment (map unit 4)

A floodplain consists primarily of channel sediment and overbank sediment. For high-sinuosity streams, channel sediment is quantitatively of much less importance than overbank sediment because of the narrow width

of the channel compared to the much larger width of the floodplain outside the channel. The width of the Wild Rice River floodplain outside the channel is three to four times the width of the channel. Probably 75 percent or more of the floodplain deposits in Sargent County are therefore overbank sediments. Most Sargent County overbank sediment is dark brown and contains several percent organic matter, indicating that it was probably deposited during the Holocene Epoch. The organic matter is finely disseminated and was eroded from adjacent prairie soils (see the section Holocene History).

Lacustrine Sediment (map unit 5)

Distinctly bedded and indistinctly-bedded silty clay or clay is common in Wisconsinan lakes and Holocene lake and slough deposits in Sargent County. Suspended-load sediment was washed into the lakes and sloughs by water from melting ice and normal runoff. Slow settling of silt and clay takes place in low-energy environments beneath the wave zone. The greater the distance from the wave zone, the higher the clay content in the sediment.

Unit 5-A.---This unit consists of lacustrine sediment deposited in standing water bodies (lakes, ponds, and sloughs) during Holocene time. The Bureau of Reclamation drilled holes through ice on many standing water bodies during winter months and generally penetrated at least 10 feet of bottom sediment. The drill-hole logs indicate that the sediment is primarily laminated silty clay. The silty clay slough sediment contains finely disseminated organic matter, which was probably derived from ad-

adjacent hillslopes. The slough sediments in some areas are not distinctly bedded because burrowing organisms destroy the original bedding.

There are basically three types of standing water bodies in Sargent County: perennial, intermittent, and temporary.

Perennial lakes and ponds are those that always contain standing water. They occur in local groundwater discharge areas and receive water both from slope runoff and from groundwater seepage. Storm Lake, White Lake, Lake Tewaukon, Clouds Lake, and Silver Lake are typical examples of perennial lakes in Sargent County.

Intermittent lakes and ponds normally contain standing water but are dry during periods of little precipitation. Minor shifts in the position of the water table determines whether the lakes will be dry or wet. The sediment in them is similar to that in the perennial lakes but generally is more oxidized because of occasional subaerial exposure. Kandiotta Lake (E $\frac{1}{2}$ sec. 19, T. 131 N., R. 53 W.) is a good example of an intermittent lake in Sargent County. In dry years the lake is tilled; in wet years the water is usually several feet deep.

Temporary ponds (sloughs) contain water only for a short time after rains and the spring thaw. They are located in groundwater recharge areas and contain sediment that is usually thinner and more oxidized than either perennial or intermittent lake sediment. Thousands of temporary ponds exist throughout central parts of the county. Their average size is about 3 acres.

Unit 5-B.---This unit consists of offshore clay and silty clay deposited in glacial Lake Agassiz during the Herman subphase (see the section

Quaternary History). The sediment is lacustrine as evidenced by its thin parallel bedding, fine texture (no sand or gravel), and flat surface occurrence below the Herman Beach (1,060 feet) in northeastern Sargent County. The sediment thins northward and is absent in Ransom County where it is in contact with fluvial sediment of the Sheyenne delta.

Unit 5-C.--This unit consists of sediment deposited in glacial Lake Agassiz during the Milnor subphase (see the section Quaternary History). Thinly laminated silt occurs above the Herman Beach (1,060 feet) and below the 1,100 foot contour. The sediment contains little sand and no gravel (field estimate). The sediment occupies about 20 square miles of northeastern Sargent County. All but 5 square miles is undulating, indicating collapse when the underlying stagnant ice melted. Numerous road-cuts expose contorted laminated silt (Figure 11). Small patches of diamicton appear in the lake sediment and are probably outliers of diamicton or were ice rafted. Thickness of the sediment is variable but it typically is less than 40 feet.

Unit 5-D.--This unit includes lacustrine sediment deposited in glacial Lake Dakota. Over four hundred drill holes up to 60 feet deep were augered in this sediment by the Bureau of Reclamation power auger. Figure 12 is a cross section of the sediment interpreted from the drill-hole logs. The cross section shows Lake Dakota laminated silt grading into fluvial sandy gravel and silty sand, glacial diamicton, and eolian sandy silt. The sediment occurs below the 1,310 foot strandline of Lake Dakota.



Fig. 11.--Collapsed lake sediments exposed in a roadcut in northeastern Sargent County (SE $\frac{1}{4}$ sec. 18, T. 132 N., R. 53 W.). The line indicates the attitude of the collapsed beds.

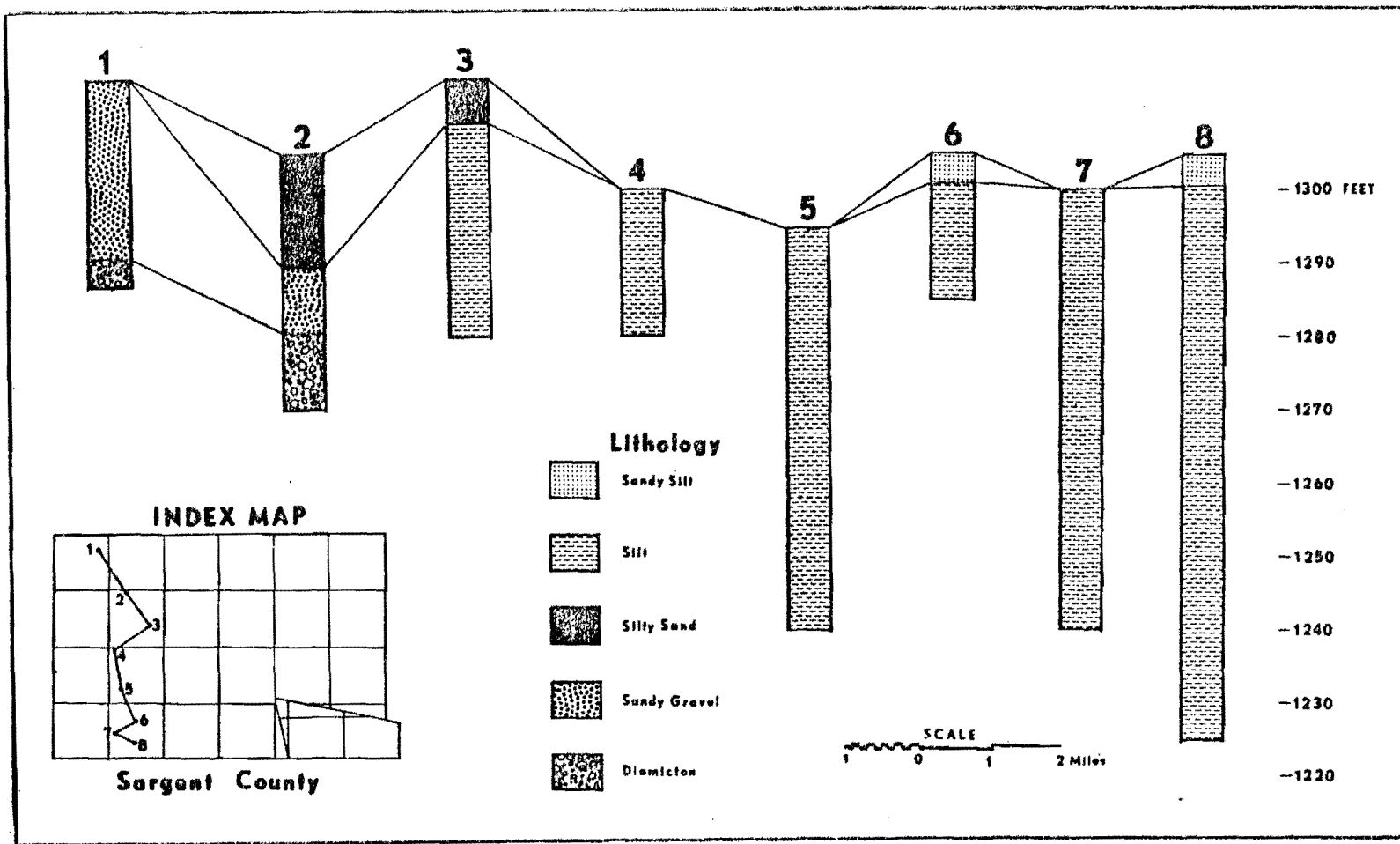


Fig. 12.--Cross section of glacial Lake Dakota deposits, fluvial sediment, eolian sediment, and glacial sediment, based on Bureau of Reclamation drill-hole logs (on file at Bureau of Reclamation office, Oakes, North Dakota).

Turbidity-Current Sediment (map unit 6)

Fresh-water turbidity currents are common where muddy water enters clear water. A more or less continuous flow of higher-density muddy water moves under the lighter-density fresh water. Gustavson (1972, p. 28) measured turbidity-current velocities as great as 18 cm/sec. along the bottom of proglacial Malaspina Lake, Alaska. He also found that Malaspina Lake water has a reverse thermal stratification. Water near the temperature of maximum density (3.94°C) occurs close to the lake surface while water as cold as 0.3°C occurs at the lake bottom. The lake is normally stratified, however, with respect to suspended sediment content, which ranges from 0.1 gm/l at the surface to 0.7 gm/l at a depth of 45 meters. He found that two of the three streams that enter the lake, enter as continuous turbidity currents or underflows. The third stream lost sediment in a series of small lakes before entering Malaspina Lake and thus entered the lake as an overflow. Gustavson found the turbidity-current sediment to be composed of laminated, commonly graded, or rippled sand and silt. The sand and silt is typically interbedded with fine silt and clay, which he interpreted to be deposited by slow settling of grains during winter months when underflows cease. A varved couplet is thus formed from the two processes.

A cross section through the Lake Oakes Hills (Figure 5) shows that the hills are composed of laminated sandy silt and silt, including some interbedded fine sand and clay. Glacial diamicton overlies the sediment in some areas of the hills. The sandy silt, sand, and silt, is interpreted to be turbidity-current sediment because (1) the presence of sand indicates

that a current was necessary for transport, and (2) the presence of interbedded clay indicate slow settling of grains in water. Other means of generating bottom currents within lakes, such as winds or seiches, probably are insufficient to generate currents strong enough to move sand grains in deep water (water deeper than one surface wave length).

The sediment at one location along the margin of the Lake Oakes Hills was observed to be distorted and discontinuous (Figure 13). The sediment was probably collapsed by melting of underlying ice.

Much of the sediment in the southern part of the Lake Oakes Hills is mantled with eolian sand and silt to depths of several feet. The northern part of the hills is covered by glacial diamicton to depths of 25 feet (Figure 5).

Nonsorted Sediment

Nonsorted sediment lacks internal stratification but may have flow foliation. It is sediment deposited primarily as a single mass or by slow accretion with no appreciable sorting taking place. There are basically two origins of nonsorted sediment, glacial and mass movement. Mass movement is important, however, in the deposition of superglacial sediment and will thus be discussed under the "Glacial" heading of this report.

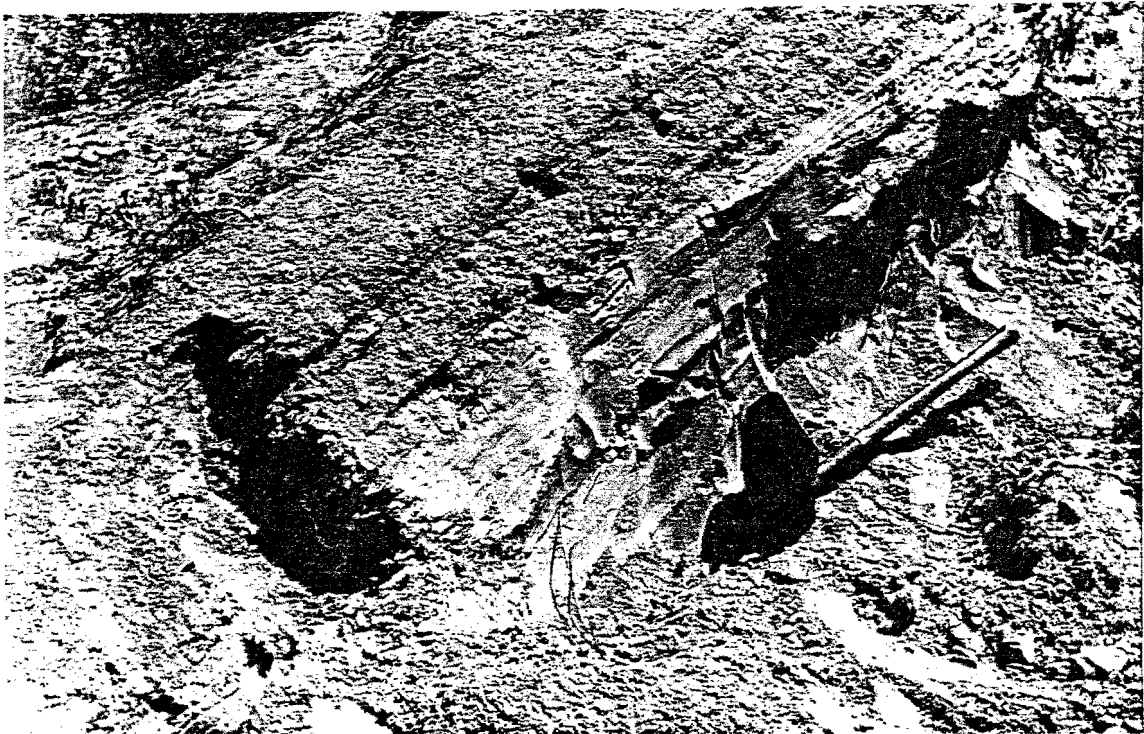


Fig. 13.--Collapsed turbidity-current sediment exposed in a small sand pit in Sargent County, North Dakota (NE $\frac{1}{4}$ sec. 11, T. 130 N., R. 58 W.).

Glacial

Superglacial Sediment (map unit 7)

Most glacial nonsorted sediment in Sargent County is texturally a diamicton. A glacial diamicton is commonly referred to as till.

Most diamicton in Sargent County (and North Dakota) was sheared into a superglacial position as a result of active ice moving against relatively stagnant ice. An insulating blanket of debris eventually accumulated over the stagnant ice producing an ice marginal stagnation zone that steadily retreated northward until a large sheet of stagnant ice existed.

Subglacial diamicton apparently does not occur at the surface, as evidenced by the absence of longitudinal shear marks (flutings). Subglacial diamicton probably occurs, however, in the subsurface throughout the county.

The thickness of superglacial debris depends to a large extent upon the degree of compressive flow producing the shearing. The way debris rolls, flows, or slumps during melting of stagnant ice depends on the thickness of superglacial debris and its clay and water content as well as the angle of slope. Most superglacial debris in North Dakota contains a large quantity of montmorillonite clay and therefore has a tendency to flow easily.

Clayton (1967, p. 29-31 and 37-38) has discussed these processes in detail and concluded that the relief on the present landscape (where there is no effect of underlying, buried, or pre-last-advance topography)

is roughly equal to the thickness of the superglacial debris. He further states that most present-day slopes on till are closely related to the original thickness and plasticity (controlled mostly by mineralogic composition and water content) of the superglacial debris.

Clayton (1972, p. 312) considers glacial deposits and landforms to be a genetic continuum of increasing superglacial-debris thickness. He further identified four basic types of glacial topography in North Dakota. Where superglacial material is nearly absent, longitudinal basal shear marks predominate. Where superglacial material is thicker but still so thin it does not coalesce, low-relief topography predominates with irregular transverse ridges (washboard moraines). Where the superglacial debris coalesces but does not obliterate the conical sinkholes in the glacier (about 600 feet in diameter), medium-relief topography with circular ridges about 600 feet in diameter predominates. Where the superglacial material is thick enough to obliterate the sinkholes, high-relief topography predominates with irregular depressions roughly 600 feet across.

The continuum model described by Clayton fits the glacial geomorphology in Sargent County except that the relief of each topographic type is generally less than what Clayton describes for most of North Dakota. The differences may be attributable to (1) plasticity differences, (2) the effects of underlying, buried, or pre-last-advance topography, or (3) more postglacial mass movement related to a locally more humid climate.

In Sargent County there are three types of topography produced by the deposition of superglacial diamicton, low-relief, medium-relief, and

high-relief.

Unit 7-A.--Low-relief glacial diamicton includes less than 10 square miles of Sargent County. The present-day relief is less than 10 feet, indicating that the thickness of superglacial diamicton was probably 5 to 10 feet. Few transverse ridges appear on the surface, suggesting that some coalescence did take place during deposition in most areas. Tonal contrasts are less on aerial photographs of this type of diamicton topography than on medium-relief and high-relief diamicton (Figure 14a).

Two holes were augered in this sediment during the 1970 field season. One hole (NW $\frac{1}{4}$ sec. 36, T. 132 N., R. 53 W.) penetrated 13 feet of oxidized diamicton before reaching sand and gravel, whereas the other hole (SE $\frac{1}{4}$ sec. 27, T. 132 N., R. 53 W.) penetrated 18 feet of oxidized diamicton before encountering sand. It is not known whether or not all the diamicton augered was superglacial in origin or even deposited from the same glacier advance.

Unit 7-B.--Medium-relief glacial diamicton has a present-day relief of about 10 to 20 feet. This type of topography was probably produced by the deposition of superglacial debris about 10 to 20 feet thick. About 200 square miles of Sargent County has this type of diamicton topography.

Much of the surface includes constructional features called "circular disintegration ridges" (Figure 14b) by Clayton (1967, p. 31-32). Clayton suggests that such features are produced by sliding or flowing of superglacial diamicton into a superglacial sinkhole in the stagnant ice and later inversion of topography when the ice melts (Figure 15).



a



b



c

Fig. 14.--Comparison aerial photographs of (a) low-relief, (b) medium-relief, and (c) high-relief glacial diamicton in Sargent County, North Dakota. The locations of the above photographs are sec. 36, T. 132 N., R. 53 W.; sec. 10, T. 132 N, R. 55 W.; sec. 25, T. 132 N., R. 55 W., respectively (United States Department of Agriculture AAD-1AA-12, AAD-2AA-8 and 79, September 1960).

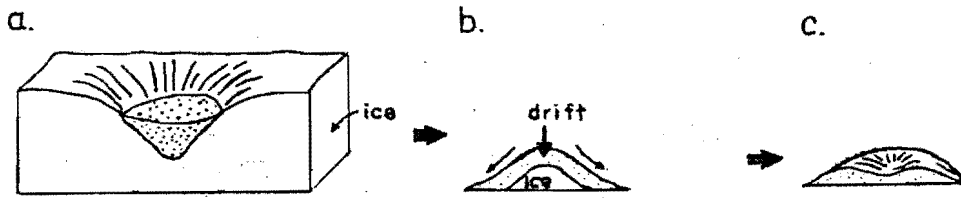


Fig. 15.--Diagram showing the three stages in the formation of a circular disintegration ridge ("doughnut") (from Clayton, 1967, Fig. A-2). Debris slides or flows into a superglacial sinkhole (a); melting of ice produces an ice-cored hill covered with drift (b); final melting of ice core produces central depression (c).

Unit 7-C.---About 300 square miles of the diamicton surface in Sargent County is high-relief topography characterized by numerous hills and depression roughly 200 to 400 feet in diameter. Local relief typically is 20 to 40 feet (Figure 14c). This type of diamicton surface is produced when the superglacial diamicton thickness is great enough to obliterate most sinkholes in the ice. Superglacial debris thickness was probably 20 to 40 feet in Sargent County where this type of topography is found. Surface thicknesses, however, were not enough to produce the high-relief dead-ice moraine topography described by Clayton (1967, p. 38) for parts of the Missouri Coteau.

QUATERNARY HISTORY

Pleistocene History Before the Last Glacial Advance

The Pleistocene history of Sargent County before the last glacial advance is poorly known. Most topographic features existing before the last overriding glacier were probably either buried, eroded, or substantially modified by the last advancing glacier. This is because most landforms of earlier advances in Sargent County generally had low to moderate relief. Most of the landforms were not large enough to change glacier flow conditions appreciably and were thus eroded or buried. This interpretation is based on the assumption that Sargent County was glaciated more than once during the Pleistocene Epoch. Evidence of previous glacier advances includes (1) the occurrence of two different drift units exposed in a roadcut on the Prairie Coteau, (2) the morphology and structure of the Whitestone Hills, and (3) the morphology and stratigraphy of the Lake Oakes Hills. Each of these areas is discussed below.

Prairie Coteau

The Prairie Coteau has an eroded preglacial bedrock core in east-central South Dakota. This interpretation is based both on scattered outcrops of Cretaceous shale in small stream valleys on the east and west

sides of the Coteau in Roberts, Marshall, and Day Counties, South Dakota, (Flint, 1955, p. 8) and on drill-hole information (Flint, 1955, p. 8; Rothrock, 1943, p. 13).

The Coteau was a topographic barrier to each advancing glacier reaching eastern South Dakota and southwestern Minnesota. Compressive flow conditions resulted in shearing of ice and local thickening of the glacier. Debris was sheared up into the ice and then concentrated over the Coteau during deglaciation as the glacier thinned and eventually became stagnant. In this way the Coteau was enlarged by deposition from each advancing ice sheet.

Deposits of different glacial advances have been found exposed in the Coteau. The deposits are commonly separated by paleosols or boulder pavements in South Dakota and southwestern Minnesota (Rutford and Matsch, 1972). Two glacial diamicton beds are exposed in a roadcut on the Coteau in Sargent County (Figure 3). The upper bed will be considered to be part of drift unit A and the lower bed, drift unit B.

Drift A

The diamicton in this drift unit is described in the "Quaternary Sediment" section of this report. The thickness of this unit at the Prairie Coteau section in Sargent County is about 25 feet (Figure 3). This unit correlates with the upper member of the Red Lake Falls Formation and the New Ulm Till. The Red Lake Falls Formation was named and described by Harris and others (1972, p. 528), based on its type section near Red Lake Falls, Minnesota. The New Ulm Till was named and described by Matsch

(1972, p. 335), based on its type section near New Ulm, Minnesota. Harris and others (p. 528) have correlated the upper member of the Red Lake Falls Formation and the New Ulm Till on the basis of textural and petrologic similarities. The similarities between the upper member of the Red Lake Falls Formation, New Ulm Till, and Drift A are summarized in Table 2. The values in Table 2 are from samples from the type section of each unit and were compiled by Harris and others (1972, p. 528).

TABLE 2

COMPARISON OF TEXTURAL AND PETROLOGICAL PROPERTIES
OF THE UPPER MEMBER OF THE RED LAKE FALLS
FORMATION, NEW ULM TILL, AND DRIFT A

	Upper Member Red Lake Falls Formation	New Ulm Till	Drift A
Mean sand, silt, and clay ratio	35:40:25	36:40:24	36:41:23
Mean shale content	12%	40%	25%

The diamicton in all three units contains appreciable quantities of shale grains. This suggests that the glacier that deposited these units advanced down the valleys of the Red and Minnesota Rivers because Cretaceous shale underlies these areas. This occurred about 20,000 years B.P. (Harris and others, 1972, p. 528).

Drift A is the surface drift in Sargent County and thus is the result of the last advance of ice. A complete discussion of the glacial

history of the last advance of ice into Sargent County can be found in the section "Last Glacial Advance and Deglaciation."

Drift B

The diamicton in this older drift is described in the "Quaternary Sediment" section of this report. This drift is found at the surface only at the Prairie Coteau section. The unit was power augered to a depth of 44 feet at the Coteau section.

This unit correlates with the lower member of the Red Lake Falls Formation and the Granite Falls Till. The Red Lake Falls Formation was named and described by Harris and others (1972, p. 528), based on the type section near Red Lake Falls, Minnesota. The Granite Falls Till was named and described by Matsch (1972, p. 335); based on the type section at Granite Falls, Minnesota. Harris and others (1972, p. 528) correlated the lower member of the Red Lake Falls Formation with the Granite Falls Till on the basis of similar textural and petrological properties. The similarities between the lower member of the Red Lake Falls Formation, Granite Falls Till, and Drift B, are summarized in Table 3. The Red Lake Falls and Granite Falls data are from Harris and others (1972).

Drift B has a low shale content in the coarse-sand fraction compared to Drift A. It also has a high carbonate content (Table 1). The Red River Valley of eastern North Dakota and western Minnesota is mostly underlain by Cretaceous shale (Figure 7). The glacier that deposited the lower member of the Red Lake Falls Formation, Granite Falls Till, and Drift B, probably moved southward along the axis of the Red Lakes

lowland east of the Red River Valley because that area is underlain by Paleozoic carbonates, not shale. The high carbonate content of the coarse-sand fraction also tends to support this interpretation.

The total areal extent of Drift B is unknown. The age of this drift is not known but is probably no older than early Wisconsinan because of the absence of extensive soil development on it in Sargent County, Red Lake Falls, and Granite Falls.

TABLE 3

COMPARISON OF TEXTURAL AND PETROLOGICAL PROPERTIES OF THE
LOWER MEMBER OF THE RED LAKE FALLS FORMATION,
GRANITE FALLS TILL, AND DRIFT B

	Lower Member Red Lake Falls Formation	Granite Falls Till	Drift B
Mean sand, silt, and clay ratio	31:45:23	40:42:18	32:40:28
Mean shale content (1 to 2 mm fraction)	6%	5%	2%

Whitestone Hills

The Whitestone Hills (about 4 miles north of Gwinner) are stream-lined and probably represent an overridden preglacial landform or a landform from a previous glacial advance. This interpretation is based on topographic expression and subsurface stratigraphy.

The Whitestone Hills have a steeper northeastern slope (2 degrees) than the southwestern slope (less than $\frac{1}{2}$ degree) and they appear to be

very similar in form to other streamlined forms found elsewhere in glaciated regions of North Dakota, such as those described by Bluemle (1970b, p. 325). The Whitestone Hills do not have the accompanying depression commonly associated with such hills in North Dakota.

The streamlined form of the hills is probably the result of compressive flow of glacier ice when an obstruction was encountered during a glacier advance. Compressive flow results in increased thickness of supraglacial debris and erosion of the upglacier-side of the obstruction.

Two holes were augered in the hills during the summer of 1970 to depths of 59 and 54 feet. In both holes oxidized shale-rich diamicton was found overlying unoxidized shale-rich diamicton. Near the bottom of each hole up to 5 feet of fluvial sediments were found overlying oxidized diamicton. Excessive water in the holes prevented good sediment recovery. Bedrock was not encountered in either hole. The oxidized diamicton at the bottom of each hole is probably from an earlier advance. If so, the hills are cored with a landform from a previous glacial advance.

Lake Oakes Hills

A series of north-south trending hills occurs in western Sargent County. Hard (1929, p. 31) interpreted the hills to be an end moraine and named them the "Oakes Moraine." The hills have a surface area of about 60 square miles and continue into Dickey, Ransom, and LaMoure Counties. The hills are up to 200 feet high and are well-drained in some areas although some closed depressions exist (Figure 16).

Most of the sediment composing the Lake Oakes Hills is interpreted

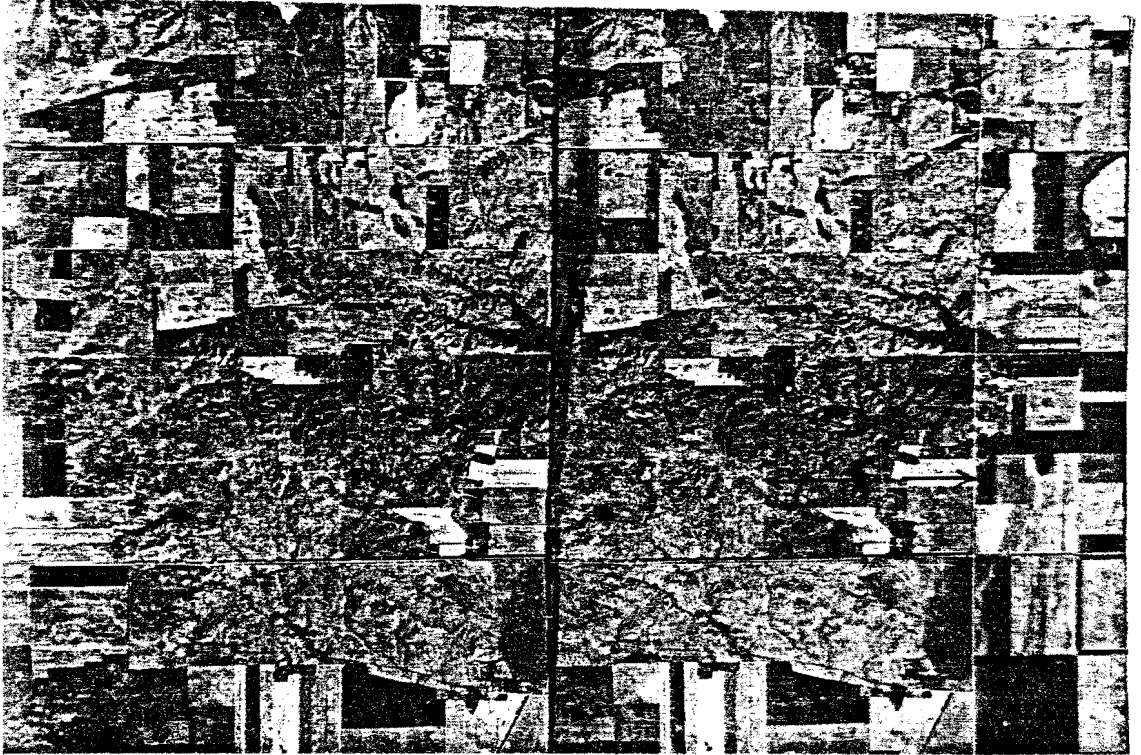


Fig. 16.--Aerial stereopair of the Lake Oakes Hills in Sargent County, North Dakota, sec. 18, T. 130 N., R. 58 W. (United States Department of Agriculture, VV BE M16 AMS, August 19, 1952).

to be turbidity-current sediment deposited in a proglacial lake (see the section Origin of Quaternary Sediment). The lake is here called glacial Lake Oakes, after the nearby town of Oakes, in Dickey County.

The Lake Oakes sediment was overridden by the last ice advance. This is indicated by the presence of glacial diamicton overlying Lake Oakes sediment in many parts of the hills (Figure 5). Bureau of Reclamation drill-hole logs indicate the diamicton to be as much as 35 feet thick (SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 25, T. 131 N., R. 58 W.). The diamicton commonly contains blocks of contorted sand and silt probably eroded by the overriding ice (Bluemle, 1970a).

Beneath the Lake Oakes sediment is diamicton evidently deposited by a previous advance of ice (Figure 5 and Appendix B). The drill-hole logs indicate the underlying diamicton is shale-rich; thus it is not part of Drift B.

Proglacial Lake Oakes was probably much like Malaspina Lake, described by Gustavson (1972). In Malaspina Lake, only those streams draining ice in contact with the lake produced turbidity currents because of their high suspended load compared to other streams in the area. Those streams not draining nearby stagnant ice lost much of their sediment before reaching Malaspina Lake and thus did not have densities great enough to form turbidity currents.

Surface Drainage Before the Last Glacier Advance

A string of lakes and sloughs, including Hultman Lake, Storm Lake, Borg Lake, Fangsrude Lake, Lake Fedge, Beere Lake, and Murach Lake, occur

in northeastern Sargent County. The lakes are generally elongate and are located in a meandering valley trending northwest-southeast. The valley has no smooth longitudinal gradient and is discontinuous throughout much of its length. The valley occurs in diamicton and has no associated fluvial sediment at the surface.

The lakes and valley are a surface reflection of a stream valley buried by the last glacial advance. This interpretation is based on the valley morphology and surface lithology. The meandering-stream valley was filled with ice during the last advance. During deglaciation the ice became stagnant beneath a cover of superglacial diamicton. The stagnant ice eventually melted, collapsing the overlying glacial sediment, thus forming a discontinuous valley generally lower than the surrounding landscape. Lakes and sloughs formed in the lower parts of the valley where the water table intersected the surface.

Last Glacial Advance and Deglaciation

The geologic events of the last glaciation and deglaciation are divided into three somewhat arbitrary phases:

Phase 1

During the last glacial advance, ice moved into North Dakota and Minnesota from several centers of accumulation in northern parts of Ontario, Manitoba, and Saskatchewan. The glacier moved southward along the axis of the lowland of the Red and Minnesota Rivers. The Prairie Coteau was a barrier to the advancing ice and caused it to split into two main lobes, the James Lobe on the west, and the Des Moines Lobe on

the east.

During this glaciation the James Lobe advanced nearly to Nebraska before halting. Several radiocarbon dates (W-1189, Y-595, Y-452, and W-801; Lemke and others, 1965, p. 17) indicate that the James Lobe reached its maximum position and began stagnating 13,000 to 14,000 years B.P. The Des Moines Lobe reached its terminus at the Bemis Moraine in Iowa about 14,000 years B.P. (W-517, W-512, W-153, and W-513; Wright and Ruhe, 1965, p. 39). At this time all of Sargent County was buried under glacier ice.

As the climate changed and the ice began to ablate at an increasingly faster rate, the margins began to thin and retreat. During the retreat of the ice margin, glacial flow was generally toward the south and southwest in southern North Dakota. Relative positions of the ice margin (based primarily on moraines) are shown in Figure 17.

Phase 2

The active shear zone of the glacier continued to retreat northeastward during the second phase, producing a broad stagnation zone along the ice margin. The presence of stagnant ice in Sargent County marks the beginning of Phase 2.

Differences in thickness of superglacial debris caused differential ablation rates of the stagnant ice (see the section Origin of Quaternary Sediment). Melt water was prevented from draining north and east by ice. Also, elevations are greater toward the Missouri Coteau, thus preventing drainage in that direction. Melt water was thus forced to drain south.

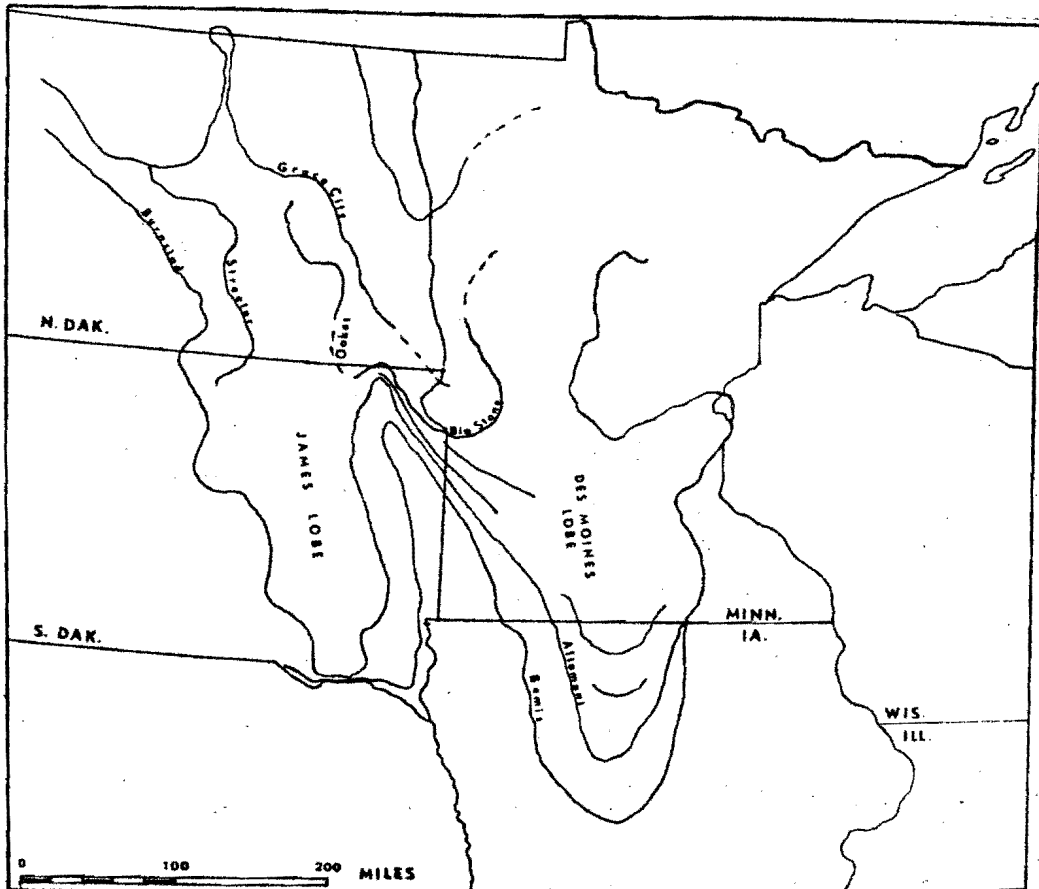


Fig. 17.--Pleistocene ice-margin positions in the Upper Midwest (modified from Clayton, 1966).

Great volumes of melt water flowed southward through the James River valley in Dickey County. The melt water was ponded by an end-moraine complex in northern Beadle County, South Dakota, resulting in the formation of a glacial lake that Todd (1885, p. 393) named "Lake Dakota."

Glacial Lake Dakota had its main axis along the James River valley in South Dakota and extended as far south as the present town of Hitchcock, in Spink County (Flint, 1955, p. 123). The total area of the lake plain in South Dakota exceeds 1,800 square miles.

Melt water flowed south through Ransom County and into Sargent County between the present towns of Stirum and Crete. The melt water then discharged into Lake Dakota and was confined by the Lake Oakes Hills on the west and by stagnant, debris-covered ice on the east (Figure 18). Superglacial diamicton slumped or flowed onto the channel sediment along the margins, as can now be seen in some gravel pits (Figure 8). The melt water flowed over solid ground in Sargent County but flowed over some stagnant ice in Ransom County, as evidenced by disintegration trenches in the channel sediment (sections 33 and 34, T. 133 N., R. 58 W.). A large part of the sediment of glacial Lake Oakes was probably eroded by the melt-water streams.

Lake Dakota increased in size and eventually occupied about 110 square miles of Sargent County. Hard (1929, p. 33) states that the lake had a maximum surface elevation of 1,300 feet. This elevation is too low for Sargent County because sediment of Lake Dakota occurs as high as 1,310 feet near Cogswell. At its maximum the lake extended to about 5 miles north of

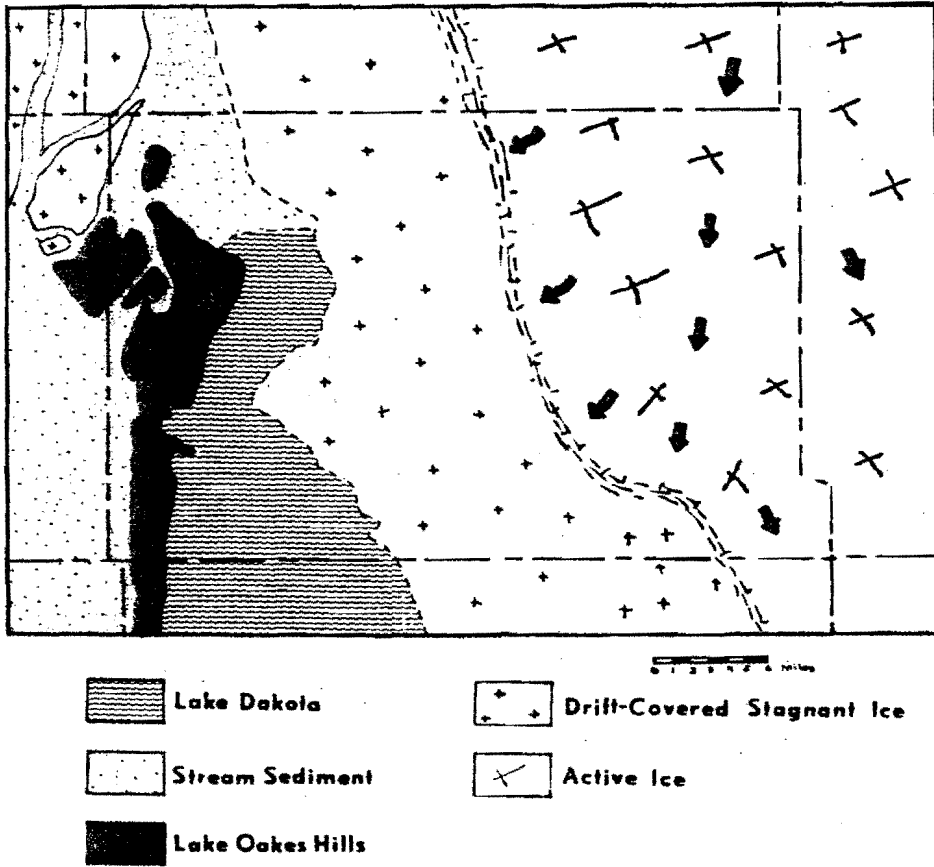


Fig. 18.—Map of glacial Lake Dakota and surrounding area during Phase 2 in Sargent County.

Cogswell and was roughly 100 miles in length.

Lake Dakota sediment occurs only on the east side of the Lake Oakes Hills. Bureau of Reclamation drill-hole logs and surface exposures indicate that the sediment is mostly laminated silt up to 80 feet thick near the Marshall County line (Figures 12 and 13). It thins northward and grades into coarse sand and gravel outwash north of Cogswell. The melt-water stream apparently ceased flowing before the Lake Dakota level started dropping because there is an absence of sand and gravel at the surface south of a point about 5 miles north of Cogswell.

Fluvial channel sediment occurs on the west side of the Lakes Oakes Hills below the highest level of Lake Dakota. The channel sediment was deposited by the James River and other smaller streams cutting through the Lake Oakes Hills. No lake sediment was found on the west side of the Lake Oakes Hills below the Lake Dakota strandline, indicating that the sediment was probably eroded by the melt-water streams.

Topographically, it appears that Lake Dakota should have found a northern outlet around the head of the Prairie Coteau because all elevations in that area are less than 1,300 feet. Evidently, active or stagnant ice along the east flank of the Coteau blocked any drainage.

Although most of the melt water supplying Lake Dakota came from the James River and other melt-water streams, some melt water was supplied from the Prairie Coteau. Stagnant ice existed on top of the Coteau both in Sargent County and Marshall County, South Dakota, as evidenced by the presence of high-relief diamicton and collapsed fluvial sand and gravel at high levels on the Coteau (see Plates 2 and 3). Sand and gravel

was encountered in several shallow (less than 15 feet) test holes augered adjacent to the Coteau. The sand and gravel was in all cases overlain by slope-wash sediment. The thickness and areal extent of the sand and gravel is unknown.

Phase 3

The ice was no longer active in Sargent County by the beginning of the third phase. Most of the county was covered by stagnant ice with variable thicknesses of superglacial debris (Plate 3). Those areas of stagnant ice covered by thick (20 to 40 feet) superglacial debris were protected the longest during deglaciation. Although the debris was not as thick in Sargent County as on the Missouri Coteau (Clayton, 1967, p. 40), some stagnant ice probably existed until late Wisconsinan time.

Melt-water streams at the surface, within, and beneath the stagnant ice deposited ice-contact fluvial sediment during this phase. After deposition most of the sediment was probably buried by superglacial diamicton, except for those areas with thin (5 to 10 feet) to moderate (10 to 20 feet) diamicton thickness. In these areas the fluvial sediment generally takes the form of hills (kames) or sinuous ridges (eskers) (Figure 19).

Milnor Subphase

Melting of stagnant ice continued to supply melt water throughout southeastern North Dakota, northeastern South Dakota, and west-central Minnesota during the subphase. Stagnant ice in central Sargent County blocked drainage of water from eastern Sargent County into the James River

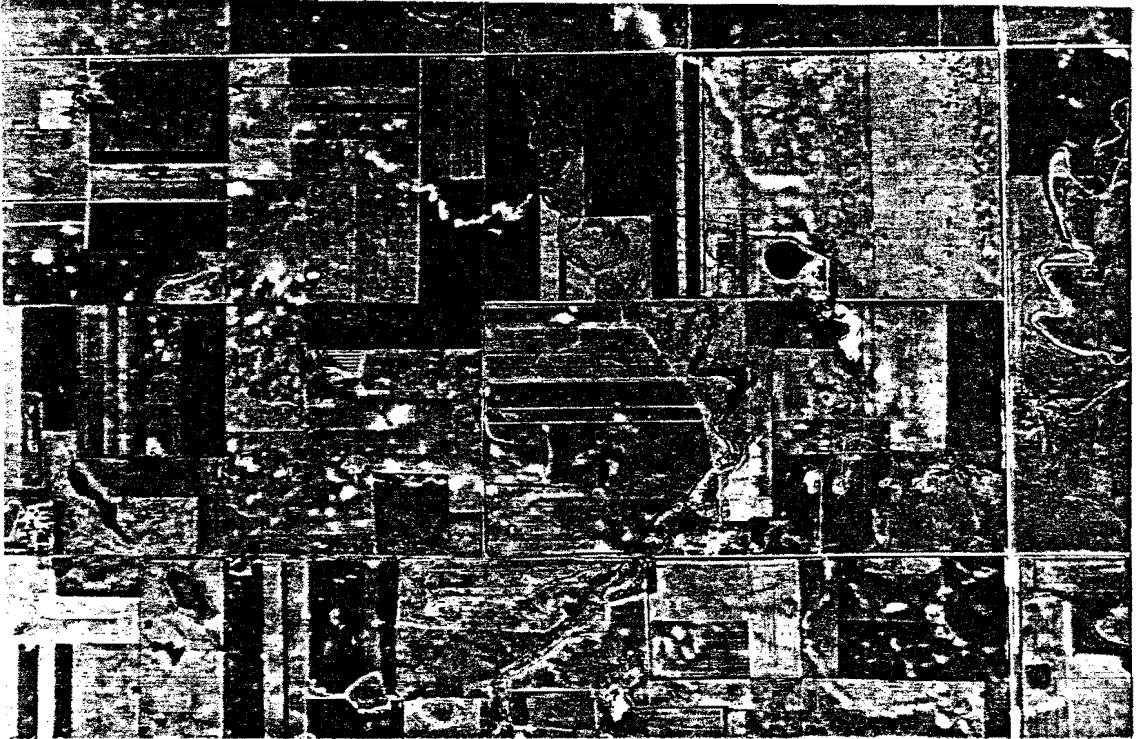


Fig. 19.--Aerial photograph showing hills (kames) and ridges (eskers) of ice-contact fluvial sediment near Cayuga, North Dakota, sec. 19-20, T. 130 N., R. 53 W. (United States Department of Agriculture, AAD-1AA-100, September 16, 1960).

valley. Drainage to the south was topographically blocked by glacial deposits and stagnant ice adjacent to the Prairie Coteau. All drainage to the north was blocked by the glacier itself.

Upham (1896, p. 310) identified beach ridges near Milnor, in northeastern Sargent County and also in northwestern Richland County at an elevation of 1,100 feet. The ridges are 40 feet above the Herman strand-line of glacial Lake Agassiz. Upham, and later Leverett (1932, p. 121), believed that the ridges were formed by a narrow ice-marginal lake, ancestral to Lake Agassiz, called Lake Milnor (named after the town of Milnor in northeastern Sargent County). The narrow lake extended from the southernmost bend of the Sheyenne River in Ransom County to near Lake Traverse in Roberts County, South Dakota (Figure 20). The South Dakota part drained across topographic low points, incising several small channels, including the one presently occupied by Cottonwood Slough about 10 miles north of Browns Valley, Minnesota (Matsch and Wright, 1967, p. 126).

Baker (1966, p. B79) interpreted the Milnor beaches to be terrace remnants formed by a diversion of the Sheyenne River. He found no evidence of a lake in Richland County above the Herman Beach and concluded that the flat area previously thought by Upham and Leverett to be the plain of Lake Milnor was actually a channel formed by the diversion of the Sheyenne River. He named the depression the Milnor Channel (discussed later in this section).

The Milnor "Beach" in Sargent County is a ridge about 2 miles in length and about 30 feet high and is located $\frac{1}{2}$ mile southeast of Milnor.

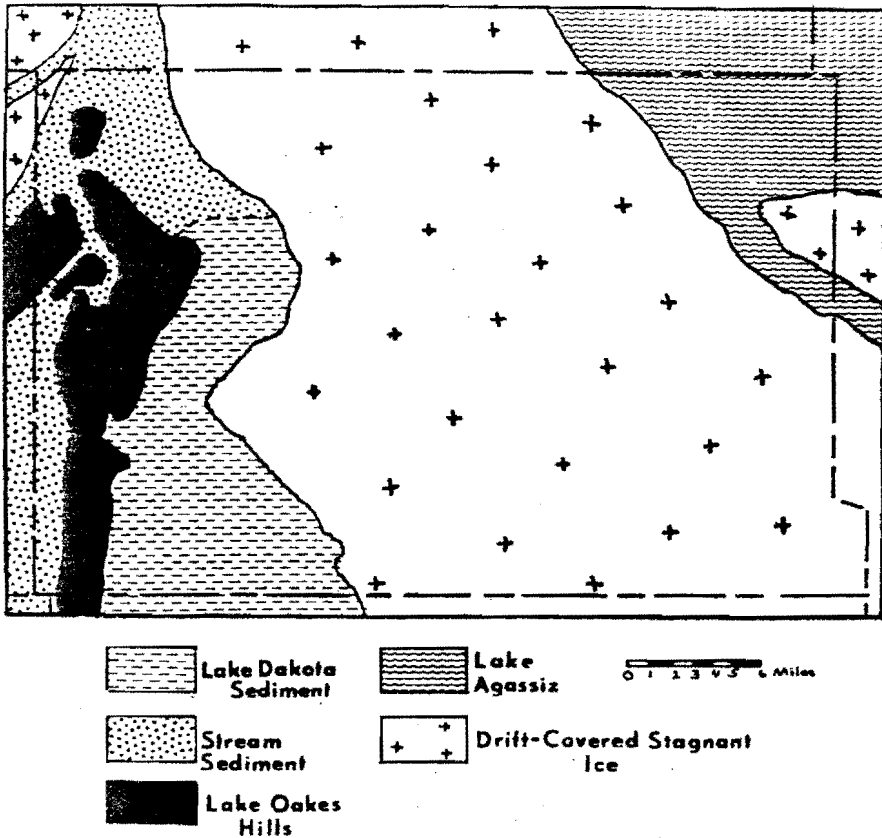


Fig. 20.--Map of glacial Lake Agassiz during the Milnor sub-phase in Sargent, Ransom, and Richland Counties, North Dakota.

The ridge is fluvial sand and gravel and is commonly overlain by diamicton. The fluvial sediment is poorly sorted and is generally contorted and folded, formed when underlying stagnant ice melted. The ridge is similar in appearance, composition, and structure to the sinuous gravel ridges (eskers) described previously in this report. It is therefore concluded to be an esker, not a beach.

Laminated silt occurs above the Herman strandline in Sargent County (map unit 5-C, Plate 3). The lake silt is generally collapsed, indicating the sediment probably was deposited on stagnant ice (Figure 11). The sediment is interpreted to have been deposited during a high-level phase of Lake Agassiz which will be called the Milnor subphase. The lake was confined on the west and south by stagnant ice and on the east and north by the receding ice margin (Figure 20).

Bluemle (1970a) indicated that high-level lake sediment exists above the highest Herman Beach in Ransom, Barnes, and Cass Counties. He also indicated that much of the lake sediment is collapsed and must have been deposited on stagnant ice. Lake Agassiz during the Milnor subphase thus probably covered a considerable area outside Sargent County.

Herman Subphase

Lake Agassiz dropped from the Milnor level to the Herman level as the ice margin receded northward. The Herman level marks the beginning of the Herman subphase in Sargent County.

In many parts of the Red River Valley the Herman strandline is beach sand and gravel. The Herman strandline in Sargent County, however,

is recognized only by a small wave-eroded scarp with no associated sand and gravel. The scarp is continuous and can be traced in the field and on topographic maps at an elevation of 1,060 feet. The scarp has no associated sand and gravel because (1) the scarp is formed in lake silt (no sand- and gravel-size particles), (2) present elevations indicate the water depth was less than 5 feet in the Sargent County part of Lake Agassiz (therefore, most wave energy was dissipated far from shore), and (3) the area was protected from the prevailing westerly winds because of its position on the east side of Lake Agassiz.

Clam shells from a fluvial terrace just below the Herman Beach near the head of the Sheyenne Delta in Ransom County have been radiocarbon dated. This date, $13,500 \pm 220$ (I-2289, Moran and others, in press), places a minimum on the age of the lowering of Lake Agassiz below the Herman level.

Milnor Channel Subphase

A shallow valley that trends primarily northwest-southeast occurs in northeastern Sargent County. It ranges in width from 1 to 3 miles. The southwest side of the valley is marked by a conspicuously steep slope; the northeast side is less distinct. The valley is poorly drained throughout much of its length. At its north end the valley terminates at the present Sheyenne River valley (Figure 21), and its floor is 40 feet above the floor of the Sheyenne River valley.

The shallow valley is floored with deposits of sand and gravel (Figure 22), interpreted by Baker (1966) to be fluvial channel deposits

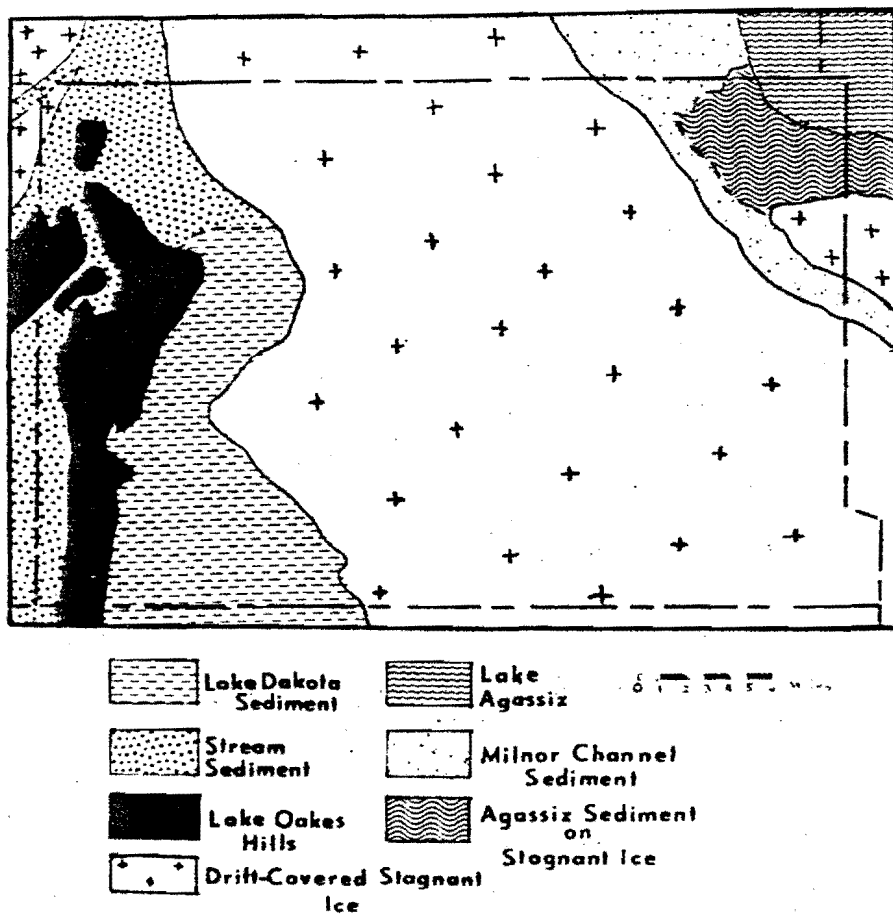


Fig. 21.--Map of Lake Agassiz during the Herman subphase and the Milnor Channel during the Milnor Channel subphase.

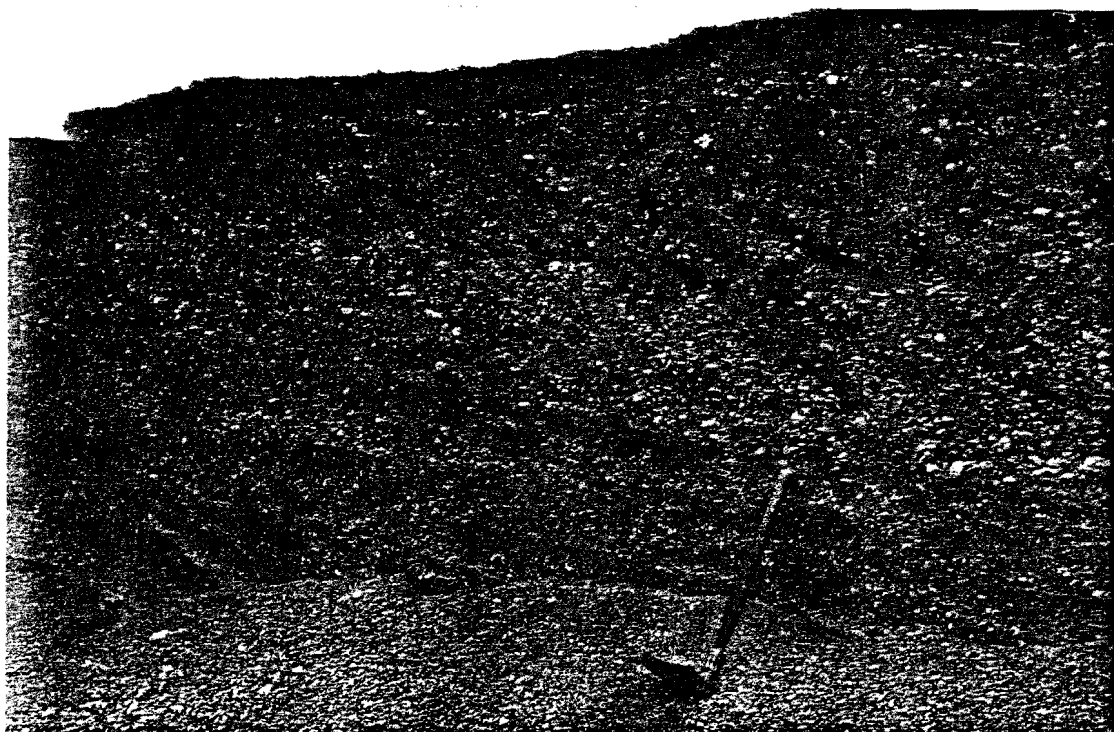


Fig. 22.--Milnor Channel sediment exposed in a gravel pit (NW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 25, T. 132 N., R. 53 W.). View facing northeast.

formed by the Sheyenne River which was diverted through parts of Ransom, Sargent, and Richland Counties. Baker called the valley formed by the Sheyenne River the Milnor Channel.

The Milnor Channel was cut by overflow from the Sheyenne River during or after the Herman subphase. Evidence for this is the fact that (1) the Milnor Channel is cut into Lake Agassiz silt deposited during the Milnor subphase and (2) no lake silt occurs on top of the Milnor Channel deposits. Lake silt on top of stagnant ice evidently formed part of the east bank of the Milnor Channel because sections of the channel perimeter are absent.

Final Deglaciation

Very little stagnant ice remained in Sargent County at the close of the Pleistocene Epoch about 10,000 years B.P. Those areas of the county covered by stagnant ice with about 20 to 40 feet of superglacial debris did not melt for several hundred to possibly a few thousand years after the ice stagnated. This estimate is based on Clayton's (1967, p. 36 and 41) work on the Missouri Coteau. If stagnation began about 13,000 years B.P. almost all the ice should have melted by 10,000 years B.P.

Holocene History

Climate and Vegetation

Glacial and postglacial climatic changes are recorded in vegetation changes of a region. Vegetation changes are recognized primarily by pollen analysis of sediment. Two separate pollen studies have been made

of areas relatively close to Sargent County, Pickerel Lake, South Dakota (Watts and Bright, 1968) and the Itasca region, Minnesota (McAndrews, 1966). Both studies involved lake or bog sampling and pollen analysis.

Pickerel Lake, South Dakota, is on the Prairie Coteau about 50 miles south of Sargent County. Watts and Bright (1968) analyzed fossil pollen, spores, seeds, leaves, and mollusks in a core from Pickerel Lake and concluded that four distinct pollen assemblage zones exist in the lake sediment. Each pollen zone reflects major vegetative changes in the area. Boreal forest existed around Pickerel before 10,670 radio-carbon years B.P. and the climate was cool and moist. Between 10,670 and 8,000 years B.P. (estimated), there were mixed deciduous trees around the lake, but on the upland areas numerous prairie-like openings with grass existed. The climate was evidently warmer than that of the previous age. From about 8,000 to 4,000 years B.P. (estimated) blue-stem prairie grass dominated the upland; deciduous forests were almost absent. The climate was characterized by recurring summer drought. Since about 4,000 years B.P. (estimated) the vegetation has been about the same as now, with prairie dominating the upland and deciduous forest common around lakes and in gullies. Summer droughts have not been so common as during the preceding period.

McAndrews (1966) studied pollen in core samples from bogs in north-western Minnesota. The bogs are located along a 66 mile-long transect. The western margin of the transect is about 100 miles northeast of Sargent County. The post-glacial vegetational history was reconstructed by McAndrews with the aid of pollen diagrams from four bog sites. From 12,000

to 11,000 radiocarbon years B.P. (Y-1418) the vegetation throughout the area was boreal and was dominated by spruce and aspen. McAndrews (1966, p. 64) suggested that a possible modern analog is the southern boreal forest adjacent to the aspen parkland in southern Manitoba and Ontario. The analog has a mean annual temperature of 32°F and a mean annual precipitation of 20 inches.

About 11,000 radiocarbon years B.P. the predominant forest vegetation was succeeded by prairie vegetation in the Agassiz lowland. McAndrews (1966, p. 64) states that the climate may have been similar to that of today in the area. Compared to previous time, this would indicate an increase of 8.5°F annual temperature and 2 inches annual precipitation for the Agassiz lowland. The precipitation increase probably did not result in increased soil moisture, because the higher temperatures increased evapotranspiration.

The prairie vegetation persisted until the time of settlement. The Ambrosia (ragweed) peak zone between 8,000 and 7,000 radiocarbon years B.P. marked the maximum of temperature and dryness. The trend toward a warmer and drier climate resulted in a replacement of pine forest by oak savanna near the eastern part of the transect.

About 4,000 years B.P. (based on sedimentation rates) deciduous forest succeeded the oak savanna on the east end of the transect. The succession indicates a trend toward greater soil moisture, probably as a result of an increase in precipitation and perhaps a decrease in mean annual temperature.

During the last 4,000 years there have been many minor fluctuations

of North American climate (Bryson and Wendland, 1967). Periods of summer drought have occurred several times in the prairie region of eastern North Dakota and northwestern Minnesota during the past 500 years.

Will (1946) studied tree-ring width of oak and juniper in central North Dakota and attributed narrow rings to drought years. The drought of the 1930's was reflected by a continuous series of 15 narrow rings from 1932 through 1937. Only three other long series of narrow rings occurred in the period from 1406 to 1940, namely 1596-1611, 1633-1649, and 1836-1851.

The relatively close correlation of pollen studies from Pickerel Lake and the Itasca transect suggests that the climatic trends interpreted from each site are regional in extent. Sargent County is located between the two sites. It can be assumed that the climate in Sargent County has been about the same as that at the two sites.

Erosion and Deposition

The climate of the Holocene is closely related to erosion and deposition. In prairie regions, such as Sargent County, periods of dryness increase surface erosion by decreasing the soil moisture. Those areas underlain by sand or silt (see Plate 2) are especially susceptible to wind erosion.

Many areas of the Lake Dakota plain are covered by dunes formed during periods of dryness (Figure 10). Most of the dunes are now stabilized by vegetation but there are some active dunes in topographically high parts of the area where soil moisture is low.

The sand and silt areas of Lake Oakes Hills are also susceptible to wind erosion because of an absence of a vegetative cover. The southern part of the hills is mantled with eolian sand and silt derived from the hills themselves as well as the Lake Dakota plain to the west.

The northern part of the Lake Oakes Hills in Sargent County is extensively eroded and has less eolian sediment than the southern part. The present form of the hills is probably the result of groundwater seepage along the flanks of the hills causing sapping at the base. The water table was encountered in all test holes augered in the hills. In most drill-holes the water table was at depths of less than 40 feet and numerous springs occur along road cuts where the water table intersects the surface. The silt and sand is so permeable that practically no surface runoff occurs. Seepage pressures cause sapping, resulting in headward gully erosion (Figure 23). This process is presently active.

Extensive slope wash has occurred during the Holocene along the flanks of the Prairie Coteau. Grass cover, reduced during dry periods, resulted in hillslope instability. The slope-wash sediment contains some black, finely disseminated organic matter, indicating that the sediment was eroded from adjacent hillslope soils after deglaciation.



Fig. 23.--A gully formed on the west side of the Lake Oakes Hills; view looking east, NW $\frac{1}{2}$ sec. 5, T. 130 N., R. 58 W.

SUMMARY AND CONCLUSIONS

The investigation of Sargent County has permitted a better understanding of the Quaternary geology of southeastern North Dakota and adjacent areas. Significant aspects of this study include:

1. The identification and mapping of two lithostratigraphic units, the Coleharbor and Walsh Formations.
2. The recognition of a glacial diamicton bed exposed in a Prairie Coteau roadcut that was deposited before the last advance of ice into Sargent County. The diamicton contains few shale fragments in the coarse-sand fraction and correlates with the lower member of the Red Lake Falls Formation of the upper Red River Valley and the Granite Falls Till of southwestern Minnesota.
3. A new genetic interpretation of a series of hills in western Sargent County previously mapped as the Oakes Moraine. The hills are composed of turbidity-current sediment formed in an ice-marginal lake called Lake Oakes. The hills, now called the Lake Oakes Hills, were overridden by the last advance of ice into the county.
4. The recognition of collapsed lake sediment above the Herman Beach of Lake Agassiz, believed to have been deposited during

the Milnor subphase of the lake.

5. A better understanding of the stratigraphy and history of glacial Lake Dakota in North Dakota.

Additional stratigraphic information from areas adjacent to Sargent County would help to differentiate specific members of the Coleharbor and Walsh Formations. The Prairie Coteau should be investigated in greater subsurface detail as it probably contains valuable stratigraphic information that would clarify the Quaternary history of that area.

APPENDIXES

TABLE 4

SIZE ANALYSES OF SAMPLES TAKEN IN SARGENT COUNTY DURING 1969 AND 1970

Sample Number	Depth (ft.) of Sample	Location	Sand:Silt:Clay (Percent)	Kind of Sediment
1	6	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	41:36:23	Glacial Diamicton
2	2	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	29:39:32	Glacial Diamicton
3	15	NW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 22, T. 129 N., R. 53 W.	48:25:26	Glacial Diamicton
4	55	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 10, T. 132 N., R. 56 W.	41:36:22	Glacial Diamicton
5	3	NW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 21, T. 131 N., R. 58 W.	31:38:31	Glacial Diamicton
6	46	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 3, T. 131 N., R. 58 W.	30:63:7	Glacial Diamicton
7	15	NW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 35, T. 129 N., R. 55 W.	28:44:28	Glacial Diamicton
8	3	NE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 27, T. 131 N., R. 58 W.	58:37:5	Glacial Diamicton
9	3	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 3, T. 131 N., R. 58 W.	34:54:12	Glacial Diamicton
10	11	NW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 6, T. 130 N., R. 58 W.	33:43:24	Glacial Diamicton
11	17	NW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 21, T. 131 N., R. 58 W.	28:35:37	Glacial Diamicton
12	5	SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 7, T. 129 N., R. 54 W.	41:32:27	Glacial Diamicton
13	37	SW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 19, T. 131 N., R. 54 W.	29:36:35	Glacial Diamicton
14	3	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 11, T. 130 N., R. 58 W.	43:38:19	Glacial Diamicton
15	56	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 3, T. 132 N., R. 56 W.	36:39:25	Glacial Diamicton
16	10	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 17, T. 129 N., R. 54 W.	40:39:21	Glacial Diamicton
17	3	NW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 10, T. 129 N., R. 55 W.	38:34:28	Glacial Diamicton
18	21	SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 28, T. 129 N., R. 55 W.	25:40:35	Glacial Diamicton
19	8	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 14, T. 139 N., R. 58 W.	46:37:17	Glacial Diamicton
20	10	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	40:38:22	Glacial Diamicton
21	3	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 21, T. 129 N., R. 54 W.	43:38:19	Glacial Diamicton
22	9	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	43:39:18	Glacial Diamicton
23	10	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	27:52:21	Glacial Diamicton

TABLE 4--Continued

Sample Number	Depth (ft.) of Sample	Location	Sand:Silt:Clay (Percent)	Kind of Sediment
24	8	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	35:44:21	Glacial Diamicton
25	8	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	36:42:22	Glacial Diamicton
26	30	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	36:41:23	Glacial Diamicton
27	12	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	34:46:21	Glacial Diamicton
28	25	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	36:31:33	Glacial Diamicton
29	15	SW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	23:30:47	Glacial Diamicton
30	6	SW $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 17, T. 129 N., R. 54 W.	34:39:27	Glacial Diamicton
31	25	SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 33, T. 130 N., R. 54 W.	22:34:44	Glacial Diamicton
32	30	SW $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 17, T. 129 N., R. 54 W.	24:37:39	Glacial Diamicton
33	2	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	39:39:22	Glacial Diamicton
34	2	SW $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	15:30:54	Glacial Diamicton
35	2	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 10, T. 129 N., R. 54 W.	38:34:28	Glacial Diamicton
36	30	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	29:42:29	Glacial Diamicton
37	31	NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 19, T. 129 N., R. 54 W.	25:41:34	Glacial Diamicton
38	42	SW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 14, T. 130 N., R. 58 W.	9:70:21	Turbidite
39	10	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 29, T. 130 N., R. 58 W.	10:71:19	Turbidite
40	2	SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 32, T. 130 N., R. 58 W.	14:65:21	Turbidite
41	15	NE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 7, T. 130 N., R. 58 W.	8:84:8	Turbidite
42	55	SW $\frac{1}{4}$ SE $\frac{1}{4}$ SR $\frac{1}{4}$ sec. 14, T. 130 N., R. 58 W.	7:82:11	Turbidite
43	15	SW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 9, T. 129 N., R. 54 W.	5:65:30	Turbidite

Appendix B

BUREAU OF RECLAMATION DRILL-HOLE LOGS

The drill-hole logs contained in this Appendix were used in constructing the cross section shown in Figure 5. The hole were completed as part of the Taayer Reservoir Project in Sargent County.

Drill Hole No. 10

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 22, T. 131 N., R. 58 W.

Total Depth: 90 feet

Surface Elevation: 1,318 feet

<u>Depth</u>	<u>Lithology</u>
1-14 feet	CLAY (TILL)--buff, large proportion of fine sand and silt, traces of gravel, slightly plastic.
14-48 feet	SAND--gray, very fine, varying proportion of silt and clay, poorly graded.
48-90 feet	SILT--gray, sandy, varying proportions of clay, moderately to well-compacted.

Drill Hole No. 11

Location: SE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 15, T. 131 N., R. 58 W.

Total Depth: 80 feet

Surface Elevation: 1,326 feet

<u>Depth</u>	<u>Lithology</u>
1-28 feet	SILT--gray, trace of clay and fine sand, moderately compacted.

28-48 feet

SAND--gray, very fine, varying
proportion of silt, trace of clay.

48-80 feet

SILT--gray, sandy, trace of clay,
moderately well-compacted.

Drill Hole No. 12

Location: SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 15, T. 131 N., R. 58 W.

Total Depth: 100 feet

Surface Elevation: 1,354 feet

<u>Depth</u>	<u>Lithology</u>
1-19 feet	SAND--buff, very fine, silty, cohesionless, poorly graded.
19-34 feet	SILT--buff, large proportion of very fine sand, trace of clay, moderately compacted.
34-84 feet	SAND--gray, fine, fairly clean to trace of clay, cohesionless, poorly graded.
84-86 feet	SILT--gray, clayey, slightly plastic, moderately compacted.
86-99 feet	CLAY--gray, silty, stiff, plastic.
99-100 feet	CLAY (TILL)--gray, silty.

Drill Hole No. 13

Location: NW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 23, T. 131 N., R. 58 W.

Total Depth: 130 feet

Surface Elevation: 1,352 feet

<u>Depth</u>	<u>Lithology</u>
0-2 feet	TOPSOIL (SILT)--black, sandy, clayey, organic.

2-33 feet	SILT--buff to tan, oxidized, well-compacted, large proportion of very fine sand, cohesionless, sufficient clay to cause slight binding from 26 to 30 feet.
33-46 feet	SAND--buff to brown, very fine, silty, well-compacted, cohesionless, clayey silt seam 35 to 36 feet.
46-123 feet	SAND--gray, fine to medium, fairly clean, included clay and lignite slake in streaks and thin layers or lenses.
123-130 feet	CLAY (TILL)--gray, silty, sandy, stiff to hard, moist, slightly plastic when saturated, small pebbles throughout.

Drill Hole No. 14

Location: Intersection of sections 13, 14, 23, 23, T. 131 N., R. 58 W.

Total Depth: 110 feet

Surface Elevation: 1,337 feet

<u>Depth</u>	<u>Lithology</u>
0-1 feet	TOPSOIL (SILT)--black, clayey, organic.
1-5 feet	CLAY (TILL)--buff, sandy, gravelly.
5-20 feet	SILT--buff, large proportion of very fine sand, clayey, moderately compacted, oxidized.
20-102 feet	SILT--gray, sandy, clay proportion varies from trace to percentage sufficient to cause silt to be slightly plastic, well-compacted.

102-110 feet

CLAY (TILL)--gray, silty, sandy,
stiff to hard in natural state,
slightly plastic when saturated,
small pebbles throughout.

Drill Hole No. 15

Location: NE $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 24, T. 131 N., R. 58 W.

Total Depth: 145 feet

Surface Elevation: 1,355 feet

<u>Depth</u>	<u>Lithology</u>
0-2 feet	TOPSOIL (SILT)--black, clayey, organic.
2-5 feet	CLAY (TILL)--buff, silty, sandy, oxidized, dries hard.
5-25 feet	SILT--buff, clayey, small pro- portion of very fine sand, oxidized.
25-65 feet	SAND--gray, very fine, large pro- portion of silt, trace of clay, moderately to well-compacted.
65-136 feet	SILT--gray, large proportion of fine sand, clayey, laminated, clay streaks and lenses throughout.
136-145 feet	CLAY (TILL)--gray, silty, sandy, stiff to hard, moist, slightly plastic when saturated, pebbles and shale particles throughout.

Drill Hole No. 16

Location: Intersection of sections 18 and 19, T. 131 N., R. 57 W., and
sections 13 and 24, T. 131 N., R. 58 W.

Total Depth: 145 feet

Surface Elevation: 1,332 feet

<u>Depth</u>	<u>Lithology</u>
0-2 feet	TOPSOIL (SILT)--black, clayey, organic.
2-20 feet	SAND--gray-brown, fine to coarse, sufficient clay to cause slight binding, poorly graded.
20-135 feet	SILT--gray, varying proportion of very fine sand, clay proportion sufficient in zones to cause silt to be slightly plastic, laminated, well-compacted.
135-145 feet	CLAY (TILL)--gray, silty, sandy, stiff to hard in natural state, slightly plastic when saturated, shale particles and pebbles and cobbles throughout.

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