GEOLOGY

of

RANSOM AND SARGENT COUNTIES, NORTH DAKOTA

by
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North Dakota Geological Survey
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Ransom County Water Management District,
and the Sargent County Water Management District**

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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts: Part I describes the geology, Part II presents groundwater basic data, and Part III describes the groundwater resources.

Additional copies of this bulletin are available from the North Dakota State Water Commission, Bismarck, North Dakota 58501

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ABSTRACT

Ransom and Sargent Counties, located at the eastern edge of the Williston Basin are underlain by 500 to 1 800 feet of Paleozoic and Mesozoic rocks that dip gently to the northwest. The Cretaceous Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations lie directly beneath the glacial drift, and shale of the Niobrara and Pierre Formations is exposed along the Sheyenne River, especially in northwestern Ransom County. The Pleistocene Coleharbor Group, which covers most of the area, consists mainly of glacial, fluvial and lake sediment. The Coleharbor Group averages about 200 feet thick, but it is as much as 400 feet thick near Gwinner. The Holocene Oahe Formation occurs in parts of the area, chiefly sloughs, river bottomland, and dune fields. It consists mainly of alluvial and eolian sediment.

Most of the two-county area is part of the Glaciated Plains, an area characterized by nearly level to undulating topography. Rolling to steep land is found along the Sheyenne River valley, on the Prairie Coteau in southeastern Sargent County, in areas of sand dunes in the eastern part of Ransom County and in western Sargent County, and in areas of intense ice thrusting, which are prominent in western Sargent County.

Several distinct till layers that have been identified in Ransom and Sargent Counties attest to repeated glacial advances, both prior to and during Wisconsinan time. Following the earliest flooding of western Sargent County by glacial Lake Dakota, a readvance of the glacier resulted in large-scale thrusting. The early glacial Lake Agassiz flooded eastern parts of the two counties, resulting in discontinuous lake and shore sediments above the Herman level. Later, the Sheyenne River built a large delta into the lake while it stood at the Herman level. After Lake Agassiz drained, wind erosion built large dunes on the Sheyenne Delta.

INTRODUCTION

Purpose

This report is published by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, and the Water Management Districts of Ransom and Sargent Counties. It is one of a series of county reports on the geology and groundwater resources of North Dakota. The main purposes of these studies are: (1) to provide a geologic map of the area, (2) to locate and define aquifers, (3) to determine the location and extent of other mineral resources in the counties, and (4) to interpret the geologic history of the area. This volume describes the geology of Ransom and Sargent Counties. Readers interested in groundwater should refer to Part II of this bulletin, which includes detailed basic data on the groundwater, and Part III, which is a description and evaluation of the groundwater resources of the two counties.

Parts of this report that are primarily descriptive include the discussions of the topography, rock, and sediment in the two counties. This information is intended for use by anyone interested in the physical nature of the materials underlying the counties. Such people may be water-well drillers or hydrologists interested in the distribution of sediments that might produce usable groundwater; civil engineers and contractors interested in such things as the gross characteristics of foundation materials at possible construction sites, criteria for selection and evaluation of waste disposal sites, and the locations of possible sources of borrow material for concrete aggregate; industrial concerns looking for possible sources of economic minerals; residents interested in knowing more about the area; and geologists interested in the physical evidence for the geologic interpretations.

Previous Work

The earliest reference to the geology of the Red River Valley was in 1823 by Keating, the geologist with the first scientific expedition to visit the area (Upham, 1895). In 1883, T. C. Chamberlin briefly referred to the moraines of Ransom and Sargent Counties. J. E. Todd (1886) described several of the surface features of the two-county area including the "Fourth moraine," which extends from Valley City to the head of the Coteau des Prairies in southeast Sargent County; Bear's Den Hillock just west of Fort Ransom; and Dead Colt Hillock about 15 miles south of Lisbon (this last feature was probably the hill now known locally as Whitestone Hill). Todd also briefly discussed glacial Lake Dakota. The first comprehensive study of any part of the area was by Warren Upham (1895), who mapped the glacial Lake Agassiz plain and named most of the geomorphic features associated with the lake plain.

In 1904, several articles were published by W. H. Westergaard, D. E. Willard, and C. M. Hall on the geology of eastern and southeastern North Dakota. Several of these dealt with various aspects of the geology of Ransom and Sargent Counties.

Frank Leverett (1912, 1932) mapped the southern end and outlet of glacial Lake Agassiz and described the surface geology of parts of Sargent County. In 1923, H. A. Hard published the results of an investigation to determine the cause of water-level decline in the artesian wells of the state, including the two-county area. He (Hard, 1929) reported on the surficial Cretaceous and Quaternary geology of a small part of Ransom and Sargent Counties, including a description of the Oakes moraine and glacial Lake Dakota deposits. He also discussed water resources, artesian conditions, and natural gas possibilities in his report.

H. E. Simpson published several papers during the 1920s and 1930s on the artesian water supply of eastern North Dakota. The most exhaustive of these, titled "Geology and groundwater resources of North Dakota" (Simpson, 1929), dealt with the geology and water content of the water-bearing formations. Reports on Ransom and Sargent Counties are included in the report.

W. C. Rasmussen (1947) reported on the hydrology, potential development of the groundwater resources, quality of water, and geologic history of the glacial Lake Agassiz deposits.

An early soil survey of Ransom County (Ely and others, 1907) included some description of the geology. In the current Soil Conservation series, the Sargent County survey has been completed (Larsen and others, 1964).

D. N. Nielsen (1973) mapped the geology of Sargent County as part of a doctoral dissertation project. Michael Camara studied the glacial stratigraphy of southeastern North Dakota as part of his master's thesis work (Camara, 1977). His study area included parts of both Ransom and Sargent Counties. Geologic reports in the current North Dakota Geological Survey county series that have been completed include Barnes County (Kelly and Block, 1967), Cass County (Klausing, 1968), Richland County (Baker, 1967), and Dickey and LaMoure Counties (Bluemle, 1979). All of these counties adjoin Ransom and Sargent Counties. In addition, a report on the geology of Marshall County, South Dakota, which adjoins Sargent County on the south, has been completed (Koch, 1975).

Methods of Study

The geology of Sargent County was mapped during the 1969 and 1970 field seasons by Dennis N. Nielsen. I mapped Ransom County during the 1970 field season, and I field-checked both counties during the 1978 field season.

Data were plotted on 1:24 000-scale topographic maps where they were available. In other areas, county highway maps, scale 1:63 360, were used. Aerial stereopairs (scale 1:20 000) and county soil-map photos (scale 1:24 000) were used to accurately place geologic contacts. The surficial mapping was done by driving along all section-line roads and trails, recording lithologies at all roadcuts and exposures. About fifty holes were bored by the North Dakota Geological Survey truck-mounted auger. The North Dakota State Water Commission provided rotary drilling equipment that was used during the 1974 and 1977 field seasons for about 25 000 feet of test drilling.

Sediment textures were estimated in the field. Forty-three samples were collected to check estimates and were subjected to sieve and pipette analysis. 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.

Regional Topography and Geology

Ransom and Sargent Counties, in southeast North Dakota, have a combined area of 1 718 square miles (Ransom, 863; Sargent, 855) in Townships 129-136 North and Ranges 53-58 West. Sargent County is located between 97° 00' 30" West Longitude on the east and 98° 00' on the west; 45° 56' North Latitude on the south and 46° 17' on the north. Ransom County is located between 97° 01' 30" West Longitude on the east and 98° 01' 30" on the west; 46° 17' North Latitude on the south and 46° 38' on the north.

Most of the two-county area is part of the Glaciated Plains (fig. 1), a nearly level to undulating area with less than 20 feet of local relief. Some rolling to steep land is found in the northwestern part of the area, near the Sheyenne River valley, and in the southeastern part of the area near the Prairie Coteau. The Prairie Coteau extends into southeastern Sargent County from South Dakota, covering about 15 square miles in North Dakota. It is characterized by numerous sloughs, lakes, and closely spaced hills. Many poorly drained depressions receive surface runoff from higher areas. The north end of the Prairie Coteau in Sargent County consists mainly of the scarp separating the Glaciated Plains from the Coteau. Numerous gullies are carved into the face of the escarpment.

Elevations over most of the two-county area range from about 1 100 feet in the east to about 1 400 feet in the west

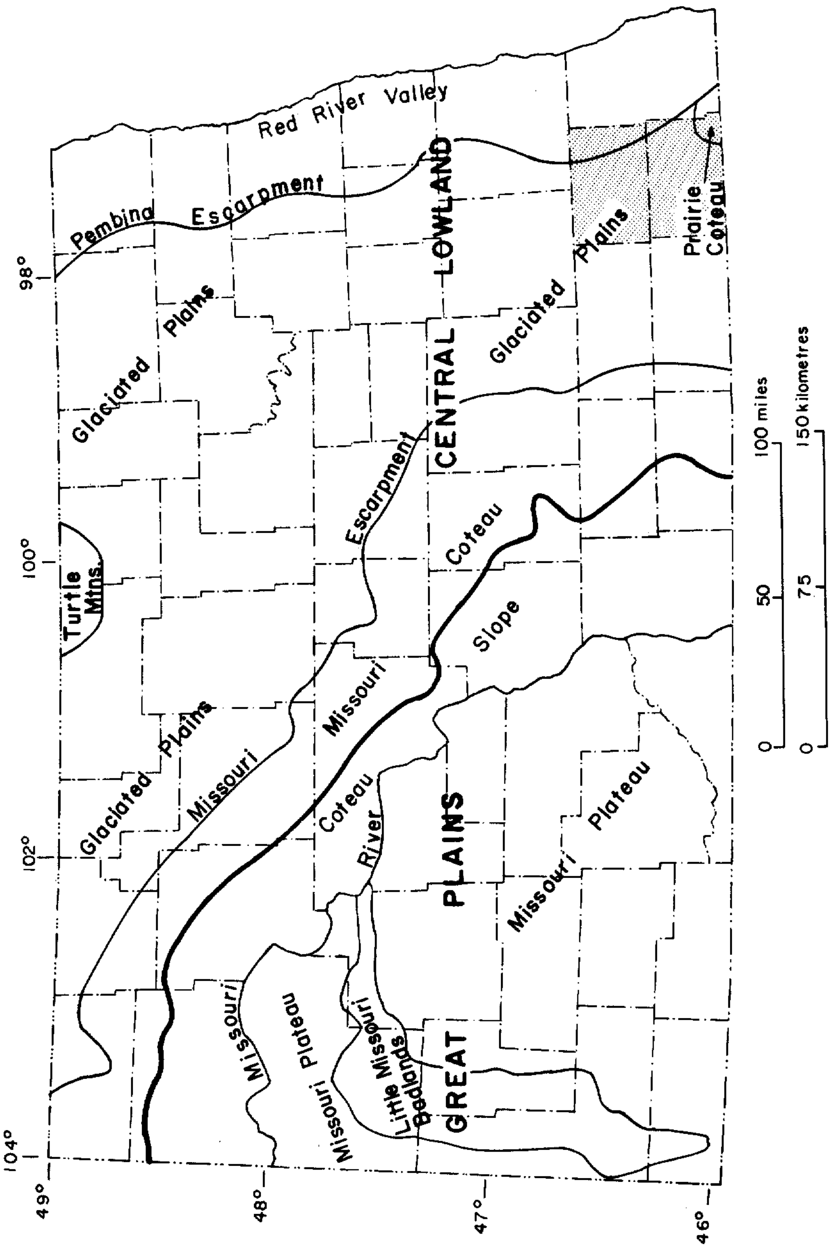

Figure 1. Physiographic map of North Dakota showing the location of Ransom and Sargent Counties (shaded area). The term "gently sloping" refers to areas that have slopes of less than 8 percent (4° 35'). Local relief is defined as the maximum difference in elevation within any township-sized area.

except on the Prairie Coteau, which rises from 400 to 700 feet above nearby areas to elevations over 1 700 feet. The lowest elevations are about 975 feet along the Sheyenne River in eastern Ransom County.

The extreme western part of the two-county area, which is drained via Bear Creek to the James River, is part of the Missouri River system and drains into the Gulf of Mexico. The remainder of the area drains into the Red River of the North and Hudson Bay. The Sheyenne River drains most of Ransom County and part of northern Sargent County. A part of north-central Ransom County is drained by the Maple River, and part of southern and eastern Sargent County is drained by the Wild Rice River.

Ransom and Sargent Counties are situated on the southeastern edge of the Williston Basin, an intracratonic structural basin consisting of a thick sequence of sedimentary rocks. The youngest sediments are the alluvium in the river valleys and the windblown silt and sand on the plains of glacial Lakes Agassiz and Dakota. Beneath these sediments is a layer of glacial deposits, which forms the surface mantle over most of the area; these glacial deposits belong to the Coleharbor Group. The Coleharbor Group deposits are underlain (from east to west) by the Greenhorn, Carlile, Niobrara, and Pierre Formations. Approximately 100 to 1 800 feet of Paleozoic and Mesozoic rocks occur beneath the area. All the formations below the Coleharbor Group have a northwesterly regional dip and become thicker northwestward.

STRATIGRAPHY

Precambrian Rocks

The Precambrian rocks of the two-county area consist predominantly of two main types: low-grade schists and gneisses, and coarse-grained granites. The distribution of these two lithologies is problematical, however, as only two exploratory wells have penetrated Precambrian rocks in the two-county area. Both of these are in Sargent County. One of the wells was an oil test drilled in 1961 (Sargent Mineral Corporation--Lampert #1, located in the NW¼NW¼ sec 9, T129N, R58W). The sample description log lists "pink, weathered granite with veinlets of green minerals, much biotite and green accessory minerals" at a depth of 1 192 feet (elevation: 192 feet above sea level). The other well that penetrated Precambrian rock was drilled in 1977 during a uranium-exploration program (Moore, 1978). Located in the northwest quarter of sec 11, T130N, R56W, it penetrated "weathered, steeply-dipping, chlorite (greenstone) schist" at a depth of 820 feet (elevation: 450 feet above sea level).

Three Precambrian tests are located in Richland County within about six miles of the border with Ransom and Sargent Counties. They penetrated "steeply-dipping weathered schist" (sec 19, T130N, R51W); "chloritic clay supporting quartz grains, grading downward to a chlorite schist" (SE¼ sec 11, T132N, R52W); and "greenstone schist intensely weathered to clays near the top, but becoming more chloritic with depth. Bottom cores, steeply-dipping stretched pebble conglomerate" (SE¼ sec 29, T135N, R52W). A fourth Precambrian test is located within three miles of the northern edge of the Ransom-Cass County line (NW¼ sec 23, T137N, R53W). It penetrated "white kaolinitic clay supporting quartz grains and small sideritic concretions and grading downward into a porphyritic granodiorite gneiss." The top of the weathered gneiss is at a depth of 558 feet and unweathered rock is 140 feet below that, at 698 feet.

Generally, the Precambrian rocks in this area are weathered to depths that exceed 200 feet. The weathered zone commonly contains kaolinite-supported, coarse, angular and embayed quartz grains. These matrix supported grains result from the in situ weathering of quartzose Precambrian rocks (Moore, 1978). When drilled, this weathered section yields clayey sand cuttings that have commonly been misinterpreted as "Dakota" sandstone.

The Precambrian surface slopes west-northwestward at a rate of about 10 feet per mile in southern Sargent County, but the gradient is somewhat steeper farther north; in northern Ransom County it is about 25 feet per mile in the same direction. The depth to the weathered Precambrian surface ranges from less than 500 feet in places along the eastern edge of the two-county area to slightly more than 1 800 feet in northwestern Ransom County.

Paleozoic Rocks

No Paleozoic rocks have been identified from Ransom or Sargent Counties. The two wells drilled to the Precambrian in Sargent County penetrated Cretaceous sedimentary rocks lying directly on weathered Precambrian igneous and metamorphic rocks. However, it is possible that the truncated lower portion of the Winnipeg Group sediments, perhaps a part of the Black Island Formation sandstone, occurs in northwestern Ransom County. If it is present in the area, the sandstone is probably no more than a few tens of feet thick.

Mesozoic Rocks

It is unlikely that Triassic or Jurassic rocks extend into the two-county area. The oldest Mesozoic deposits are likely the basal Cretaceous clastics of the Dakota Group. In central

Sargent County, these clastic rocks are about 110 feet thick and contain coarsening upward sequences ranging from shale to interbedded shale and thin ripple-laminated sandstone to planar cross-bedded sandstone several feet thick (Moore, 1978). These clastics thin to between 90 and 100 feet thick along the eastern edge of Sargent County and to less than 30 feet in northeastern Ransom County. In extreme southwest Richland County a few miles east of the Sargent County line, they range from siltstone to fine sandstone. Farther north in Richland County along the northeastern border of Ransom County, a clay-matrix, pebble-conglomerate with highly variable clasts at the base occurs. The conglomerate is overlain by a thin lignite bed.

The basal Cretaceous clastics thicken westward to over 400 feet in southwestern Sargent County where they are interbedded with gray to white, fine, clayey sandstone and siltstone. Siderite pellets and pyrite are abundant in the basal Cretaceous clastics in this area and some of the materials are carbonaceous and micaceous.

The basal Cretaceous clastics are overlain by gray to black marine shale layers that tend to be somewhat silty and sandy. These noncalcareous shales, equivalent in part to the Belle Fourche Formation, range from about 150 to 300 feet thick across the area.

The Greenhorn Formation shale overlies the noncalcareous shale sequence in all but the northeastern part of the two-county area (pl. 2). Except where its upper surface is truncated by erosion, the Greenhorn Formation consists of from 30 to 40 feet of calcareous, gray shale with white specks (limestone nodules) and some micro-crystalline, clayey limestone layers. The Greenhorn Formation directly underlies the Quaternary deposits in parts of northern and eastern Ransom County and in extreme northeastern Sargent County (pl. 2).

The shale of the Greenhorn Formation is overlain by the Carlile Formation shale. The upper surface of the Carlile forms the unconformity with the overlying Quaternary deposits over much of Sargent County and central Ransom County. The Carlile Formation consists mainly of medium gray to black, soft, noncalcareous shale that, in places, has an earthy texture. Its thickness varies greatly from place to place across the two counties because of its eroded upper surface. Where it is conformably overlain by the Niobrara Formation (pl. 2), the Carlile Formation is about 250 feet thick.

The Niobrara Formation overlies the Carlile Formation in western Ransom and Sargent Counties and on the Prairie Coteau in southeastern Sargent County. It outcrops in places in the Sheyenne River valley between Little Yellowstone Park and Fort Ransom (fig. 2). The Niobrara Formation has a maximum thickness of about 250 feet in northwestern Ransom County.

The Niobrara Formation consists of light-gray, silty, calcareous shale with white specks (tiny limestone nodules). In

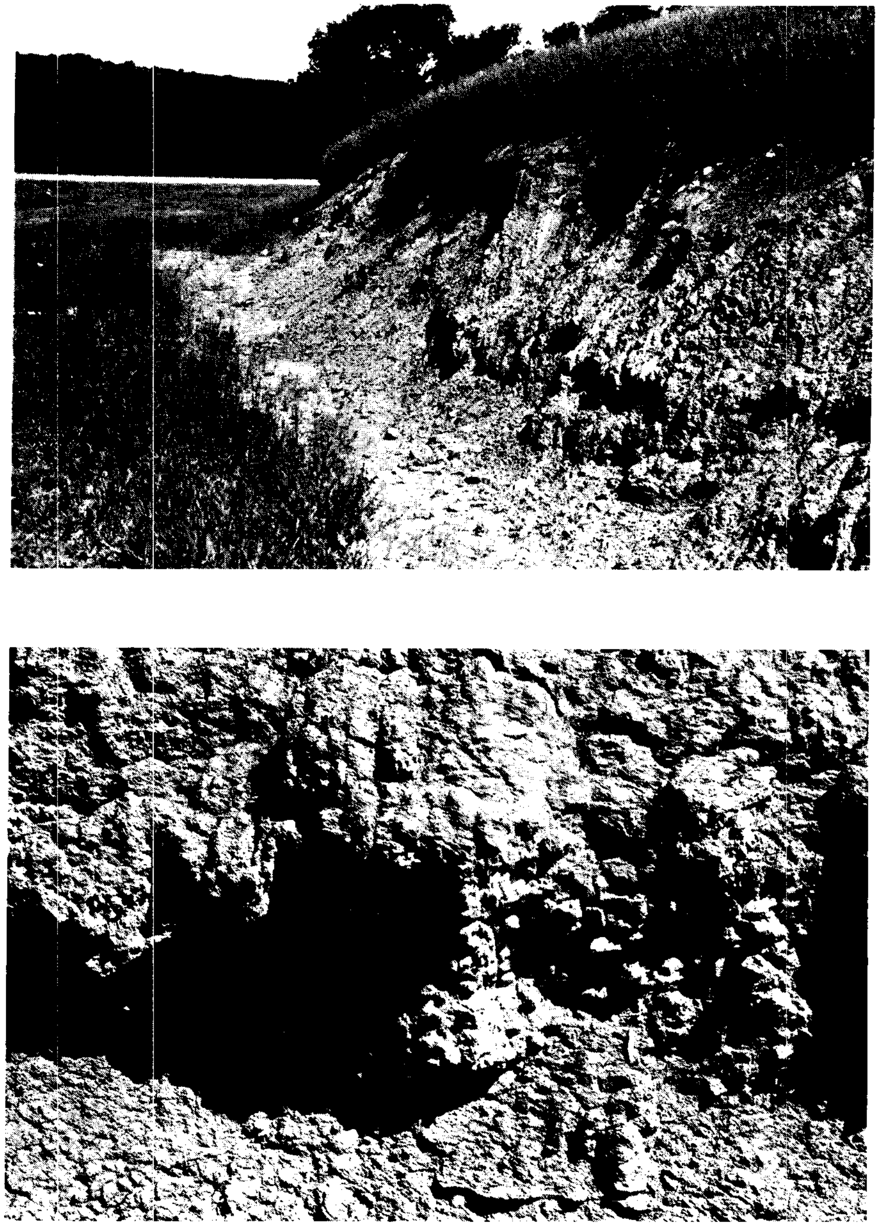

Figure 2. Two typical exposures of Niobrara Formation shale outcropping in the Sheyenne River valley. Located in sec 30, T136N, R57W. The lower photo shows the typical dried bentonitic clay surface that weathers to the golden hues found on weathered Niobrara shale exposures in this area.

some places, the Niobrara Formation is a gray to white, clayey limestone. In outcrops, it weathers to yellowish-brown to pale-orange hues (hence the name "Little Yellowstone Park") and consists mainly of light-gray, calcareous, thin-bedded shale, and blocky, clayey marlstone. Shale is more abundant than marlstone in outcrops, but the shale is commonly poorly exposed due to its weathering characteristics; it tends to slump over the outcrop. The marlstone has abundant white specks on bedding planes, and it is jointed with selenite crystals on the joint faces.

Generally, fossils are not abundant in the Niobrara Formation in North Dakota, but fragments of clams and oysters (Inoceramus and Ostrea) are common in some places. John A. Brophy and his students at the North Dakota State University Geology Department collected fossil remains of a marine reptile of the mosasaur group from the Niobrara Formation in northwestern Ransom County near the Little Yellowstone Park (Brophy, 1978). According to Brophy, the specimen consists of well-preserved to highly fragmented skeletal elements, including teeth, palatal fragments, cranial fragments, quadrates, vertebrae, rib fragments, limb fragments, and phalanges. His studies of the remains and their distribution on the surface of the outcrop and in the adjacent undisturbed rock suggest that the fragments represent a single individual with an overall length of about 12 to 15 feet.

Documented fossil finds of marine reptiles similar to the one just described have been uncommon in North Dakota. Most discoveries consist of only a few bones and teeth. Brophy's mosasaur find is the most complete and best documented in North Dakota. However, marine reptile fossils are common in the Cretaceous shale formations in North Dakota. Marine reptile vertebrae were collected from the Niobrara Formation along the Park River in Walsh County by Harold Bliss and his students at Mayville State College. The bones collected at this site are now on display in the Mayville State College Science Department. Similar marine reptile bones, mainly vertebrae, were collected from Pierre Formation shale near McVille in Nelson County by Alan Cvancara and his students at the University of North Dakota. A marine reptile tentatively identified as Platycarpus (?) sp. (a genus of mosasaur) was collected from Cretaceous shale near Kathryn, which is located about four miles north of the Ransom-Barnes County line, by a group of boy scouts in the early 1960s. The location of the find was never exactly determined, however, and it may have been from either Barnes or Ransom County and from either the Niobrara or Pierre Formation, although the shale with the fossil bones looks more like Pierre than Niobrara. Both the Nelson County and the Barnes/Ransom County fossil specimens are now included in the University of North Dakota Geology Department collection.

The Pierre Formation conformably overlies the Niobrara in extreme western Ransom County and on the Prairie Coteau in southeastern Sargent County. It outcrops in many places in the Sheyenne River valley north of Fort Ransom; in several outcrops the contact with the underlying Niobrara Formation is exposed.

Only the bottommost part of the Pierre Formation is exposed in outcrops in Ransom County. This material consists of dark-gray to black, fissile, noncalcareous shale with several buff to pale-orange bentonite beds near the base. Gypsiferous phosphate nodules, manganese concretions, and selenite crystals are found on the outcrops. Poorly preserved fragments of clams (*Lucina*, *Inoceramus*) and ammonoids (*Baculites*) have been found in the Pierre Formation in Ransom County (ammonoids were squid-like cephalopods; they are now extinct). Some of the best exposures of Pierre Formation shale are found at Little Yellowstone Park where State Highway 46 crosses the Sheyenne River. Here, about 170 feet of Pierre shale is exposed, lying on the Niobrara Formation. Some of the Pierre exposures in the Sheyenne River valley consist of blocks of material that have moved downslope from their original position by slumping and earthflow.

In general, the Pierre Formation thickens westward. In this area, however, part of the shale was removed by post-depositional erosion. The maximum thickness in northwestern Ransom County is probably no more than 200 feet. On the Prairie Coteau in southeastern Sargent County from 250 to 300 feet of Pierre Formation shale may be present beneath the glacial deposits.

Pleistocene Sediment

All the sediment related to glacial deposition in Ransom and Sargent Counties, that is, all the materials that were deposited by the glacial ice as well as by flowing and ponded water associated with the ice, are collectively referred to as the Coleharbor Group. The Coleharbor Group has been subdivided into a large number of informal units and formally named formations by various geologists. Some of these units are apparently regionally correlatable, but others seem to have local extent at best. I have generally avoided using the many formally named Coleharbor Group formations, referring instead to informal units with two exceptions: the Gardar and Dahlen Formations seem to be regionally extensive, properly defined, and, in general, useful stratigraphic units. In the section of this report entitled "stratigraphic correlations," various informal till units, plus the two formally named units just mentioned, are utilized in the discussion.

Sediment of the Coleharbor Group is exposed throughout Ransom and Sargent Counties. The Coleharbor Group sediment in the two counties apparently ranges up to more than 400 feet thick beneath the Whitestone Hills near Gwinner, although there exists the possibility that the Whitestone Hills consist partly of bedrock as no test hole has yet been drilled on the hills that penetrated all the way to bedrock. Figure 3 is a thickness map of the Coleharbor Group in the two-county area. The Coleharbor Group sediment consists of four main facies in Ransom and Sargent Counties: till; silt-till; sand and gravel; and silt and clay.

Till Facies

Terminology.--Till is the only sediment derived directly and only from glacial ice and the term is therefore both sedimentologic and genetic. For a discussion of the meaning of the term, please refer to appendix 1 of this report.

Composition.--The till of the Coleharbor Group found at and near the surface in Ransom and Sargent Counties is typically a mixture of varying proportions of sand, silt, clay, pebbles, cobbles, and boulder-sized particles. The matrix, composed mostly of silt and clay-sized particles, in oxidized exposures is most commonly pale yellow (2.5Y 8/4) when dry to light olive brown (2.5Y 5/4) when wet. Fresh, unoxidized exposures of till or cuttings from test holes commonly range from light gray (2.5Y 7/2) in color when dry to light brownish gray (2.5Y 5/2) when wet. The till found near the surface in Ransom and Sargent Counties is commonly poorly indurated and it may be weakly jointed (some notable exceptions exist to both of these conditions), but it generally has no other recognizable structure, such as bedding or sorting except in places where sliding or overriding has occurred (figs. 4, 5, and 6).

The coarser-grained materials in the till are generally angular to subrounded and consist mainly of carbonate, igneous, metamorphic, and shale rock fragments with small amounts of lignite. Petrologic examination of the coarse-sand fraction of some of the near-surface samples used for textural analysis indicates that igneous and metamorphic or carbonate rock fragments predominate (Nielsen, 1973). Soft, gray or black, Cretaceous shale fragments are present in smaller amounts.

In general, the igneous and metamorphic rock fragments in the till were ultimately derived from the Precambrian rocks of the Canadian Shield, to the east and northeast of Ransom and Sargent Counties or from the sandstone formations of western North Dakota. However, it is unlikely that the sandstone of western North Dakota contributed much material to the glacial sediment of southeastern North Dakota because the glacial flow was generally southerly and because the sandstone of western North Dakota does not contain much coarse sand. Carbonate rock fragments were derived from Paleozoic rocks of

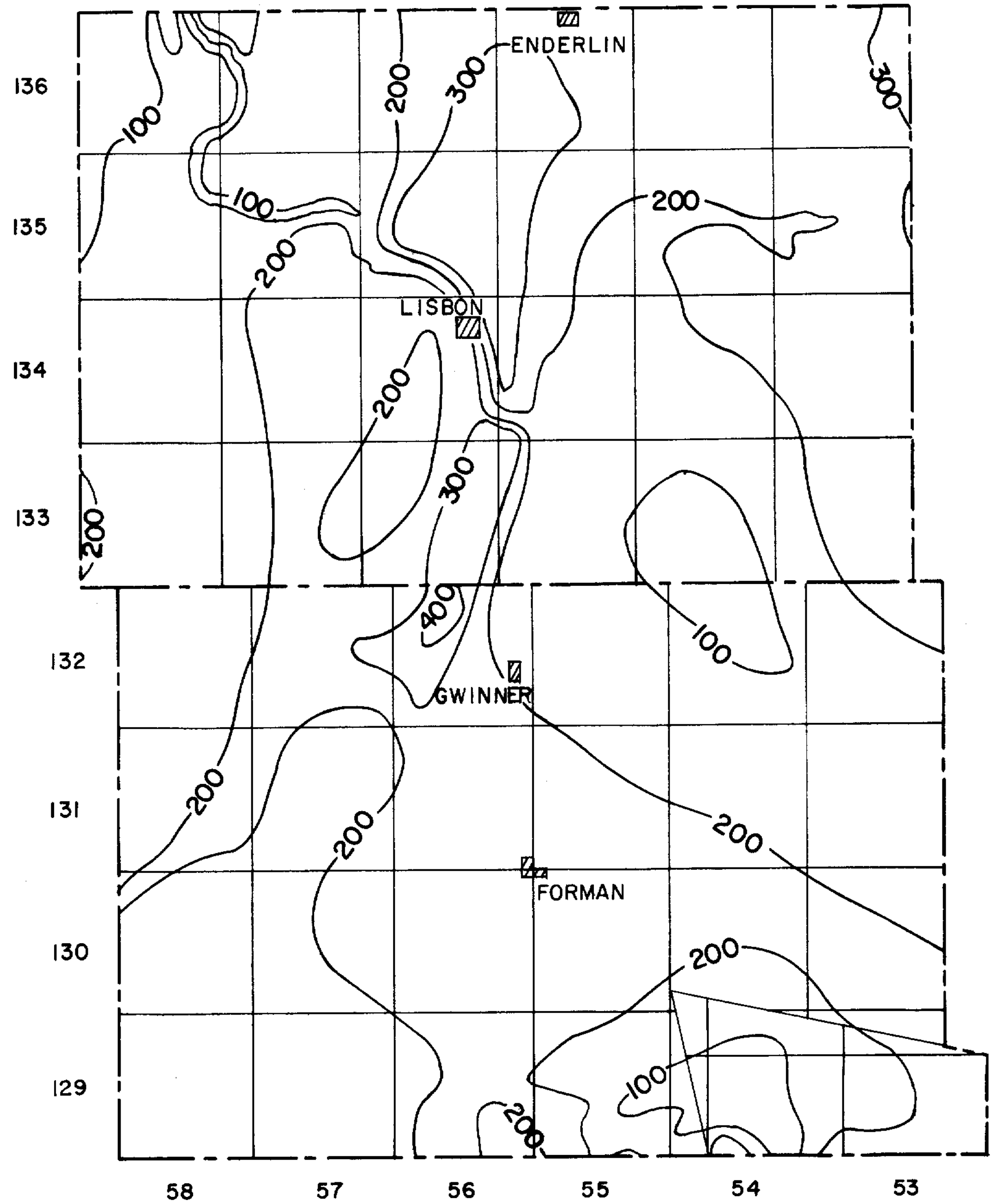

Figure 3. Map of Ransom and Sargent Counties showing the thickness of glacial and related deposits on top of the preglacial bedrock surface.

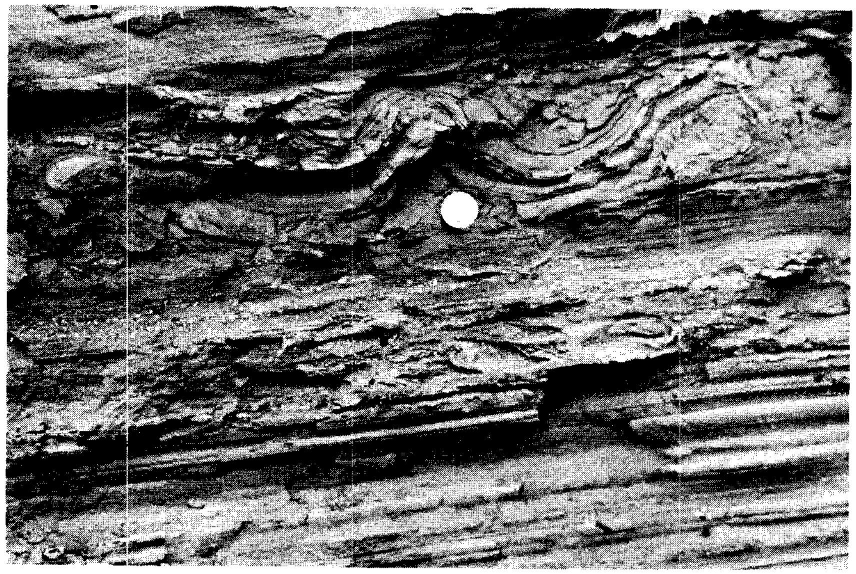

Figure 4. Convolutions in lake sediment that is overlain by till. The till was probably deposited as a result of a mudslide rather than by actual glacial advance. Exposure is located along the southwest edge of sec 16, T135N, R57W (see figs. 5 and 6). Till at the top of the photo, contorted lake sediments beneath till (nickel for scale), and undisturbed fluvial(?) and lake deposits on the bottom.

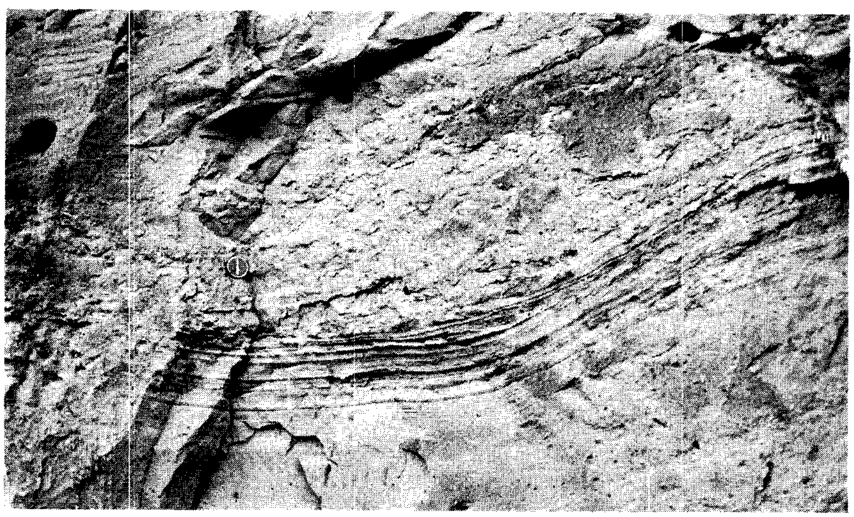

Figure 5. Lake silt deposit interbedded with till. The till has flowed or slid over the lake deposits. This exposure is located along the southwest edge of sec 16, T135N, R57W along the Sheyenne River trench. In some places, the sliding till has "bulldozed" the underlying lake beds (see fig. 6). Camera lens cap for scale.

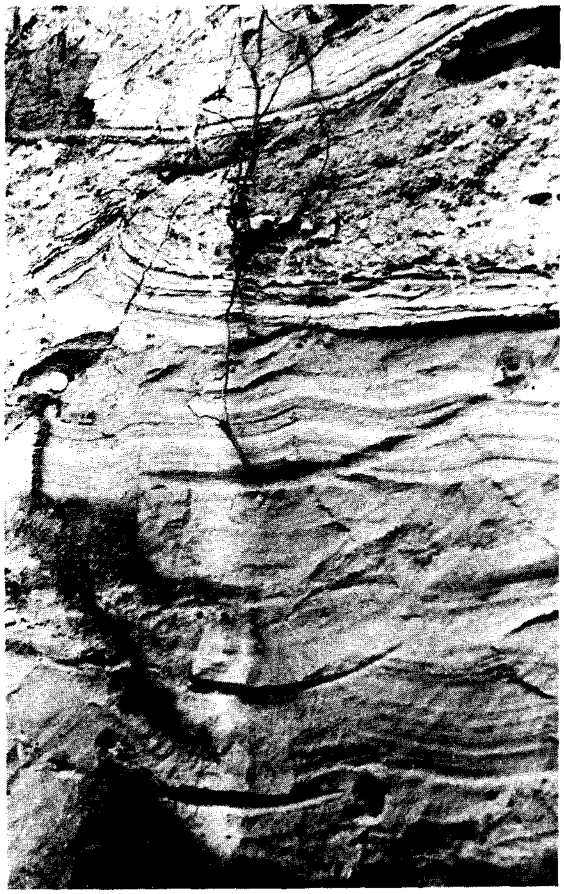

Figure 6. Illustration of the "bulldozing" effect of till that flowed over lake sediment. Same location as figure 5 (sec 16, T135N, R57W). Lake sediments are contorted near their upper surface with the till. Later lake sediments overlie the block of till, which was emplaced as a mudflow. Nickel for scale.

the northern Red River Valley, to the north and northeast of the two counties, and shale fragments were derived largely from the Cretaceous shale formations, which are the surface bedrock formations under much of eastern North Dakota, including Ransom and Sargent Counties. Many of the grains were not transported directly from their outcrop areas to their final resting place during a single advance of the glacier. An undetermined proportion of the sediment from each glacial advance was derived from older glacial sediment.

Stratigraphic Correlations of Till Units

General discussion.--Sieve and pipette analyses made on 27 surface and near-surface samples of till from Sargent County indicated that the material has a mean sand, silt, clay ratio of

32:40:28 (Nielsen, 1973). No attempt was made by Nielsen to devise a stratigraphic scheme to correlate the till layers (he refers to till as "diamicton") either regionally or with one another.

No serious attempt was made to correlate till units from one location to another in Ransom and Sargent Counties. However, at least six different glacial lithostratigraphic units were recognized and correlated considerable distances in exposures along the Sheyenne River valley in the Lisbon-Fort Ransom area (Moran, et al., 1976). Each of these units is composed of till and each has a characteristic texture and coarse-sand petrology (table 1).

Michael Camara (unpublished master's thesis, 1977) attempted to correlate the stratigraphy of the various till units in an area extending from near Carrington to Grand Rapids in the area of the James River meltwater trench and in the Sheyenne River meltwater trench of western Ransom County. Camara's study also included other parts of Ransom County and the northern part of Sargent County.

Camara recognized seven glacial lithostratigraphic units in southeastern North Dakota. The units consist of till layers, each of which were deposited by a separate glacial advance. Table 2 shows the grain-size distribution and the lithologic composition of the coarse-sand fraction of the several till layers he recognized. The normalized crystalline value was calculated by dividing the number of igneous and metamorphic fragments by the number of igneous and metamorphic fragments plus limestone and dolomite fragments.

A comparison of Moran's and Camara's stratigraphic correlations suggests that Camara's till units A, B, and C correspond to Moran's LFtR-60, LFtR-50, and LFtR-40 units, respectively (table 3). Bluemle's till unit P of LaMoure County (Bluemle, 1979) is probably equivalent to Camara's unit B and his unit P' may be equivalent to Camara's unit C. Bluemle considered his units P' and Q' to be weathering profiles on top of his till units P and Q, respectively.

Camara's Gardar Formation is equivalent to Moran's LFtR-30 unit and to Bluemle's LaMoure County unit Q. The Gardar Formation is considered to be early Wisconsinan in age, more than 40 000 years old. Camara's Dahlen Formation is probably equivalent to Moran's LFtR-20 unit and to Bluemle's LaMoure County unit R. The Dahlen Formation is considered to be late Wisconsinan in age, deposited more than 20 000 years ago.

Camara's unit D is probably equivalent to Moran's unit LFtR-10 and to Bluemle's LaMoure County unit S. Camara's unit E is equivalent to Bluemle's unit T in LaMoure County. This till is not present in Ransom and Sargent Counties.

In this report, the till units referred to will, unless otherwise specified, be those used by Camara (1977) (tables 2 and

TABLE 1. Lithostratigraphic units in the Lisbon-Fort Ransom area. The textural data for the matrix of the till is expressed as a percent. The sum of the sand (2.0 mm to 0.0625 mm), silt (0.0625 mm to 0.0039 mm) and clay (less than 0.0039 mm) is equal to 100 percent. The petrology of the coarse-sand fraction (2.0 mm to 1.0 mm) is expressed as a percent. The sum of the fragments of crystalline rocks (Xln: igneous and metamorphic-rock fragments), carbonate fragments (Carb: limestone and dolomite fragments), and shale grains (Sh) is equal to 100 percent. Grains of other lithologic types are present in generally small quantities, but are not included in the data summary. Table is taken from Moran and others (1976).

	Lithology	Color	Comments	Texture Sand-Silt-Clay	Coarse Sand Petrology Xln-Carb-Sh
LFtR-10	Till	Light olive gray; oxid. light olive brown	Thin, discontinuous, limited to eastern part of area	24-46-30	39-29-32
LFtR-20	Till	Light olive gray; oxid. light olive brown	Unjointed, soft, readily disaggregated	24-45-31	27-19-54
LFtR-30	Till	Olive gray; oxid. olive brown	Abundant shale	18-48-34	15-15-70
LFtR-40	Till	Lt. olive gray or lt. yellow gray; oxid. yellow-olive brown	Sandy, low shale	46-31-23	40-30-30
LFtR-50	Till	Very dark gray (unoxid.)	Appears to contain carbonate grains	33-44-23	26-22-52
LFtR-60	Till	Yellowish brown (oxid.)	Appears clayey	28-40-32	38-27-35

TABLE 2. Grain-size distribution and lithologic composition of the coarse-sand fraction of the glacial sediment (till) in southeastern North Dakota. Taken from Camara (1977).

Unit	% Sand	% Silt	% Clay	% Igneous & Metamorphic Fragments	% Limestone & Dolomite Fragments	% Shale	Normalized Crystalline Value
Unit E	34	43	23	67	23	10	0.74
Unit D	33	40	27	52	29	19	0.64
Dahlen Formation	30	43	27	31	25	44	0.55
Gardar Formation	22	49	29	19	16	65	0.54
Unit C	29	41	30	40	30	30	0.57
Unit B	37	42	21	29	23	48	0.56
Unit A	29	43	28	38	26	36	0.59

TABLE 3. Tentative correlations of layers of glacial sediment recognized by three different workers in southeastern North Dakota (Moran, et al., 1976; Camara, 1977; and Bluemle, 1979). Unless otherwise specified, the till units used in this report will be those of Camara as his study was of a more regional nature than were the other two.

Moran, et al. Ransom County	Bluemle LaMoure County	Camara Southeast North Dakota
	T	E
LFtR-10	S	D
LFtR-20	R	Dahlen Fm.
LFtR-30	Q' (weathered Q)	
	Q	Gardar Fm.
LFtR-40	P' (weathered P)	C
LFtR-50	P	B
LFtR-60	P?	A

3) as his study was of a more regional nature than others made in southeastern North Dakota.

Till unit A.--Unit A is exposed in several places northeast of the town of Fort Ransom. It ranges from 10 to 33 feet thick in the exposures Camara examined. In one location (SE¼ sec 35, T136N, R58W), at the bottom of a dirt road downhill from the Standing Rock Cemetery, the till structure is strong, very coarse, prismatic, and blocky. Gray (5Y 6/1) clay skins cover the moist, olive-brown (2.5Y 4/4) till. Dry, the oxidized till is light olive brown (2.5Y 5/4); the unoxidized till is gray (5Y 5/1). Manganese-oxide staining is common on many of the blocks and prisms. Lignite and spots of red ochre are conspicuous in the oxidized till. The lower contact of unit A is not exposed at this site.

The grain-size distribution and lithologic composition of the coarse-sand fraction of the till of unit A changes little throughout the area Camara studied. The average grain-size distribution of all samples of the till is 29 percent sand, 43 percent silt, and 28 percent clay. The mean lithologic composition of the coarse-sand fraction of all samples of the till is 38 percent igneous and metamorphic rock fragments, 26 percent limestone and dolomite fragments, and 36 percent shale fragments. In most of the exposures examined by this writer, shale appeared to comprise more than 36 percent of the total content.

The till of unit A was differentiated from the till of other units on the basis of grain-size distribution, the lithologic composition of the coarse-sand fraction, and the stratigraphic position. It is a relatively clayey unit with a moderate amount of shale in the coarse-sand fraction. Unit A is the only clayey till in Camara's study area that contains lignite fragments. The sand content and the stratigraphic position are the bases for differentiating the till of unit A from the till of unit B. Unit B contains a relatively sandy lignitic till whereas unit A contains a relatively clayey lignitic till.

Till unit B.--Unit B is exposed in some of the same locations as unit A, near the town of Fort Ransom. It ranges from 10 to 170 feet thick in exposures and in the test holes Camara examined. Just northwest of Fort Ransom (NE¼ sec 35, T136N, R58W), a road that extends along the western border of the Sheyenne trench passes up through the Pierre Formation, unit B, a thin layer of the Gardar Formation, and a thick section of unit D. Out of the valley, at the top of the road, is a section of clay, silt, and sand above unit D. In another good exposure (NE¼ sec 11, T135N, R57W), Niobrara Formation shale is overlain by soft, black to olive-brown shaly till through which considerable groundwater is moving. In this exposure, the till is composed almost entirely of shale and might easily be mistaken for Pierre Formation shale except that it does contain some igneous and carbonate pebbles.

The till of unit B is generally a dark-grayish-brown (2.5Y 4/2) (moist) till with a strong-medium platy structure. Small pieces of lignite and red ochre are conspicuous, although they occupy less than one percent of the exposed surface of the till. Sand lenses of different sizes are also present, but they are not common.

Unit B is a silty and sandy till with a mean grain-size distribution of all samples of 37 percent sand, 42 percent silt, and 21 percent clay. The mean lithologic composition of the coarse-sand fraction of all samples collected by Camara is 29 percent igneous and metamorphic fragments, 23 percent limestone and dolomite fragments, and 48 percent shale fragments. Dry, the unoxidized till is gray (5Y 5/1). Lignite is common in the till of unit B and, in places, the total coarse-sand fraction contains as much as 8 percent lignite. Camara differentiated unit B from other units in his study area because of its silty-sandy lignitic till content coupled with its moderate to high shale content (40 to 50 percent). Stratigraphic position also helped him to differentiate unit B from other till units.

Till unit B is overlain by an extremely hard conglomerate, which is highly limonite stained (NW¼ sec 11, T135N, R57W) (fig. 7). The conglomerate consists of coarse sand and gravel that is cemented throughout. Joint traces, which extend downward from the overlying till (unit C) pass through both the cementing material and the pebbles and cobbles of the conglomerate. The degree of cementation and resulting hardness of the conglomerate is unusual; I have observed similar situations in only a few other places in North Dakota and probably nowhere so hard as here.

Till unit C.--The cemented conglomerate described as overlying unit B (NW¼ sec 11, T135N, R57W) is overlain by a hard, stony, sandy till that is interpreted to be unit C. It ranges up to 100 feet thick in some of the test holes Camara examined. This till is light-yellowish gray in oxidized exposures, mottled with shades of light-olive gray. Iron staining is extensive in the till, especially along joint traces. This hard till has both horizontal and vertical jointing (fig. 8), which, as noted above, extends downward into the underlying conglomerate. The till breaks along joints, and free-standing vertical exposures are common. A discontinuous boulder pavement overlies the till; many of these boulders and cobbles are striated (fig. 9). Two sets of striae were observed; most of them trend approximately north-northwest to south-southeast, but some of the deeper ones trend east-west (the striae observed on the boulder shown on figure 9 trend N20°E). The till contains numerous sand inclusions and a few hard sandstone boulders up to a foot in diameter (fig. 10). These sandstone boulders were apparently derived from Tertiary sandstone formations that occur throughout the western half of North Dakota. Only a few small pieces of coal were found in the till. One small piece of Knife River Flint was found embedded in the till. The nearest known exposure of this particular type of flint is about 200 miles west-northwest of this site, although the flint may occur beneath the glacial deposits over a large part of western North Dakota. This particular till appears to be similar to till originally designated as "Dead Man Drift" (Bluemle, 1971) in McLean County. The Dead Man Drift has since been renamed the Medicine Hill Formation (Ulmer and Sackreiter, 1973).

Camara (1977) subdivided unit C into two subunits, an upper, silty till subunit and a lower, sandy till subunit. The lithologic composition of the coarse-sand fraction of these units is identical. The best exposure of unit C is in the NE¼, sec 15, T135N, R57W, a roadcut through the south wall of the Sheyenne River trench. The lower, sandy portion of unit C, an overlying unnamed unit, and the Dahlen Formation are all exposed here. The moist, oxidized till of unit C ranges from dark-grayish brown (2.5Y 4/2) to olive-brown (2.5Y 4/4). Unoxidized, the till is gray (5Y 5/1) to black (5Y 2/1). The dark color of the till makes limestone and dolomite fragments easily visible. Abundant lenses of fine-grained sand give a sandy appearance

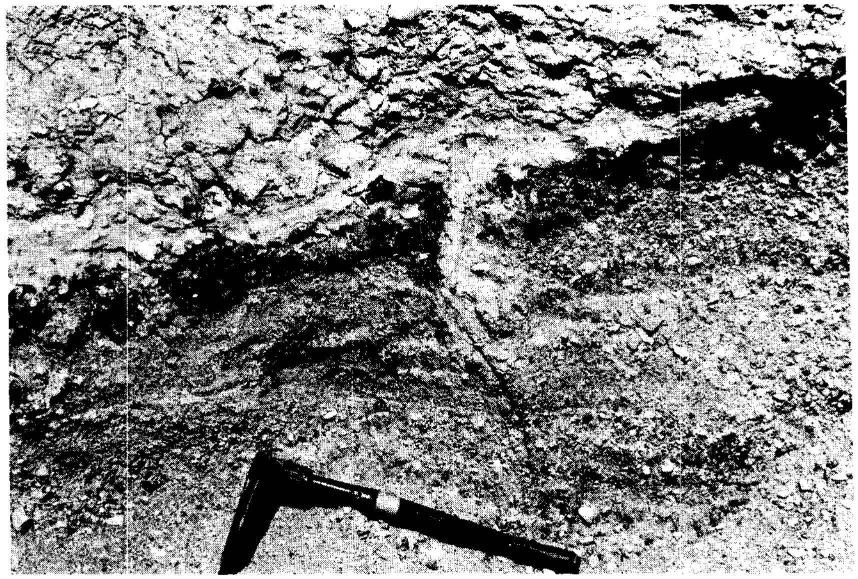

Figure 7. Till unit C (on top) overlying an extremely hard, cemented gravel layer (the dark zone). The gravel grades downward into less cemented gravel. Notice the till-filled joint that extends downward through the cemented gravel into till unit B (shovel rests on the contact between the gravel and the underlying till unit B).

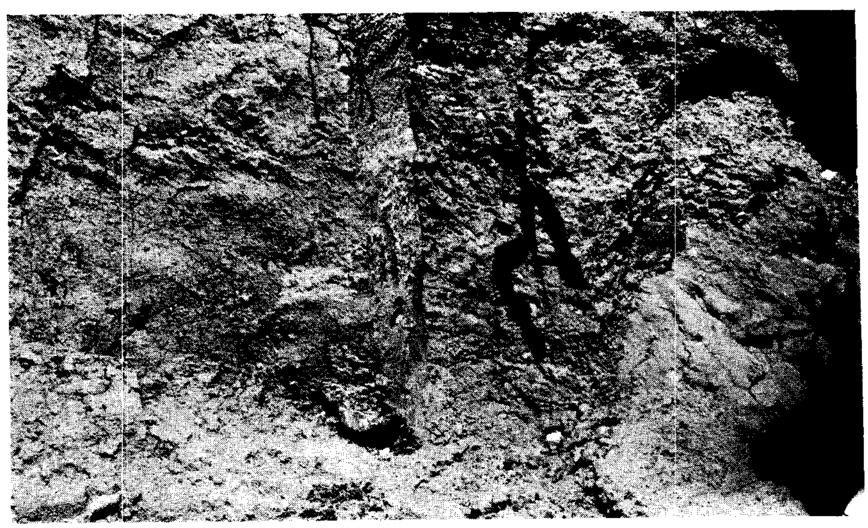

Figure 8. One of many well-developed joint faces exposed in till unit C (NW¼ sec 11, T135N, R57W). Notice the sandstone boulder or inclusion in the lower, right-hand part of the picture.

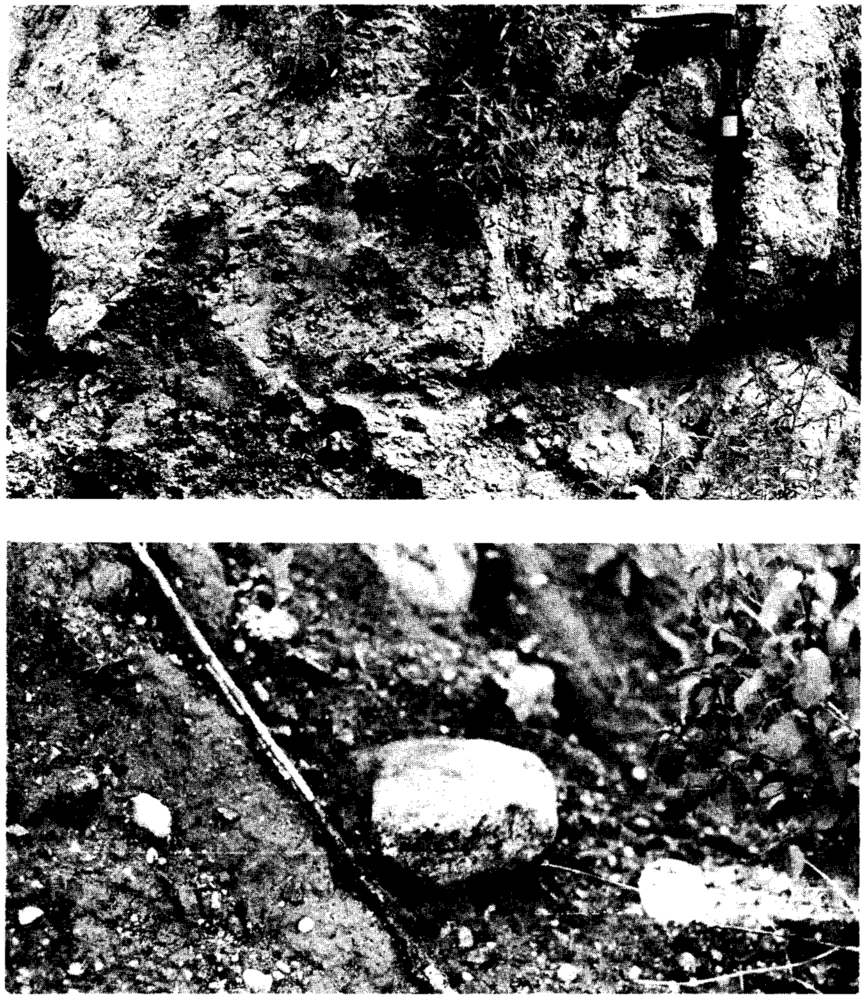

Figure 9. Exposure of two tills. Located at the northeast corner of sec 30, T136N, R57W, the tills are separated by a boulder pavement. One faceted, striated boulder from the pavement is shown in the lower photo. The upper till is probably equivalent to till unit C; the lower one may be equivalent to till unit B, based on coarse sand sample lithologic and textural data (Camara, 1977). Striae, which are only poorly defined on this photo, trend N 20° E, and indicate that the glacier that deposited the upper till probably advanced from this direction at this location.

Figure 10. Sandstone boulder (or inclusion) in till unit C (NW¼ sec 11, T135N, R57W). This sandstone block was derived originally from one of the Tertiary Fort Union Group formations several hundred miles to the west. The lower photo is a closer view of the boulder. Camera lens cap, about 2½ inches across, shows the scale.

to the till, which is pebbly and compact. The till of unit C has a strong coarse-prismatic structure with manganese-oxide staining on many of the prism surfaces.

Unit C was differentiated from other units in Camara's study area by the sparse amount of shale in the coarse-sand fraction of the till and by the stratigraphic position of the unit. The till of unit C contains much less shale than either units A or B or the overlying Gardar and Dahlen Formations. Unit C is the only unit in Camara's study area that he could subdivide into two subunits; no attempt was made to differentiate Camara's two C subunits in this study. In outcrop, unit C was the only unit Camara found that contains numerous sand and gravel lenses. Although it is relatively sandy, the till is compact and hard to dig in fresh exposures.

Gardar Formation.--The Gardar Formation is commonly found in exposures along the Sheyenne River in Ransom County. The best exposure of the Gardar Formation (named by Hobbs, 1975) in the two-county area is in the SE¼ sec 18, T135N, R56W. Here, the till is exposed in a gully by a roadcut. The gully cuts through units B and C and the Gardar and Dahlen Formations. At this location, the till of the Gardar Formation is dark grayish brown (2.5Y 4/2) when moist. It is compact with abundant shale pebbles. The till has a strong, coarse-prismatic structure. The prisms and pebbles are heavily stained with manganese oxide and so well cemented that, in places, the material resembles highway pavement. This gravel marks the upper contact of the Gardar Formation.

The Gardar Formation in LaMoure County is commonly in excess of 100 feet thick, but in Ransom County its thickest reported occurrence is 95 feet in a test hole located in the SE¼ sec 7, T136N, R57W. It generally thins westward across Ransom County. The till of the Gardar Formation contains abundant shale. The mean lithologic composition of the coarse-sand fraction of all samples of Gardar till is 19 percent igneous and metamorphic grains, 16 percent limestone and dolomite grains, and 65 percent shale grains. The mean grain-size distribution of all samples is 22 percent sand, 49 percent silt, and 29 percent clay. The unoxidized till is gray (5Y 5/1) when dry. The till is pebbly and has a relatively large amount of coarse sand included.

The till of the Gardar Formation has a shale content that is the highest of any till Camara studied, 65 percent in the coarse-sand fraction. Till unit B and the Dahlen Formation till are the only other till units that have shale contents greater than 40 percent. The Gardar Formation till is distinguished from the underlying till of unit B and from the overlying Dahlen Formation till primarily on the basis of its high silt and clay content.

The Gardar Formation was tentatively identified in several LaMoure County test holes (Bluemle, 1979). It was found in only one outcrop in Sargent County.

Dahlen Formation.--The Dahlen Formation is present throughout southeastern North Dakota. In Ransom County, the Dahlen Formation is well exposed in two locations: NE¼ sec 15, T135N, R57W on the road leading out of the Sheyenne River valley; and in the SE¼ sec 18, T135N, R56W. The Dahlen Formation, named by Hobbs (1975), ranges up to about 90 feet thick in some LaMoure County test holes, but it thins eastward and averages about 25 feet thick over the four-county area (Dickey, LaMoure, Ransom, and Sargent).

The first location listed above (NW¼ sec 15, T135N, R57W) is a road cut through the south wall of the Sheyenne River trench to the top of Oestreicher Hill. The till here has a strong, coarse-prismatic structure and the blocks of the till are lightly stained with iron oxide. The till is easy to dig. Cobbles and boulders are rare, but pebbles are common. Most of the pebbles are shale but, because of the dark color of the till, the limestone and dolomite pebbles appear to be more abundant. The bottom contact of the unit can be seen on the east side of the roadcut, where a two-inch-thick bed of red clay occurs. A 10-foot bed of fine-grained, oxidized sand lies below the red clay bed.

Three miles east (SE¼ sec 18, T135N, R56W), the Dahlen Formation is exposed in a gully by a roadcut. The Dahlen Formation here is olive gray (5Y 5/2) when moist. The till has a strong, medium-platy structure. Small sand lenses are common and pebbles are abundant, especially limestone and dolomite pebbles. Boulders and cobbles are rare. No iron-oxide staining occurs on the till at this outcrop.

In LaMoure County (NW¼ sec 32, T136N, R62W), the Dahlen Formation rests on a soled boulder pavement that marks the top of the Gardar Formation. Here, the Dahlen Formation has a strong, medium-platy structure. Cobbles and boulders are rare, but pebbles are common. The till is lightly stained with manganese oxide. Sand lenses are common, but not abundant.

The shale content of the Dahlen Formation till (45 percent) is higher than that of the overlying till, but lower than that of the Gardar Formation till. The Dahlen till is sandier, and contains fewer limestone, dolomite, and shale grains than does the till of unit C. The grain-size distribution and the lithologic composition of the coarse-sand fraction are similar to that of the tills of units A and B, but the Dahlen Formation till contains no lignite. Stratigraphic position is the main criterion for distinguishing the Dahlen Formation till from the tills older than the Gardar Formation (Camara, 1977).

According to Hobbs (1975), the Dahlen Formation was deposited during the main late Wisconsinan glaciation. Hobbs correlated the Dahlen Formation with the upper part of the Red Lake Falls Formation (Harris and others, 1974) in Minnesota; and Anderson (1976) correlated the upper part of the Red Lake Falls Formation with the New Ulm till (Matsch, 1971) and with the Dunvilla Formation of west-central Minnesota.

Till unit D.--In Ransom County, the best exposures of unit D are in the NE¼ sec 35, T135N, R58W, at the end of the road that extends along the western border of the Sheyenne River trench. The till of unit D here is olive (5Y 5/3) when moist, pebbly, somewhat sandy, and easy to dig. No structure is developed in the till at this outcrop. The till of unit D ranges up to 40 feet thick in western Ransom County, and it is somewhat thicker to the west in LaMoure County. It thins eastward and may be absent along the eastern border of Ransom and Sargent Counties.

In LaMoure County, unit D is exposed south of Adrian in a gully alongside a road that passes over an earth-filled dam. The most notable characteristic of the till here is the strong, coarse-angular to subangular-blocky structure. The till near Adrian is gray (5Y 5/2) when moist; the clay skins are grayish brown (2.5Y 5/2). At the Adrian site, the till of unit D feels relatively clayey when compared to the till of the overlying unit E. Unit D has less shale than any other till unit in Ransom and Sargent Counties. The mean lithologic composition of the coarse-sand fraction of all the samples analyzed by Camara (1977) is 52 percent igneous and metamorphic fragments, 29 percent limestone and dolomite fragments, and 19 percent shale fragments. The mean grain-size distribution of all samples from till unit D is 33 percent sand, 40 percent silt, and 27 percent clay.

Where observed in Stutsman and LaMoure Counties, north and west of the Ransom-Sargent County area, till unit D contains more shale fragments and fewer igneous and metamorphic rock fragments than the overlying till unit E. Unit E, the youngest unit in Camara's study area, contains fewer shale fragments than any other glacial stratigraphic unit he studied, but it is not found east of LaMoure County. The coarse-sand fraction of unit E contains a mean of 10 percent shale fragments.

Implications.--The petrography of a layer of till can sometimes reveal the direction of transport of the sediment. If the source of the transported rock particles is known, it may be inferred that the glacier incorporated at least some of the rock fragments from the source area and the fragments were transported along the line of glacier flow. Thus, the petrography of the components of a layer of till may be used as an indicator of the direction of glacial transport, particularly if the source area is nearby. Camara (1977) analyzed the change in the amount of shale in the coarse-sand fraction of each till because the amount of shale in the till was the main criterion for correlating the units of glacial sediment and because the bedrock in the area is shale.

The large amount of shale fragments in the coarse-sand fraction of the Gardar and Dahlen Formations indicates that the contributing glacier advanced from the north or northeast into the area over subcrops of Cretaceous shale. The glacier that deposited the sediment of the Gardar Formation probably advanced from a northerly direction into the area and incorporated an increasing amount of shale as it flowed southward. The amount of shale in the Gardar Formation increases east, south, and west from central Ransom County.

The small amount of shale and the large amount of igneous and metamorphic rock fragments in the coarse-sand fraction of till units D and E indicates that the glacier that deposited the sediment of these tills probably advanced from a generally northwesterly direction. The igneous and metamorphic rock fragments were probably derived from older glacial sediment rather than directly from the Canadian Shield to the northeast because till units D and E are absent in much of the eastern part of the area; unit E is not present in the two-county area at all.

Camara's lower three till units, A, B, and C, were recognized in Ransom County and in northern Sargent County, but not elsewhere in his study area. In parts of the two counties, the three units have a combined thickness of over 100 feet. Generally, individual sub-Gardar till units are less than 30 feet thick, but they range up to 100 feet thick. Camara was able to correlate till units A, B, and C over wide areas. He also recognized additional isolated till units in individual holes, but he could not correlate these with any other units. It is therefore likely that several more till units than those recognized by Camara (that is, units A, B, and C) occur below the Gardar Formation.

Boulders in the Till

About two-thirds of the boulders found on the surface in most places in the two counties consist of gray or pink granite. The remainder are dolomitic limestone, gneiss, and dark basaltic rocks in about equal proportions. Dolomitic limestone boulders are abundant in places, as on the walls of the Sheyenne River valley near Fort Ransom. They are usually gray or pink in color. Many boulders are striated or polished (figs. 9 and 11).

Silt-Till Facies

The silt-till facies of the Coleharbor Group is exposed over an area that extends from north-central Ransom County southeastward into northern Sargent County and in a part of eastern

Figure 11. A view of a striated boulder located in NE¼SW¼ sec 11, T135N, R58W, just south of the village of Fort Ransom. Several large granite boulders that occur on the slopes of the Sheyenne River valley here have surfaces that have been flattened by glacial abrasion. Some of the boulders are apparently marked by pictograph symbols as well as by glacial striae.

Sargent County (areas designated Qcru and Qcrt on pl. 1). Areas covered by this material are characterized by landforms that have been designated "composite lake-glacial landforms."

The material that makes up the silt-till facies is less than ten feet thick wherever it was observed in a complete section. It consists in some places of poorly indurated, vaguely bedded silt; an unsorted, unbedded, unjointed mixture of angular, subangular, and rounded blocks of rock, gravel, and sand in a loose, silty matrix in places; and till in the remainder of the area. The matrix is generally yellowish brown to tan where it is exposed; somewhat darker when taken from auger samples. The coarser-grained materials in the silt-till are essentially identical to those found in the conventional till. No petrologic or textural analyses were performed on the silt-till.

Materials of the silt-till facies tend to be exposed best on small hills and ridges where bedding in the silt fraction may be undisturbed (fig. 12); on hillslopes bedding is generally slumped. No exposures were found throughout the area mapped as silt-till facies in which the silt was overlain by conventional till, and this argues against the possibility that the area is one

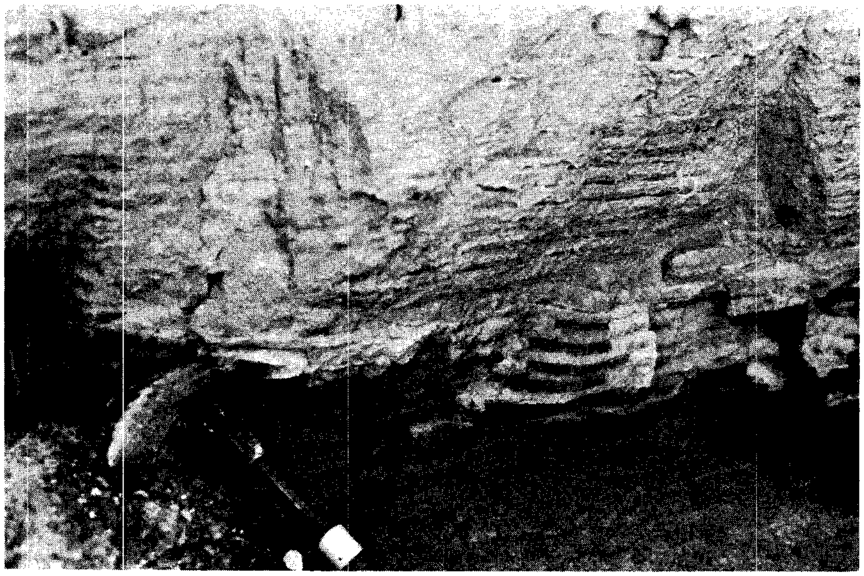

Figure 12. Bedded silt deposit. This rhythmically banded, varve-like deposit is located at the southwest corner of sec 13, T136N, R55W at an elevation of about 1 125 feet, above the Herman level of glacial Lake Agassiz in this area. Bedded silt deposits, such as this one, occur in several places in the area mapped as silt-till facies (Qcrf or Qcru) in central Ransom County.

in which a glacier overrode a lake deposit. It seems much more likely that the silt-till facies resulted when an early stage of glacial Lake Agassiz flooded an area in which the glacial ice had not yet all melted. As a result, lake beds were deposited on both stagnant glacial ice and on till (in areas where the ice had already melted). Inclusions of lake sediment were left intact in some places, but, in most places, the silty lake sediments simply became mixed with the other materials resulting in a till that is distinctly more silty than is the till in areas that were not flooded.

Silt and Clay Facies

The laminated silty clay, clayey silt, and fine sand facies of the Coleharbor Group consists of materials that were deposited in lakes. Such deposits are exposed at the surface mainly in western Sargent County (areas designated Qcss and Qcsv on pl. 1) although large amounts of material of the silt and clay facies occur beneath the surficial sand of the Sheyenne Delta of eastern Ransom and northeastern Sargent Counties. In that area, the silt and clay is exposed only where the Sheyenne, and, to a much lesser extent, the Wild Rice River, has incised deeply enough to expose the silt and clay in their valley walls (Qcsi on pl. 1).

Generally, where it is exposed, the silt and clay facies consists of about 65 percent silt with the remaining 35 percent clay and fine sand. The sediment is typically laminated, the laminations (in western Sargent County) ranging in thickness from about 0.1 to 0.5 inches. Laminations are generally horizontal except in areas of undulating topography where they are commonly tilted, contorted, or faulted (Qcsc). The silt and clay facies in southwestern Sargent County ranges up to nearly 100 feet thick in basins that were flooded by glacial Lake Dakota. The basins probably resulted from glacial thrusting, which shoved up hills, leaving the depressions, which then were flooded by the lake.

Sand and Gravel Facies

Gravel and sand of the Coleharbor Group covers the surface area of about 20 percent of the two counties, about 10 percent of Sargent County and 30 percent of Ransom County. Both fluvial and lake shore sediment are included in the sand and gravel facies. Field observations indicate that the sand and gravel have a mineralogic composition similar to that of the till. It typically contains granitic and metamorphic rock particles, dolomite, limestone, and shale. Shale is most abundant in the ice contact deposits (red lines on pl. 1) and least abundant in beach deposits.

Most of the fluvial sediment consists of poorly sorted, rippled, cross-bedded sand and plane-bedded gravel along with some sandy silt, as well as some lenses of flat-bedded sandy gravel. Most of these sediments were deposited by meltwater runoff that resulted in outwash (Qcgu, Qcgp), especially in western Ransom County, and in terrace or bar deposits (Qcgt) in several places along the Sheyenne River. Fluvial sediments also make up a large part of the Sheyenne Delta materials (Qcgs). Terrace gravel deposits are extensive in some places and they are important sources for commercial gravel operations. The fluvial sediment is generally horizontally layered except in hilly areas such as northwestern Ransom County (areas designated Qcgp) where it is faulted or contorted. The sandy gravel found in many irregular-shaped hills and ridges that formed in contact with stagnant glacial ice (areas shown as red lines on pl. 1) is typically poorly sorted, coarse-grained material that contains chunks of till and boulders of all sizes.

Lake shore deposits (Qcgx, Qcgl) consist mainly of well-sorted sand and sandy gravel with some lenses of silt. Much of this material is fluvial sediment that has been reworked by wave action along the lake shore. A few beach ridges that occur contain somewhat cleaner, shale-free sand, but such beach deposits are generally less than 10 feet thick.

The sand and gravel facies occurrences just described are all at or near the land surface. Sand and gravel lenses and layers also occur throughout the Coleharbor Group section within the till and silt and clay facies and as layers separating buried till and silt and clay units. These buried sand and gravel horizons may contain important groundwater resources and the extent and hydrologic properties of these aquifers will be discussed in detail in Part III of this report, which deals with groundwater resources.

Holocene Sediment

The Oahe Formation sediment consists of a variety of clay, sand, silt, and gravel deposits that accumulated during Holocene and latest Wisconsinan time. It consists of river, pond, windblown, and mass-movement sediment. In Ransom and Sargent Counties, two main facies are included in the Oahe Formation. These are a clay facies and a sand and silt facies.

Clay Facies

The clay facies of the Oahe Formation (Qocp) in Ransom and Sargent Counties consists mainly of sediment in modern ponds and sloughs. The sediments of the clay facies were brought to the ponds and sloughs through slopewash process and, to some extent, eolian processes, and redeposited by the pond water. Only a few of the ponds and sloughs are shown on plate 1 as most were too small to map.

The sediment is well-sorted, gray to black clay and silty clay. It is commonly obscurely to finely bedded (0.1 to 0.3 inches) and generally less than 4 feet thick. In some deposits, the bedding has been destroyed by organisms. Terrestrial fossils (shells and pollen) are common. Most areas covered by pond and slough sediment are flat with less than 1° slopes.

Sand and Silt Facies

The sand and silt facies of the Oahe Formation in Ransom and Sargent Counties consists of river and windblown sediment. The river sediment (Qosr) is found beneath flood plains along the Sheyenne, Maple, and Wild Rice Rivers and along some of the smaller streams as well. It is generally light to dark gray sand and silt that has indistinct horizontal bedding. Terrestrial and aquatic fossils such as shells, wood fragments, and bones are common.

Windblown sediment (Qosw) is extensive in eastern Ransom County and in parts of western Sargent County. It is typically well-sorted, fine sand with some black, sandy silt that was derived from windblown topsoil. Obscure bedding, indistinct cross-stratification, and weak paleosols can be seen in some exposures. Fossils are uncommon although some rodent bones and teeth were found in the SW¼ sec 13, T131N, R53W. (Nielsen, 1973). The windblown sediment, which occurs as dunes or as a nearly flat sheet of sand, generally overlies fluvial sediment of the Coleharbor Group (sand and gravel facies), but in some places dunes have blown over areas of till (Tps 129-130N, R58W).

GEOMORPHOLOGY

General Description

The modern landscape in Ransom and Sargent Counties is the surface that was formed by the advance and retreat of the glaciations that occurred in Wisconsinan time. The two-county area can be arbitrarily subdivided into about six physiographic areas.

The largest physiographic area is the Glaciated Plains, which covers about 500 square miles in central Sargent County and another 200 square miles in west-central Ransom County, or a total of about 40 percent of the two-county area. The Glaciated Plains consists mainly of undulating to rolling glacial sediment with numerous potholes and generally poorly integrated drainage. Landforms of the Glaciated Plains include those formed by the moving glacier. They range from pre-last glacial sediment-draped topography through ice-thrust features and varying degrees of collapsed glacial topography, although large-scale glacial stagnation was not a significant land-forming process on the Glaciated Plains.

A generally hilly area with complex geology that occurs in western Sargent County and extends northward through western Ransom County covers about 20 percent of the area (350 square miles). It consists largely of glaciofluvial gravel and sand; silt and fine sand of glacial Lake Dakota; and, in places, areas of windblown sand. The lacustrine and fluvial materials, along with large amounts of till, have undergone considerable thrusting by the glacier resulting in hilly areas such as the Lake Oakes Hills, Bear's Den Hillock, and Standing Rock Hill.

Another 20 percent of the area (350 square miles) in eastern Ransom County and northeastern Sargent County is covered by the Sheyenne Delta, a nearly flat area that consists of fine sand and silt that were deposited at the mouth of the Sheyenne River in glacial Lake Agassiz. Windblown dunes are common over much of this area.

About 15 percent of the area (250 square miles), mainly in central Ransom County, is silty till with undulating topography similar to the Glaciated Plains. This area consists of glacial sediment with many patches of lake and shoreline sediment that

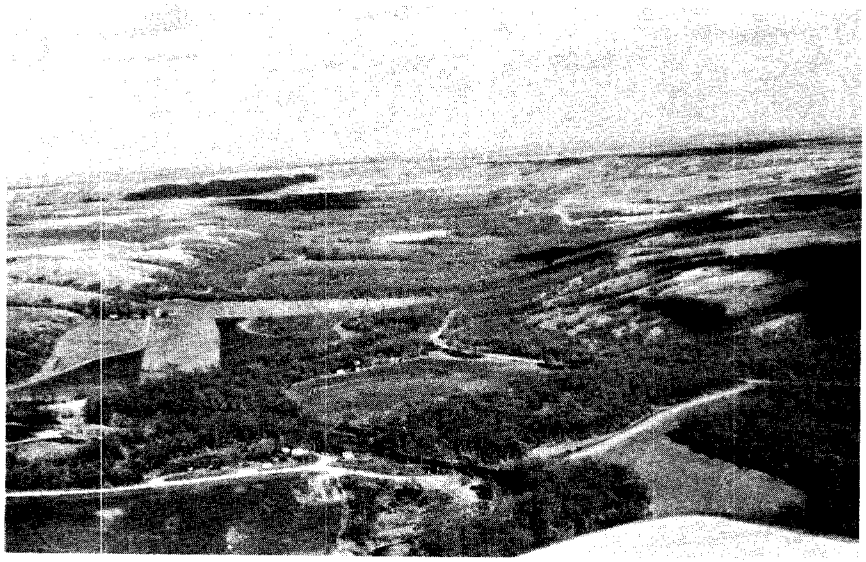

Figure 13. Sheyenne River valley north of the town of Fort Ransom. The meltwater trench in this area is generally about a mile wide from rim to rim and about 200 feet deep.

were deposited largely on stagnant glacial ice. Many small, discontinuous sand ridges occur over the area.

The Prairie Coteau, which covers about two percent of the total area, is located in southeastern Sargent County. It is mainly hilly glacial topography. Most of the landforms on the Prairie Coteau formed due to the collapse of glacial sediment on stagnant glacial ice, which melted between about 9 000 and 12 500 years ago.

The Sheyenne River valley crosses Ransom County and includes about two percent of the two-county area. It is about 200 feet deep near Fort Ransom, and in that area it has steep, bouldery walls cut mainly in till and in the Cretaceous Niobrara and Pierre Formations (fig. 13). The valley is only about 50 feet deep in eastern Ransom County where it is cut into fine sand and silt of the Sheyenne Delta.

Glacial Landforms

Most of the landforms that will be described were formed by the late Wisconsinan glacial ice, especially as it receded from the two-county area. Some topographic features, such as the north-south trending till ridge between Englevale and Elliott, and Whitestone Hill near Gwinner, may date to pre-last glacial time. The configuration of the surface topography is, in most places, unrelated or is related in only a general way, to the topography on the bedrock surface (pl. 2). An exception is the Prairie Coteau, which corresponds to a large preglacial bedrock mesa.

Areas in which the till facies of the Coleharbor Group are exposed are represented by shades of green (pl. 1) and designated by the symbol Qct, with an additional lower-case letter to designate the landform type. These areas are characterized by landforms composed mainly of glacial sediment, materials that were deposited from the last glacial ice.

Collapsed Glacial Topography

At the end of the last glaciation, an irregular thickness of insulating sediment (supraglacial sediment) on top of the stagnating glaciers resulted in irregular glacial decay, rather than an orderly retreat of the ice margin. Broad patches of ice that stagnated and became detached from the main, active glacier persisted for several thousand years. Large-scale glacial stagnation occurred on the Prairie Coteau in southeastern Sargent County (area designated Qcth) resulting in a thick covering of supraglacial material. Stagnation also occurred on a smaller scale over much of central Sargent and Ransom Counties (areas designated Qctu and Qctr) and probably over the eastern parts of the two counties, but subsequent flooding by lakes covered evidence of the stagnation.

The collapsed supraglacial sediment consists mainly of mudflow materials (till) that slid into position as the ice melted (fig. 14). In general, the thickness of the supraglacial sediment, in metres, approximates the maximum slope angles in degrees on the land surface (Clayton and Moran, 1974). Topography on the Prairie Coteau is hilly, and, in most other places in the two counties where collapsed supraglacial sediment is found, it is undulating to rolling.

Hilly surface.--Hilly collapsed glacial topography with high relief is found on the Prairie Coteau in southeastern Sargent County (Qcth on pl. 1). This type of landform is sometimes referred to as "dead-ice moraine" or "hummocky moraine." The hilly collapsed glacial topography in Sargent County has from 50 to 250 feet of local relief. Large kettle holes are common in places. Most of the hilly collapsed moraine slopes northward and deep gullies are carved into the slopes in places.

The landforms in areas of hilly collapsed glacial topography are the result of large-scale glacial stagnation. Most of the landforms were formed when glacial till slid into place as mudflows on the melting stagnant glacier (fig. 14). As the glacier melted, topography on the surface of the ice was continually inverted. When sinkholes in the stagnant glacier finally melted through to the solid ground beneath, circular holes formed in the glacier and the mudflow material flowed down the sides of the holes. In some instances, the mudflow material completely

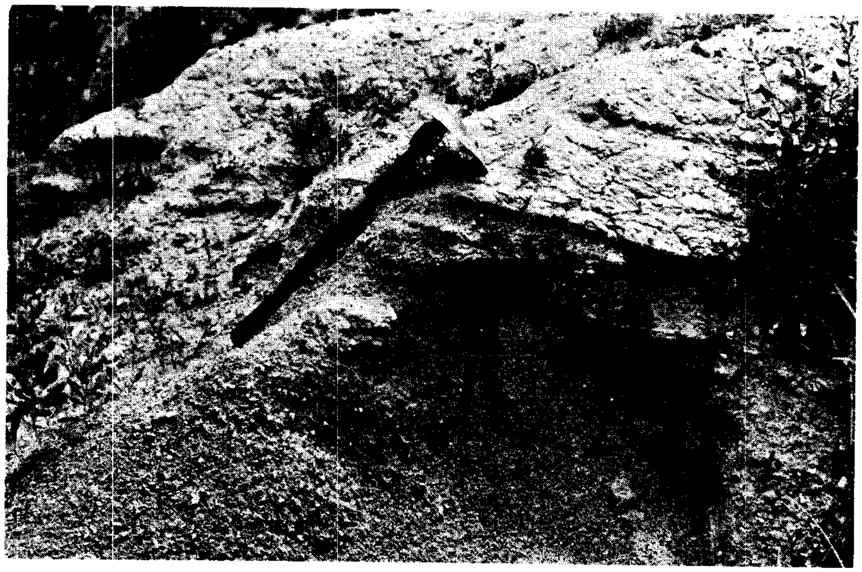

Figure 14. Typical exposure of till overlying gravel along the edge of the Prairie Coteau, southeastern Sargent County. At this location (SW¼ sec 26, T129N, R55W), the till on top has apparently slid northward from higher land to the south, onto gravel that is probably part of a mile-long "kame terrace" type of landform that was deposited by water flowing between the glacier on the lowland and the adjacent Prairie Coteau.

filled the holes, resulting in hills of material occupying the positions of former sinkholes after all the ice had melted. If the amount of mudflow material flowing into a hole was not enough to completely fill it, the material formed doughnut-shaped ridges at the sides of the hole; these ridges are commonly called "circular disintegration ridges" or "doughnuts." If, in the final stages of topographic inversion, thick deposits of material in the bottom of sinkholes caused them to invert into ice-cored cones, the material may have flowed down the sides of the cones, producing, when all of the ice had melted, doughnut-shaped ridges, also called "circular disintegration ridges." Any ridges formed by mudflow material moving down the ice slopes and collecting at their base are called "disintegration ridges." The ridges generally form random patterns and they may be any shape, from circular to straight, depending on the shape of the former ice slope and the fluid content of the sediment as it slid into place.

The maximum hummock diameter in most areas of hilly collapsed glacial sediment is about 650 feet; the diameter of circular disintegration ridges is also about 650 feet (Clayton and Moran, 1974). Differences in the steepness of hillslopes in hilly collapsed topography are mainly the result of differences in the viscosity of the supraglacial sediment. Since the grain size and clay mineralogy of all of the Late Wisconsinan till in Ransom and Sargent Counties was probably essentially similar everywhere, the variable that produced the largest differences in amount of flowage was water content. Water content is related to the rate of ice melting, which, in turn, is dependent mainly on the thickness of the insulating cover of supraglacial sediment. Thicker supraglacial sediment has less water in it, is more viscous, and produces hummocks with steeper sides. Therefore, local relief in hilly collapsed topography is related to the thickness of the supraglacial sediment.

Rolling surface.--Rolling surfaces of collapsed glacial topography are found over about 300 square miles in central Sargent County (Qctr on pl. 1). These surfaces are characterized by numerous ice-disintegration features such as "doughnuts" and short linear disintegration ridges, which are generally not obvious to the ground-based observer, but which can be seen on aerial photographs (fig. 15). Potholes are abundant in many places and the numerous hills and depressions found in the area average about 200 to 400 feet in diameter. Similar areas in other parts of North Dakota have been variously termed "ground moraine" or "low-relief dead-ice moraine." Relief on the rolling surfaces ranges from 5 to 40 feet locally and averages about 15 feet. The land slopes upward to the west at from 5 to 20 feet in a mile. Washboard ridges are found in some areas mapped as rolling surfaces, but the topography in these places tends to be more undulating than rolling.

The rolling surfaces in Sargent County developed when the thickness of the supraglacial sediment was about 20 to 40 feet, thick enough to obliterate most of the ice sinkholes, but not thick enough to produce high-relief hilly collapsed topography like that found on the Prairie Coteau.

Undulating surface.--Undulating surfaces of collapsed glacial topography with low relief are found over broad parts of western Sargent and Ransom Counties (Qctu on pl. 1). Essentially similar areas with comparable relief and topography have been termed "ground moraine" in many previous North Dakota Geological Survey publications. However, ground moraine means a variety of things to different people and may apply to a variety of sediment textures, landform origins, or types of topography.

The collapsed glacial topography with an undulating surface has local relief less than 10 feet in most places, and it slopes generally eastward at about 10 to 20 feet in a mile in most places. In some places in Sargent County, a few washboard ridges and trenches are found that trend mainly northeast-southwest. These are poorly developed, however, and they appear to be relicts of landforms that formed during an ice advance prior to the last one that moved over the area. The

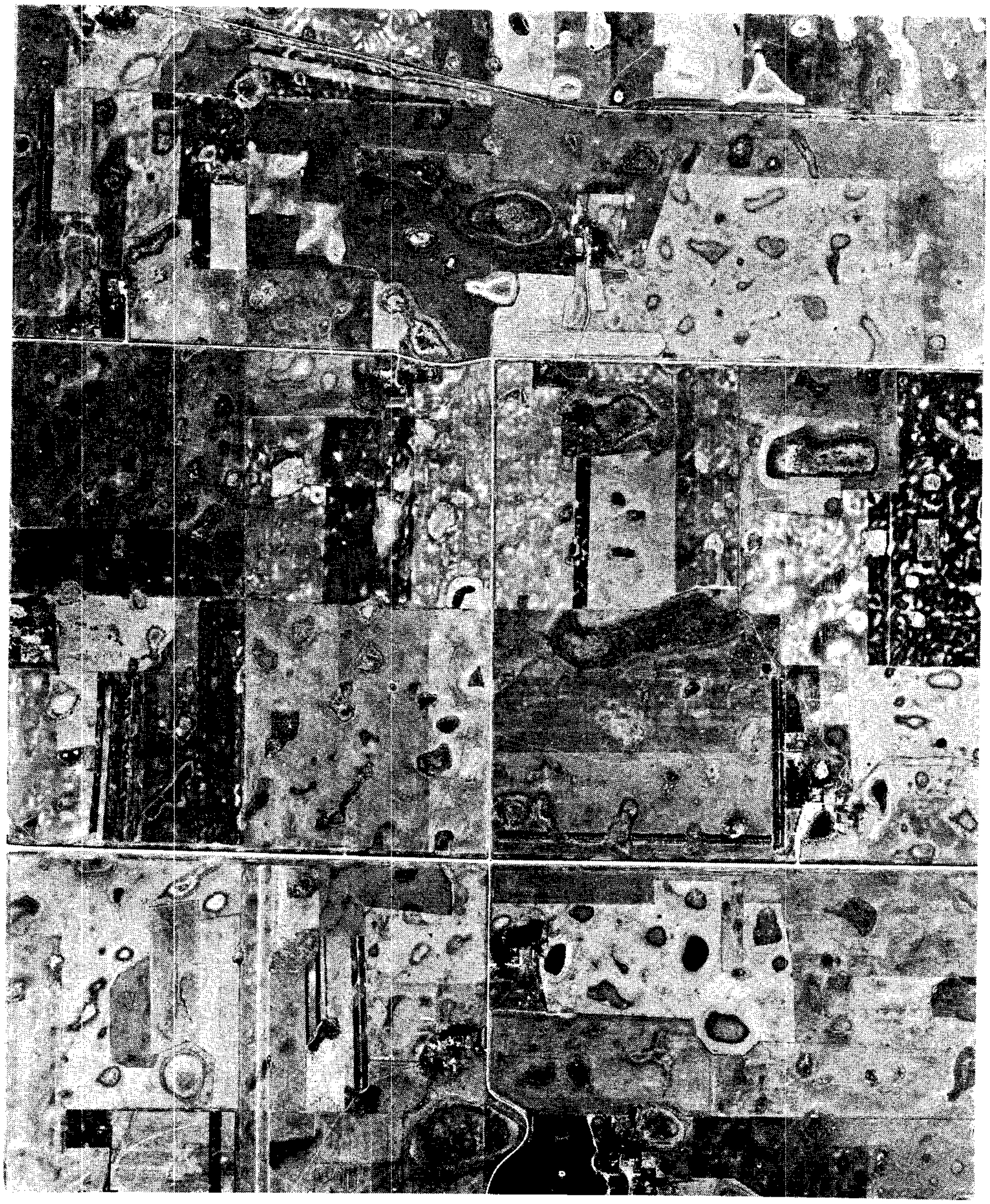

Figure 15. Air photo of typical collapsed glacial topography with a rolling surface. This area includes parts of secs 5, 6, 7, 8, 17, and 18, T130N, R54W, just north of Rutland in Sargent County. Numerous markings typical of areas of glacial stagnation can be identified on the photo. Drainage is not integrated. Local relief is about 20 feet over this area.

ridges and trenches are gently curved, with a radius of curvature of about 6 to 10 miles. Washboard ridges commonly form as the result of greater concentration of glacial sediment along periodically-spaced transverse shear zones near the margin of the glacier. They are oriented with the concave side pointing up-glacier. However, the ice-thrust topography in western Sargent County was apparently deposited mainly by southwest-moving ice, and the transverse lineations in these areas of ice-thrust topography are much better defined than are the washboard ridges and trenches found over areas of undulating collapsed glacial topography.

The total thickness of glacial sediment beneath areas of undulating glacial topography ranges up to about 300 feet. However, the uppermost layer of glacial sediment, the one that forms the surface topography, is generally only about 5 to 10 feet thick. "Pre-last" topographic features that are only veneered with the sediment of the last glacial advance, are found in several places.

Ice-Thrust Materials

Ice-thrusting near the terminus of the active glacier in many parts of North Dakota resulted in compressional folds and thrusts of the subglacial sediment. Vertical displacement was typically tens of feet and the individual folds or thrust masses are commonly about 600 feet across. The folds are commonly overturned. Their axial plane and the thrust faults dip up-glacier at 30° to 60°. The strike is parallel to the ice margin. In map view, the thrust masses are concave up-glacier, commonly with a radius of curvature of about three miles.

The largest known confirmed ice-thrust mass in the two-county area is Standing Rock Hill on the Ransom-Barnes County line (W½ sec 6, T136N, R57W and E¼ sec 1, T136N, R58W). Standing Rock Hill consists of a large "boulder" of Cretaceous Niobrara Formation shale that was transported southwestward from an area now the site of a depression approximately a mile and a half northeast of the hill in Barnes County. The undisturbed contact between the Niobrara and Pierre Formations can be seen exposed in cuts along State Highway 46 where it crosses the Sheyenne River valley about a half mile west of Standing Rock Hill. The elevation of the contact is about 180 feet lower than is the Niobrara Formation shale exposed on Standing Rock Hill indicating that the shale in the hill was lifted by the glacier at least 180 feet from its former position when the thrusting took place.

It has been postulated that ice-thrust masses such as Standing Rock Hill form in the marginal part of a glacier where: (1) the glacier is decelerating, (2) the glacier is frozen to its bed, and (3) there is excess groundwater pressure (Bluemle, 1970; Moran, 1971; Christiansen and Whitaker, 1976).

Deceleration is necessary to cause the compression and the upward shearing of the material. A frozen bed is thought to be necessary to allow the subglacial material to be incorporated into the glacier; the effective base of the glacier, as a flowing mass, is beneath the ice-sediment interface. My own recent observations, however, do not generally confirm this part of the hypothesis; that is, I believe that much ice-thrusting took place in areas where the bed was unfrozen. Excess groundwater pressure reduces the shear strength of the materials beneath the ice, thereby helping the glacier to move the sediment. Ice-thrust sediment blocks in North Dakota and Saskatchewan are most commonly found associated with buried valley-fill deposits, apparently because extremely high excess pore-water pressure can develop in the buried aquifers. Ice-thrust blocks also occur in areas where the glacier advanced against an upland under which the groundwater-flow systems did not allow rapid dissipation of the excess pore-water pressure.

Much of the rugged topography in western Sargent County almost surely resulted from ice thrusting (areas designated Qctt). The thrusting occurred when a glacier readvanced generally westward over an area that had been flooded by the early glacial Lake Dakota. Prior to the readvance, the area consisted of complex topography including offshore and near-shore lake sediment and an extensive area of windblown dunes (discussion on page 46). As the glacier advanced over this topography, intense thrusting was initiated in some places, but in other places the ice flowed smoothly over the existing landforms.

Examples of ice-thrust hills that resulted from the glacial readvance include those associated with Meszaros Slough in T130N, R57W; Dill Slough (fig. 16), Pickell Slough and the hills southwest of Crete in T131N, R58W; and a range of steep hills in T132N, R58W associated with several sloughs, including Bruns Slough and Big Slough. Most of these ice-thrust hills have steep faces along the side that adjoins the accompanying slough; the hill that adjoins Dill Slough rises about 100 feet above the slough floor in a distance of about 0.2 mile. Most of the ice-thrust hills stand about 60 to 80 feet above the adjacent slough.

In contrast to ice-thrust hills in some parts of central North Dakota where the ice-thrust blocks are generally almost the same shape and size as the depressions from which they were excavated, the western Sargent County ice-thrust blocks appear to be more "compressed," that is, the thrust material was piled into a tighter configuration. This may have been due to fluid content of the thrust materials, or it may have to do with the composition and texture of the sediments themselves.

Much of the rugged topography along the Sheyenne River valley between Fort Ransom and the Barnes-Ransom County line

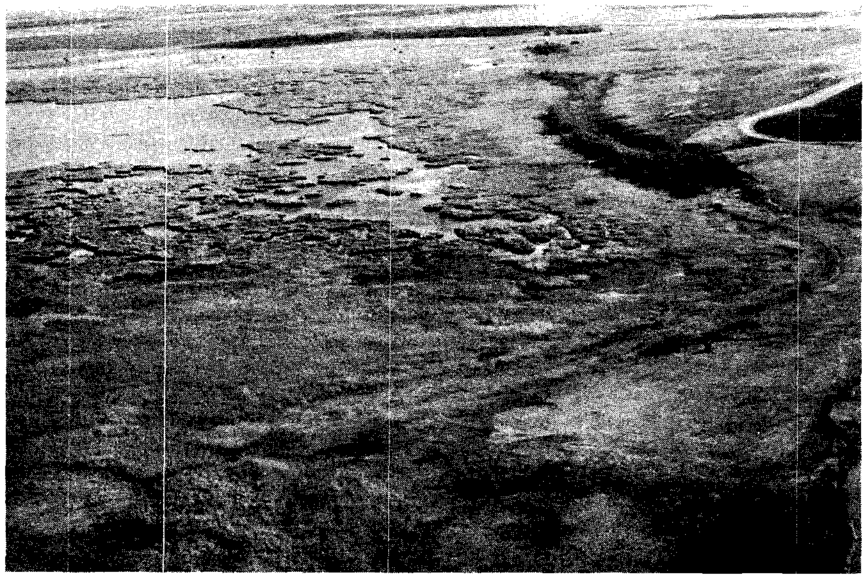

Figure 16. View to the southeast over Dill Slough and associated ice-thrust hill. This view of the heavily vegetated slough shows parts of secs 22, 23, 26, and 27, T131N, R58W. The well-defined escarpment that borders the southwest side (right side of photo) of the slough is about a hundred feet high. The ice-thrust ridge is about a half mile wide and two miles long. The sediments in the ice-thrust hill are greatly compressed and appear to have been "stacked" or "squeezed" by the glacier, indicating that the materials were too fluid to be moved as discrete blocks.

may consist of ice-thrust materials. Bear's Den Hillock just northwest of Fort Ransom may consist of ice-thrust materials, but evidence is scanty in this area; it may also be a buried feature of some other origin. The unusual ridge in sec 31, T136N, R57W and sec 6, T135N, R57W (fig. 17) may be a related ice-thrust feature. Niobrara Formation shale appears to be exposed on top of this ridge at an elevation of about 1 405 feet, probably about 150 feet above the expected bedrock surface in this area.

Steep Eroded Slopes

Steep slopes of till (Qcts on pl. 1) occur along the sides of the Sheyenne River valley through all but the eastern two townships in Ransom County and along some of the larger tributary gullies of the Sheyenne River, such as Timber Creek and Dead Man Creek. They also occur along the Maple River valley near Enderlin and on the face of the Prairie Coteau Escarpment (fig. 18). These slopes consist of deeply-incised topography that was eroded by slopewash and small streams. Drainage is mainly integrated. Relief ranges up to 150 or 200 feet locally along the

Figure 17. Northwest view of probable ice-thrust ridge (sec 31, T136N, R57W). The eastern edge of this ridge, shown here, is bordered by an elongate depression, possibly the source of thrusting. The streamlined configuration of the ridge (pl. 1) suggests that the ridge may represent a slab of Niobrara Formation shale on end (shale is exposed in a roadcut on the crest of the ridge). Two other ice-thrust features are nearby; Bear's Den Hillock is three miles to the west and Standing Rock Hill is five miles to the north.

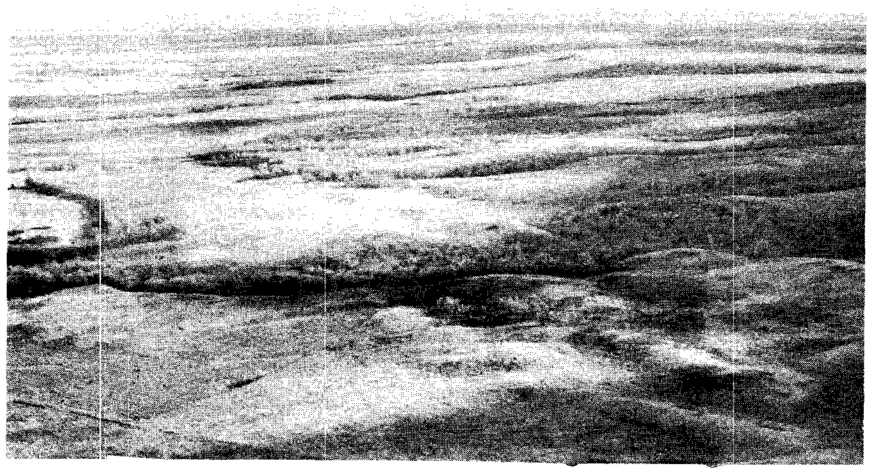

Figure 18. Northern end of the Prairie Coteau escarpment in southeastern Sargent County. The deeply gullied escarpment rises 400 feet in a distance of about three miles in Sargent County. Just south of the state line, in South Dakota, a more abrupt rise of 200 to 300 feet occurs. This view is southward along the east face of the escarpment into South Dakota.

Sheyenne River valley sides near Fort Ransom, about 100 feet on the face of the Prairie Coteau, and 50 feet or less on the Maple River and on the Sheyenne River downstream from Lisbon. In many places, the slopes are partially covered by colluvial debris. Boulders are locally abundant.

Water-Worn Glacial Topography

Several areas of till that have been eroded by either running water or wave action along a lake shore are found in the two counties (Qcte on pl. 1). Such land is mainly flat with local relief generally less than a foot. It commonly has scattered patches of sand and gravel left by the water that washed the surface. In some places large boulders were left behind as a lag when the waves or running water removed the finer materials from the surface.

River-eroded glacial sediment is most common in western Ransom County. It grades in many places into thicker deposits of gravel and sand. Apparently, large amounts of running water flowed over these areas before the Sheyenne River valley was formed. Initially, the water flowed mainly southward past Elliott, probably into glacial Lakes Oakes and Dakota when the glacier still covered land to the east. When the glacier receded, the water flowed eastward along the route that was to become the Sheyenne River valley in the Lisbon area.

Wave-eroded till surfaces are associated with relatively early levels of glacial Lake Agassiz. The most extensive area identified as wave-eroded topography is a two-mile-wide strip that extends northward from Lisbon to the Barnes County line. Wave-eroded topography is also found south of De Lamere in northeastern Sargent County.

Composite Lake-Glacial Landforms

Two broad areas, the first extending from north-central Ransom County southeastward into northern Sargent County and the second in eastern Sargent and southwestern Richland Counties, are mapped as composite lake-glacial landforms (Qcrf and Qcru on pl. 1). They are covered largely by materials interpreted to have been deposited on discontinuous patches of stagnant glacial ice by shore and near-shore lake waters and by streams. The surface that resulted is a complex mosaic of silt-till, flat-bedded and contorted silt beds, and gravel and sand.

To the casual ground-based observer, the overall landscape looks much the same as undulating collapsed glacial topography (Qctu on pl. 1). On aerial photographs, however, many small hills and ridges can be seen. The ridges bear a superficial resemblance to washboard ridges, but nearly all of them are composed of water-laid materials rather than glacial sediment.

Most of the ridges are composed of cross-bedded gravel and sand that was apparently deposited by ice-contact streams flowing over the stagnant ice-covered terrain in a south to southeasterly direction. Some of the ridges may be shoreline deposits.

Many of the innumerable knob-like hills found throughout the area have hillsides composed mainly of till with as much as one to three feet of rhythmically-bedded silt draped over the hilltops; other hilltops consist of till. In many places, bedding in the silt is contorted indicating that it was deposited on top of or in contact with stagnant ice. An example of this is found in the SW¼ sec 13, T136N, R55W where a cut exposes rhythmically-bedded silt on a hilltop. "Chunks" of silt with contorted bedding occur in close association with till in many places.

In secs 3, 4, 9, 19, 15, and 16, T133N, R55W, elevations on a flat plain, a water-washed surface (Qcte), range between 1 185 and 1 190 feet. Elevations on the adjacent rolling land, onto which the water had to flow from the washed surface, is between 1 140 and 1 170 feet. For this reason, it seems probable that the adjacent surface (secs 14, 15, 22, 23, T133N, R55W) must have been covered by 15 to 50 feet of stagnant ice. Most of the lake sediment-draped hills throughout the area of composite lake-glacial landforms are also in this height range so it is likely that about 15 to 50 feet of stagnant ice must have covered much of the area when it was flooded.

Even though the occurrence of extensive discontinuous ponding on the stagnant ice is a possibility and would have resulted in a mosaic of textural types similar to that observed, it is likely that a larger lake flooded the area at some time prior to the formation of glacial Lake Agassiz at the Herman level (Bluemle, 1974). A wave-eroded zone (Qcte) extends northward from Lisbon to the Barnes County line. Several associated north-trending beach ridges are located just east of the east-facing scarp that forms the western border of the wave-washed zone. Wave action along this shoreline must have rapidly removed any stagnant ice, forming the scarp and the associated beach.

Buried Features

In some places, the most recent, uppermost layer of glacial sediment is only a veneer (1 to 3 feet thick) that is draped over and only slightly modifies the pre-existing topography. In other places, the layer is somewhat thicker, perhaps several tens of feet thick, but still the underlying topography remains the major landform. In such areas, the overall relief is mainly that of the pre-existing topography. In some places, chains of potholes mark the routes of valleys that are otherwise buried beneath one or more layers of till.

In Ransom and Sargent Counties, several areas of older topography thinly mantled with till (Qctd on pl. 1) can be identified. They include such prominent features as the Whitestone Hills and the Lake Oakes Hills as well as certain smaller hills and ridges.

A range of hills in Ransom County extending from about sec 16, T136N, R58W, southeastward past Englevale to about sec 9, T133N, R57W, stands as much as 50 to 75 feet above the surrounding plain. The area has numerous sloughs and it is somewhat more bouldery than the till surface typical over much of the area. Although its origin is unclear, it appears to have characteristics of some sort of buried feature and it has been designated as such on the geologic map (Qctd on pl. 1).

Colton, Lemke, and Lindvall (1963) showed the range of hills as a continuation of an ice-marginal position which they did not name. Kelly and Block (1967, p. 35) named it the Luverne End Moraine. It is now apparent, however, that the feature does not mark a significant ice-marginal position in Ransom County. Camara (1977) showed that the uppermost till unit on the ridge, his unit D, extends over the ridge from the east and westward into the subsurface in LaMoure County. The ridge is therefore the surface expression of a topographic feature that was formed prior to the last glacial advance over the area. A series of test holes drilled just west of Elliott, one east of the ridge and two on the ridge show that the bedrock elevations beneath the ridge and just east of it are considerably greater than is the bedrock elevation east of the ridge.

A test hole at Elliott about a mile east of the ridge (NW¼ NW¼ sec 23, T134N, R57W) penetrated 218 feet of glacial sediment on top of Niobrara Formation shale at 1 102 feet. A test hole on top of the ridge (SE¼SW¼ sec 16, T134N, R57W) penetrated 318 feet of glacial sediment and hit shale at 1 190 feet. The third test hole, drilled on the western edge of the ridge (NW¼NE¼ sec 20, T134N, R57W) penetrated 196 feet of glacial sediment and hit shale at 1 159 feet.

Higher bedrock elevations continue westward from the ridge indicating that the ridge is not simply a surface expression of bedrock topography. The ridge may be an accumulation of ice-thrust materials that were subsequently buried beneath later layers of glacial till.

Whitestone Hills

The Whitestone Hills, located about four miles north of Gwinner, stand about 175 feet above the surrounding undulating collapsed glacial sediment surface. They have relatively steep eastern and northern faces, rising about 100 feet in less than a mile. Southern and western faces are more gentle. On aerial photographs, the Whitestone Hills appear to have an overall northeast-southwest linearity, with northwestward concavity suggesting deposition from the northwest. However, this linearity is obscured by an apparently later layer of glacial sediment and it is not known how the feature originated. Nielsen (1973) suggests that the hills may be an area of overridden ice-thrust topography and this is a possibility.

A test hole drilled in the NW¼NW¼SW¼ sec 10, T132N, R56W as part of a sanitary landfill study, bottomed in wet sand at a depth of 82 feet (Kehew, personal communication, June 19, 1978). The stratigraphy penetrated by the auger hole is complex, with at least four distinct till units and possibly a fifth till unit. From the surface downward, the test hole penetrated 4 feet of clay (lake sediment); 6 feet of oxidized, pebbly, sandy till; 12 feet of partly oxidized, sandy till; 19 feet of unoxidized silty, pebbly till; 36 feet of unoxidized, very sandy, lignitic till; and 5 feet of gray sand.

Two test holes drilled in the Whitestone Hills to depths of 59 and 54 feet (SE¼SE¼SE¼ sec 3, T132N, R56W; NE¼NE¼NW¼ sec 10, T132N, R56W) penetrated oxidized shale-rich till overlying unoxidized shale-rich till (Nielsen, 1973). Near the bottoms of each hole, up to 5 feet of fluvial sediments were found overlying oxidized till. Preglacial bedrock was not penetrated in either hole. The oxidized till at the bottom of each hole is likely from an earlier glacial advance.

Lake Oakes Hills

The Lake Oakes Hills extend from near Fort Ransom, southeastward past Oakes into Sargent County and then, as discontinuous patches of hilly topography, into Marshall County, South Dakota. They loop northward near Britton, South Dakota and back into Sargent County where they merge with the Prairie Coteau. The hills were considered to be an end moraine and they were named the "Oakes Moraine," by Hard (1929), who considered them to be a recessional feature formed at the glacier margin as a lobe of the glacier receded northward west of the Prairie Coteau. Nielsen (1973) named the hills the Lake Oakes Hills and his terminology will be used here.

The Lake Oakes Hills have a surface area of about 60 square miles. They are as much as 200 feet high and well drained in some places, but some closed depressions are present.

Nielsen (1973) considered most of the sediment in the Lake Oakes Hills to be turbidity-current sediment that was deposited in a proglacial lake, which he called glacial Lake Oakes. Nielsen argued that the interbedded, laminated sandy silt, sand, and silt is turbidity-current sediment because the sand indicates that a current was necessary for transport, while the presence of interbedded clay indicates slow settling of grains in water. The Lake Oakes Hills sediment has a thin covering of till in many places. The till includes many blocks of contorted sand and silt that were probably eroded by the overriding ice.

The Lake Oakes Hills are obviously an overridden feature. When the glacier overrode the area, repeated ice-thrusting also occurred. It is probable that the glacier overrode the materials deposited during an early stage of glacial Lake Dakota, which flooded a several-township portion of western Sargent County. Elevations on the flatter areas of the till-mantled lake plain in western Sargent County are nearly identical to (less than 10 feet difference) elevations on parts of the lake plain farther west in Dickey County, which were not overridden. The early western Sargent County glacial Lake Dakota plain, prior to the time it was overridden by the glacier, consisted of complex topography that included offshore lake silt beds; shore features, perhaps including beaches; and broad areas of windblown sand dunes.

When the glacier readvanced over this area from the east and northeast, it overrode this suite of landforms. Overriding resulted in much thrusting of the overridden materials; it resulted in a layer of silty or sandy till over the flat-lying underlying silt or sand in some places; and it resulted in spectacular hill-depression ice-thrust features in other places.

The till mantle over the area appears to reach a maximum of about 15 feet, but it generally has a gradational lower contact with the underlying silt or sand. The till mantle is not present everywhere, but a few scattered boulders are present over the entire area.

It seems likely that the glacier flowed over many flat areas of the early glacial Lake Dakota plain without disturbing it much at all, while depositing only a few feet of silty till on the surface. These areas are still flat and look the same as undisturbed lake plain. In other areas that once were flat lake plain, thrusting destroyed the flat lake plain and piled up hill-depression combinations such as Dill Slough and the adjacent hill, which is composed almost entirely of silt. The boundaries between ice-dug depressions and adjacent flatlands are so sharp it is unlikely that glacial Lake Dakota ever flooded the area again and the present flatness of the area is not an original lake plain, but rather a till-veneered lake plain, at least in the area east of the Lake Oakes Hills.

An excellent example of an area of glacially overridden windblown sand dunes occurs in sections 2, 3, 4, 5, 8, 9, 10, 11, 14, 15, 16, 21, 22, and 23 of T130N, R58W (fig. 19). It is much of this overridden, windblown sand that Nielsen (1973) considered to be turbidity-current sediment. Fine-grained, silty, cross-bedded sand with frosted grains, typical of those found in windblown sand deposits, is common in exposures. Nothing at all was found that could be identified as turbidity-

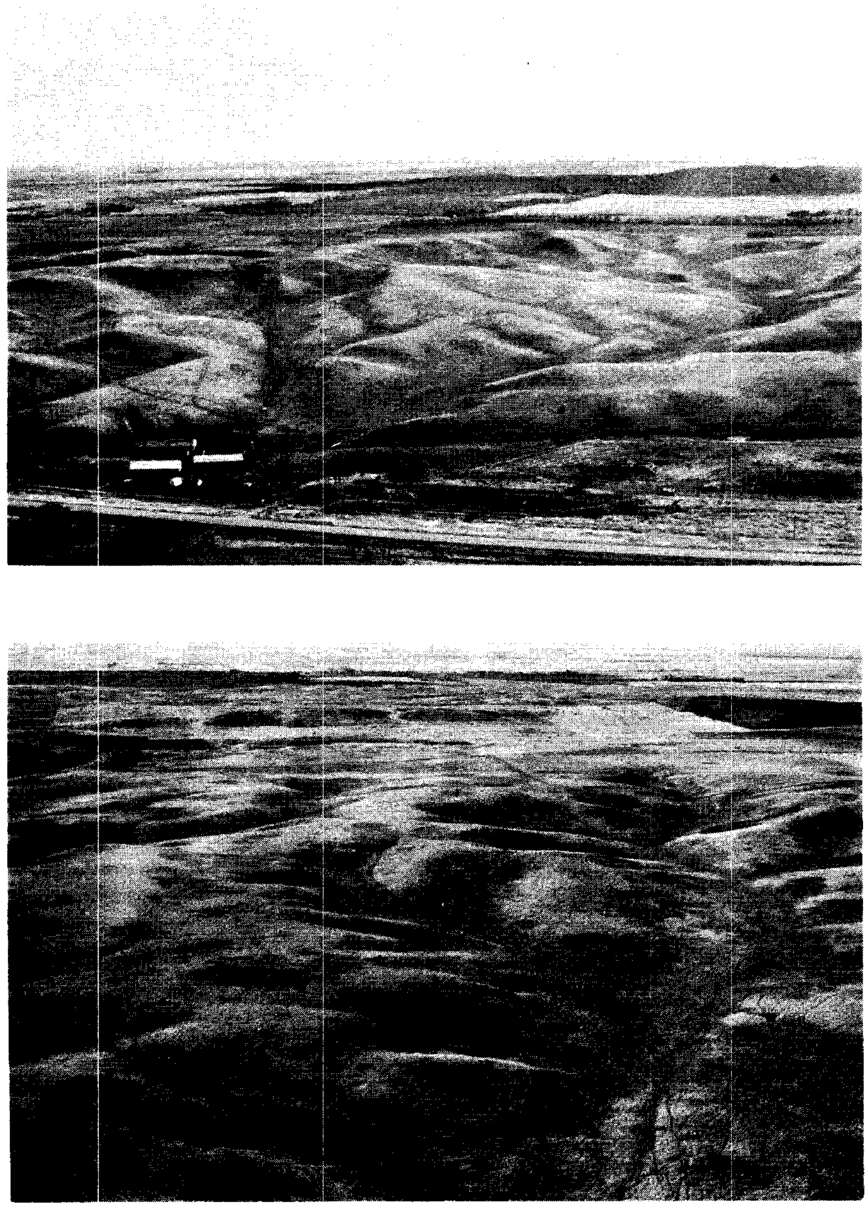

Figure 19. Two views of the Lake Oakes Hills in western Sargent County. Glacial ice overrode an area of windblown sand dunes here, depositing a veneer of sandy till on the surface and partially obscuring the characteristic dune configuration (see figs. 26 and 27 for typical dunes on the Sheyenne Delta). The upper picture is a view of an area in sec 21, T130N, R58W. The lower picture is of sec 15, T130N, R58W.

current sediment in any of the exposures that were examined or in any of the auger holes that were drilled.

Buried sand dunes are not often reported in the literature, but such features do occur in Portage County, Ohio (Winslow and White, 1966). There, an irregular sheet of fluvial sand, the uppermost part of which was reworked by wind, is overlain by a clay-rich till. The situation differs from that in the Lake Oakes Hills in several important ways, however. The overridden Ohio sediment is a relatively thin, discontinuous sheet, generally less than 10 feet thick, and much of that thickness consists of fluvial, not eolian material. A few low dunes were recognized though. Further, the clay-rich till that overlies the windblown sand indicates that the ice that moved over the sand left it almost entirely undisturbed. The till veneer that covers the windblown sand of the Lake Oakes Hills consists almost entirely of sand that was derived from the underlying sediment as the ice moved over it. Finally, the overridden dunes of the Lake Oakes Hills were large and had local relief of at least 130 feet in places. The relief may have been even greater before the glacier advanced over the dunes, smoothing the topography somewhat.

Buried Valleys

Several "kettle chains," rows of potholes situated in poorly defined discontinuous valleys, are found in association with the area of composite lake-glacial landforms in northern Ransom County. The most prominent of these are in the area between Enderlin and Lisbon; one of the buried valleys extends for six miles, from sec 10, T135N, R55W to sec 4, T134N, R55W. The valleys containing the potholes are generally about 10 to 30 feet below the surrounding plain and not at all obvious on the ground. Apparently, the buried valleys may represent early routes of the Maple River or other southerly drainage at a time when glacial ice still covered the area to the east.

Lacustrine Landforms

Landforms resulting from flooding by lakes that formed as the late Wisconsinan glacier was melting from the area as well as lakes and sloughs found today in depressions that resulted from prairie potholes are found in many places in the two-county area. Those landforms are considered to be primarily of lacustrine origin, that is, formed by offshore and shoreline processes. They are identified in shades of blue and gray on plate 1 (Qcsv, Qcss, Qcsc, and Qoc). The late Wisconsinan lakes are generally shown in blue shades on plate 1, whereas Holocene sloughs are shown in gray. Modern lakes are depicted as uncolored areas. Areas of deeply-incised and eroded lake deposits (Qcsi), found in places along the valley walls of the Sheyenne and Wild Rice Rivers are, perhaps, more erosional than lacustrine landforms, but they will be discussed in this section too. The Sheyenne Delta, which includes the eastern third of Ransom County as well as the northeastern corner of Sargent County, is considered to be primarily a fluvial landform and will be discussed in the portion of the report dealing with fluvial landforms.

Flat-Bedded Sediments

Several areas of lake deposits associated with glacial Lake Dakota are located in western Sargent County (Qcss on pl. 1). Over 400 holes ranging up to 60 feet deep were augered into the glacial Lake Dakota sediment by the U.S. Bureau of Reclamation. They revealed a sequence of laminated sandy to clayey silt at least 75 feet thick near the South Dakota border, grading northward and upward into coarser textures. In places, windblown sandy silt covers the lake deposits, and dunes are present in some areas. The lake silt deposits occur below the 1 310-foot strandline of glacial Lake Dakota.

The lack of an appreciable clay fraction in the lake deposits is probably due to the steady movement of water through the lake basin. The upper stratigraphic sequence of lake deposits, the only sediments exposed, was laid down when the water was comparatively shallow and current velocities were relatively great. Under such conditions, most of the clay-sized particles would remain in suspension and be transported out of the lake basin.

Although the exact depth of the lake at any time is unknown, the overall relief, the few recognizable shore features, and the maximum sediment thickness suggest that the total depth of the lake in North Dakota was never more than about 100 feet and the lake was not that deep most of the time. Probably a considerable current flowed through the lake most of the time it existed. This current, coupled with wave action in the relatively shallow lake, acted to keep the bottom deposits stirred up. It seems likely that conditions quiet enough to permit the settling of clay particles may have existed only locally and temporarily on the lake floor (Flint, 1955).

The modern surface on the Sargent County portion of the glacial Lake Dakota plain is a flat plain that ranges from about 1 290 feet to 1 315 feet above sea level. Some low-relief beach ridges occur at 1 310-1 315 feet in the Straubville area. Except where they have been reworked by the wind, the surface is exceptionally flat with less than two feet of relief in most places. Some large sloughs, apparently ice-dug depressions associated with thrusting that formed the Lake Oakes Hills, mar the otherwise exceptionally flat lake plain. These depressions must have been filled with blocks of stagnant ice when the Lake Dakota sediments were deposited.

Contorted Sediments

Scattered lake silt deposits are found in many places in the area of composite lake-glacial landforms (Qcvf on pl. 1). Most of these lake deposits were too small to map separately and they are simply included in the composite landform unit. A 1/3-square-mile area of lake silt is mapped in secs 16 and 17, T135N, R56W, and other smaller areas of similar lake sediments are found nearby (Qcsc on pl. 1). All of these sediments were deposited in close association with stagnant glacial ice and the bedding is commonly disturbed due to collapse in places.

Other deposits of lake sediment that have collapsed bedding are found near De Lamere in northeastern Sargent County in association with deposits of lake shore sediment. These areas are all too small to show on plate 1. Numerous road cuts in the area (T132N, R53W) expose contorted, laminated silt. Thickness of the lake sediment is generally less than 40 feet.

Veneer of Lake Sediment on an Older Surface

Thin, discontinuous layers of lake silt occur in several places, mainly in southeastern Sargent County (Qcsv on pl. 1). These deposits are located adjacent to the Prairie Coteau upland and they may represent, in part at least, short-lived damming of drainage off the uplands by glacial ice in the area to the north. Bedding in the lake deposits is commonly indistinct and sorting is poor. The sediments generally overlie till. The silt beds are interbedded in places with fine sand layers that may be slopewash sediments that were derived from the nearby uplands. The black color of much of the sediment indicates that it was washed onto the area at a time when prairie soils were already predominant.

Incised Lake Sediments

The Sheyenne River valley walls consist of steep slopes eroded into lake and fluvial sediments east of sec 9, T135N, R54W (Qcsi on pl. 1). Similar slopes occur along the Wild Rice River in sections 25 and 26, T132N, R53W in Sargent County. These slopes are deeply-incised by small gullies eroded back from the main rivers. Drainage is mainly integrated. Relief ranges up to 75 feet along the Sheyenne River, 25 feet along the Wild Rice River. In a 50-foot-thick river cut (sec 18, T135N, R63W), alternating layers of silt and clay, deposited in glacial Lake Agassiz, overlain by sand, deposited in the Sheyenne Delta can be seen (see discussion of stratigraphy on page 47).

Modern Lakes and Sloughs

Modern sloughs in the two counties (Qocp on pl. 1) are most abundant in areas of collapsed moraine and composite lake-glacial landforms. Many of them are too small to show on

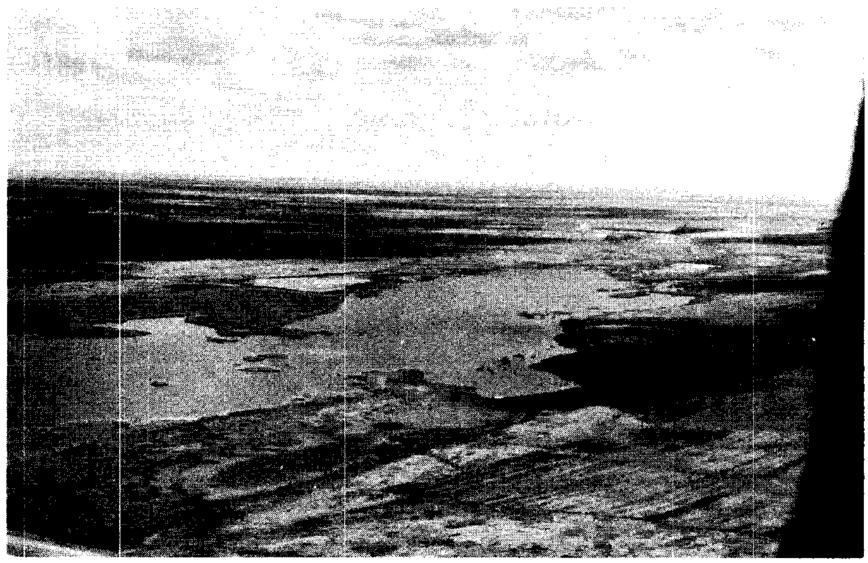

Figure 20. Southeasterly view over Lone Tree Lake in western Ransom County. Lone Tree Lake, located in secs 10, 15, 22, and 23, T134N, R58W, is one of the largest perennial lakes in the two-county area.

plate 1. The sloughs are flat areas covered by lake sediment and by water during wet periods. The Bureau of Reclamation has drilled holes through the ice on many standing water bodies during winter months and found that the bottom sediments are generally at least 10 feet thick. Drill-hole logs indicate that the sediment is mainly laminated, silty clay. The slough sediment contains disseminated organic matter that was probably derived from adjacent hillslopes. In some areas, the slough sediments are not distinctly bedded because burrowing organisms have destroyed the original bedding (Neilsen, 1973).

Three types of standing water bodies are common in Ransom and Sargent Counties: perennial, intermittent, and temporary. Perennial lakes and ponds always contain standing water. They occur in local groundwater discharge areas and receive water from both slope runoff and groundwater seepage. Lone Tree Lake in Ransom County (fig. 20) and Storm Lake, White Lake, Lake Tewaukon, Clouds Lake, and Silver Lake in Sargent County are all typical perennial lakes.

Intermittent ponds and lakes commonly contain standing water, but they are usually dry during periods of low precipitation. Variations in the height of the water table determine whether the intermittent lakes and ponds are dry or wet. Intermittent lake and pond sediment is similar to perennial lake sediment, but somewhat more oxidized due to periods of drying.

Kandiotta Lake in Sargent County is a good example of an intermittent lake. In dry years, the Kandiotta Lake bed is tilled, whereas in wet years it is flooded by several feet of water.

The thousands of temporary ponds in the two counties contain water only after rains and after the annual spring thaw. They are located in groundwater recharge areas and generally have thinner, more highly oxidized sediment than do the intermittent and perennial lakes.

Shoreline Features

Lake sediments associated with shoreline processes tend to be sandy and gravelly. In the two-county area, the most prominent shoreline features are found along the former shorelines of glacial Lake Agassiz; few shoreline landforms can be identified along the former shoreline of glacial Lake Dakota. Most of the features that involve shoreline sediment deposition were built in areas that consist mainly of fluvial sediment, that is, sediment deposited by the Sheyenne River on its delta in glacial Lake Agassiz. In these areas, shoreline features consist mainly of only slightly reworked fluvial deposits.

Shore scarps and associated beach ridges.--Several east-facing scarps that were interpreted as having developed as the result of wave-erosion along former lake shorelines, occur in the two counties. In northern Ransom County, a scarp extends northward from sec 32, T136N, R57W to sec 2 of the same township and on into Barnes County. This scarp is poorly defined in many places, averaging about 40 feet high (higher elevations on the west side of the scarp) at the 1 330- to 1 370-foot level. It apparently developed along an early shoreline of glacial Lake Agassiz (Bluemle, 1974). Virtually no sand is associated with the scarp, which is cut into till.

A second, lower east-facing scarp occurs for 2 to 3 miles east of the one just described. This scarp extends from sec 3, T135N, R57W to sec 1, T136N, R57W and on into Barnes County. It is about 50 feet high and much better defined than the first scarp. It occurs at an elevation of about 1 290 to 1 340 feet and is easily observed in the field, on air photos, and on topographic sheets. Like the first scarp, this one is cut mainly in till, but beach ridges occur just east of the scarp in several places (secs 13, 24, 25, T136N, R57W). A discontinuous sheet of shore sand and gravel occurs in secs 26 and 35, T136N, R57W and in secs 2 and 3, T135N, R57W.

A third east-facing scarp extends from near Lisbon northward to the Barnes-Cass County line (from sec 35, T135N, R56W to sec 1 and 2, T136N, R56W). This scarp is poorly defined in some places, and it is generally less than 20 feet high at an elevation of about 1 200 feet. However, a two-mile-wide area adjoining the scarp on the east is highly wave-washed and bouldery. A series of small beach ridges occur on this wave-washed area, paralleling the scarp along its eastern side. Individual beach ridges are as much as a mile long, all at an elevation between 1 200 and 1 210 feet.

All of the above-mentioned scarps occur at elevations above the highest Herman level of glacial Lake Agassiz and represent an early phase of the lake (Bluemle, 1974). A scarp, apparently cut while Lake Agassiz was at the Herman level, can be traced from sec 32, T134N, R54W where it ends at the Sheyenne River, southeastward into Sargent County to sec 13, T134N, R53W and on into Richland County. This scarp is about 15 to 20 feet high at 1 075 to 1 090 feet. In the northern half of T133N, R54W in Ransom County, till occurs west of the scarp and a nearly level to undulating sand plain occurs east of the scarp. In the southern half of this township and in Sargent County, the sand plain occurs on both sides of the scarp. Beach ridges are not closely associated with the scarp. However, beach ridges do occur at the 1 070- to 1 075-foot level in Tps134 and 135N, R54W and in T136N, R53W in Ransom County. These low beach ridges of gravel and sand probably formed at about the same time as did the scarp.

Undulating sand plain.--A nearly level to undulating plain of sand that was deposited along the shore of glacial Lake Agassiz occurs in southeastern Ransom and northeastern Sargent Counties (Qcgx on pl. 1). Relief on this sand plain is generally less than 5 feet except on beach ridges where it is greater. The material is interpreted as fluvial sediment that was reworked by wave action. In many places in the area, bedded lake silt is also exposed.

Hilly sand plain.--In the Sheldon area of Ransom County (T135 to 136N, R54W) an otherwise flat plain of sand is pitted by large numbers of potholes that result in about 30 feet of local relief (fig. 21). At the edges of some of the potholes, the sand is slumped over lake silt deposits. It must have been deposited on the silt beds before the blocks of stagnant glacial ice melted.

It is sometimes difficult to differentiate the sheets of shoreline sand from fluvial deposits. Both types of sediment are closely associated in many places. In the westernmost portions of the Sheyenne Delta, interbedded lake and stream sediments are commonly seen in close association; farther east in Ransom County most of the surface cuts expose stream sediment and the interbedded lake and stream sediment occurs at slightly greater depths.

Fluvial Landforms

Landforms deposited and eroded by running water and consisting of stream sediment are found in all parts of the two-county area. They include meltwater trenches, modern river

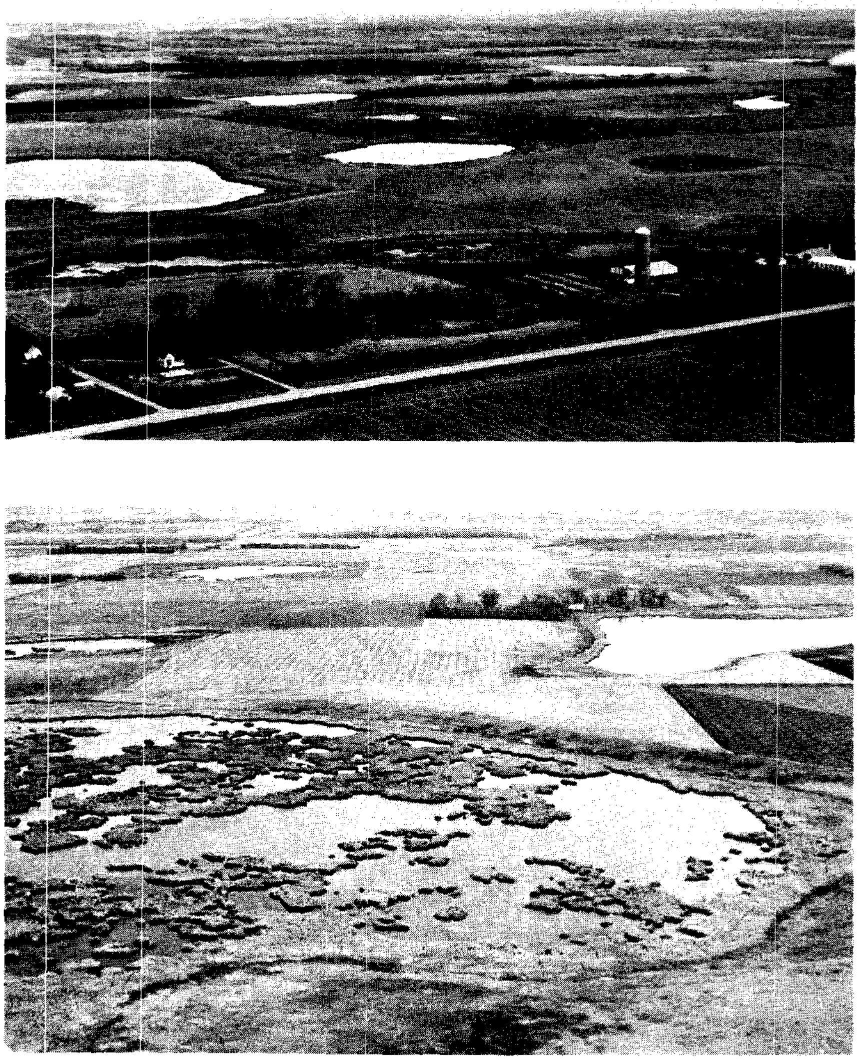

Figure 21. Two views of potholes in the sand plain near Sheldon. The initial Sheyenne Delta deposition occurred in this area while it was still covered by discontinuous patches of stagnant glacial ice. The otherwise flat, fluvial sand of the delta is pitted by numerous potholes left when blocks of stagnant ice melted. The upper photo is a view to the east over sec 28, T136N, R54W. The lower photo is of a larger (half-mile across) slough in sec 4, T135N, R54W.

flood plain deposits (Qosr on pl. 1) river terrace deposits along the Sheyenne and Maple Rivers (Qcgt), ice-contact sand and gravel deposits such as eskers (Qcgc), level and rolling gravel plains that were deposited in large part by streams flowing from melting glacial ice (Qcgu and Qcgp), and a broad sand plain, the Sheyenne Delta, that was deposited at the mouth of the Sheyenne River where it flowed into glacial Lake Agassiz (Qcgs). The Sheyenne Delta deposits consist of interbedded lake sediments and river sediments in places and they are covered by a sheet of windblown sand and dunes in places, but river sediment constitutes the largest proportion of the surface materials on the delta. Most of the stream sediment in the two counties was deposited during deglaciation. Except for the Sheyenne and Wild Rice Rivers, modern streams are intermittent and have not deposited large amounts of sediment.

Meltwater Trenches

The largest and most important meltwater trench in the two-county area is the valley of the Sheyenne River (fig. 13). It is about 200 feet deep, and 0.5 to 0.8 miles across from rim to rim near Fort Ransom where it has steep, bouldery walls cut mainly in till and in the Cretaceous Niobrara and Pierre Formations. The trench is only about 50 feet deep in eastern Ransom County, but over a mile wide in places. Here it is carved into the fine sand and silt of the Sheyenne Delta. The meltwater trench was carved mainly by water draining from glacial Lake Souris in north-central North Dakota into glacial Lake Agassiz. At the point where this large river of meltwater flowed into Lake Agassiz, it built a delta.

Considerable meltwater flowed over the surface of the ground along many portions of the route of the Sheyenne meltwater trench prior to the time the trench was initiated. This water deposited broad plains of outwash gravel and sand. Such an area of glacial outwash is found in western Ransom and Sargent Counties. It was deposited by meltwater flowing southward, perhaps at a time when glacial ice still covered much of the eastern part of the area. When the ice melted, allowing the meltwater to flow in a more easterly direction, the Sheyenne meltwater trench was formed. Gravel terraces occur within the Sheyenne meltwater trench in several places along its route (fig. 22). In Ransom County, the most extensive of these are covered by important commercial gravel resources (Qcgt on pl. 1).

Other meltwater trenches in the two counties include the valley of the Wild Rice River in eastern Sargent County and the valleys of Bear Creek and the Maple River in Ransom County. Bear Creek meltwater trench was carved by a stream that flowed into glacial Lake Dakota. A four-mile portion of the Maple River meltwater trench crosses extreme northern Ransom

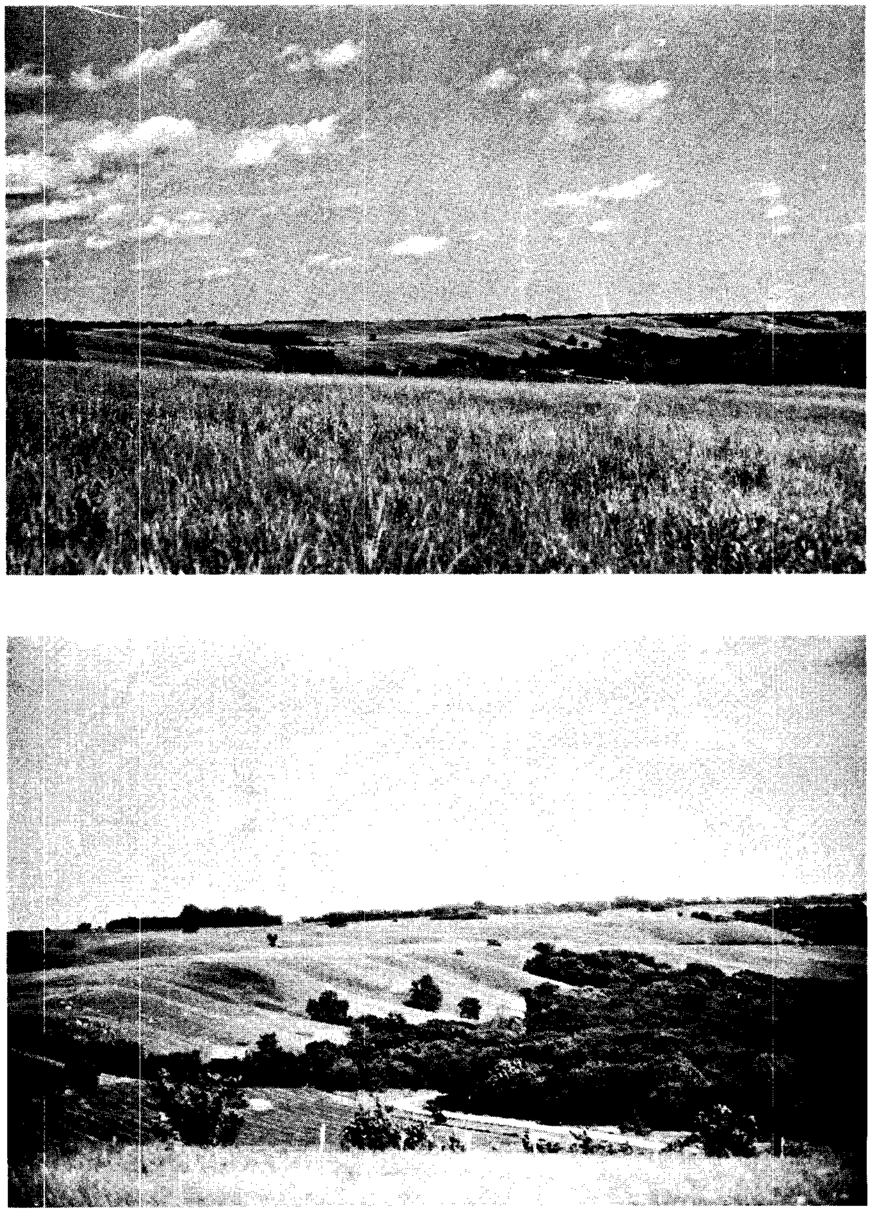

Figure 22. Two views of gravel terrace along the Sheyenne River meltwater trench (lower photo is a telephoto shot). Located in secs 12 and 13, T135N, R57W, the trench at this point is about 160 feet deep and the terrace surface is about 130 feet above the valley floor.

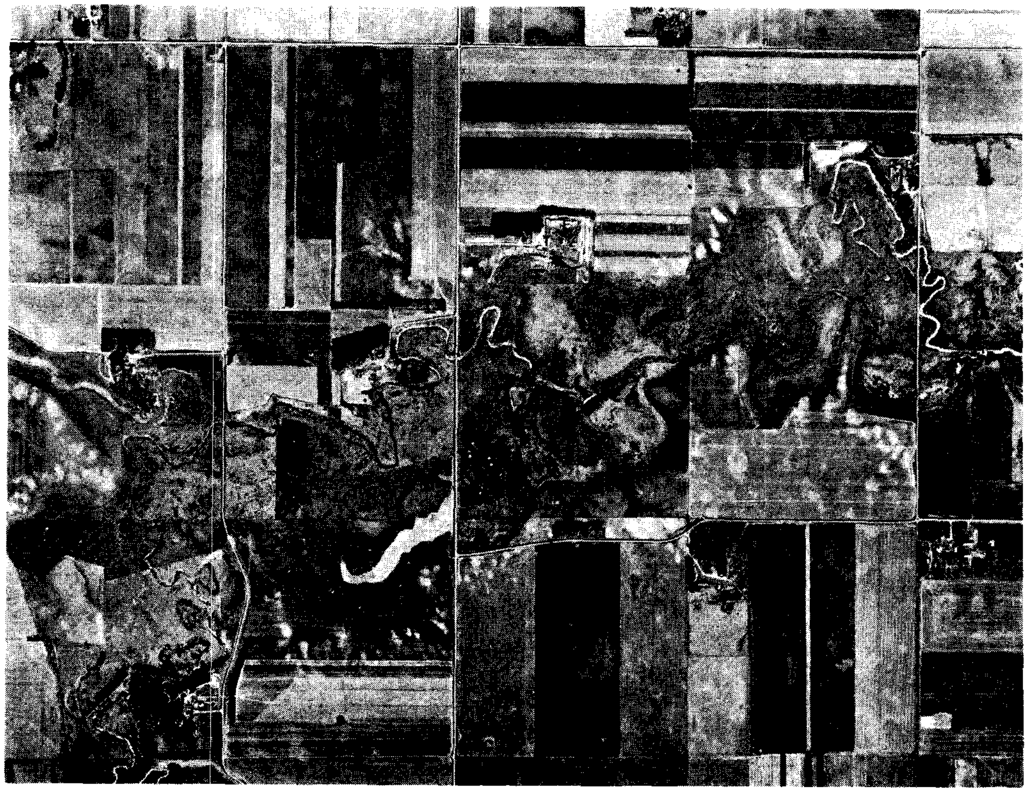

Figure 23. Air photo of the Wild Rice River valley at the point where it leaves Sargent County and enters Richland County (parts of secs 25, 26, 35, and 36, T132N, R53W are shown). Notice the tortuous route of the river and the irregular meander pattern. The slopes of the valley here are cut in till. The upland is mainly thin fluvial sediment lying on till; the surface has been modified by both wave action during an early stage of glacial Lake Agassiz and by later eolian activity. The valley at this point is about 30 feet deep.

County in the Enderlin area. It is about 50 feet deep and a half mile wide. The Maple River meltwater trench formed along the western edge of the ice margin, water flowing southward through western Cass and into eastern Ransom County. When the ice melted, the water was able to flow eastward and the east-trending portion of the meltwater trench formed.

The Wild Rice River meltwater trench is diffuse and generally less than 20 feet deep (fig. 23). It apparently formed from meltwater flowing northward off the northern part of the Prairie Coteau and was never an important feature in Sargent County.

Another meltwater trench that was apparently an important route for a time is the Milnor Channel, which extends southeastward through northeastern Sargent County (Baker, 1966)

Figure 24. View to the southeast from near the northwesternmost end of the Milnor Channel. Water from the early Sheyenne River flowed southeastward through this shallow valley, which may have been ice marginal on its southeast (left, on this photo) side. Large amounts of shaly gravel occur in this area in association with the Milnor Channel.

(fig. 24). Ridges of ice-contact gravel are found near Milnor in association with the channel. It seems likely that water from the early Sheyenne River meltwater trench may have flowed southeastward through the Milnor Channel from a point about six miles southeast of Lisbon at a time when glacial ice in the Red River Valley still blocked what was to become the route of the Sheyenne River meltwater trench downstream from that point.

River Flood Plains and Terraces

Broad plains of gravel and sand are found in northwestern Ransom County and in parts of western Sargent County (Qcgu and Qcgp on pl. 1). Most of this material is glacial outwash that consists of lower-flow-regime fluvial sediment deposited in river channels on solid ground (Qcgu) and in some places in contact with stagnant glacial ice which later melted, resulting in collapse of the sediment and the formation of potholes (fluvial sediment deposited in contact with stagnant ice is designated Qcgp on pl. 1). Gravel pit exposures, roadcuts, drill-hole logs (Bureau of Reclamation), and hand auger holes generally show the presence of poorly sorted, cross-bedded gravelly sand occurring in linear channels. Some upper-flow-regime channel sediment is present in the channels, but it is less abundant than is the lower-flow-regime channel sediment.

Relief over areas of glacial outwash gravel and sand is generally less than 10 feet locally (Qcgu) except where the sediment was deposited on top of stagnant glacial ice where it is as much as 30 feet (Qcgp). On terraces along the Sheyenne River (Qcgt) in the Lisbon area relief averages about 10 to 15 feet.

A broad gravel plain that occurs in the Englevale area consists of an upper, rolling surface with up to 15 feet of local relief and a lower, nearly flat level that has been channeled into the upper one. Apparently, the higher gravel was deposited, in part at least, on top of stagnant glacial ice. When the lower level was formed, the water was eroding the gravel rather than depositing it, and the stagnant ice beneath had melted. The gravel in the Englevale area is not as massive a deposit as its aerial extent suggests. In most places it averages about 25 to 30 feet thick, although two test holes north of Englevale, both in sec 13, T134N, R58W, penetrated 113 and 121 feet of gravel. These two deeper test holes apparently are located in a narrow valley that extends southward beneath the gravel area; no other test holes were drilled in the valley. The Englevale gravel extends eastward beneath the low ridge of till that loops around the north and east sides of the Englevale area (Qctd on pl. 1). This loop apparently marks the position of the ice margin while the gravel was being deposited. When the glacier readvanced over the easternmost portion of the gravel deposit, it mantled the gravel with a layer of till.

In parts of southwestern Sargent County, the wind has modified the surface considerably, forming dunes and blowouts. Dunes are common on fluvial sediments in the Straubville-Brampton area. The fluvial sediment is protected from deflation in places where the water table intersects the surface, forming sloughs.

Most of the gravel and sand of the river flood plains and terraces is poor in quality, tending to be silty and shaly. The best quality gravel and sand is found on some of the terraces of the Sheyenne River (Qcgt on pl. 1). River terrace gravel contains somewhat less shale and is better sorted than is the river sediment found in meltwater trenches and broad glacial outwash plains.

Ice-Contact Fluvial Deposits

Small hills and ridges (kames and eskers) of gravel and sand that were deposited in contact with stagnant glacial ice are found in great numbers in central Ransom County in association with the area of composite lake-glacial landforms (Qcrf). Ice-contact deposits are shown on plate 1 as red lines. Relief on a few of the larger ridges is as much as 50 feet locally. Material in the eskers and kames consists mainly of lower-flow-regime fluvial sediment and some upper-flow-regime sediment. As this fluvial sediment settled onto the subglacial surface, gravity faulting displaced it. Mudflows from adjacent ice covered some of the fluvial sediment with a discontinuous veneer of till. The gravel and sand in the eskers is mainly a poorly sorted material, rather "dirty," with a ratio of sand to silt and clay of about 3:1. The shale content may be high, up to 80 percent in places. Cobbles, boulders, and inclusions of till are commonly mixed in with or overlie the gravel in the ridges.

A large esker extending from sec 32, T134N, R54W into sec 4, T133N, R54W has a steep northeastern face that was modified by wave action along the shore of the early Lake Agassiz (fig. 25). The ridge contains relatively good quality gravel that was probably deposited at the same time water began flowing southeastward from the early Sheyenne River along the glacier margin; the water also eroded the Milnor Channel. An ice-contact ridge that extends southeastward from sec 6 to sec 23, T132N, R54W past the town of Milnor (pl. 1) probably formed at about the same time as the one described above, that is when the early Sheyenne River flowed southeastward along the glacier margin. Ice-contact gravel deposits are common in the southwest corner of Ransom County (T133N, R58W); in the area north of Havana in Sargent County; and in the Cayuga area where some ridges are as much as a mile long and up to 50 feet high.

Sheyenne Delta

Much of the information on the Sheyenne Delta presented here is the result of research by Dr. John Brophy of the Geology Department at North Dakota State University in Fargo. Dr. Brophy has done much more work on the delta than has anyone else.

The Sheyenne Delta stands above the floor of glacial Lake Agassiz as a low plateau in the southwest corner of the Lake Agassiz basin. It includes approximately the eastern third of Ransom County, the northeasternmost corner of Sargent County; a small portion of southern Cass County, and much of western Richland County. The delta is characterized by a generally low-relief, east- to northeast-sloping surface that is covered by irregular, partly stabilized hills of windblown sand (Qosw). Local relief on some of the dunes exceeds 75 feet. The Sheyenne River valley (Qosr) is entrenched as much as 100 feet below the delta surface and exposes an incomplete cross section of the deltaic stratigraphy. The northeast edge of the delta is marked by a 75-foot-high, wave-cut scarp that becomes less pronounced southward.

The earliest mention of the Sheyenne Delta was by Warren Upham (1895) who described it as a "delta built by the Sheyenne River in Lake Agassiz with sediments supplied from

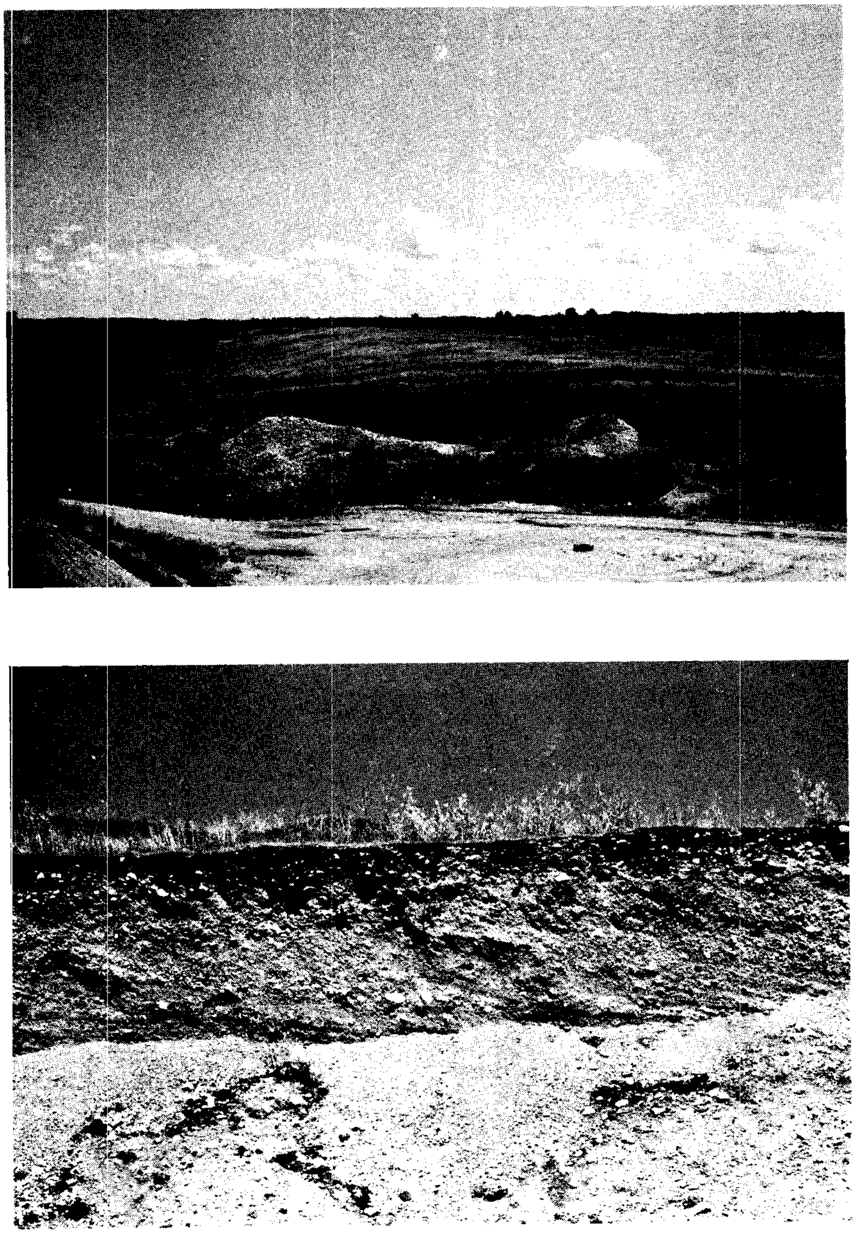

Figure 25. Ice-contact ridge in sec 4, T133N, R54W. The northeast face of this ridge appears to have been washed by waves when glacial Lake Agassiz stood at this level (1 075-1 110, an elevation equivalent to or slightly above the presumed Herman level in this area). Lower photo shows fluvial gravel in a pit in the ridge. Deposition was from the northwest.

melting glacial ice and from the erosion of the Sheyenne valley." Frank Leverett (1912; 1932) suggested that the Sheyenne Delta is not a true delta, but rather that it was deposited directly from a glacier front that lay along the steep, northeastern edge of the feature. Brophy (June 16, 1978, personal communication) disagrees with Leverett's theory, pointing out that he has found no evidence of any glacial till within the deltaic sequence. The so-called "pebbles" or "pebbly clay" that led Leverett to his glacial deposition theory are, in reality, merely limy concretions and nodules dispersed through the fluvial and lacustrine sediment in some places. The prominent escarpment along the northeast of the delta was cut by wave action while glacial Lake Agassiz was at the Campbell level. In places, both a wave-cut scarp and a wave-cut terrace occur at the Campbell level.

Dennis, Akin, and Jones (1950) provided the first reliable subsurface data for the delta. Their test holes showed the sediments to be 170 to 180 feet thick near the eastern margin of the delta in Richland County. Test holes drilled during the present study show that the Sheyenne Delta sediments lying on the underlying glacial till surface thicken eastward from about 50 feet at the westernmost edge of the delta to about 150 feet at the Ransom-Richland County line. In this distance, the elevation of the underlying till surface slopes from about 1 050 feet to less than 900 feet. Most of the eastward thickening of the deltaic sequence is accounted for in the lower sediments; the upper surface of the delta over the same area is essentially flat in Ransom County at about 1 070 to 1 075 feet.

Generally, the lowermost sediments lying on the pre-delta till surface in Ransom and Sargent Counties are gravel and sand deposits that occur in Tps132-133N, Rs53-54W. These fluvial sediments apparently were deposited by the early Sheyenne River as soon as it abandoned its ice-marginal Milnor Channel position when the glacier margin receded from this four-township area. The gravel and sand is the deepest fluvial sediment in the area, with between 5 and 15 feet of it lying on till at elevations between 950 and 975 feet; these buried fluvial sediments apparently have no lateral equivalent in the two-county area.

Along the western margin of the delta, in Tps133-136N, R54W, in Ransom County, sand overlies the till in most places at elevations ranging from about 1 025 to 1 050 feet. These sand deposits (Qcgs) are restricted to the location where the river entered the rapidly flooding lake. They become much finer just a short distance eastward, grading into silt and clay, which generally overlies till, but is itself buried in most places beneath windblown materials. I am in agreement with Brophy's belief that the silt-clay unit is largely turbidity-current sediment. The turbidity-current sediment ranges up to over 70 feet thick in parts of eastern Ransom County, and it is exposed in several places along the Sheyenne River trench (it is exposed mainly in areas designated Qcsi on pl. 1). No attempt was made to differentiate the sand from the silt-clay unit on the geologic map (pl. 1). In areas near the western margin of the Sheyenne Delta, where fluvial sand was deposited on top of discontinuous patches of stagnant glacial ice, the ice eventually melted and the materials on top collapsed, resulting in a rolling surface (Qcgl) like that in the Sheldon area.

In a 50-foot-deep cut along the Sheyenne River in eastern Ransom County (NE¼sec 18, T135N, R53W), about 17 feet of alternating beds of silt and clay can be seen (turbidity-current sediment; see table 4 for a description of the materials exposed in the cut). These silt and clay beds are overlain by 27 feet of apparently fluvial sand. The sediments exposed in the cut suggest that deposition of the materials was rapid; in fact, the entire lacustrine sequence of 15 to 20 feet may have been deposited in about three years, based on a count of the individual bands. After deposition of the turbidity-current sediments ended, the overlying sand was rapidly deposited by a stream (the Sheyenne River?) or streams spreading out over the surface as it aggraded its flood plain into the lake. It is this fluvial sediment that is exposed in many places on the Sheyenne Delta of Ransom and Sargent Counties. Fluvial sediment is uncommon on the surface in Richland County.

Eolian Landforms

Broad areas of the Sheyenne Delta in eastern Ransom County and parts of the glacial Lake Dakota plain in western Sargent County (Qosw on pl. 1) have been subject to intense erosion and deposition by the wind since deglaciation. Windblown sediment consists of well-sorted, fine sand with no gravel. Indistinct cross-bedding is found in some of the dunes. The many dunes and shallow blowouts on the Sheyenne Delta impart a hummocky appearance to the landscape (figs. 26 and 27). Dunes about 25 feet high are common with some over 75 feet high near the Sheyenne River in eastern Ransom County (figs. 26 and 27). Dunes up to 40 feet high are found in sections 19 and 30, T130N, R58W in southwestern Sargent County and dunes up to 20 feet high are common in that area.

The dunes on the Sheyenne Delta lie mainly in the area opposite the old mouth of the Sheyenne River and along both sides of the east-west stretch of the Sheyenne trench. It seems likely that dune formation began early, wherever sand was exposed in delta-building, with wind action perhaps quite intensive before a vegetation cover became established. The dunes of the wedge-shaped area spreading from the old mouth of the Sheyenne River represent wind reworking of sandy delta

TABLE 4. Description of materials exposed in a cut along the Sheyenne River. Located in the NE¼ sec 18, T135N, R53W in eastern Ransom County. The cut is about 50 feet high and exposes turbidity-current lake sediments overlain by fluvial sediments. Lowermost unit is number 1; uppermost unit is number 11.

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11. 27 feet of sand; structureless, loose to poorly compacted, soft, buff-colored. The sand exposed here is similar to that that occurs throughout the Sheyenne Delta area of Ransom and Sargent Counties.
10. 6-inch bed of silt; sandy, gray, with horizontal banding.
9. 6-inch bed of clay similar to unit 7; silty, dark gray with nodules of black clay and a few tiny pebbles.
8. 4-foot bed of sand; fine-grained, tan to buff with lighter shades upward, distinct color banding at base, becoming more vague upward. The upper surface of this bed is contorted, apparently due to pressure compaction by the overlying load.
7. 1-foot bed of clay; similar to unit 5, except slightly less pebbly.
6. 3-foot bed of silt; sandy, gray to buff, compact, banded, highly contorted in places, apparently due to pressure compaction by the overlying load.
5. 2-foot bed of clay; dark gray with numerous black clay nodules that are probably pieces of topsoil that washed in; excellent banding; a few cobbles and numerous igneous pebbles.
4. 4-foot bed of silt; clayey, compact, dark brown with black clay nodules included.
3. 6-inch bed of sandy gravel; considerable clay included. Springs issue from this unit.
2. 1-foot bed of sandy clay, dark gray, compact. The base of this unit is covered by slump.
1. 7 feet of slumped material down to river level.

Sheyenne River level.

Figure 26. Sand dunes in eastern Ransom County on the Sheyenne Delta. This view toward the east of dunes in sec 1, T135N, R54W shows typical relief in areas of strong dune development on the delta. Local relief in this area due to dune development exceeds 80 feet in places.

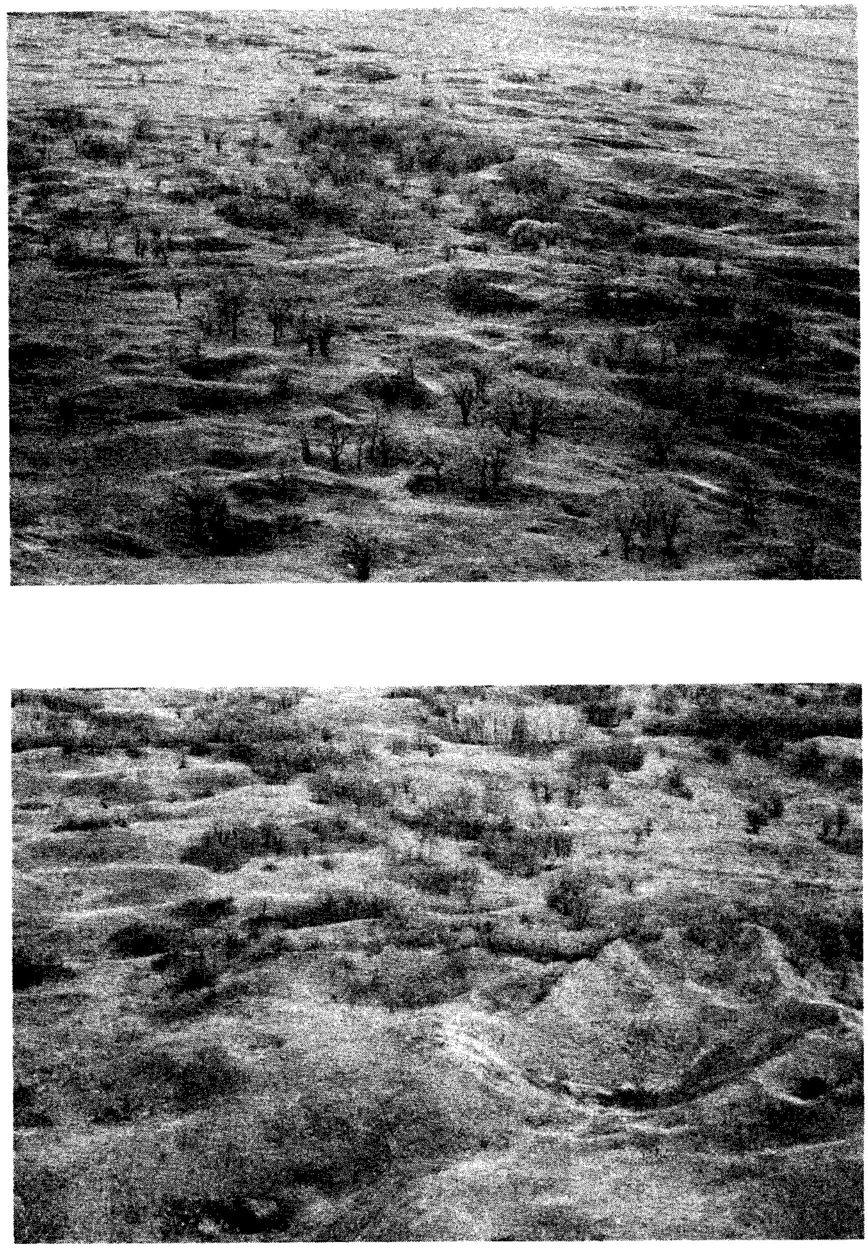

Figure 27. Sand dunes in eastern Ransom County on the Sheyenne Delta. Both of these aerial views are of dunes in T135N, R54W.

beds, but at least some of the dunes along the trench may have originated from river sand laid down during the cutting of the trench. Prevailing wind direction during dune formation appears to have been from the south, although recent blowouts in the area indicate northwesterly winds.

With the development of a vegetation cover, the dunes became more stable, but they are still subject to wind erosion and redeposition wherever that cover is broken. Many wind-eroded blowouts in the present dunes show that this reshuffling still goes on when the vegetation is breached by such things as cattle, burrowing animals, or vehicles. Periods of sand stability are shown by buried soils, some of which are better developed than the present surface soil.

Eolian activity has complicated the distribution pattern of near-surface materials. Wind has scoured hollows in the fluvial and turbidity-current deposits, re-sorted them by removing the finer fraction, and left the coarser constituent piled as dunes. The pattern of eolian activity and resultant distribution of dunes on the Sheyenne Delta seems to be controlled by the presence or absence of a layer of clay that is less than a foot thick in most places where it occurs on top of the ground. Wherever the clay is present, it forms a protective seal, effectively preventing wind erosion; where it is lacking, the sand is free to blow. Groundwater discharge has carried the clay upward, apparently from buried layers of turbidity-current sediment, and deposited it on the surface. In some places, the wind has scoured to the water table, which also acts as a barrier to further downward erosion by the wind.

SYNOPSIS OF GEOLOGIC HISTORY

Preglacial History

The oldest rocks in Ransom and Sargent Counties are probably schistose and gneissic metamorphic rocks. In general, all of the Precambrian basement rocks in the two-county area are of Early Precambrian age, older than 2.6 billion years. Little is known of their geologic history, however. The Precambrian rocks are deeply weathered. They are everywhere covered by Cretaceous sediments; and it cannot be determined when the last episode of weathering began, although it continued until the Cretaceous sands and shale were deposited.

Since the Precambrian, the preglacial history of Ransom and Sargent Counties has been largely a series of marine transgressions and regressions. The area is located at the southeastern edge of the Williston Basin, and most of the Paleozoic sediments that may once have been present in the area were removed by erosion during times when the land was emergent. However, many of the Paleozoic formations found farther west were probably never deposited in Ransom and Sargent Counties.

The only Paleozoic sediments that may be present are possible Winnipeg Group sands and shales in extreme western Ransom and Sargent Counties. However, no exploratory wells have penetrated any Paleozoic sediments in the two counties and their occurrence is only speculation.

If they were deposited in Ransom and Sargent Counties, any Triassic (and perhaps late Paleozoic) sediments were removed by erosion prior to the time of the flooding of the area in late Jurassic or early Cretaceous time. The lowermost known Mesozoic sediments are the basal Cretaceous clastics (sands and shales) of the Dakota Group, which underlie most of the area. Marine deposition continued through Cretaceous time, although southeastern North Dakota was a shelf area at the edge of the Williston Basin in which shallow water, near-shore and fluvial sand deposition alternated at times with deeper-water deposition of shales. Near the end of Cretaceous time, the seas receded westward, with the Pierre Formation marking the end of marine deposition in the two counties. Since deposition of the Cretaceous sediments, erosion has been the dominant geologic process in Ransom and Sargent Counties.

Erosion continued through Pliocene time. By the end of the Pliocene Epoch, a gently rolling landscape had developed on the shales of the Cretaceous Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations (pl. 3). The area sloped generally northeastward with the highest elevations in southeastern Sargent County on the northernmost end of the Prairie Coteau and in northwestern Ransom County (fig. 28). At least one large river valley extended northeastward from westernmost Sargent County to northern Ransom County. The valley may represent the preglacial course of the Cheyenne River, which flows northeastward from the Black Hills area of South Dakota as far as the modern Missouri River; its course east of the Missouri River is presumably buried beneath the glacial sediment (the Cheyenne River bears no relationship to the Sheyenne River of North Dakota in spite of the similarity of the two words). The stream that flowed through the buried valley probably flowed into the ancestral Red River of the North.

Early Glacial History

Several distinct layers of till, each of which may represent a separate glacial advance, although this is by no means a certainty, can be recognized in Ransom and Sargent Counties. They include the early Wisconsinan Gardar Formation and the Late Wisconsinan Dahlen Formation, both units that have been recognized elsewhere in North Dakota. Three distinct till units that have been petrologically and texturally characterized occur

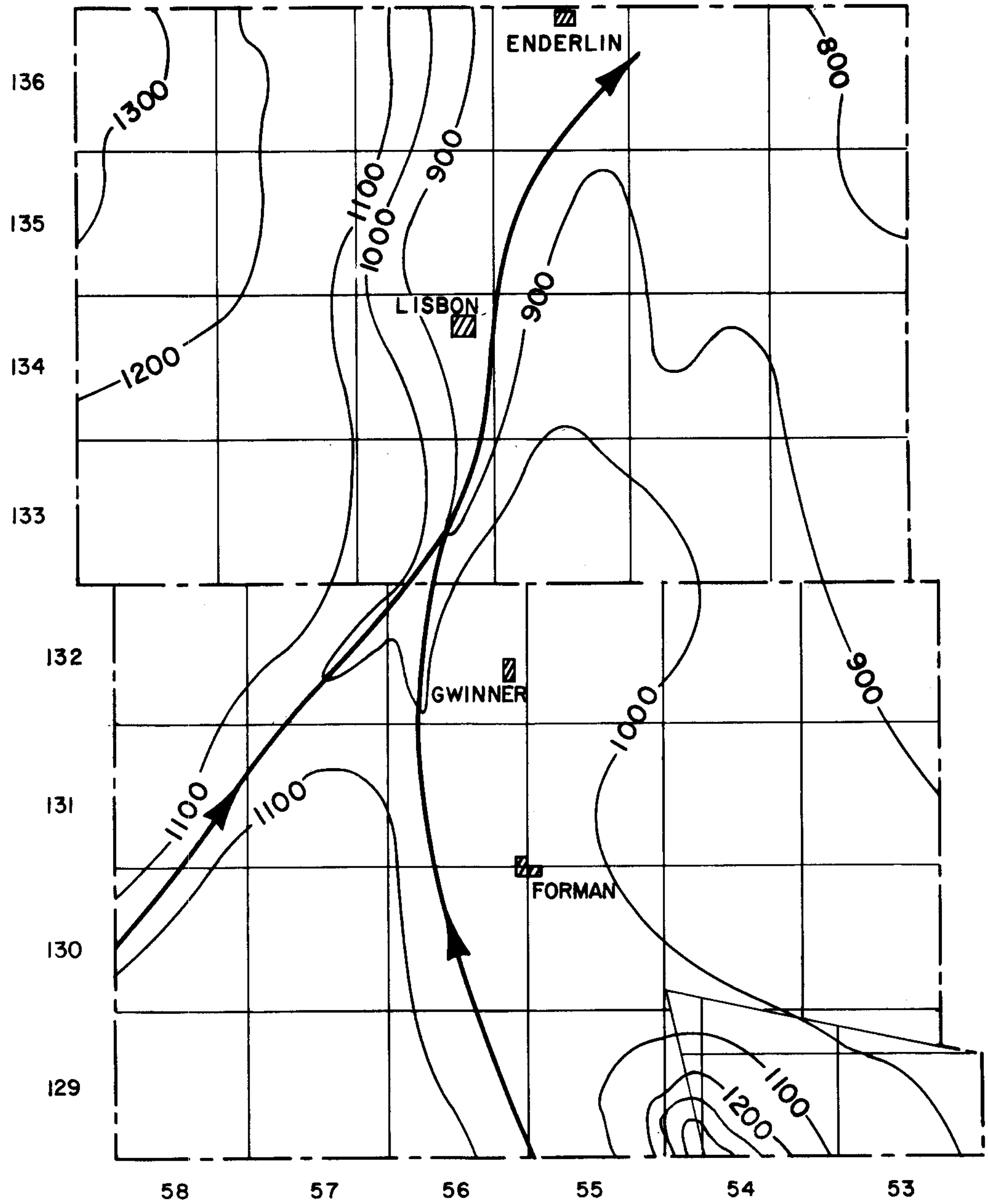

Figure 28. Conceptualization of the configuration of the Ransom and Sargent County landscape prior to glaciation. The area was drained northeastward by one major stream (the preglacial Cheyenne River?).

stratigraphically below the Gardar Formation in Ransom and Sargent Counties (table 3). In LaMoure County, Bluemle (1979) recognized the existence of several pre-Wisconsinan till units, but he was unable to determine how many glacial advances are represented by these units; certainly it is more than three. Bluemle tentatively identified a weathering profile on the upper surface of one of his lower units, but Camara (1977) identified a unit, which apparently corresponds to the weathered profile, as a separate till. The true nature of this unit is not resolved.

Generally, test-hole data in the two counties shows that the preglacial bedrock surface in most places is overlain directly by till rather than by lake or fluvial sediment. Possibly, the earliest glacial advances through the two-county area did not result in extensive drainage diversion or the formation of widespread proglacial lakes. The glaciers may have advanced in directions mainly normal to the drainage of the area, or it is possible that any lake or river sediments deposited as a result of early glacial-caused drainage disruptions were removed when drainage returned to its preglacial course when the early glaciers receded. Our subsurface test-hole data is still too sparse to rule out possible buried lake deposits.

Using petrographic data, Camara (1977) was able to tentatively determine the direction of transport of the till of the early Wisconsinan Gardar Formation in the two-county area, but he was unable to determine transport directions for the widely scattered till units older than the Gardar. The lower three till units (Camara's A, B, and C--pages 15 to 18 of this report) were examined in exposures in the Sheyenne River valley. All three of these till units contain lignite particles and unit C also contains pieces of Knife River Flint. These three till units, all of which are presumed to be of pre-Wisconsinan age, must have been deposited by glaciers advancing from northwesterly directions.

Certainly, a long and complex series of glacial events took place in the area prior to Wisconsinan time. The pre-Wisconsinan glacial history probably extends two or three million years into the past and includes, perhaps, a dozen glacial advances and intervals of interglacial erosion. In parts of eastern North Dakota and northwestern Minnesota, at least one period of extensive erosion that followed the deposition of certain deeply buried tills has been documented (Moran and others, 1976), and Bluemle (1979) tentatively identified two buried weathering profiles in LaMoure County, one on a deeply buried till and one on what is probably the early Wisconsinan Gardar Formation (Bluemle's unit Q' of LaMoure County).

Wisconsinan Glacial History

The Gardar Formation is generally considered to be early Wisconsinan in age and the Dahlen Formation is late Wisconsinan.

The large amount of shale fragments in the coarse-sand fraction of these two tills indicates that the glacier that deposited them advanced from the north or northeast over subcrops of Cretaceous shale. The amount of shale in the till of the Gardar Formation increases east, south, and west from central Ransom County (Camara, 1977).

The small amount of shale and the large amount of igneous and metamorphic rock fragments in the coarse-sand fraction of Camara's unit D indicates that the glacier that deposited the sediment of this unit probably advanced from the northwest. The igneous and metamorphic rock fragments were probably derived from older glacial sediment rather than directly from the Canadian Shield to the northeast.

Even though Camara's (1977) petrographic data on the uppermost till covering most of the two-county area suggests a northwesterly sediment source, geomorphic relationships strongly indicate that the last ice movement in the area was southwestward and resulted in the emplacement of the many ice-thrust blocks in western Sargent County. The ice-thrusting episode was probably short lived; and the readvance that accomplished it was only a few miles, or even less, not far enough to introduce a unique, new sediment type to the surficial till.

Between 15 000 and 14 000 years ago, the glacial ice melted from most of the two-county area, although the Red River Valley was still largely filled with ice 14 000 years ago. As the ice melted from the two counties, most of the surface landforms now found in the area were emplaced.

It appears that, insofar as the glacier margin receded in an orderly fashion in some places, the last ice movement was generally southwestward. However, over most of the central part of the area (all the areas shown as Qcth and Qctr as well as most of the area shown as Qctu on pl. 1), the glacier stagnated and melted, resulting mainly in subdued stagnation features.

As the ice melted from the western part of the two counties, glacial Lake Dakota expanded into the area from Dickey County. It flooded approximately the western third of Sargent County and a small part of extreme southwestern Ransom County. Massive shore features developed along the eastern shore of the lake and considerable wind action at that time blew the shore sand into large dunes in Townships 130 and 131 North, Ranges 57 and 58 West.

The glacier then readvanced into the lake from the northeast, overriding the shore and windblown landforms. The readvancing glacier caused widespread, massive thrusting of the underlying materials. Several discrete ice-thrust blocks and adjacent depressions were formed in western Sargent County by this thrusting. They include the hills adjacent to Meszaros

Slough, Dill Slough, Pickell Slough, and the hills southwest of Crete. The thrusting that formed Standing Rock Hill and Bear's Den Hillock in Ransom County may have occurred at about this time, too, or it may have taken place a few hundred years later during another short readvance of the glacier.

The readvance of the glacier that caused the western Sargent County thrusting also covered the shore and windblown landforms with a veneer of glacial sediment while smoothing off the dunes and modifying the topography somewhat, resulting in the Lake Oakes Hills (pl. 1). When the glacier again receded, glacial Lake Dakota reflooded the lower parts of the area, partially filling many of the thrust depressions with silt and resulting in areas of flat, lake-bottom topography in some places (Qcss on pl. 1).

Between about 14 000 and 13 500 years ago, large volumes of water poured southward over the freshly exposed till surface in western Ransom and Sargent Counties. This water apparently flowed into glacial Lake Dakota and then southward into the James-Missouri River system in South Dakota. In western Ransom County, in the Englevale area, the water deposited considerable amounts of gravel and sand. In places where patches of stagnant glacial ice were still present, the gravel and sand were deposited on top of the ice and eventually, when the ice melted, the gravel and sand beds became collapsed, resulting in an undulating, pitted surface (areas shown as Qcgp on pl. 1); however, most of the gravel and sand were deposited on solid ground and resulted in flat plains (areas shown as Qcgu on pl. 1). The water that deposited the gravel and sand in western Ransom and Sargent Counties was probably a result of the combined flow of melting glacial ice in areas to the north of the two-county area and runoff from the large amounts of precipitation falling at that time.

As the glacier continued to melt between about 13 500 and 12 800 years ago, most of the eastern part of the two-county area became free of ice, although broad, discontinuous patches of stagnant ice probably remained for several hundred years more. By this time, the glacier margin in the Red River Valley had receded far enough to open the southern drainage divide at Browns Valley, Minnesota (Arndt, 1977). A lake flooded much of east-central Ransom County (approximately the area shown as Qcrf on pl. 1), which was still covered in places by stagnant glacial ice (Bluemle, 1974). This pre-Lake Agassiz lake drained southeastward, initially through valleys carved in the stagnant glacial ice near Milnor (see the eskers shown near Milnor on pl. 1) and later through the Milnor Channel (see pl. 1) and out the Browns Valley outlet into the Minnesota River valley.

Glacial Lake Agassiz History

The earliest stages of glacial Lake Agassiz in North Dakota are only poorly understood. Initially, a lake flooded much of central Ransom County (Qcrf on pl. 1) at elevations as much as 335 feet above the Herman level in Ransom County (Bluemle, 1974). The lake-related landforms in north-central Ransom County that can be identified as a result of this flooding are mainly wave-cut scarps and poorly defined beach ridges as well as small amounts of bedded silt. The original configurations of the landforms were destroyed on the melting of the stagnant ice on which they had been deposited.

As the glacier receded from the Red River Valley and drainage was opened through the Browns Valley outlet, the lake level fell. It continued to fall in response to erosion at the outlet, stabilizing only when the erosion had cut down to layers of Precambrian granite that were more resistant to erosion; the lake then stabilized at this (the Campbell) level.

Between about 12 800 and 11 000 years ago, the Sheyenne Delta was built in eastern Ransom and Sargent Counties and in parts of Richland and Cass Counties. The lake stood at the Herman level during part of this time. Glacial ice probably still filled the northern part of the Red River Valley in North Dakota and Minnesota, briefly readvancing as far south as central Traill County about 12 800 years ago.

The Sheyenne Delta was formed when a flood of sediment-laden water poured into glacial Lake Agassiz at the mouth of the early Sheyenne River. Most of this water was probably overflow from glacial Lake Souris in north-central North Dakota. It is not known for certain whether the flow was relatively continuous or whether it was a series of periodic, "catastrophic" events. The water flowing out of glacial Lake Souris was probably relatively free of sediment (the sediment having settled out in the lake) and cold and therefore capable of intense erosion; it probably carved the Sheyenne River trench quite rapidly. Evidence of repeated flooding is found in the form of patches of bedded silt in several places on the rim of the Sheyenne trench. The vaguely bedded silt deposits have been identified in Eddy, Nelson, and Griggs Counties.

The Sheyenne Delta construction was initiated when the Sheyenne River abandoned its Milnor Channel position and began depositing the coarser fraction of its load in the then still narrow, ice-marginal Lake Agassiz, which probably already stood at the Herman level (1 070-75 feet) or perhaps even a few feet higher (Bluemle, 1974). Shallow, linear depressions on the surface of the delta along its westernmost margin suggest that the flow direction of the initial distributaries was southeastward, indicating that the ice was still present to the east and north.

The timing and manner of construction of most of the delta are not yet entirely clear. The delta was probably built rapidly of turbidity-current sediments while the lake was at the Herman level. Deposition took place from a single shifting channel or from a series of distributaries coming from the Sheyenne River valley at the delta head. The large load of suspended sediment delivered to the cold water of Lake Agassiz by the Sheyenne River probably resulted in steady turbidity currents over the already-built delta surface and spasmodic turbidity currents at the prograding delta face. As the lake levels dropped through the Norcross and Tintah levels and finally to the Campbell level, the Sheyenne River responded by entrenching into the Delta. The evidence and theoretical considerations favoring this explanation are: (1) the overall form of the delta is arranged fairly symmetrically around the old mouth of the Sheyenne River; (2) no topographic breaks exist to suggest increments of delta-building at the lower Norcross or Tintah levels; (3) low ridges at appropriate levels on the delta surface may be beaches built on the delta surface at the Norcross and Tintah stages of the lake; (4) the fine texture in the eastern part of the delta, as documented by Baker (1967a), suggests deposition in a small lake lacking wave and current erosion strong enough to keep pace with sedimentation; and (5) the size and load of the Sheyenne River would have been greatest while glaciers in the headwaters still were contributing meltwater to it, providing it with its greatest delta-building potential during early lake history.

If the outline just described is correct, the delta itself was already built by the end of the Herman stage of glacial Lake Agassiz, although the outer part of the delta did not become dry land until the lake dropped to the Campbell level.

As the level of glacial Lake Agassiz fell in response to the erosion of the southern outlet, the Sheyenne River became entrenched in the course it was occupying at the end of the delta-building, probably before Tintah time ended. Poorly defined beach ridges that may be either Herman or Norcross can be seen on the surface of the delta in northeastern Ransom County (T136N, R53W).

About midway up the north-flowing segment of the Sheyenne River (T134-135N, R54W) at the head of the delta in Ransom County, is a terrace just below the delta surface that may mark the initial entrenchment of the river. The gravel on the terrace looks like it was derived from till. Clam shells at the top of the gravel are of the genus _Lampsilis_ and have been radiocarbon dated at 13 500 years old (Moran, _et al._, 1973), a date that appears to be somewhat older than other estimates for the early stages of glacial Lake Agassiz. Possibly, the shells are not related to the entrenchment of the river.

Elson (1967) proposed that, after a brief stand at the Norcross level (about 1 060 feet in the delta area) Lake Agassiz fell briefly to the Campbell level (1 000 feet elevation) and then returned to the Norcross level about 12 000 years ago. Evidence compatible with this fluctuation can be seen in a cut-bank exposure about five miles east of the eastward bend of the trench (sec 7, T136N, R53W). A cross-bedded fluvial sand containing valves of small clams of the Sphaerium or Pisidium type lies at an elevation of about 1 015 feet. This is below the Norcross level and also below the Tintah level (about 1 020 feet elevation in the delta area). The fluvial sand may represent river aggradation as the lake rose from the early Campbell stand to the second Norcross stand. A radiocarbon date on the clam shells of 12 000 years before present (Moran, et al., 1973) supports this hypothesis.

After the second Norcross stand, the lake fell briefly to the Tintah level and then to the Campbell level where it remained for a relatively prolonged period of time as the result of stabilization of the southern outlet on its Precambrian bedrock sill. During this Norcross stand, the Sheyenne River had sufficient time to become adjusted to the Campbell base level, and a prominent set of terraces graded to that level preserves parts of the flood plain at that time.

About 10 500 years ago, Lake Agassiz began a well-documented major fluctuation in response to the alternating opening and re-closing, by glacial retreat and readvance, of northeastern outlets into the Superior basin. Elson (1967) suggests that the lake dropped to the Burnside level (the Burnside strandline does not extend south of the latitude of Grand Forks) starting about 10 500 years ago and then refilled to the Campbell level by about 9 900 years ago.

Lowering to the Burnside level would have resulted in drying up of the southern part of the basin up to the latitude of Grand Forks. The Sheyenne River probably would have adjusted to a lower base level by cutting an inner valley below the Campbell grade in the Sheyenne Delta trench. As the last increment of lake sediments, amounting to about 30 feet at the center of the basin, had not yet been deposited, the new base level of the Sheyenne as it extended its course across the lake floor may have been as low, or lower than its present base level. Evidence within the trench suggests that the Sheyenne did cut below the present channel during this stage. The evidence consists of the presence of remnants of a thin-bedded, fossiliferous silt and clay unit that is interpreted to be a deltaic-lacustrine fill deposited in a trench "estuary" created as the lake rose again to the Campbell level (Brophy, personal communication). The top of one such remnant is a terrace that is at an elevation close to the Campbell level. Both this remnant and another one about six miles upstream, continue to an unknown depth below the present river flood-plain level. This is the section exposing the upstream remnant of the estuarine clay, and the sediment is peaty in the upper part, representing swampy conditions on the floor of the estuary after the lake fell again from the Campbell level. Radiocarbon dating of wood in the peaty sediment gives a date of about 9 130 (Moran, et al., 1973) years ago, which is slightly younger than Elson's proposed date of 9 500 years ago for the beginning of the final decline from the Campbell level.

Fossils in the peaty sediment show that by this time a diverse fauna of mollusks, insects, and other forms had entered the area. A study of the plant fossils and pollen by McAndrews (1967) shows a local cattail marsh community changing to a shrub bog community dominated by dwarf birch, willow, and alder.

As lake levels fell in response to the permanent opening of the Canadian outlets by glacial retreat about 9 500 years ago, a brief pause occurred at the McCauleyville level (about 970 to 975 feet in the delta area). Lake levels continued to drop and the Sheyenne River again extended itself across the lake plain to join the Red River of the North. Regrading of the delta trench then destroyed most of the estuarine fill, leaving a few remnants as terraces. The details of the regrading to post-lake levels are not yet clear, but it is evident that it was not simply a case of continuous degradation to present levels. At least one instance of aggradation, perhaps representing a response of the river to climatic change, can be documented from trench stratigraphy (Brophy, personal communication). Radiocarbon dates of wood from some of these aggraded sediments show that the 20 feet of river deposits above the water level in the aggraded area were deposited in the last 2 500 years. At other sites, buried soil zones occur within this sequence, showing periods of stability within this aggradational episode. At one site, charcoal from just below the top of the low terrace has been dated at 235 years old, showing that the terrace has been flooded at least that recently.

The sand dunes over much of the Sheyenne Delta surface (Qosw on pl. 1) may have begun to form when the level of glacial Lake Agassiz first dropped to the Campbell level or they may date to a later, possibly hypsithermal time, which lasted from about 8 000 until about 5 000 years ago. Baker (1967) believes that, as the lake drained from the surface of the delta, the surface sediments were probably highly susceptible to wind erosion. The largest sand dunes are concentrated especially near the northeast margin of the delta; they become smaller and less numerous southwestward. Baker suggested that the fluvial sand plain on the southwest part of the Sheyenne Delta may have served as a source for the windblown sand.

The sand dune area has hummocky topography, not discrete, well-formed barchan or longitudinal dunes, and a study of the orientation of the dunes is generally inconclusive in determining the wind direction responsible for the formation of the dunes. Vague east-west ridges with apparently concave northern slopes suggest barchans formed by southerly winds; but the northern slopes of the ridges are generally much more heavily vegetated than are the southern slopes, and it may be that the pattern of vegetation has been the factor responsible for controlling the current shape of the hills. Stratification within the dunes is not well enough exposed in many places and cannot be used to determine the direction of deposition of the windblown sediments. Modern blowouts in the dune areas indicate northwesterly winds.

The lineations on the glacial Lake Agassiz plain have been interpreted as ice-drag markings formed by wind-driven ice floes, the prevailing winds having been from the northwest or southeast late during the history of glacial Lake Agassiz (Clayton and others, 1965).

The sediments near the lakeward margin of the Sheyenne Delta are mainly silt, whereas the material in the dunes is mainly fine sand. No source of fine sand exists to the north, east, or southeast of the delta front. These circumstances do suggest a southwesterly source for the dune sand.

Much of the sand in the dunes may have been locally derived while the delta was prograding. Exposed areas of well-sorted turbidity-current sand would likely be subject to intense erosion by the wind as soon as the lake water drained from the area.

Postglacial History

From about 10 000 years ago until perhaps 8 500 years ago, the climate in Ransom and Sargent Counties was cool and humid, probably somewhat wetter than it is today (Clayton and others, 1976). A warming trend that began about 10 000 years ago ended the forest cover over the area and transformed most of the lakes to sloughs (fig. 29). From 8 500 until 5 000 years ago, the area had a drier, slightly warmer climate than it does today. Several feet of windblown silt and sand were deposited during this 3 500-year interval of time. Extensive windblown deposits occur on the glacial Lake Dakota plain in western Sargent County and on the Sheyenne Delta, although much of this material may be pre-Holocene in age. Many ponds were transformed into sloughs, and the grass cover was greatly reduced over the two-county area during the warm, dry 3 500-year interval. Hillslopes became unstable, more erosion took place over the Prairie Coteau area, and sloughs received coarser sediment with less organic content. With the return to increased precipitation about 4 000 years ago, the grass cover again increased, effectively stabilizing most hillslopes in the two-county area.

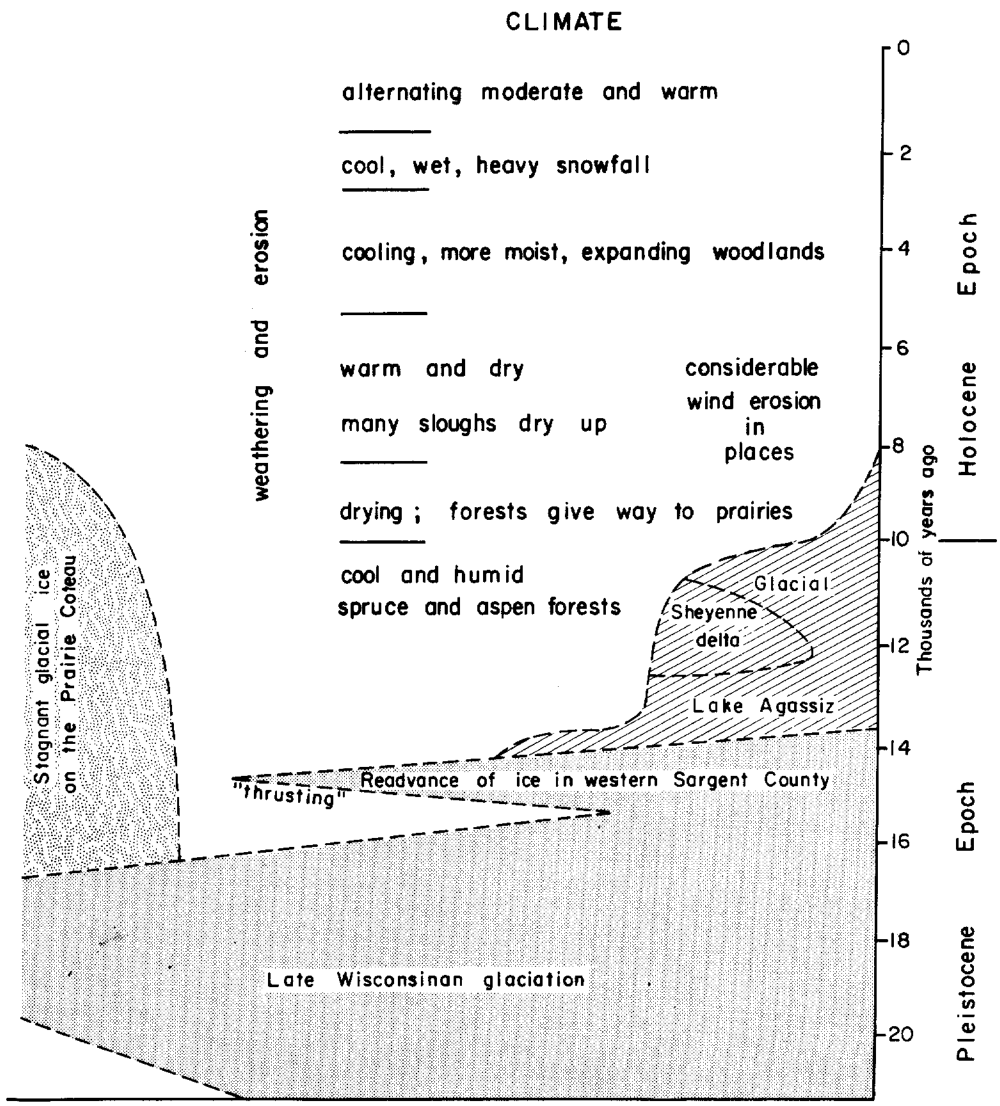

Figure 29. Time-distance diagram showing the changing climate in Ransom and Sargent Counties since the last glacier melted from the area. Time is vertical direction on this diagram; distance is horizontal. The glacier stagnated on the Prairie Coteau and took somewhat longer to melt there than on the Glaciated Plains.

ECONOMIC GEOLOGY

Hydrocarbons

Only two exploratory oil wells, both in Sargent County, have been drilled in the two-county area. No production was found and there is little evidence of petroleum resources in the area.

Sand and Gravel

Sand and gravel are found in a variety of situations in the two counties. The most important source of relatively good quality gravel with a low percentage of shale is in the terraces of the Sheyenne River valley, especially in the Lisbon area. The gravel found in glacial outwash, such as that in the Englevale area, and in ice-contact deposits commonly contains shale in amounts detrimental for use in concrete.

Uranium

One test hole was drilled in Sargent County during a search for potential uranium-bearing minerals in the Red River Valley (Moore, 1978). No noteworthy occurrences of uranium-rich minerals were identified during the study.

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APPENDIX 1
DISCUSSION OF THE TERM "TILL"

Many Quaternary geologists have objected to the term till because it has both sedimentologic and genetic connotations. They have proposed numerous terms that apply to either the sedimentologic or the genetic aspect of the material, but not to both. Synonyms include boulder clay and stony loam as well as a variety of translations or similarly-constructed granulometric descriptions in other languages (Dreimanis, 1976). Neither boulders, nor clay, nor stones are the main constituents of most tills, and terms such as boulder clay are now losing popularity. The French term moraine and moraine profonde are used in translation in various non-English languages. In North America, the term moraine is usually applied only to landforms. The nongenetic term diamicton, defined as "nonsorted terrigenous sediments... containing a wide range of particle sizes regardless of genesis," correctly describes the material I refer to as till. Although a diamicton need not have a glacial origin (a nonglacial mudflow might be lithologically and texturally indistinguishable from till), at least one reference, the American Geological Institute (AGI) Glossary of Geology (1972) lists till as a synonym for diamicton. Pebble loam and stony loam, sedimentologic terms sometimes used to refer to the same material I am calling till, sound like soil terms rather than geologic terms and I think that they should be avoided.

The most widely-used term in North America for sediment deposited by glacial ice is "till," and that is the term I have used in this report. The dual genetic/sedimentologic implications of the term should cause no problems as the meaning (i.e., origin or material) should be clear from the context in which the word is used. The definitions of till vary from one author to another, but most of them stress the following characteristics: (1) glacial origin; (2) presence of a variety of rock and mineral fragments of various sizes, many of them having been transported a considerable distance; (3) poor sorting, in the geologic meaning of the term, that is, presence of a wide range of particle sizes, usually with bi-modal or multi-modal distribution; (4) lack of stratification (although some tills are foliated, even truly bedded); and (5) compactness or close packing, also with certain exceptions (Dreimanis, 1976).