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Geology and Ground Water Resources of GRAND FORKS COUNTY

Part I
GEOLOGY

by
Dan E. Hansen and Jack Kume

Prepared by the North Dakota Geological Survey
in cooperation with the North Dakota State
Water Commission, the United States Geological Survey,
and the Grand Forks 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 ground water basic data, and Part III describes the ground water resources.

Part III will be published later and will be distributed as soon as possible.

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THE GEOLOGY OF

GRAND FORKS COUNTY

by

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ABSTRACT

Grand Forks County in northeastern North Dakota is underlain by glacial drift, westward-dipping Paleozoic and Mesozoic sedimentary rocks and Precambrian igneous and metamorphic rocks. Glacial drift that covers the bedrock reaches a maximum thickness of 455 feet. It can be differentiated into 5 drift sheets, each of which in turn can be separated into till units, lake clay and silt units, and sand and gravel units. Relief on the bedrock surface is much greater than that on the present glacial topography. In western Grand Forks County, the bedrock rises 600 feet from east to west at the Pembina escarpment, whereas the surface elevations rise only 300 feet.

Western Grand Forks County is covered mainly by ground moraine. Stratified drift occurs in kames, eskers, and disintegration ridges and outwash plains. To the east, the relatively flat Agassiz lake plain is modified only by a few ridges and scarps. The strandlines of glacial Lake Agassiz recognized in Grand Forks County are the Herman, Norcross, Tintah, Campbell, McCauleyville, Blanchard, Hillsboro, Emerado, and Ojata (oldest to youngest). Most of the strandlines consist of multiple beach ridges which implies a combination of low and high water deposits and offshore bars. The Campbell and McCauleyville beaches, although separately named, also appear to be a combination.

Eastern Grand Forks County is mainly a lake plain underlain by clay and silt and, in places, sand and gravel. Northwest of the city of Grand Forks, saline soils occur above the shallow subcropping Dakota Group sandstones. An extensive but discontinuous bed of silt underlies the lake plain in the eastern part of the county. It has been interpreted by some workers as evidence for two stages in the history of Lake Agassiz. However, as concluded from this study, Lake Agassiz originated as a small proglacial lake which expanded in area and rose to

the maximum level of the Herman beaches. Later, as the glacial ice receded, the lake receded and drained in a number of steps marked by strandlines.

Economic mineral deposits of Grand Forks County include sands and gravels of the beach ridges and large quantities of ground water from the outwash and delta plain aquifers. Other mineral deposits are the near-surface marlstones of the Niobrara Formation in western Grand Forks County, the associated bentonitic clays of the immediately overlying Pierre Formation, and subsurface deposits of the Red River and Winnipeg limestones in eastern Grand Forks County. Although seven wells have been drilled in an unsuccessful attempt to find oil in Grand Forks County, stratigraphic changes occur in the rocks of the Winnipeg and Dakota Groups that could trap petroleum in commercial quantities.

INTRODUCTION

Scope and purpose of study

This bulletin, published in three parts, presents the results of an investigation of the geology and occurrence of groundwater in Grand Forks County. The study was a cooperative project involving three agencies: the North Dakota Geological Survey, the North Dakota State Water Commission, and the United States Geological Survey.

Part I is a descriptive and interpretative report of the geology of Grand Forks County. The main objectives of the geological investigation are: (1) mapping the glacial and associated deposits to locate and define aquifers; and (2) mapping the bedrock geology.

Methods of study

The surficial geologic mapping of Grand Forks County began in 1964 and was completed in 1965. The southern part of the county was mapped by Dan E. Hansen, and the northern part by Jack Kume.

Base maps used for the mapping consisted of county highway maps, scale 1:63,360, prepared by the North Dakota State Highway Department and topographic maps prepared by the United States Geological Survey. Aerial photographs were used during the mapping to accurately place geologic contacts. These included photo index mosaics, scale 1:63,360, prepared by the Department of Agriculture and stereopairs, scale 1:63,360, taken in 1952 by the Army Map Service.

Lithologic information was obtained with soil auger and shovel. In areas of poor exposures, holes were dug by hand to obtain the necessary information.

Subsurface geologic information was obtained by test drilling. The extent, thickness, and lithology of the various deposits were determined. Drill cuttings were studied by a geologist who prepared sample descriptions. Electric logs were run in each test hole to accurately determine the depth and thickness of the various sedimentary beds or layers.

Acknowledgments

The help of the various individuals and agencies involved in this study is appreciated. Lithologic descriptions of the test holes were provided by Clifford Beeks of the North Dakota State Water Commission. T. E. Kelly of the United States Geological Survey provided test hole data and other valuable information. Dr. Alan M. Cvancara, University of North Dakota, identified most of the fossils and provided stratigraphic information. The data supplied by the Agricultural Research Service and the Soil Conservation Service is appreciated.

GEOGRAPHY

Location and extent of area

Grand Forks County is in northeastern North Dakota and lies within Twps. 149 to 154 N., Rs. 49 to 56 W. (fig.1). It is bordered on the east by the Red River of the North which is the boundary between North Dakota and Minnesota. It is bordered on the south by Traill and Steele Counties, on the west by Nelson County, and on the north by Walsh County. The county has an area of 920,320 acres, or approximately 1,438 square miles.

Climate

The dry subhumid climate is characterized by a wide temperature range, variable precipitation, and rigorous winters. Weather statistics kept from 1900 to 1940 at Grand Forks (U. S. Dept. Agriculture, 1941) show that the coldest temperature was -43 degrees F., the

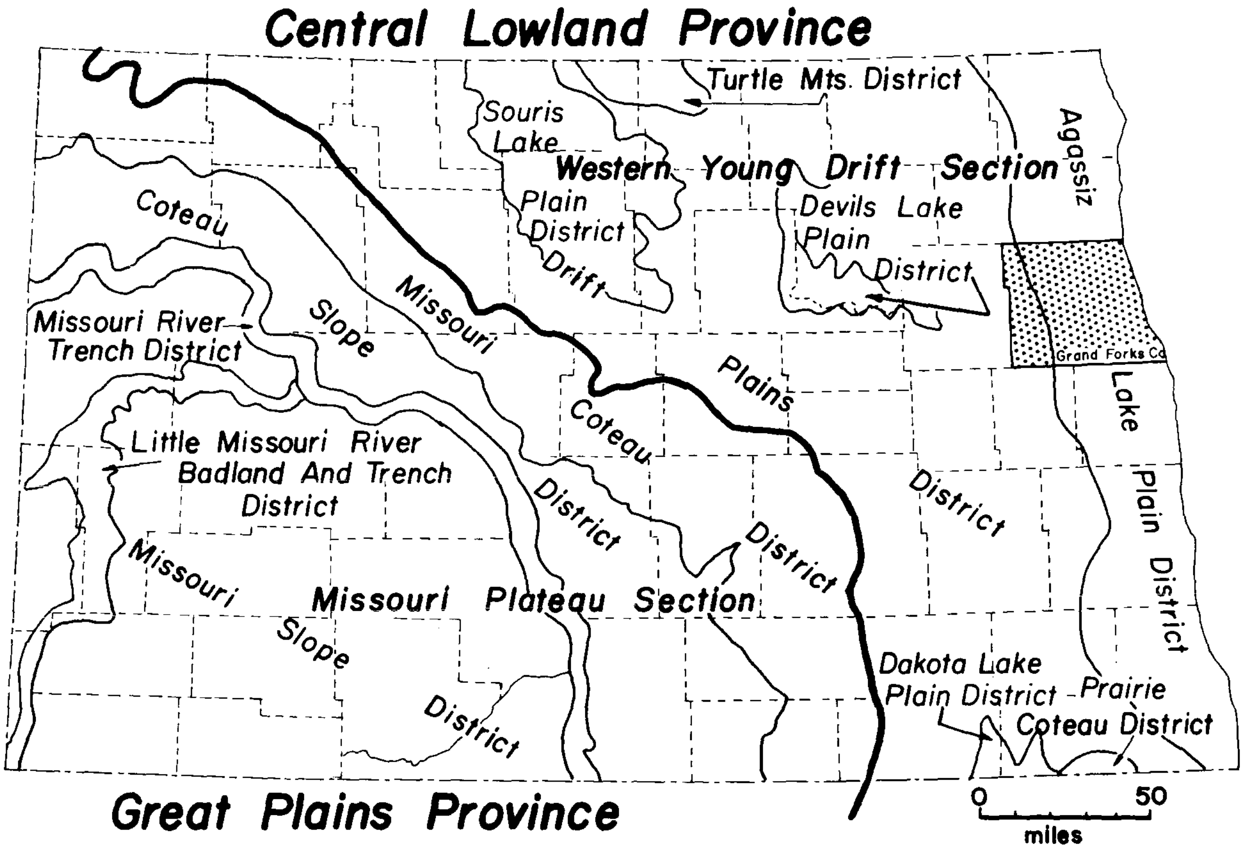

FIGURE 1. Index map showing location of Grand Forks County and the Physiographic units of North Dakota.

warmest temperature was 109 degrees F., the mean annual temperature was 38.8 degrees F., the average January temperature was 3.7 degrees F., and the average July temperature was 68.5 degrees F. The average last killing frost is May 16 and the average first killing frost is September 25. The growing season averages 132 days. Annual precipitation is 19.18 inches, of which over three-fourths falls during May through September. The prevailing wind direction is from the northwest.

Soil

The general soils map of Grand Forks County (fig.2) shows that black soils and very limy soils of the subhumid grassland predominate along with minor amounts of clay soils of glacial lake plains (Omodt, and others, 1961). Most of the soils are of the solonchak and solonetz groups; very few are true chernozems.

The level, stone-free soils are used for the intensive production of spring wheat, barley, sugar beets, and potatoes. The rolling, stony soils are used for the production of spring wheat and other small grains such as barley, oats, and corn. Poorly drained areas are used for hay production and stock raising.

Physiography

Grand Forks County lies within the Interior Plains major division, the Central Lowland province, and the Western Young Drift section (Fenneman, 1938, 1946 map). The Western Young Drift section in North Dakota can be divided into seven districts (Kume and Hansen, 1965,fig.1), the characteristics of which are summarized in Table 1.

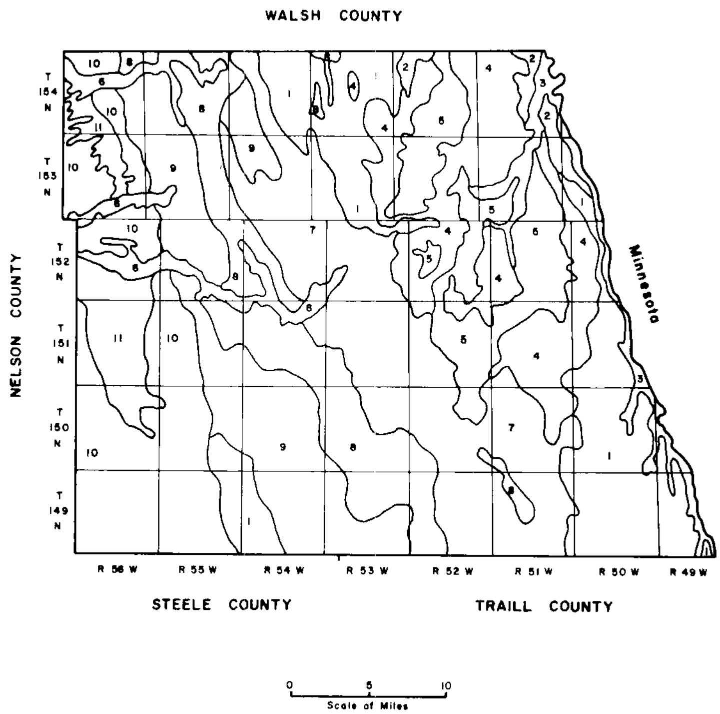

FIGURE 2. **General soils map of Grand Forks County. (Adapted from Omodt, and others (1961) and Soil Conservation Service, General Soils Map, Grand Forks County).**

EXPLANATION

Black Soils of Subhumid Grassland
- Loams and silt loams:
  - 11. Barnes-Hamerly
  - 9. Glyndon-Gardena
  - 10. Hamerly-Svea-Vallers
- Sandy loams and loamy sand:
  - 8. Ulen-Embden-Hecla

Clay Soils of Glacial Lake Plains
- Silty clay, loams, and silt loams:
  - 2. Fargo-Hegne
  - 9. Glyndon-Gardena

Very Limy Soils of Subhumid Grassland
- Loams, silt loams, and silty clay loams:
  - 1. Bearden-Glyndon
  - 9. Hamerly-Svea-Vallers
- Loams and clay loams
  - 7. Glyndon-Renshaw and Glyndon-Vallers
- Sandy loams and loamy sand:
  - 8. Ulen-Embden-Hecla
- Saline silt loams and silty clay loams:
  - 5. Strongly saline
  - 4. Glyndon-Bearden (moderate saline)

Soils of Stream Valleys
- Loams and silty clay:
  - 6. Buse-Zell-Fairdale
  - 3. Cashel-Fairdale-Zell

	Drift Plains	Agassiz Lake Plain	Souris Lake Plain	Devils Lake Plain	Dakota Lake Plain	Turtle Mountains	Prairie Coteau
Drainage	Mostly Integrated Partly non-integrated	Integrated to poorly integrated	Integrated Non-integrated	Internal	Integrated	Non-integrated	Non-integrated Integrated
Streams	Perennial Intermittent	Perennial Intermittent	Perennial Intermittent	Intermittent Ephemeral	Perennial	Nearly absent or very short segments Ephemeral	Intermittent Perennial
Landform	Ground moraine End moraine Outwash plains Meltwater channels	Lake plain Delta-lake plain End moraine Beaches Beach scarps	Sand plain Lake plain	Lake plain Ground moraine	Lake plain Sand plain End moraine	Dead-ice moraine	Dead-ice moraine End moraine
Age of Drift Radio-Carbon Dates	Lt Wisconsinan	Lt Wisconsinan 9,900 10,080 10,960	Lt Wisconsinan	Lt Wisconsinan	Lt Wisconsinan	Lt Wisconsinan	Lt Wisconsinan

TABLE 1

Characteristics of the seven districts of the Western Young Drift section in North Dakota

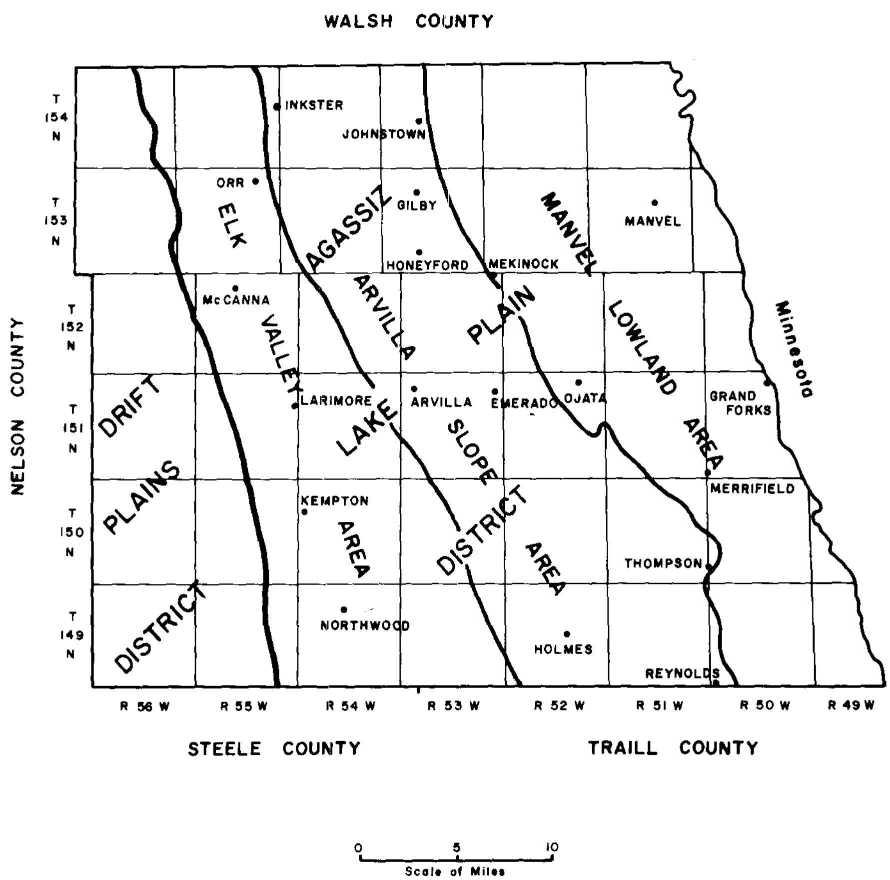

FIGURE 3. Physiographic units of Grand Forks County.

Drift Plains District

The Drift Plains, the largest physiographic district in North Dakota, includes most of the area east of the Missouri Coteau except for lake plains and upland areas. Characteristically, it is a lowland prairie situated upon a gently rolling ground moraine area interrupted by ridged end moraines and flat outwash plains.

The Drift Plains district in Grand Forks County is characterized by ground moraine on Cretaceous bedrock. Its eastern boundary is placed at the westernmost extent of glacial Lake Agassiz deposits. This boundary occurs at an elevation ranging from 1,160 to 1,170 feet above sea level. The Drift Plains reach an elevation of 1,500 feet above sea level along the western county boundary. This rise of the land surface is a southern extension of the more conspicuous Pembina escarpment of Cavalier, Pembina, and Walsh Counties. The underlying bedrock escarpment ranges in elevation from about 800 to 1,400 feet above sea level and the bedrock outcrops in the valley walls of the deeper drainage.

Agassiz Lake Plain District

The Agassiz Lake Plain district includes a large area of eastern North Dakota and northwestern Minnesota. It is a flat area that slopes almost imperceptibly toward the Red River of the North. Modifications on the lake plain include short segments of end moraine, beach ridges and scarps, and tree-lined river valleys.

The westernmost boundary of the Agassiz Lake Plains district is on the west side of the Herman strandline except in northwestern Grand Forks County where it is along the west edge of an outwash plain. The lake plain slopes from an elevation of 1,060 to 1,070 feet above sea level in western Grand Forks County northeastward to an elevation of about 800 feet above sea level in northeastern Grand Forks County.

The Elk Valley area is mainly a delta-outwash plain. The other landforms of this area are an end moraine and beach ridges. The Arvilla slope area is mostly ground moraine planed by the receding waters of glacial Lake Agassiz. Beach ridges are numerous and conspicuous in this area. The Manvel lowland area is essentially a flat surface on lake deposit.

Present drainage

Present streams.–Grand Forks County is in the Red River drainage basin. Perennial streams include the Red River of the North and its tributaries the Forest, Turtle, and Goose Rivers. All of the remaining streams are intermittent. The consequent tributary streams flow generally east and northeast as determined by the eastern slope of the Pembina escarpment and the northeastern slope of the lake plain.

Drainage pattern.– In western Grand Forks County the streams have a parallel drainage pattern (pl. 2) with regular spacing of parallel or near parallel streams. It is best developed in the areas of pronounced slope on the Pembina escarpment, especially in the area west and northwest of Larimore.

The streams in an area 10 miles wide trending northwest-southeast from Inkster to Reynolds have a rectangular drainage pattern. Both the main stream and its tributaries have right-angle bends where they cross the beach ridges. The streams are subparallel to parallel, aligned along the strike of the beach ridges.

Drainage texture.–The relative spacing of the surface drainage lines (drainage texture), is influenced by precipitation, permeability of mantle, rock, amount of relief, and topography. The western part of the county has a fine texture with an abundance of drainage lines due to the influence of the impermeable till and shale and the high relief. The Elk Valley area has a coarse texture and except for perennial streams crossing the area, it has a general lack of drainage lines, due to permeable sand and gravel surface. The area of rectangular drainage has a medium texture, a moderate number of drainage lines, due to the impermeable till, beach ridges, and very gentle, smooth slopes. The eastern part of the county is transitional from a medium to a coarse texture, due to the influence of the impermeable silty clay and the nearly flat plain. The extreme eastern part of the county is very poorly drained. Numerous intermittent streams terminate in the flatness of the lake plain, and ditches have been constructed to extend the drainage to the Red River (pl.2).

BEDROCK STRATIGRAPHY

Beneath the glacial drift of Grand Forks County, up to 2,050 feet of westward-dipping sedimentary rocks of Paleozoic and Mesozoic age overlie igneous and metamorphic rocks of Precambrian age (fig. 4). All of these Paleozoic and Mesozoic sedimentary rocks thin to the east (fig. 5). Erosion that caused the thinning occurred prior to deposition of the Paleozoic rocks, prior to deposition of the Mesozoic rocks, and prior to deposition of the glacial drift. A few small outcrops of the Mesozoic Pierre and Niobrara Formations occur along the Pembina escarpment in western Grand Forks County (pl. 1).

Precambrian rocks

Composition of the Precambrian rocks, based on samples available from 6 oil well tests, indicate that granites underlie the Paleozoic rocks in northern Grand Forks County. In southeastern Grand Forks County, samples from test wells 2616 and 2669 of this study were identified as amphibolite by Dr. F. R. Karner, University of North Dakota. In these test wells, the metamorphic rock lies immediately below glacial drift. Test well 2616 was drilled in the SW 1/4 sec. 11 T. 149 N., R. 50 W., and test well 2269 in the SE 1/4 sec. 7, T. 159 N., R. 49 W. Goldich, and others, (1966, p. 5386) indicate that Grand Forks County is underlain by Precambrian rocks greater than 2.5 billion years old, or early Precambrian age.

Paleozoic rocks

ORDOVICIAN

The Ordovician rocks in Grand Forks County consist of three formations of the Winnipeg Group plus the overlying Red River and

Era	SYSTEM	GROUP	FORMATION	LITHOLOGY	THICKNESS (feet)	DEPTH TO UNIT(feet)
MESOZOIC		Unc.				
	Cretaceous	Montana	Pierre	Shale	0-200	0-40
			Niobrara	marlstone	0-115	0-190
		Colorado	Carlile	shale	0-260	15-305
			Greenhorn	marlstone	0-95	210-600
		Dakota	Belle Fourche	shale	0-130	240-690
			Newcastle	sandstone	0-82	120-830
			Skull Creek	shale	0-40	155-890
			Fall River - Lakota	sandstone, shale siltstone, & claystone	0-285	95-920
		Unc.				
	Jurassic			siltstone	0-20	1,030-1,070
		Unc.				
PALEOZOIC	Ordovician	Big Horn	Stony Mountain	dolomite & shale	0-135	730-1,100
			Red River	dolomite & limestone	0-585	150-1,250
		Winnipeg	Roughlock	shale	0-43	
			Icebox	shale, sandstone, & limestone	0-169	215-1,830
			Black Island	sandstone	0-19	
		Unc.				
	Precambrian			granite & Amphibolite		315-2,050

FIGURE 4. Bedrock stratigraphic Column of Grand Forks County, North Dakota.

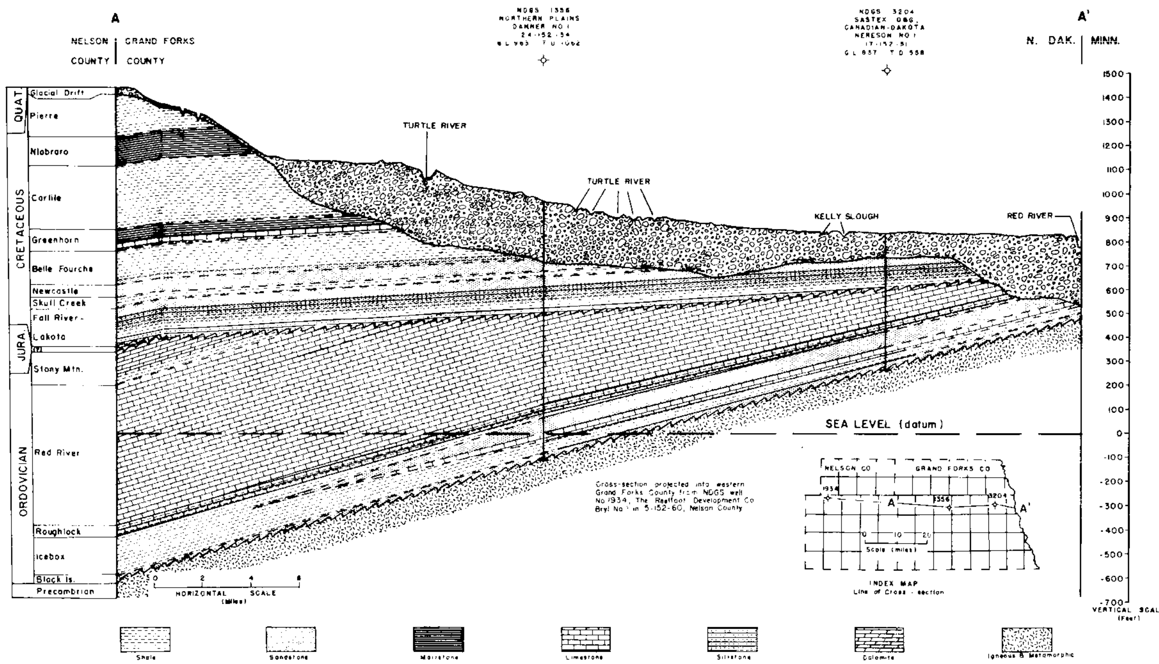

FIGURE 5. Startigraphic cross section of Grand Forks County.

Stony Mountain Formations. All the Ordovician rocks are of marine origin. The Ordovician rocks range from 0 to 940 feet thick. They thin eastward by erosion and are absent in southeastern Grand Forks County (pl. 3, subcrop map).

The three formations of the Winnipeg Group are the Black Island, Icebox, and Roughlock. In Grand Forks County, the Black Island is a thin, basal fine-to coarse-grained quartzose sandstone. The Icebox is generally a greenish-gray shale, but in central Grand Forks County it consists of a facies that can be subdivided into (1) a basal yellowish-green, dark gray, and pale red shale, (2) a light brownish-gray, silty limestone, (3) a fine-to coarse-grained quartzose sandstone with thin interbeds of greenish-gray shale, and (4) an uppermost greenish-gray or pale red shale. The overlying Roughlock consists of interbedded calcareous and silty greenish-gray shale and light-gray limestone.

Transitional with the Roughlock Formation, the overlying Red River Formation is generally a light-yellowish-gray and pinkish-gray, crystalline to granular, dolomitic limestone. Conformable over the Red River Formation, the Stony Mountain, although not penetrated by wells in this county, should be present in the subsurface of western Grand Forks County. The Stony Mountain Formation in eastern North Dakota consists of a lower pale red, fossiliferous shale interbedded with dolomite and an overlying dense, finely crystalline, light orange-pink and white dolomite.

Mesozoic rocks

The Mesozoic rocks in Grand Forks County consist of several Cretaceous formations of the Dakota, Colorado, and Montana Groups, and possibly an undifferentiated Jurassic rock unit. Except for the basal Cretaceous, these rock units were deposited in a marine environment. The basal Cretaceous rocks are probably a mixture of continental and marine beds. The Mesozoic rocks, 0 to 1,080 feet thick, thin eastward by erosion and deposition.

JURASSIC

The undifferentiated Jurassic rock unit, which was not penetrated in any well, but may occur in the subsurface of western Grand Forks County, consists of pale-reddish-brown siltone, claystone, and fine-grained sandstone. Its presence is projected on the basis of thicker Jurassic units which lie to the northwest in Nelson, Walsh, and Ramsey Counties.

CRETACEOUS

The Lower Cretaceous Dakota Group includes the Fall River-Lakota Formations undifferentiated. In northern Grand Forks County, these formations consist of basal, pale red and light gray claystones and siltstones interbedded with fine-grained quartzose sandstones. The basal beds are overlain by interbedded gray shales and siltstones and fine- to coarse-grained quartzose sandstones. Clay makes up most of the matrix in the sandstones. Minor constituents in this section are small crystals of pyrite, fragments of coal and carbonized wood, and spherulites (pellets) of light-brownish-gray siltsone. Generally the uppermost unit, the Fall River Formation, is a fine-to coarse-grained, clean quartzose sandstone. This sandstone is transitional between the underlying beds that were deposited in the mixed environment and the overlying beds that were deposited in the marine environment. In southern Grand Forks County, the Fall River-Lakota interval is thicker, but siltstone and fine-grained sandstone are the more prevalent lithologies. The Fall River-Lakota interval is not over 200 feet thick in northern Grand Forks County, but it is up to 285 feet thick in the southern part of the county.

Overlying the Fall River Formation, the Skull Creek Formation is a medium-to dark-gray, silty and sandy shale. This formation thins to the east both by erosion and non-deposition. The Skull Creek Formation is overlain by the Newcastle Formation, which in Grand Forks County consists of silty, fine-grained quartzose sandstones and interbedded gray shales. To the west in Nelson County and counties to the north and south, the sandstones of the Newcastle Formation are thicker, coarser grained, and less argillaceous.

Overlying the Newcastle Formation, the Belle Fourche Formation of the Colorado Group is a dark-gray, flaky to massive and spongy shale with thin interbeds of light-gray and light-bluish-gray bentonite clays. The basal part of the Belle Fourche Formation is silty and sandy. Conformable above the Belle Fourche Formation, the Greenhorn Formation consists of medium-dark-gray to dark-gray marlstone, calcareous shale, and thin beds of limestone. Interbedded with the shales, marlstones, and limestones are thin beds of light-bluish-gray bentonitic clays. Fossils of the minute coccolithophorids and the foraminifera, particularly *Globigerina sp.*, are common; fragments and calcite prisms from the oysters *Inoceramus sp.*, are also common. A minor constituent is crystals of pyrite. The Greenhorn Formation thins eastward to extinction due to erosion and non-deposition.

Above the Greenhorn Formation, the Cariile Formation is a medium-and dark-gray, flaky to spongy shale that contains thin interbeds of light-gray and light-bluish-gray bentonitic clays. Some thin beds of calcareous shale are also present, although the formation is generally non-calcareous. The overlying Niobrara, the uppermost formation of the Colorado Group, is a light-gray to light-brownish-gray marlstone and shale sequence. Tests and fragments of the protists are common, and most of the whitish flecks (specks) of the formation are probably coccolithophorid remains.

The Niobrara is exposed in four small outcrops on the slopes of the Pembina escarpment in western Grand Forks County. The largest exposure measured is in the NE 1/4 sec. 23, T. 152 N., R. 56 W., a few feet north of the intersection of a north-south gravel road with U. S. Highway 2. Here, the calcareous shale and marlstone is highly jointed at the base of the exposure and has a slight color banding. About 10 feet above the base of the exposure is a horizontal band, not more than 3 inches thick, in which clusters of fossil oysters were found. The fossil oysters were identified by Dr. A. M. Cvancara, University of North Dakota, as *Crassostrea congesta* (Conrad). The contact of the Niobrara with the overlying Pierre Formation is poorly exposed. A detailed description of the beds at the contact is given in the appendix of this report. Where exposed in Grand Forks County, the contact of the Niobrara and Pierre Formations ranges from about 1,265 feet to 1,271 feet above sea level.

The lowest part of the Pierre Formation, poorly exposed in western Grand Forks County, consists of a bed of thin, alternating dark-gray and light-yellowish-gray bentonitic clays. The bed is not more than 5.5

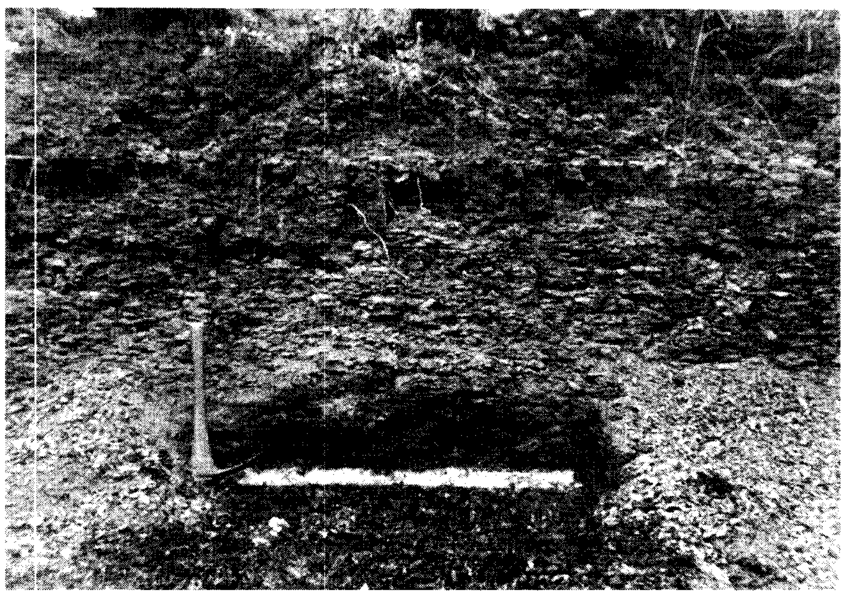

FIGURE 6. Bentonitic clay bed in Pembina member of the Pierre Formation, western Grand Forks County. Photo taken at the roadcut exposure in the SW 1/4 SW 1/4 SW 1/4 sec. 4, T. 153 N., R. 56 W. Exposure faces south.

feet thick. This is probably the basal part of the Pembina Member of the Pierre Shale as defined by Gill and Cobban (1965) for eastern North Dakota. Immediately above the basal beds, little of the shale is exposed. In the Moraine Township section (NW 1/4 sec. 1, T. 151 N., R. 56 W.), however, the bentonitic clay beds are overlain by 5 feet of olive-gray shale. To the north, in sec. 4, T. 153 N., R. 56 W., a stratigraphically higher bentonitic clay was found in the Pembina Member (fig. 6). This clay, at elevations of about 1,280 feet above sea level, lies above the basal bentonitic clays that were measured further south in the Moraine Township section.

Above the Pembina Member of the Pierre Shale, about 2 feet of light-brownish-gray, calcareous shale is exposed within a badly slumped section of gray shale in the NE 1/4 SE 1/4 sec. 9, T. 152 N., R. 56 W. Small ironstone concretions are also common on the surface of the slumped beds. At elevations of 1,330 to 1,340 feet above sea level, these beds may be equivalent to a part of the Gregory Member as defined by Gill and Cobban (1965, p. A5 and A10-14).

Higher in the Pierre Shale, at elevations from 1,350 to 1,402 feet above sea level, the slumped block of shale that is exposed in the NE 1/4 sec. 6, T. 152 N., R. 56 W., about 1.5 miles north of Niagara, may be made up of beds equivalent to the DeGrey Member as defined by Gill and Cobban (1965, p. A14-15). The beds in this slumped section are olive-gray to dark-gray shales and claystones that contain thin bentonitic clay beds. Dark manganese coatings occur along bedding planes and on the limestone concretions. Further south in a small exposure, the Pierre Shale in the NW 1/4 NE 1/4 sec. 27, T. 151 N., R. 56 W., consists of fractured, olive-gray shale with a few manganese concretions. The bed in this small section is at elevations of 1,370 to 1,385 feet and may be a part of the DeGrey Member.

The only other bed exposed in Grand Forks County that is at higher elevations is in the NE 1/4 sec. 20, T. 150 N., R. 56 W., along the Goose River. Here, up to 14 feet of badly fractured, flaky to blocky, jointed, medium-to dark-gray shale is exposed at elevations from 1,430 to 1,445 feet above sea level. The bed in this exposure may be a part of the Odonah Member as defined by Gill and Cobban (1965, p. A15). The shale here is harder than that examined lower in the section.

Bedrock topography

The bedrock topography in Grand Forks County was formed mostly during late Tertiary and early Quaternary time. There is no record in Grand Forks county of the very latest Cretaceous and earliest Tertiary rocks that are present in western North Dakota, but the streams that formed the bedrock topography in Grand Forks County may have removed this record. The topographic bedrock map shows that the lowest elevations are in the southeastern part of Grand Forks County (pl.3). In general, the eastern half is a broad, dissected plain, and the western half is a gently eastward sloping surface. A hilly topography and a deep preglacial stream valley exist in the southeastern part of the county.

Preglacial drainage

There has been much speculation about the direction of the preglacial drainage in the Red River valley. Recent theories held that the preglacial Red River drainage basin included eastern North Dakota and western Minnesota and was joined by the Cheyenne drainage basin of north-central South Dakota. This integrated drainage consisted of eastward, northeastward, and northward flowing rivers that joined a main trunk stream in the Red River valley that flowed northward to Canada and Hudson Bay.

The ancient Cheyenne River flowed eastward in South Dakota from Armstrong County to Brown County where it made a sharp bend to the north into North Dakota. In Dickey County it joined the preglacial Red River (Flint, 1955, pl. 7 and p. 148). The preglacial Red River flowed northeastward from Dickey County to Traill County and has been shown as flowing northward along the State boundary into Canada (Lemke and Colton, 1958, fig. 2).

The bedrock topographic map indicates that the drainage in southeastern Grand Forks County slopes toward the south. This suggests that the main preglacial drainage in the Red River valley was further east than the present channel, and the southward drainage in southeastern Grand Forks County was probably a tributary of that system. In north-central Grand Forks County the bedrock slopes are to the north.

GLACIAL STRATIGRAPHY

Quaternary

Glacial drift

The late Wisconsinan glacial drift is the most extensive surface lithology in Grand Forks County. The bedrock is at the surface only in small exposures, and most of the Holocene sediments occur only in the stream valleys or as wind-blown material. The thickness of the glacial drift ranges from 0 to 455 feet (fig. 7). It has been divided into five drift sheets, the upper three of which are thick and extensive in area. The stratigraphic relationships and lithologies of the drift sheets are illustrated by the several cross-sections (pl. 4).

Beginning with the oldest, the numbered drift sheets are as follows:

(1) A buried brownish-gray to olive gray till and associated olive gray and light brownish-gray sandy lake clay and silt. This drift sheet occurs in the deeply buried preglacial river valley of southeastern Grand Forks County.

(2) A buried olive-olive-gray silty till olive-gray lake silt and clay that occurs generally in the deeply buried preglacial river valleys of southeastern Grand Forks County.

(3) An extensive-buried olive-gray and brownish-gray, gravelly to silty till that may be partially oxidized. It is overlain by buried lake clays and silts in eastern Grand Forks County.

(4) An extensive buried olive gray, sandy to silty till that contains lenses of sand and gravel and lake silts and clays.

(5) A surficial olive gray silty till overlain by the clays and silts of glacial Lake Agassiz in eastern Grand Forks County. In western Grand Forks county, the till of this drift sheet is overlain by ice-contact deposits, by outwash and lake deposits in the form of a delta, and by strandline deposits.

The drift sheets comprise units that represent at least three glaciations prior to the deposition of the surficial till and lake sediments. The buried lake clay and silt units are deposits of glacial

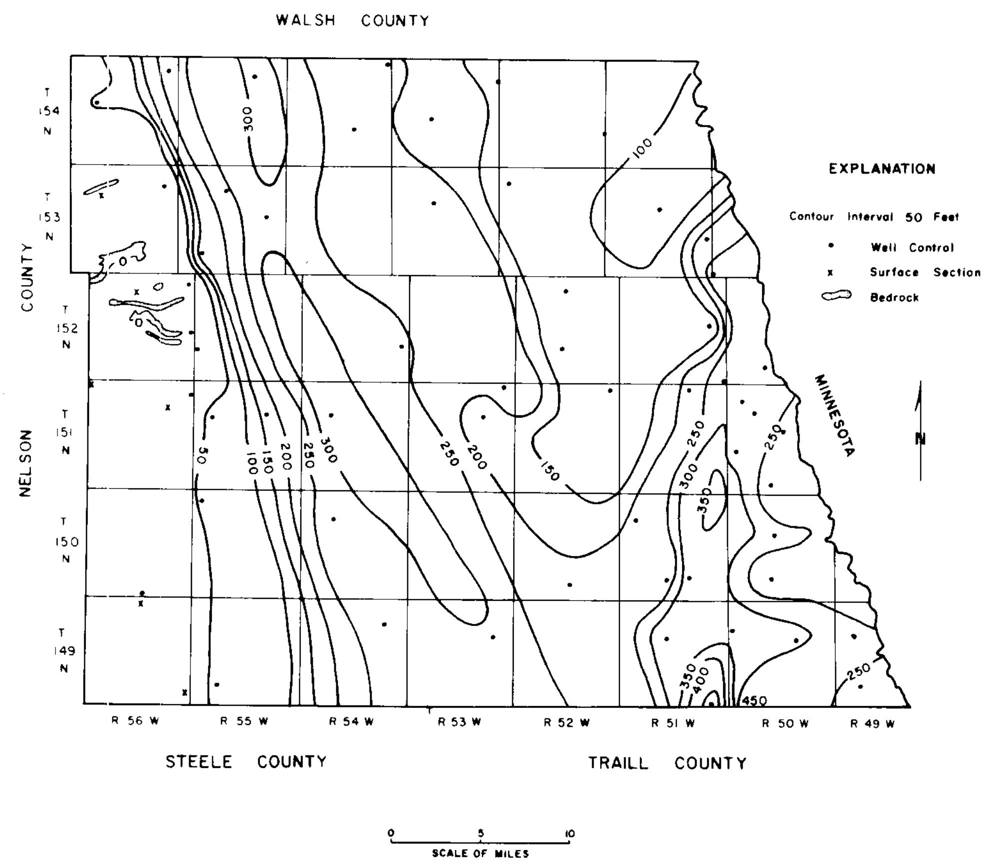

FIGURE 7. Thickness map of glacial drift in Grand Forks County.

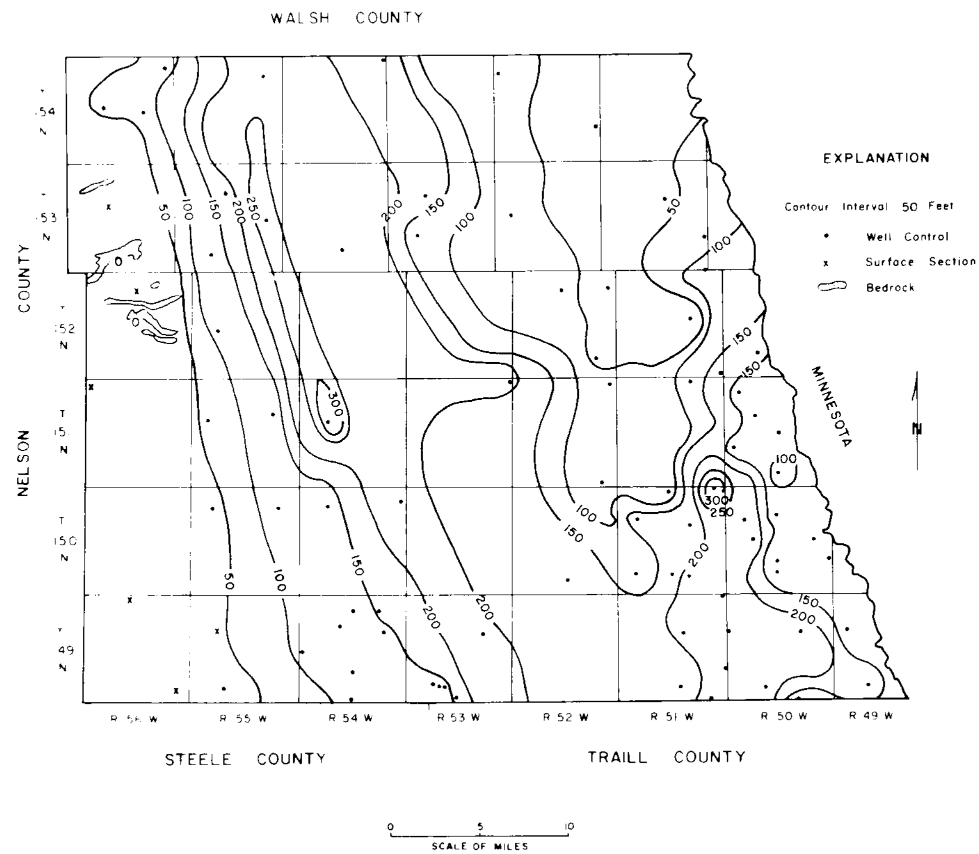

FIGURE 8. Thickness map of glaical till in Grand Forks County.

lakes formed before the late Wisconsinan Lake Agassiz. All of the drift sheets consist of three basic lithologic groups: (1) till, (2) sand and gravel, and (3) clay and silt.

Till–The till in Grand Forks County, both surface and subsurface, is an unsorted clayey mixture of stones, gravel, sand, silt, and clay, the composition of which varies over short distances. Till has also been referred to as stony clay-loam, sandy mud, and boulder-clay. Usually less than 5 per cent of the surficial till is coarser than granular size. However, the textural composition of the till generally becomes coarse in the subsurface, and some of the buried drifts are locally quite stony.

Counts of pebbles ranging between 1/2 inch and 2 inches in diameter, made in the field show an average of 53 per cent carbonate fragments, 22 per cent igneous and metamorphic fragments, 22 per cent shale fragments, and 3 per cent miscellaneous fragments. The miscellaneous group includes fragments of iron-claystone and manganese concretion, common constituents in the Cretaceous shales, as well as fragments of sandstone, marlstone, or white-flecked, dark gray limestone. Most of the pebbles of the granitic and metamorphic rock fragments are highly weathered. Field observations indicate a large increase in shale fragments of granule size, which were not included in the field count.

Boulder and cobble counts made in the field show that 76 per cent are granitic igneous boulders, 9 per cent are other igneous boulders, 14 per cent are carbonate boulders, and 1 per cent are boulders of miscellaneous rock. The miscellaneous rocks are generally cobbles of iron-claystone concretions, sandstone, and quartzite.

Observations of minor constituents and color show that the surficial till is generally oxidized to a depth of about 20 feet. The first 7 to 10 feet are light-brownish-gray and the remainder light-olive-gray. Minor constituents include iron oxide concentrations that indicate root stems that were planed during deposition of the beaches and lake sediments of Lake Agassiz, concentrations of gypsum salts near the land surface in the poorly drained areas of till, and disseminated calcium carbonate that causes most of the glacial drift to be calcareous. Thickness of the till varies with the configuration of the underlying bedrock topography. The thickness ranges from 0 to 310 feet (see fig. 8) and reaches a maximum along the base of the partly buried Pembina bedrock escarpment in western Grand Forks County and in the buried valley of southeastern Grand Forks County.

Sand and gravel–Most of the surficial sands and gravels in Grand Forks County occur either as an extensive sheet of outwash and lake deposits in the western part of the county or as narrow, linear strandline deposits associated with glacial Lake Agassiz. In addition, a few isolated, glaciofluvial, ice-contact deposits of sand and gravel occur on the ground moraine in western Grand Forks County (pl. 1).

The surficial sands and gravels vary in texture from the relatively dirty, bouldery, sandy gravels and gravelly sands of the glaciofluvial, ice-contact deposits to well-sorted, fine-grained sands of the beach deposits. The sandy gravels are found mostly in the outwash plain of northwestern Grand Forks County or in the uppermost part of the more extensive strandline deposits, for example, the Campbell, McCauleyville, and Herman beaches. Several factors have controlled the character of the gravel of the strandline deposits; they include the length of time involved in their development, the kind and texture of source material, the weather of the time, and the slope of the glaciated land surface. In areas of till, the gravel content in the beaches generally increases where the slope of the till surface changes due to a localized rise or where there is a change in magnitude of the general eastward slope.

Bedding in the strandline deposits varies from prominent, thin and almost horizontal to thick, distinct, and cross-bedded. The bedding planes range from sharp to diffuse. The bedding in the ice-contact deposits and outwash is thin to thick, distinct to faint, and cross-bedded to nearly horizontal. Bedding planes are usually obscure. Beds in the ice-contact deposits usually have high dips, due to slump.

Pebble and granule composition of the gravels is similar to that of the till, except gravel generally contains less shale. Shale pebbles are most common in the ice-contact deposits and in the highest strandline deposit, the upper Herman beach. The finer fractions of sand consist mostly of quartz and feldspar fragments, which become angular as the grain size decreases. Although not measured, the rounding of the gravel-size particles in the washed sediments seems to be only slightly more pronounced than that of the gravel-size particles in the till.

The color of the surficial gravel is usually brownish-gray, although where it is made up of shale granules it may be olive gray to black. The surficial sands are usually light-brownish-gray. The color of the subsurface sands is generally olive to light gray.

In the area of outwash and delta deposits in western Grand Forks County, the thickness of the surficial sand and gravel deposits is a maximum of more than 72 feet in test well 2426, in the SW 1/4 sec. 14, T. 154 N., R. 55 W. In the strandline deposits, the thickness ranges from 2 to 3 feet or less in the lower beaches to a maximum of 20 to 30

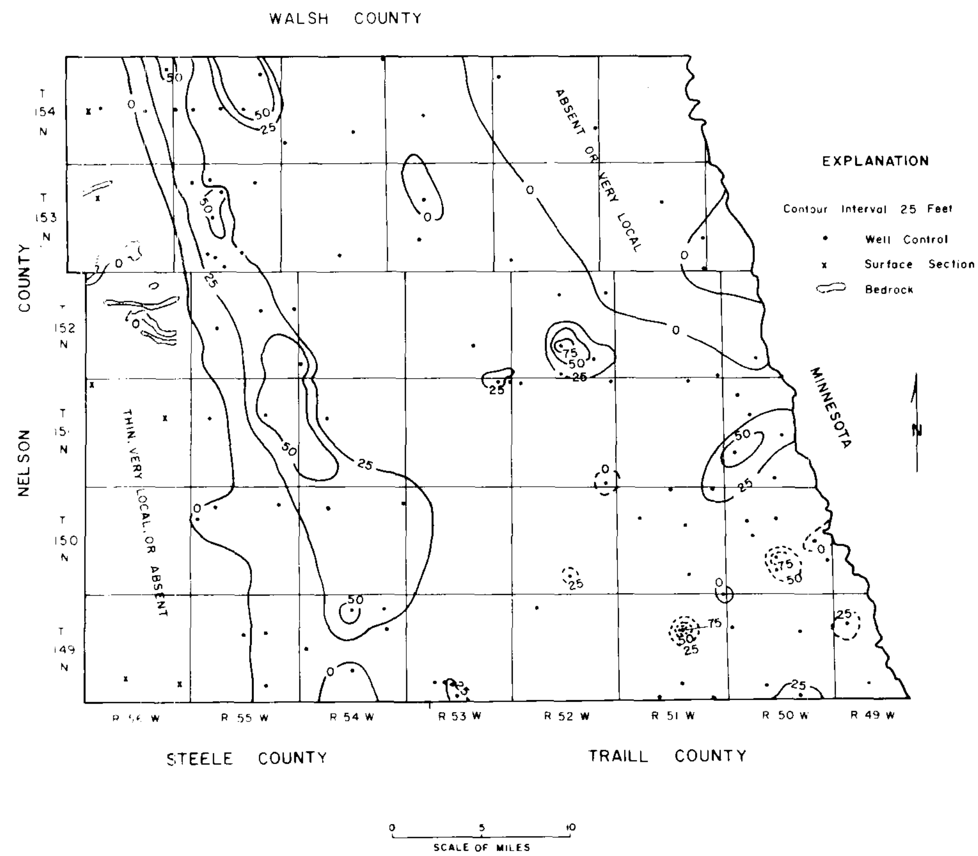

FIGURE 9. Thickness map of glacial sand and gravel in Grand Forks County.

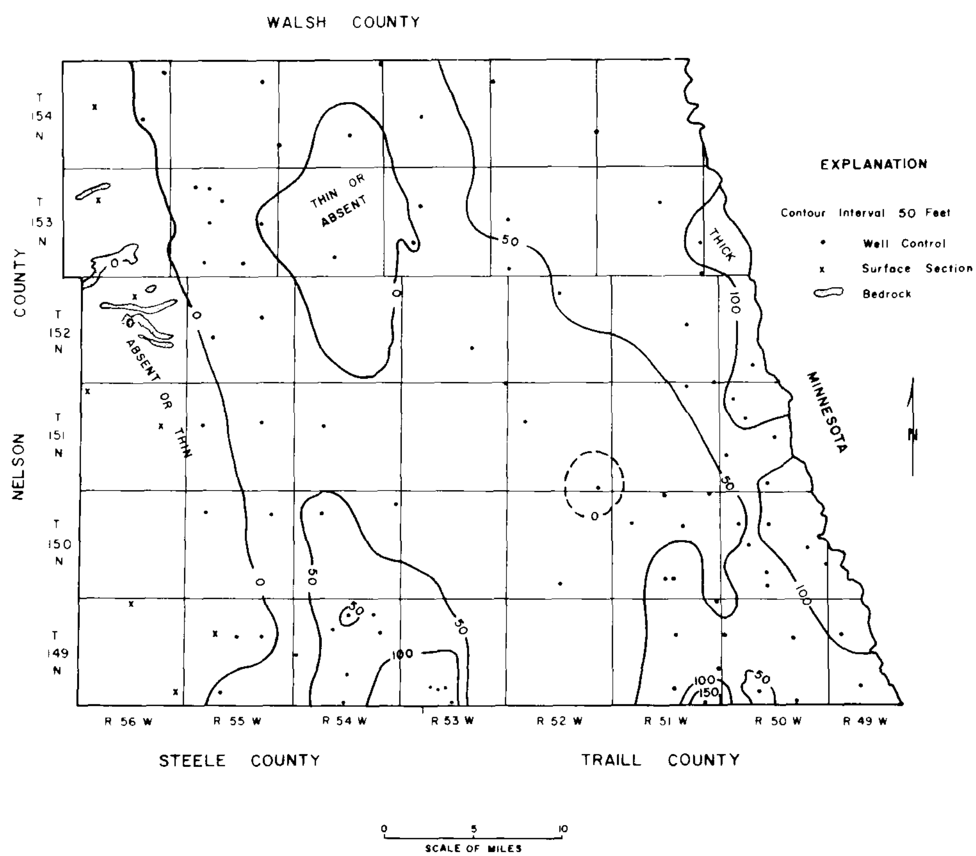

FIGURE 10. Thickness map of glacial clay and silt in Grand Forks County.

feet in the Campbell and McCauleyville beaches, although the sand and gravel in these beaches is usually less than 15 feet thick. The maximum thickness of the subsurface sands and gravels is more than 88 feet in test well 2615, in the NE 1/4 sec. 28, T. 150 N., R. 50 W.

Clay and silt–The clays and silts are mostly lake deposits, but they also occur as alluvium along the river valleys and along the base of the Pembina escarpment in western Grand Forks County. The most extensive lake clays and silts in Grand Forks County are those of glacial Lake Agassiz. The maximum thickness of lake clays and silts penetrated was in test well 1959, in the SW 1/4 sec. 36, T. 149 N., R. 51 W., where they were 155 feet thick; most of the clays and silts are sandy in this well (fig. 10).

The surficial clay and silt of glacial Lake Agassiz is light-yellowish gray to a depth of about 7 feet, light olive gray to about 20 feet, and olive gray at greater depths. Except for a massive surface silt, the Lake Agassiz clays and silts are interbedded with thin to medium, usually distinct bedding. The thickness of this clay and silt reaches a maximum of 95 feet in test well 2607, in the NE 1/4 sec. 25, T. 153 N., R. 51 W. The buried lake clays and silts are generally olive gray to greenish gray, silty, calcareous, tough, and contain enough sulphates to give off a hydrogen sulfide odor.

Fossils–Exposures of fossiliferous sediments are rare in the glacial drift of Grand Forks County. Surface exposures of fossiliferous sediment occur in Turtle River State Park near Arvilla and collections have been made there. The exposure in the SE 1/4 SE 1/4 sec. 36, T. 152 N., R. 54 W., was studied by Tuthill, and others (1965, p. 135-140). In this exposure a 10-inch bed of fossiliferous silty marl is overlain by 6 feet of Campbell beach sand. This marl bed overlies 47 feet of loose, silty till. Tuthill identified 9 species of freshwater mollusks from this marl bed. The identified species are the branchiate gastropods *Valvata tricarinata, Valvata lewisi,* and *Amnicola limosa;* the pulmonate gastropods *Lymnaea humilis, Gyraulus parvus, Helisoma anceps,* and *Physa* sp.; and the pelecypod *Pisidium nitidum* and fragments of the superfamily Naiadacea. The stratigraphic position and elevation of the marl bed indicates it was deposited above the wave-cut scarp of the Campbell strandline. It also antedates the covering beach sands. The marl bed was probably deposited in a lagoon marginal to Lake Agassiz when the lake was forming the Campbell strandline. Later, it was covered by the sands piled onto the back of the beach during periods of storms.

Fossiliferous sediments (sandy silt and clay) were also collected where Tuthill made his collection. These sediments are in the same stratigraphic relationships to the underlying till and the overlying Campbell beach sands. In the NE 1/4 sec. 36, T. 152 N., R. 54 W., gastropod shells of *Helisoma* sp., *Helisoma antrosa, Gyraulus* sp., *Sphaerium* sp., and *Amnicola* sp. were collected. Pelecypod shells collected were unionid fragments and *Pisidium* sp.

In a gravel pit in the Herman beach of southwestern Grand Forks County (NE 1/4 SW 1/4 NW 1/2 sec. 2, T. 149 N., R. 55 W.), a 2-inch silty-clay bed was found to contain a few fossil gastropods. This clay bed is below 5 feet of thickly bedded gravelly sand and overlies a pebbly till surface. The clay bed occurs under the west side of the beach and is covered by sand and gravel deposited during storms. The beds of gravel and sand dip westward at 40 degrees and have been tossed over almost horizontal, thin sand and sandy gravel beds that make up the frontal or east side of the beach. The clay was deposited as a marginal lagoon sediment that was later covered by the beach sands.

Glacial phases and associated landforms

Although there is a vertical sequence of 5 drift sheets in Grand Forks County, the late Wisconsinan surficial drift sheet, the youngest, is the only one about which an idea of the succession (phases) of deposition can be readily determined. The older, buried drift sheets were probably deposited under similar conditions, but until further drilling and regional studies are made, only generalized speculations about their deposition can be made. Stratigraphic relationships of the drift sheets are shown by cross-sections (pl. 4).

Subsurface glacial phases

If there are any pre-Wisconsinan drift sheets in Grand Forks County, drift sheet 1 that lies buried in southeastern Grand Forks County qualifies because of stratigraphic position; it is overlain by all the other drift sheets. This older drift sheet, 0 to 143 feet thick, is made up of lake silts and clays and partly oxidized till. The glacial drift was deposited in the deep preglacial valley incised into the Precambrian and Ordovician rocks. The map (fig. 11) shows the relationships of the lake sediments and the till dam that blocked the valley. Whether this is the original extent of the drift sheet or whether this is an erosional remnant is difficult to determine.

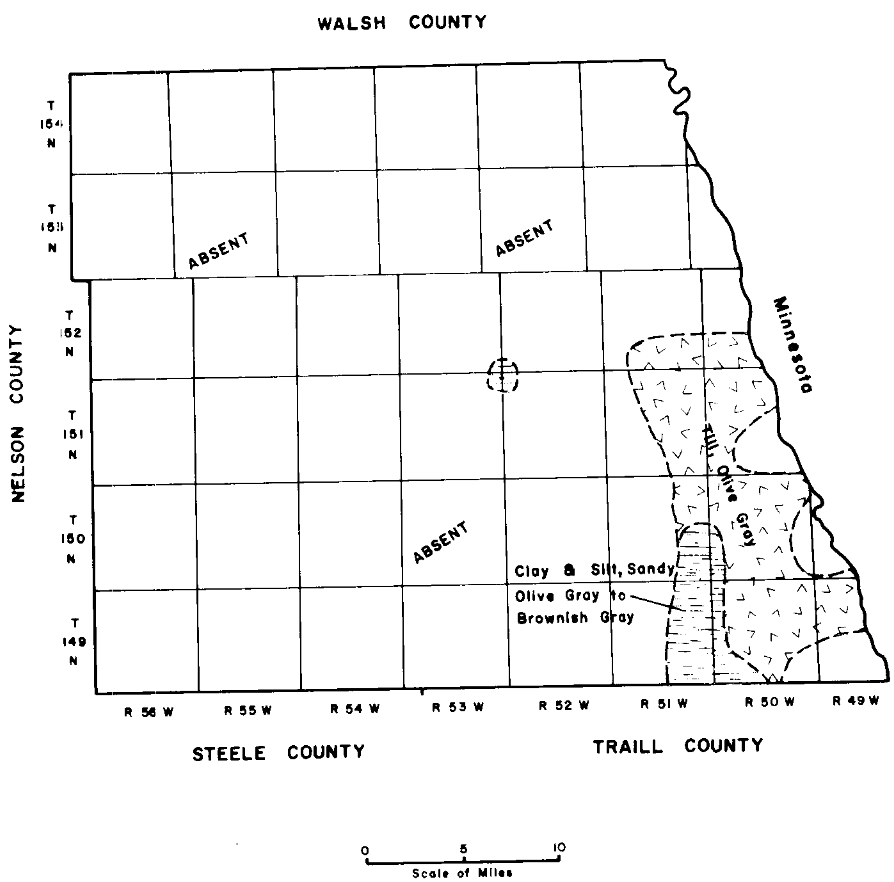

FIGURE 11. Areal extent of glacial drift sheet No. 1 in Grand Forks County.

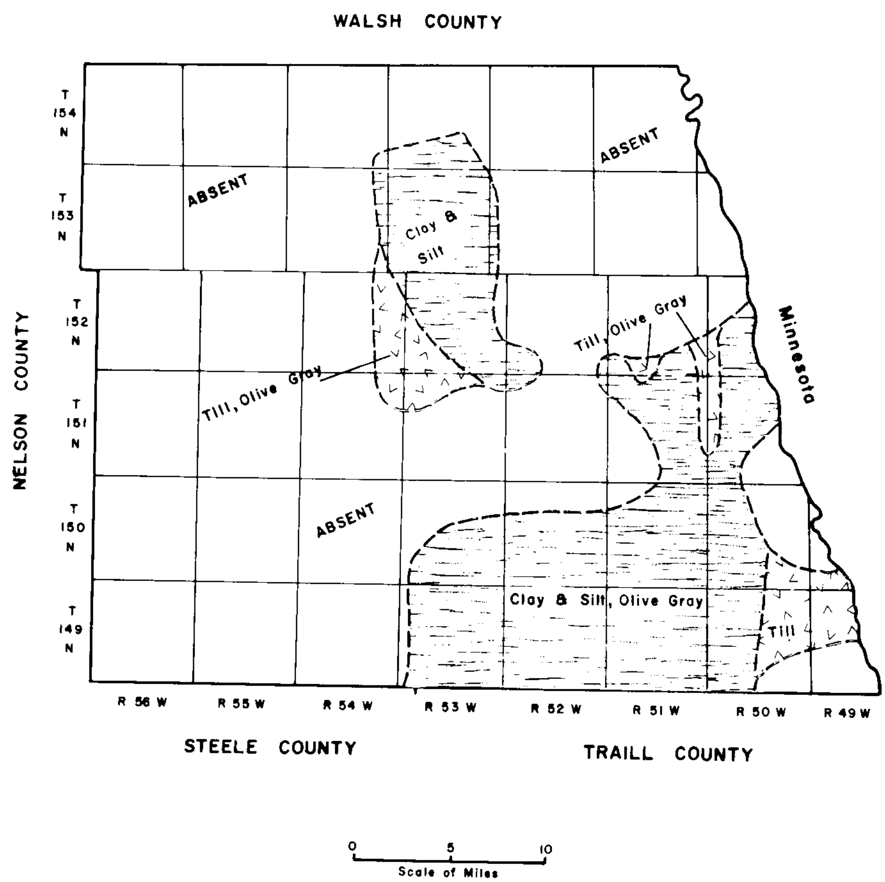

FIGURE 12. Areal extent of glacial drift sheet No. 2 in Grand Forks County.

Drift sheet 2 overlies the older drift of southeastern Grand Forks County and may also be pre-Wisconsinan. Whatever its age, drift sheet 2 consists of till, gravel, and lake silts and clays that are 0 to 140 feet thick. The lake clays and silts lie above the till and are at elevations between 650 and 740 feet above sea level. The position of the lake sediments above the till suggests that the glacial ice of this phase of deposition served as a dam. In addition, gravel occurs as a tabular body in the till in the vicinity of the City of Grand Forks. This gravel deposit is continuous enough to signify a break in deposition of till, but the horizon could not be extended to subdivide the equivalent till of the surrounding area. The approximate areal extent of the till and lake sediments is shown by Figure 12.

Above the lake sediments and till of drift sheet 2, the till of drift sheet 3 extends at least up onto the higher elevations of the Pembina escarpment in western Grand Forks County. This means it overlaps all the older drifts. Glacial sediments had begun to fill the valley, and possibly during this glaciation a thin veneer of drift was deposited outside the Red River Valley. Because drift sheet 3 is more coextensive with the overlying younger drift sheets that are late Wisconsinan age, it is considered to be no older than early Wisconsinan. Drift sheet 3 consists of till, lake sediments, and in northwestern Grand Forks County, a tabular deposit of sand and gravel.

The till of drift sheet 3 ranges from 0 to at least 110 feet thick. It is usually olive gray, but in eastern Grand Forks County a part of it is brownish-gray. Several things indicate that the coloration is due to the local incorporation of the underlying bedrock and not to weathering. The underlying bedrock is of the Winnipeg Group which commonly has brown and red coloration. The bedrock in this area consists of sandstone, limestone, and shale; consequently, the brownish-gray till is more sandy and contains a greater number of carbonate pebbles. The brownish-gray coloration of the till is uniform rather than mottled. Mottled coloring is characteristic of oxidized till. Lithologic descriptions of test well samples indicate parts of the till are yellowish-browns, which may indicate oxidation, although the yellowish-brown coloration is also characteristic of the weathered Winnipeg sandstones. In addition, the limited areal extent of this particular till negates the idea it is a different till sheet. The grayish-brown till is overlain by unoxidized, dark olive-gray lake sediments that were probably deposited during the closing phases of this glaciation.

The areal extent of the brownish-gray till, the associated olive-gray till, and the lake sediments is shown on Figure 13. The lake sediments are at elevations of 740 to 830 feet above sea level and lie above the

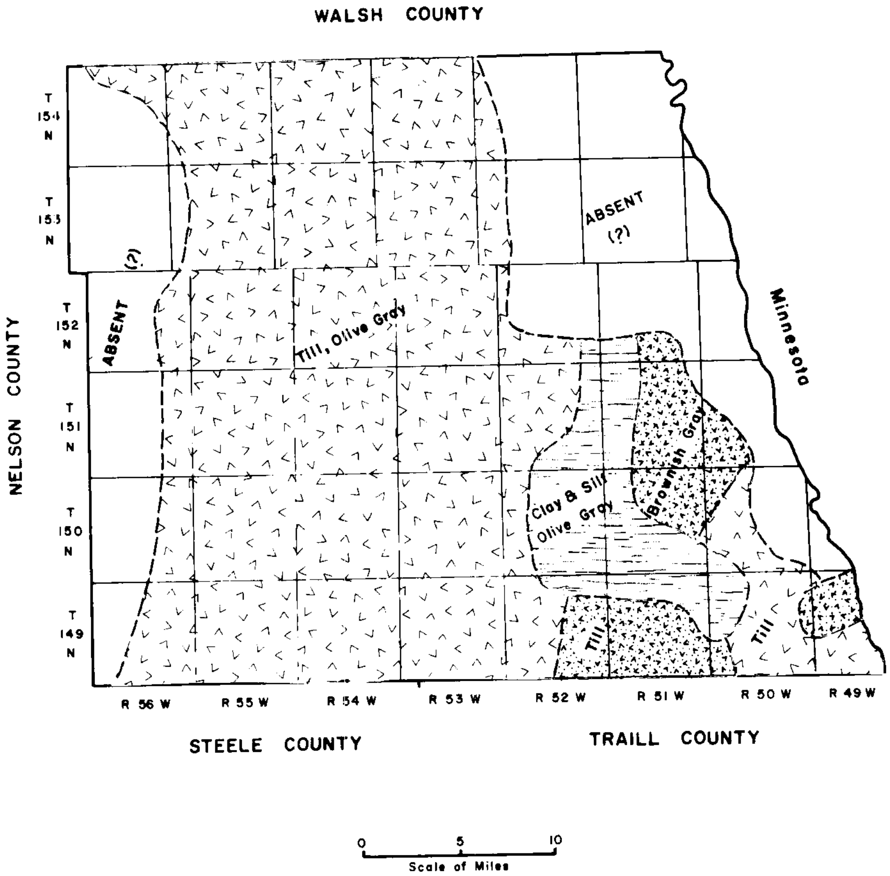

FIGURE 13. Areal extent of glacial drift sheet No. 3 in Grand Forks County.

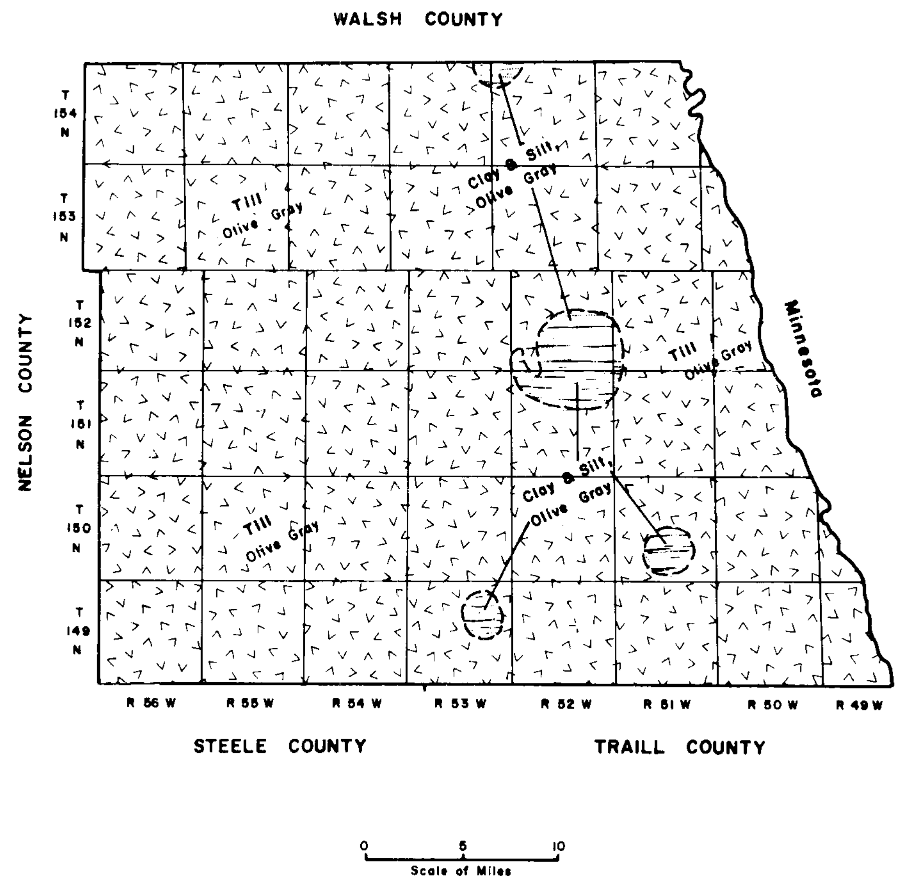

FIGURE 14. Areal extent of glacial drift sheet No. 4 in Grand Forks County.

tills of drift sheet 3. The lake sediments and the tills are overlain by drift sheet 4.

Drift sheet 4 is extensive and extends far beyond the confines of the Red River Valley. In Grand Forks County the drift of this sheet is mostly till with only isolated, thin gravels and lake sediments. The thickness of drift sheet 4 is as much as 150 feet, but it probably averages 80 to 90 feet. The age of the drift sheet is late Wisconsinan, and it may be equivalent to the surface drift deposited during the Burnstad phase in central and northwestern North Dakota. The areal extent of the till and associated lake sediments in Grand Forks County is shown on Figure 14. The drift sheet is overlain by tills, lake clays and silts of drift sheet 5, which were deposited in Grand Forks County during the Luverne, Edinburg, and Lake Agassiz phases of glaciation. Drift sheets 4 and 5 are closely affiliated and most of the evidence for their separation is based on the buried lake clays and silts and glaciofluvial gravels. In the lower elevations of the Lake Agassiz plain and beneath the silt and clay deposits of the glacial lake distinguishing the tills of the two drift sheets is usually impossible.

Surficial glacial phases

The glacial phases associated with the deposition of drift sheet 5 in Grand Forks County are phases that followed the maximum advance of this particular glaciation in the area west of the Red River Valley. The maximum advance of this glaciation is now marked largely by the late Wisconsinan Kensal and associated end moraines in eastern North Dakota. During the recession of this glacial ice, several end moraines that signify glacial stillstands were deposited. When the last major stillstand occurred west of the Red River Valley in Grand Forks County, the Luverne end moraine was deposited in a north-south trend through western Steele County. In the Red River Valley the last glacial stillstand in Grand Forks County is marked by the Edinburg end moraine. After deposition of this end moraine, the development of Lake Agassiz and its associated landforms took place in Grand Forks County.

Luverne Phase

The drainage during the deposition of the drift of the Luverne phase in western Grand Forks County was in small meltwater trenches cut in the drift. The trenches formed as the glacier ice front receded down slope to the east. These southeastward trending trenches carried

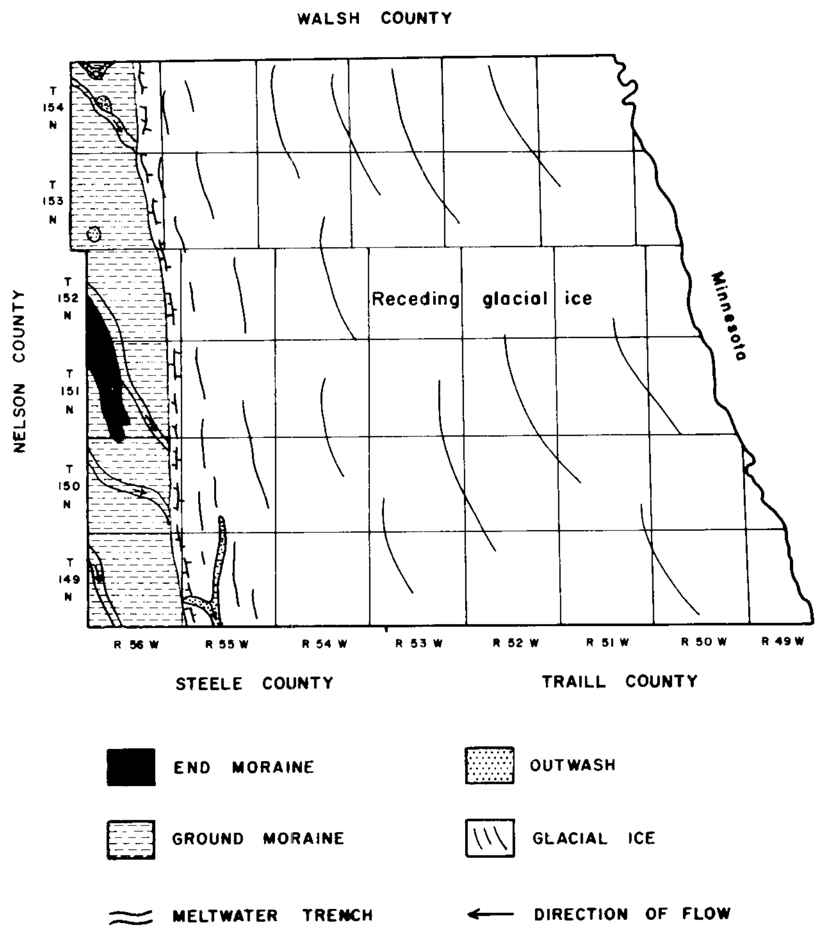

FIGURE 15. **Luverne glacial phase in western Grand Forks and southern Walsh Counties. Meltwater trenches, ground moraine, isolated outwash, and subdued end moraine.**

runoff that either turned down slope into the ice margins of the glacier or emptied into small lakes along the margin of the glacier (fig. 15). At the same time, some runoff came from glacial ice which existed above the Red River Valley in the basin north of Devils Lake. However, most of the runoff from the Devils Lake lobe went into the Sheyenne River drainage which formed during deposition of the Luverne end moraine.

East of the Luverne end moraine, the drift is mostly till of the ground moraine that was deposited on the face of the Pembina escarpment in western Grand Forks County. Other glacial features include several meltwater trenches, subdued end moraine, and glaciofluvial ice-contact deposits (mostly kames and eskers) in western Grand Forks County. These features occur at elevations of about 1,160 to 1,500 feet above sea level. At lower elevations the drift of this phase is overlapped by drift deposited during the Edinburg and Lake Agassiz phases. The drift of the Luverne phase is 0 to 40 feet thick in western Grand Forks County, although it may be thicker in the subdued end moraine.

Landforms

Subdued end moraine–End moraine is a glacial landform composed of drift, mostly till, deposited at the margins of an active glacier. End moraines may consist of linear belts of high or low individual ridges or they may be a linear belt of knobby hills. Usually the local relief within an area of 1/4 square mile is moderate to high, although special kinds of end moraine such as subdued end moraine can be of lower local relief.

In western Grand Forks County the area of more rugged relief in the western part of Tps. 152 and 153 N., R. 56 W., has been mapped as a linear belt of knobby hills that have moderate relief (pl.1). Perhaps this subdued end moraine exists because of the influence of the underlying bedrock topography, so that the constructional relief is exaggerated by this buried topography.

Whatever the cause, this linear area of subdued end moraine when compared to the surrounding ground moraine has a greater density of undrained depressions, somewhat higher, at elevations up to 1,520 feet (from a base of about 1,430 feet) above sea level, and has greater local constructional relief per 1/4 square mile, 20 to 50 feet, than the 10 to 30 feet on the ground moraine. Slope angles are between 2 degrees and 6 degrees on the subdued end moraine, higher than the 1 degree to 3 degrees on the surrounding ground moraine.

The drift in the subdued end moraine is a silty, clay till. Boulders are scarce. Exposures in road cuts show a rather high content of clay pebbles and granules. This pebble and granule content is the same as that of the drift of the surrounding ground moraine.

Ground moraine–Ground moraine is a glacial landform consisting mainly of drift accumulation, chiefly till, deposited directly from an active glacier behind its margin. Part of the accumulation also consists of ablation debris derived from the last remaining stagnant ice. Ground moraine landforms have low constructional relief and may have minor lineations.

The ground moraine in western Grand Forks County is dissected by numerous intermittent consequent streams that flow down the slope of the Pembina escarpment (pl. 1). This dissection plus the rolling surface of the ground moraine gives the area moderate to high local relief. In contrast, the areas of ground moraine at higher elevations have low local relief. Some of the stream valleys are deep; for example, the valley of the North Branch Turtle River northeast of Niagara has a depth of 100 feet. However, many other valleys are 25 to 50 feet deep. The local relief of the ground moraine, not including the depth of the drainage, ranges from 10 to 40 feet.

Numerous minor lineations occur on the ground moraine and are generally oriented either in a north-south or northwest-southeast direction (pl. 1). Several prominent north-south lineations occur northeast of Niagara in T. 153 N., R. 56 W., and have local relief of 10 to 20 feet. These lineations are aligned with the trend of the escarpment. South of Niagara along the Little Goose River in T. 151 N., R. 56 W., numerous minor lineations trend in a northwest-southeast direction. Many of these lineations are either dissected by or are parallel to minor intermittent tributaries of the Little Goose River. Because of this drainage the local relief of these lineations has been increased and ranges from 10 to 30 feet. The southwest corner of the county in T. 149 N., R. 56 W., also has numerous northwest-southeast lineations.

Eskers and linear disintegration ridges–Ice-contact, glaciofluvial deposits in narrow, sinuous ridges are eskers. If the narrow ridges are short, relatively straight, and contain mostly till, the landform is a disintegration ridge. Two rather large eskers and several smaller, similar ridges were mapped in western Grand Forks County (pl. 1). The largest esker, the Dahlen esker, is in both Grand Forks and Walsh Counties. This spectacular ice-contact ridge (fig. 16) occurs in secs. 5 and 6, T. 154 N., R. 56 W., Grand Forks County and in secs. 31, 32, and 33, T. 155 N., R. 56 W., and secs. 25 and 36, T. 155 N., R. 57 W., south-central Walsh County.

The Dahlen esker is roughly V-shaped in plan view having ridge segments to the northwest and northeast and an apex to the south. The apex has an adjoining subdued ridge segment, looped around an undrained depression. The entire ridge is approximately 4 miles long and its width is approximately 400 feet. Elevation of the base of the northeast ridge segment is 1,250 feet, and its crest is 1,330 feet. The crest is somewhat irregular with minor gaps. The ridge is asymmetrical with the north-facing slope much steeper than the south. At the apex the relief is 53 feet on the north slope and 39 feet on the south slope. About a half mile to the northeast it is 63 and 29 feet for the north and south slopes, respectively. Maximum relief of the esker is 80 feet near the terminus of the northeast segment.

The Spring Creek esker southwest of Northwood consists of two ridge segments: a large, north-south, narrow ridge in secs. 8, 17, 20, 21, 28, 29, and 32, T. 149 N., R. 55 W., joined by an east-west ridge in sec. 29 which extends west to sec. 25, T. 149 N., R. 56 W. The north-south segment of the esker is almost 5 miles long and up to 700 feet wide. The east-west segment is about 3 miles long and up to 200 feet wide. Where the two ridge segments join in sec. 29, Spring Creek is in a deep but rather narrow valley.

The constructional relief on the north-south segment of the Spring Creek esker is about 80 feet on the north limb and about 30 feet on the south limb. The glaciofluvial material in this part is a very thick bedded gravelly sand containing many shale pebbles. Sand, silt, and clay are exposed in a roadcut in sec. 32 in beds that are distorted and irregular in thickness and extent. At the south end of north-south segment, the glaciofluvial material is mostly fine sand. Boulders are scarce on this north-south ridge.

The east-west segment of the esker is a series of lower and smaller ridges, 5 to 20 feet high, composed mainly of gravelly sand and till. The ridges are north of a tributary of Spring Creek. Boulders are scarce on this segment of the esker too.

Linear disintegration ridges (ridges formed by sliding or washing of drift into open cracks in stagnant glacial ice) were mapped in sec. 18, T. 149 N., R. 56 W.; sec. 35, T. 149 N., R. 55 W.; secs. 9 and 16, T. 149 N., R. 55 W.; and in secs. 20 and 21, T. 151 N., R. 55 W. The ridges are short, commonly less than 0.5 miles long, narrow, and from 5 to 20 feet high. They consist of stony till and gravelly sand, although in the ridge of sec. 18, T. 149 N., R. 56 W., silt, clay, and fine sand make up a part of the ridge.

FIGURE 16. Dahlen esker in northwestern Grand Forks County. This is a segment of the high relief part of the ridge in the SE 1/4 sec. 6, T. 154 N., R. 56 W.

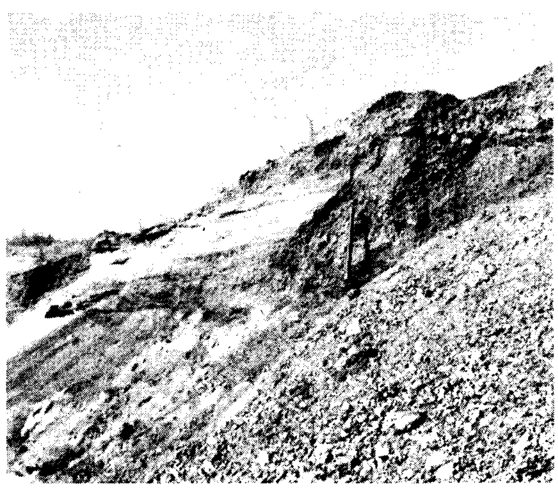

FIGURE 17. Exposure at a gravel pit at a kame in NW 1/4 sec. 14, T. 151 N., R. 56 W., Grand Forks County. Thick and thin bedding and slump structure are shown at this southward facing exposure.

Kames–Kames are conical hills and mounds of glaciofluvial drift, mostly sands and gravels and some till. The sediments were deposited in glacial ice and later slumped into position as the ice melted. In western Grand Forks County there are a number of kames on the ground moraine (pl. 1). They range from low mounds to conical hills to coalescing groups of mounds. One of the larger kames was mapped in the NW 1/4 sec. 13, T. 150 N., R. 56 W. This kame is only 15 to 20 feet above the surrounding terrain and not over 500 feet in diameter. The glaciofluvial material in this kame is gravelly sand that is thick-bedded and slumped. It contains many shale pebbles and granules.

Outwash plains–Small, isolated plains of glaciofluvial sand and gravel formed as ice-restricted outwash. In Grand Forks County such sand plains are at and slightly above the elevations of the surrounding ground moraine.

The ice-restricted outwash plain along N. D. Highway 32 in secs. 16 and 17, T. 154 N., R. 56 W., northwestern Grand Forks County (pl. 1), consists of coarse–to very coarse-grained sand, gravelly sand, and granular gravel. The bedding is mostly horizontal although some of the lenticular deposits of gravel are cross-bedded. The gravel pit in the SW 1/4 sec. 16, T. 154 N., R. 56 W. contains sands and gravels in a low hill with a level crest. In this pit, 10 to 15 feet of the glaciofluvial deposits are exposed. They probably are not much thicker than this.

The ice-restricted outwash plain along N. D. Highway 32 in sec. 32, T. 153 N., R. 56 W., one mile north of Niagara, is a plain of thin gravel. In a roadcut exposure 2 to 10 feet of sandy gravel overlying till was seen. The isolated deposit of sandy gravel in secs. 8, 9, and 16, T. 150 N., R. 55 W., along the Little Goose River is in very small, coalescing ridges. The thickness of this ice-restricted outwash is from 2 to 6 feet, although it may be thicker in some of the ridges. Another ice-restricted outwash plain is in secs. 34 and 35, T. 149 N., R. 55 W., on the south bank of Spring Creek. At this locality the glacial drift is a thick-bedded sandy gravel that is 1 to 5 feet thick.

Other smaller deposits of isolated outwash are in secs. 4 and 5, T. 151 N., R. 56 W., along the west bank of the Little Goose River (pl. 1). These poorly sorted gravels average less than 3 feet thick. The landforms appear to be kame terraces that were deposited along the west wall of the meltwater trench. These small, isolated deposits have flat surfaces and lie about 10 to 15 feet above the channel of the intermittent stream. A very small deposit similar to those found along the Little Goose River was mapped along the west bank of Beaver Creek in secs. 28 and 33, T. 149 N., R. 56 W. At Beaver Creek, the sandy gravel lies 5 to 10 feet above the creek channel.

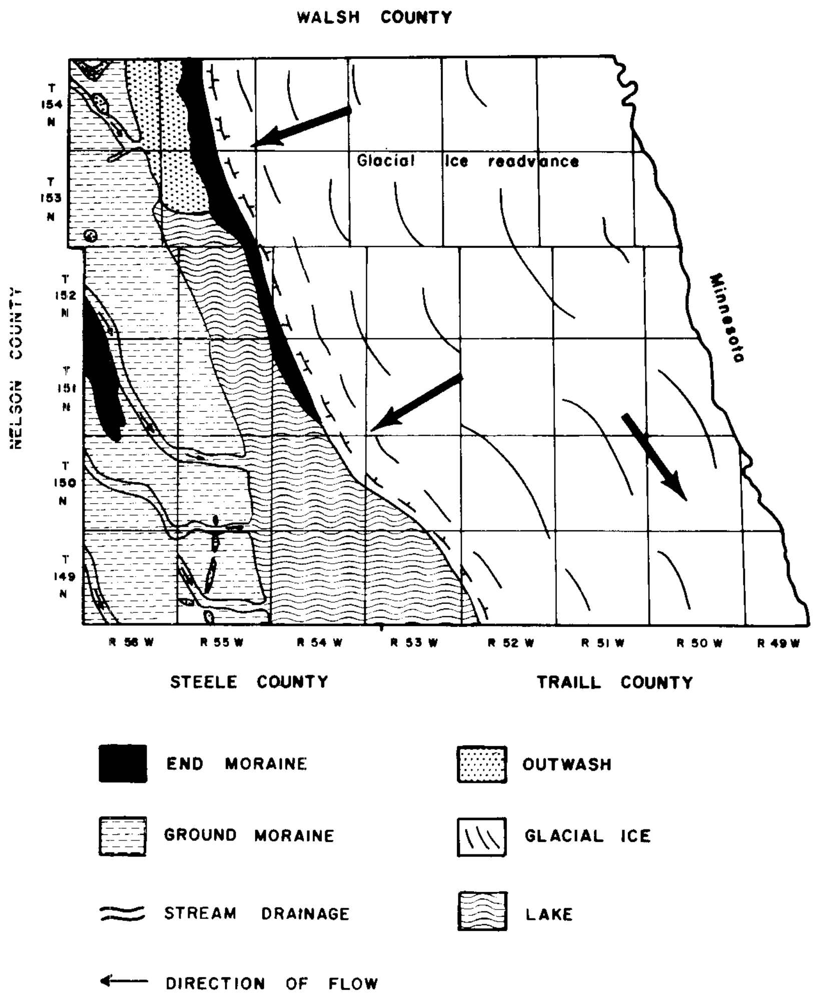

FIGURE 18. Edinburg glacial phase in western Grand Forks County. The deposition of the Edinburg end moraine, lake clay and silt, and sand and gravel took place at the ice margin. The stratified sediments make up the outwash and delta plain. Ground moraine was later deposited to the east of this area.

Meltwater trenches–Most of the meltwater trenches that were eroded by runoff during the recession of the glacial ice of the Luverne phase, run normal to the regional northeast slope of the Pembina escarpment for a relatively short distance, and then turn downslope. Four trenches south of Niagara are now occupied by Beaver Creek, Spring Creek, the Goose River, and the Little Goose River. North of Niagara the only meltwater trench trends southeast until it joins the northeast-trending Skunk Coulee. The trenches are cut mostly into till and contain little outwash and only thin alluvium. Spring Creek, the Goose River, and the Little Goose River have probably deepened parts of their trenches since the draining of Lake Agassiz.

The meltwater trench now occupied by Beaver Creek starts in Nelson County and trends southeastward into Steele County. This 20-to 30-foot-deep trench was cut by runoff that carried sediments into a proglacial lake in Steele county. The trench that contains Spring Creek is generally 20 to 30 feet deep, although where it crosses the Spring Creek esker it is 40 to 50 feet deep. The runoff in this trench, and the trenches containing the Goose and Little Goose Rivers, flowed toward the glacial ice front. The trench containing the Goose River is 20 to 40 feet deep, and the trench containing the Little Goose River is 40 to 50 feet deep.

Edinburg Phase

The Edinburg phase started with a glacial stillstand with the ice lobe margin in western Grand Forks County. During this pause in the recession of the glacial ice, the runoff and the meltwater were ponded between the ice front and the Pembina escarpment. Initial drainage into this proglacial lake carried in silt and clay sediments. The Edinburg end moraine was contemporaneously deposited along the ice margin (fig. 18).

A large increase in the amount of meltwater and runoff resulted in the deposition of coarser-grained material over the silts and clays initially deposited in the proglacial lake. Large deposits of valley train sand and gravel in northern Grand Forks County grade southward into the fine-grained sands, silts, and clays of south-central Grand Forks County. These deposits make up a delta-outwash plain (the Elk Valley delta) bounded on the east by a scarp. When the ice front receded slightly, sand and gravel were deposited east of the Edinburg moraine for a short distance, in the depressions of the Edinburg moraine, and further south, over the top of the till ridge. Recession of the glacial ice continued and subglacial till was uncovered, only to be covered again by the waters of the rising Lake Agassiz of the next glacial phase.

The landforms deposited during the Edinburg phase were modified by deposition and erosion of the Lake Agassiz phase. Edinburg phase landforms are between 875 and 1,225 feet above sea level and the associated glacial drift is 20 to 120 feet thick.

Landforms

End Moraine.–The Edinburg end moraine of northwestern Grand Forks County is a narrow, sandy till ridge that extends northeastward from McCanna toward Edinburg in Walsh County. The segment of the end moraine in Grand Forks County is about 11 miles long, commonly less than a mile wide, 1,140 feet to 1,225 feet above sea level, and up to 75 feet high. Land slopes are as much as 6 degrees. Narrow, internal lineations no more than 5 feet high are superimposed on the end moraine in Grand Forks County, but only a few small undrained depressions exist on the ridged, rocky till surface.

The end moraine is partly buried by lake sediments and outwash. These deposits completely cover the ridge southeast of McCanna, where outcroppings of till along the river valleys reveal a continuation of the end moraine. Southeast of Larimore the continuation of the ridge can be traced for some distance in the subsurface, but further south no corresponding buried till ridge was found by test drilling. Instead, a few discontinuous lenses of till along with the surrounding lake sediments and outwash of the delta plain were found.

Ground moraine.–The till surface of the ground moraine that was deposited east of the Edinburg end moraine was modified by erosion during the formation of the Lake Agassiz strandlines and lakeplain. Consequently, the ground moraine is now a flat, gently northeastward sloping plain of clayey till at elevations between 670 and 1,040 feet above sea level. Local relief on the ground moraine, assuming there was some, was completely subdued by the planing action of the lake waters and by deposition of beach and lake sediments. Beach sediments, deposited over till of the ground moraine, consist of thin, discontinuous layers of clay, sand, and gravel seldom more than a foot thick.

Outwash and delta plain.–Commonly known as the Elk Valley delta and the Golden Valley delta (Upham 1896, p. 333-337), the sand and silt plain is continuous across Grand Forks County from T. 154 N., Rs. 54 and 55 W., to T. 149 N., Rs. 53 and 54 W., (see pl. 1). Local relief on the surface is less than 5 feet and land slopes are low.

FIGURE 19. Outwash of the Elk Valley and Golden Valley delta at Fordville, Walsh County. This large gravel pit exposes the stratified coarse-grained material that grades southward into sand, silt, and clay in western Grand Forks County. Exposure faces south.

FIGURE 20. Elk Valley delta plain sediments exposed in the NW 1/4 sec. 7, T. 149 N., R. 54 W., Grand Forks County. The photo is of fine to medium grained, current-bedded sand. This shows the southward gradation into the finer grained sediments of the delta plain. Exposure faces east.

Elevations are from 1,035 to 1,150 feet. Modification of the surface by wind or water erosion occurred during the later glacial phases and the Holocene and has resulted in up to 20 feet of local relief. The plain is drained by the Forest, Turtle, and Goose Rivers in Grand Forks County. The Forest and Turtle Rivers cut across the outwash and delta plain.

Modifications of the landform, in addition to the dissection by the stream systems, are the wind blown areas and dunes of the surface sands (pl. 1). The surface of the plain was also modified during the Lake Agassiz phase, which followed, and ridges of the strandline deposits cross the plain.

Below the thin veneer of windblown sands and silts, the sediments of the outwash and delta plain consist of brownish-gray, thick-bedded, cross-stratified sandy gravel and gravelly sands in the outwash plain of T. 154 N., Rs. 54 and 55 W. The photo (fig. 19) taken in a gravel pit at nearby Fordville, Walsh County, shows the texture of the sand and gravel in the area. From northern Grand Forks County, the outwash grades southward into brownish-gray sand along the eastern part of the delta plain and along the eastern slope of the Edinburg end moraine. Along the western edge of the delta plain the outwash grades into thin to thickly bedded, inter-laminated, brownish-gray to olive-gray, fine-grained sand and silt. Although the photograph (fig. 20) shows only the current-sorted, thin to thickly bedded sand at an exposure near U. S. Highway 2–and along a creek bed--in the NE 1/4 sec. 34, T. 152 N., R. 55 W., the sand silts are generally thinly bedded, cross and horizontally stratified, and interlaminated. The finer grained components increase downward in the exposure. Further south, the sand and silt grade into silt and clay. At a roadcut exposure in the NW 1/4 sec. 7, T. 149 N., R. 54 W.–along the Goose River west of Northwood–the delta plain sediments are mostly yellowish-gray to olive-gray, interlaminated, thinly bedded silt, clay, and fine sand. From the vicinity of Northwood the sediments grade southward into mostly clay and silt.

The southward horizontal sorting trend of the outwash and delta plain deposits also has a counterpart in the vertical section. The coarser material is generally near the surface, but at depth the sand and gravel overlie lake deposits of sandy silt and clay. The buried silt and clay cannot be distinguished from the silt and clay that lies at the surface south of Northwood.

The areal extent and the thickness of the sand and gravel of the outwash and delta plain is shown on Figure 21. The maximum thickness of the sand and gravel underlying the plain was drilled in test hole

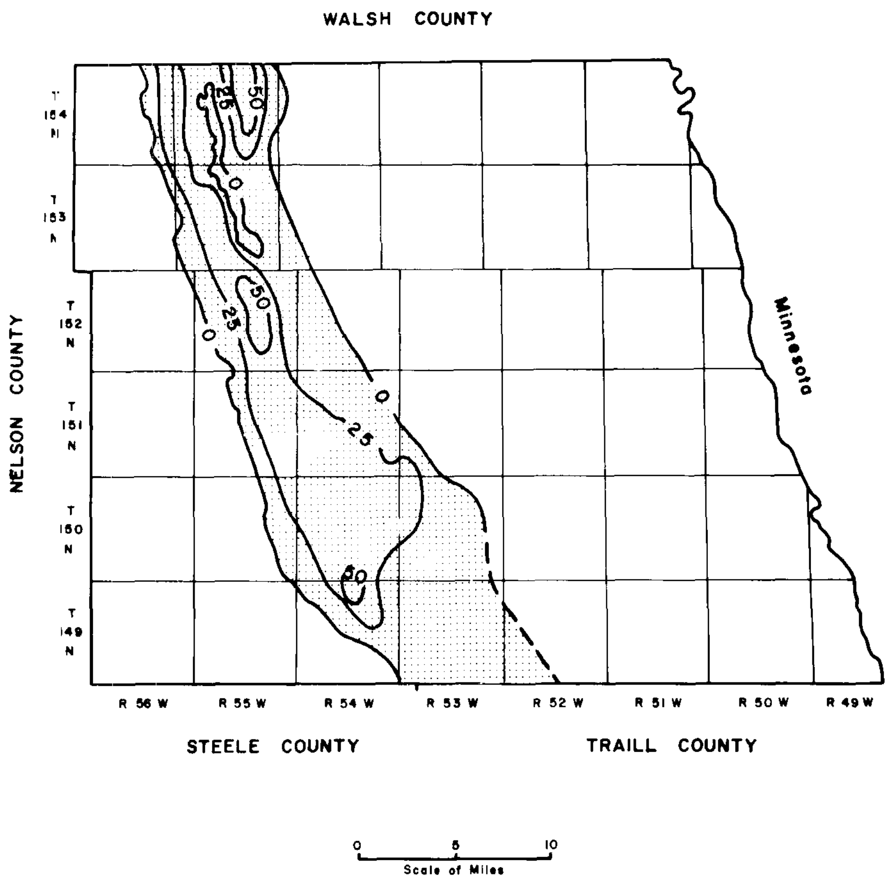

FIGURE 21. Thickness map of the glacial sand and gravel of the outwash and delta plain, western Grand Forks County.

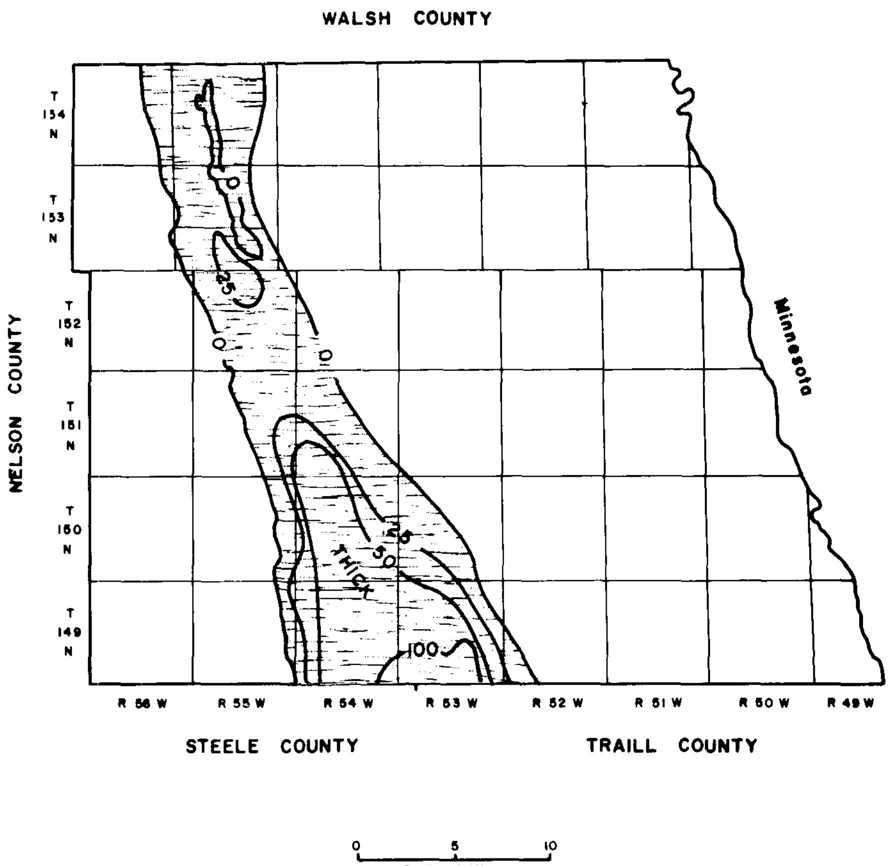

FIGURE 22. Thickness map of the glacial clay and silt of the outwash and delta plain, western Grand Forks County.

2426, SW 1/4 sec. 14, T. 154 N., R. 55 W., where 72 feet of sand was drilled from surface before penetrating till. The areal extent and the thickness of the silt and clay of the outwash and delta plain is shown on Figure 22. The maximum thickness of the silt and clay was drilled in test hole 762-3, SW 1/4 sec. 28, T. 149 N., R. 53 W., where, under 20 feet of surficial sand, 114 feet of clay and silt was drilled before penetrating the underlying till. The stratigraphic relationships of these sediments are shown on the cross sections of Plate 4.

Lake Agassiz Phase

The beginning of the Lake Agassiz phase in Grand Forks County closely followed the deposition of the ground moraine of the Edinburg phase. The shallow proglacial lake that existed in front of the glacial ice during the preceding Edinburg phase may have been simply expanded northward in area when the ice receded. Lake sediments were deposited along the axis of the Red River Valley, where the greatest thickness of glacial ice had existed. Fluctuations of the water level may account for the desiccation surfaces at depth noted by Rominger and Rutledge (1952). After formation of the Pembina delta (to the north in western Pembina County), the water level began to rise so that it reached its maximum elevation of about 1,160 feet above sea level in Grand Forks County. This means that at least 330 feet of water covered the area now occupied by the City of Grand Forks.

The ground moraine, end moraine, and outwash-delta plain of the Edinburg phase were covered by the lake which lapped onto the lower part of the ground moraine of the Luverne phase. At its highest level, the erosive action of the water washed most of the clay and silt out of the till. The two sets of gravelly beach ridges of the Herman strandline were deposited over the disconformity on the till. These beaches mark the maximum area of the glacial Lake Agassiz (Upham, 1896). By this time, the southern outlet of Lake Agassiz had been enlarged (the trench through the Big Stone moraine of Minnesota and northeastern South Dakota) and the water level of the lake began to drop. The stream systems that eroded into the clayey deposits of the Pembina escarpment were extended as the lake receded.

As the level of the lake dropped, successive strandline deposits were formed at lower elevations. The finer material was washed out of the till, transported to the center of the basin, and deposited as laminated sediments. In addition to the Herman deposits, the beach ridges and the scarps formed when the glacial Lake Agassiz drained southward are the Norcross, Tintah, and Campbell-McCauleyville levels

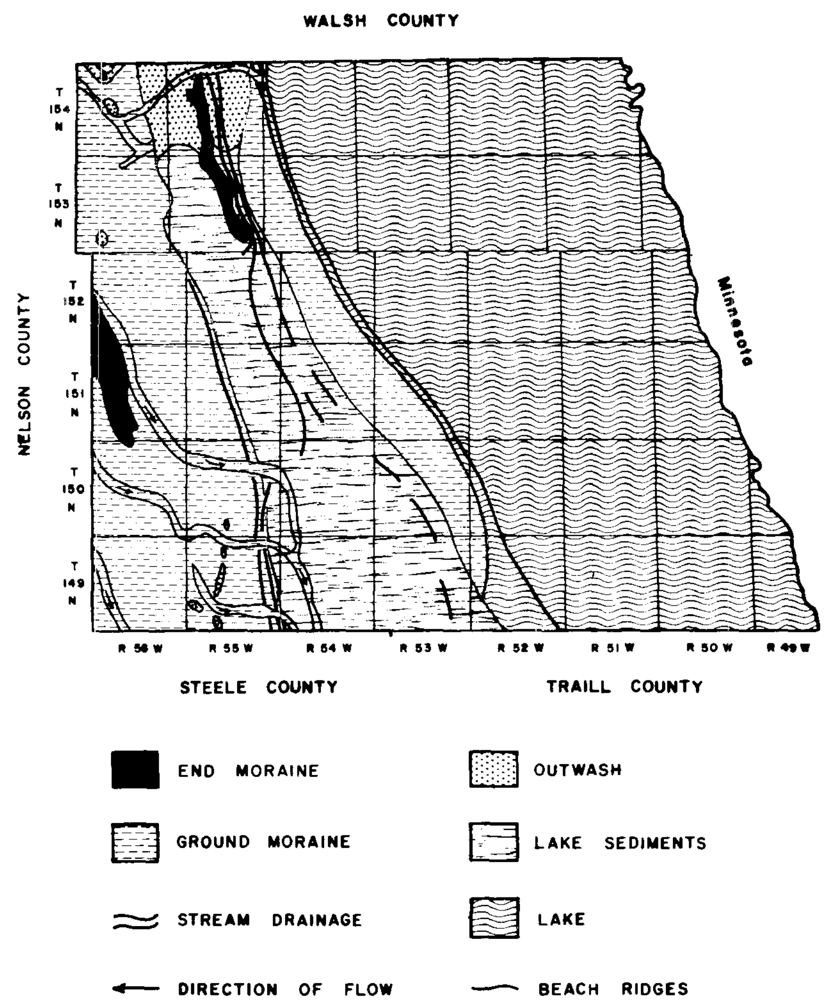

FIGURE 23. Lake Agassiz phase in Grand Forks County. The lake is shown to be at the Campbell-McCauleyville level, when the outlet of the lake was to the south.

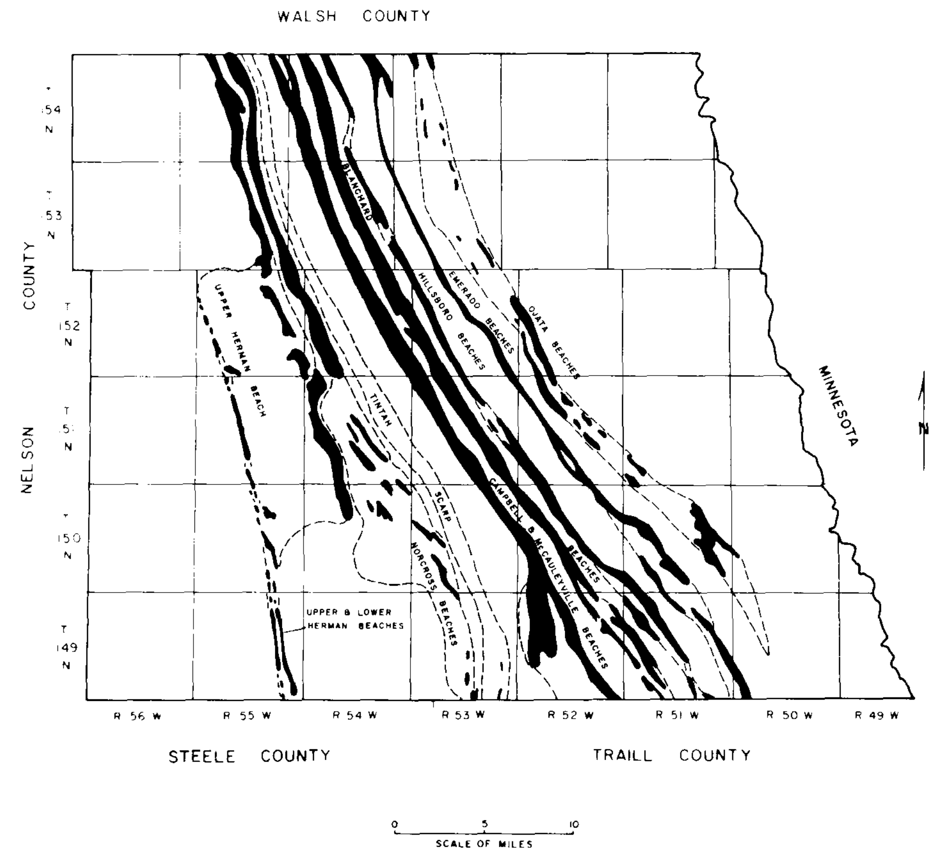

FIGURE 24. Extent of the strandline deposits of glacial Lake Agassiz in Grand Forks County.

(the proper nouns are from Upham, 1896). After deposition of the Campbell and McCauleyville beaches (fig. 23), the lake drained eastward into the Superior basin. Field evidence was not apparent in the Grand Forks County study to indicate whether there were one or two blockages of this eastern outlet and a subsequent rise to the Campbell level to where the lake drained southward again (Zoltai, 1965). In any event, successively lower Blanchard, Hillsboro, Emerado, and Ojata beaches were formed when the glacial Lake Agassiz drained eastward, because they are all below the elevation of the southern outlet.

The landforms of the Lake Agassiz phase are between 830 and 1,165 feet above sea level in Grand Forks County. The maximum thickness of the glacial drift associated with this phase is 95 feet of lake clay and silt, but thickness of the beach sand and gravel and associated shore deposits is generally 2 to 15 feet and never more than 30 feet.

Landforms

Strandlines–The several northwest-southeast trending beach ridges, associated scarps, and other shoreline deposits in Grand Forks County are at elevations ranging between 865 to 1,165 feet above sea level. Most of the strandlines are marked by narrow ridges of sand and gravel; but some are marked in places by wave-cut scarps. The Tintah strandline in Grand Forks County is marked almost entirely by a wave-cut scarp, and the Ojata strandlines are marked by a very low scarp. The characteristics of the strandlines are given in Table 3, and their aerial extent is shown in Figure 24.

In addition to the characteristics unique to each strandline (Table 3), there are characteristics common to most of the beaches. For example, the bedding is thin to thick, cross-stratification is common, and variation of texture among beds of the larger beaches is great. The relationships of the strata within the larger beaches are shown on Figure 25, a photo of the upper Herman beach in the SW 1/4 sec. 3, T. 153 N., R. 55 W.

Some of the beach ridges were drilled with a truck-mounted auger to check composition and thickness. Most of the gravel content was found in the upper parts of the larger beaches. Generally the grain size was found to decrease downward and fine sand, silts, and clays were found to overlie a pebble and boulder zone above the till. In places the equivalent of this zone was found to be a gravel (see Figure 27, a photo of an abandoned gravel pit of the Blanchard beach in the NW 1/4 sec. 32, T. 152 N., R. 53 W., near Arvilla).

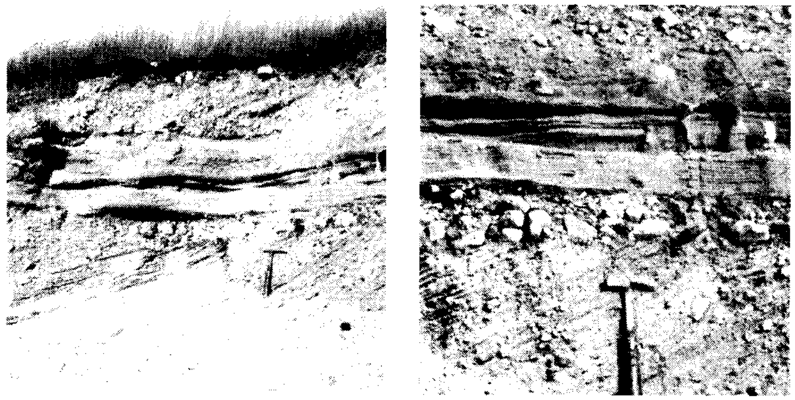

FIGURE 25. Upper Herman beach, northwestern Grand Forks County. The photos taken at a gravel pit in the SW 1/4 sec. 3, T. 153 N., R. 55 W., show the westward inclined beds overlain by nearly horizontal beds. The texture ranges from fine-grained sand to cobble size particles. Exposure faces south.

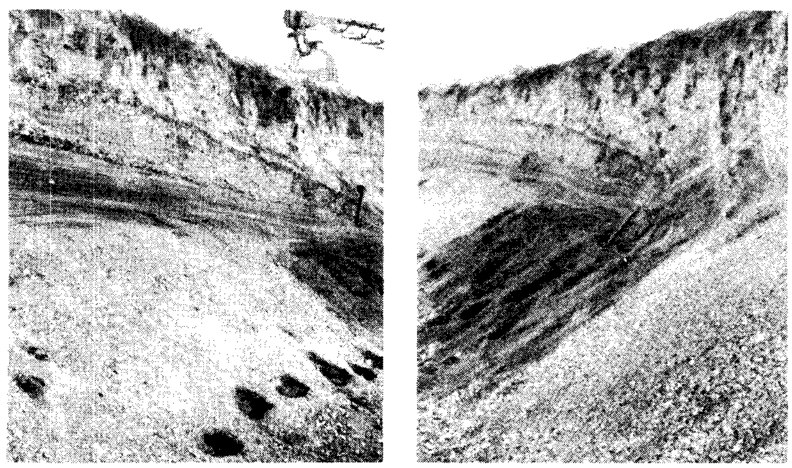

FIGURE 26. Upper Herman beach, southwestern Grand Forks County. The photos, taken at a gravel pit in the NW 1/4 sec. 2, T. 149 N., R. 55 W., show the inclined strafification of gravelly sand that laps against the almost horizontal, finer grained sediments deposited on the east of the beach ridge. This exposure faces north.

Buried soil zones were found in only a few exposures of the beach sands. One of the more obvious is the washed soil zone shown by Figure 28, a photo of a roadcut across the Norcross beach in the SW 1/4 sec. 28, T. 152 N., R. 54 W. This washed soil zone apparently underlies the medium and coarse sand of the beach ridge and overlies the fine, current-sorted sand of the outwash and delta plain. In addition, a few buried soil zones were discovered during the augering of the beaches. In the SE 1/4 sec. 34, T. 151 N., R. 52 W., 2 to 3 inches of buried black soil beneath sand of the Emerado beach was found to overlie the till surface. This soil zone was found to be underneath the sediments only on the west side of the beach. Another soil zone was augered at depths of 6 1/2 to 7 feet below the surface on the west side of the Hillsboro beach in the NE 1/4 sec. 5, T. 150 N., R. 52 W. It was absent below the gravelly sands on the east side of the beach deposit.

The depositional pattern of the beaches indicates that many of the multiple ridges may have been deposited almost simultaneously. All the Herman beaches, for example, could have been deposited when the lake was at its maximum level. The cross-stratified beds in the upper beach may mean it was formed at the high water mark. The occurrence of the thin, lower beach on a bench below the scarp of the upper beach indicates that the lower beach was the berm or bar deposited during low water and by offshore currents or, as occurred in Tps. 150 and 151, N., R. 54 W., the sand and gravel were deposited as rather large offshore bars. The successively lower Norcross and Tintah beaches do not have such a close relationship.

The Campbell and McCauleyville beaches have much the same close, parallel relationship as the upper and lower Herman beaches. The greatest differences that exist between the Herman set and the Campbell-McCauleyville set of beaches, aside from the elevation, is the steeper scarp associated with the Campbell beach. In some places, the SW 1/4 sec. 21, T. 151 N., R. 53 W., for example, the Campbell scarp is cut in till, and there is no associated gravel or sand ridge. Also, the McCauleyville is thicker and wider than the comparable lower Herman beach. In secs. 4 and 5, T. 149 N., R. 52 W., and to the south, the Campbell and McCauleyville beaches diverge, because the original slope of the land was lower in this area. Here, the Campbell is marked mostly by a low, wide spit and a scarp cut into the east edge of the sand and silt of the Elk Valley delta plain. The McCauleyville is a gravelly sand ridge that probably formed as a large offshore bar.

East of the Campbell and McCauleyville beaches the land slope is lower and the beaches are smaller. The first set of beaches east of the McCauleyville are those of the Blanchard shoreline. The two to three distinct beach ridges of the Blanchard set were deposited without great changes in the level of the lake. The beach ridges were probably

FIGURE 27. Depleted gravel pit of the Blanchard beach ridge in the NW 1/4 sec. 32, T. 152 N., R 53 W., Grand Forks County. The photo shows the boulders that lie on the till at the base of the beach ridge. View toward south.

FIGURE 28. Exposure of soil zone between the medium-to-coarse-grained sand of the Norcross beach ridge and the underlying fine-grained sand of the outwash and delta plain. The exposure is a roadcut in the SW 1/4 sec. 28, T.152 N., R 54 W.

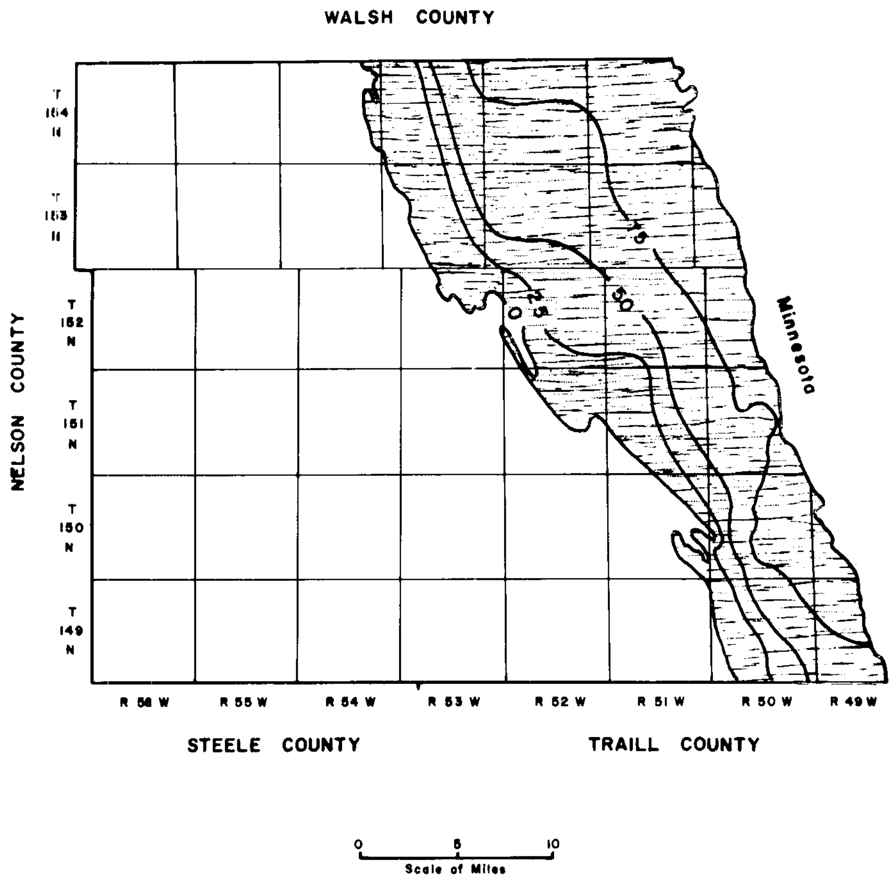

FIGURE 29. Thickness map of glacial clay and silt of the lake plain in eastern Grand Forks County.

deposited during minor fluctuations in the water level. The same relationship applies to the thin and parallel multiple beaches of the Hillsboro set. The Emerado beach, however, is mostly a single ridge. Few offshore bars are associated with it because at the time of its deposition nearby offshore and lagoonal finer grained lake sediments had already been deposited over much of the source of gravelly material, the underlying till. Also, the land slope is low in this area and because the lake was shallow, its erosive action was negligible. East of the Emerado beach, the Ojata set of beaches was formed mostly on fine grained sand and silt of the underlying lake sediments. The Ojata beaches in T. 150 N., R. 51 W., northwest of Thompson, consist of reworked sand and gravel of an isolated ice-contact deposit.

Lake Plain.–The interlaminated clays and silts lie mostly east of the beaches, the center of the Red River Valley, beneath a lake plain surface that is at elevations from 830 to 900 feet above sea level. This lake plain is almost flat and drainage is poorly developed. Except for the areas close to the Red River of the North and a few of its tributaries, much of the land must be ditched in order to drain.

The interlaminated clay and silt underlying the lake plain is olive to light gray, thick bedded, and up to 95 feet thick (fig. 29). These lake sediments are exposed in only a few places in the county. A roadcut exposure along the Grand Forks and Traill County boundary (NE 1/4 NE 1/4 sec. 5, T. 149 N., R. 49 W.) shows the interlaminated bedding characteristic of the lake sediments (fig. 30). When dry, these sediments have a blocky fracture. Minor rare constituents include concretions of calcareous silt or sulphate minerals.

A near-shore deposit of fine-grained sand is exposed along a drainage ditch in the NW 1/4 NW 1/4 sec. 30, T. 152 N., R. 52 W. Here, lake sand underlies the low Ojata beach No. 1. At this locality up to 11 feet of thinly bedded, cross-stratified, current-sorted, fine-grained sand and silt is exposed (fig. 31). A sedimentary flow structure was seen in this drainage ditch exposure (fig. 32). The dark zone in the photo of the flow structure (fig. 32) is a bed of woody material. An equivalent of woody material is exposed further southeast of the NW 1/4 NW 1/4 NW 1/4 sec. 32, T. 152 N., R. 52 W., but in sec. 32 the wood fragments lie within thin to thick bedded, interlaminated clays, silts, and fine-grained sands (fig. 33). Samples of the wood previously collected from this horizon were radiocarbon dated at 10,960±300 BP (W-723) and 10,080±280 BP (W-900). The wood was washed into the lake prior to the formation of the Ojata beach, but it is fairly extensive and in good condition, so the material of the bed must not have been transported far before it was deposited. The wood in the bed may have been derived

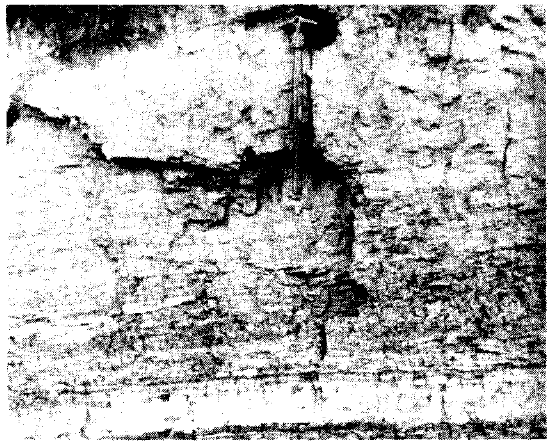

FIGURE 30. Interlaminated glacial lake clay and silt exposed south of the Grand Forks-Traill County line road between the SE 1/4 SE 1/4 sec. 33, T. 149 N., R. 49 W., Grand Forks County, and the NE 1/4 NE 1/4 sec. 5, T. 149 N., R. 49 W., Traill County. The photo shows the thin to thick bedding and the blocky fracturing.

FIGURE 31. Exposure in eastern Grand Forks County in a drainage ditch of fine-grained sand so the Ojata beach overlying the current sorted, cross-stratified, thin, fine-grained sand and silt beds of glacial Lake Agassiz. The irregular contact between the beach and lake sediments is at the head of the pick. The exposure is in the NW 1/4 NW 1/4 sec. 30, T. 152 N., R. 52 W. Exposure on south side of ditch.

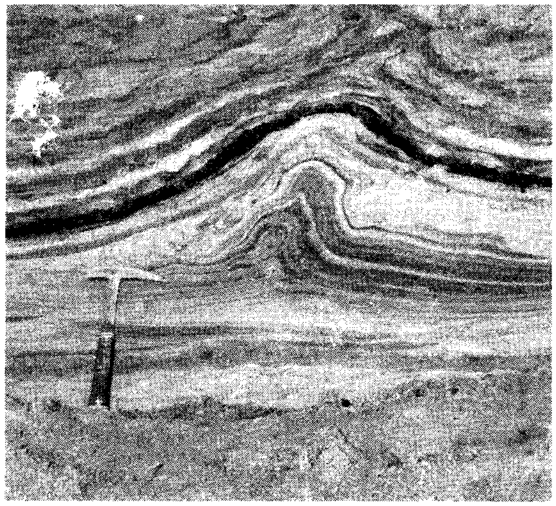

FIGURE 32. Sedimentary flow structure exposed in the NW 1/4 NW 1/4 sec. 30, T 152 N., R. 52 W., eastern Grand Forks County.

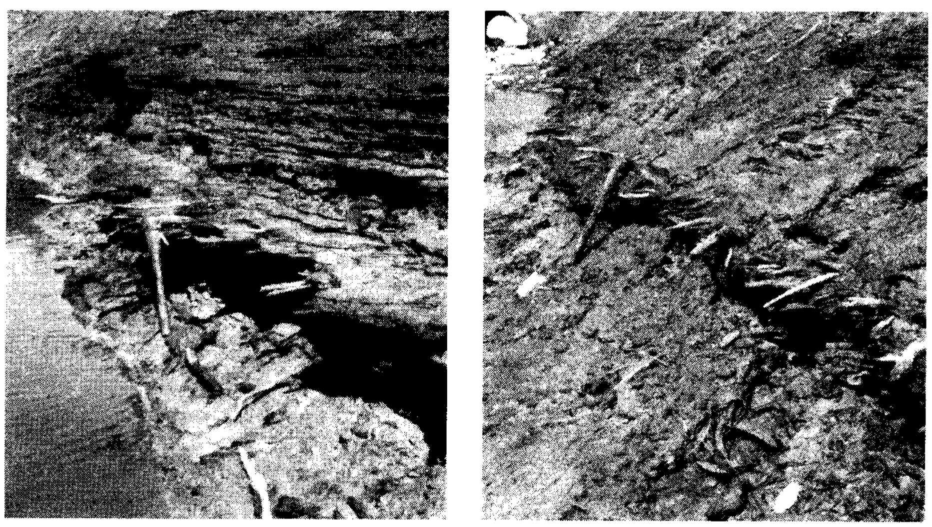

FIGURE 33. Exposure in the NW 1/4 NW 1/4 sec. 32, T. 152 N., R. 52 W., eastern Grand Forks County, showing bed of wood fragments in interlaminated clay, silt, and very fine-grained sand.

from growth near the shores of the lake (as the lake receded) or it may have been washed off the surface of the pre-existing till. It is possible that growth on ablation till of drift sheet 6 was covered by the rising lake only to be later reworked into the lake sediments as the lake receded.

Overlying the interlaminated clay and silt and directly underlying the lake plain surface is a massive bed of yellowish-gray silt that is up to 6 feet thick. The contact of the silt and the underlying interlaminated clay and silt is exposed in the NW 1/4 sec. 28, T. 152 N., R. 51 W. (fig. 34) where the silt is about 3 feet thick. The contact with the underlying clay and silt is difficult to determine in hand auger holes. Southeast of sec. 28, however, the silt is well exposed along the Thompson-Red River bridge road between Tps. 149 and 150 N., Rs. 49 and 50 W. These exposures indicate the silt is fairly extensive in area though it may not be continuous. Penecontemporaneous with the deposition of the Ojata beaches, the silt was deposited during the recessional phase of Lake Agassiz when extended low-gradient stream systems were ponding into a shallow almost stagnant lake and more silt was available for deposition.

Lineations occur on the clay and silt of the lake plain. The lineations are very low, narrow, ridges, and grooves that are difficult to see on the ground but distinctive on aerial photos. They are most numerous in northeastern Grand Forks County (pl. 1). Several reports theorizing on the origin of the lineations and their pattern have been published. Horberg (1951) said that the lineations are either an unusual type of permafrost patterned ground or fracture fillings formed in lake ice. Colton (1958) theorized that the ridges formed when the lake was shallow by squeezing of soft lake sediment up into the cracks of thick late ice. Clayton, and others (1965) wrote that the lineations resulted when wind-driven ice blocks moved over the lake and dragged on the soft sediments of the nearly flat lake floor.

NON-GLACIAL STRATIGRAPHY

Although some of the surface sediments of western Grand Forks County could be of glacial origin, most of the veneer of wind blown sand is Holocene age (less than 5,000 years old). Low dunes and small blowouts are common on the surface of the outwash and delta plain in western Grand Forks County. The largest dunes are in an area around

FIGURE 34. Exposure in the NE 1/4 sec. 28, T. 152 N., R.51 W., eastern Grand Forks County, showing the massive light yellowish-gray silt that overlies the light olive gray to olive gray clay and silt. The contact is at the head of the pick.

Larimore and east of Kempton, where the Herman and Norcross beach ridges have been extensively modified by wind.

Other Holocene deposits are the organic rich gravels, sands, silts, and clays along the stream channels. Most of the coarser stream alluvium is in areas of till and beach deposits. Finer material is found where the stream gradients are low (areas of lake clay and silt east of the beaches).

Holocene swamp deposits occur in Kelly Slough in T. 152 N., R. 52 W. They consist of swamp grasses and organic clays and silts that have been enriched with salt minerals. The relatively steep walls of the slough are caused by spring sapping due to artesian water escaping to the surface. The till overlying the sandstones is thin and the sand that lies on the till is close to the surface in places. The area north of Kelly Slough also has much the same geologic setting. Soils there are saline due to percolating waters from the underlying Dakota Group. Natural drainage is poorly developed in these areas.

ECONOMIC GEOLOGY

Sand and Gravel

Sand and gravel is the most valuable mineral produced in Grand Forks County. The value of the 1962 mineral production was about double that of 1961, and in 1963 when it ranked third in the state it more than doubled the 1962 value. The increased production during this period was accounted for primarily by construction of U. S. Highway 2 and the Minuteman missile sites.

The sand and gravel of the county is of glacial origin. Glaciofluvial sand and gravel occurs in modern stream channels, meltwater trenches, and outwash plains. Ice-contact deposits consist of kames, eskers, and ice-contact outwash. Glaciolacustrine sand and gravel occurs in deltas and various shore deposits that include beaches and bars. Commercial sand and gravel pits occur throughout most of the county in these various landforms. The pit locations are shown on Plate 1.

Some of the gravel in the county contains shale in amounts detrimental for use in concrete. The shale content of the sand and gravel deposits is highest in the western part of the county near the escarpment of the Cretaceous shales. It decreases east of the escarpment, especially in the beaches.

Surface water.–The largest source of surface water in the county is the Red River of the North. The municipal water supply of Grand Forks is obtained from the Red Lake River of Minnesota at its junction with the Red River. This municipal water is also transported by pipeline to the Grand Forks Air Force Base.

Surface water can be obtained from the smaller permanent streams such as the Forest River, Turtle River, and the Goose River. However, the water of the Forest and Turtle Rivers is salty due to salt water leakage from the subcrop and artesian well overflow of the Dakota aquifer. Therefore, good quality water is obtainable only from the upper or western reaches of these two streams.

Ponded water occurs behind small earth dams but no significant permanent lakes crest in the county. Some of the undrained depressions that occur in the ground moraine in the western part of the county contain intermittent lakes. Reservoirs have been built in the upper parts of the Goose River, Little Goose River, Whisky Creek, and the North Branch of the Turtle River.

Ground water.–The most abundant sources of ground water are in the unconsolidated gravel, sand, and silt deposits of glacial origin and in the bedrock sands of the Dakota Group. Ground water is also available from the sands of other bedrock formations, but this source is of minor significance.

The aquifers of glacial origin include glaciofluvial deposits found in present stream channels, partly buried stream channels, meltwater trenches, and outwash plains; glaciolacustrine deposits found in deltas, beaches, offshore bars, and lake plains; and ice-contact deposits found in kames, eskers, and ice-contact outwash. Minor to significant aquifers can be found in the lenticular sand and gravel deposits within the till sheets.

The areas of glacial origin having the greatest groundwater potential are in the west-central part of the county, especially the Inkster and Elk Valley areas. The Inkster area consists of an outwash-delta deposit modified by wave action and overlain by beach ridges. The Elk Valley area consists of an outwash, delta, and lake deposit modified by wave action and overlain by beach ridges. The central part of the county has moderate groundwater potential from glacial deposits, especially the Lake Agassiz strandline and the wavecut ground moraine areas. The latter area contains aquifers in lenticular outwash deposits such as the one in the Grand Forks Air Force Base area. The eastern part of the county has the poorest groundwater potential from glacial deposits.

Bedrock aquifers have their greatest groundwater potential in the east-central part of the county where the Dakota Group sandstone subcrops. Artesian wells, many of which flow at the surface, are common in this area.

The quality of the groundwater differs greatly from one area to the next. Generally, the water in the areas of glacial origin are hard and mineralized, and the water from the Dakota Group is saline. In areas overlying the Dakota Group sands, aquifers usually have saline water due to leakage and percolation from these sands.

Petroleum

Seven petroleum exploratory wells have been drilled in Grand Forks County. Five of them were drilled to the granite basement, one to the Winnipeg Formation, and one into the basal Cretaceous sandstones. Summaries, providing lithologic descriptions of three of these wells, have been published (Nelson, 1955; Carlson, 1957; Hansen, 1958). A summary including the depth to the formation tops is also provided in the Appendix B. There has been no oil production in the county, and there were no oil shows reported from these seven exploratory wells.

Cement Rock and Limestone

The Niobrara Formation was studied in northeastern North Dakota as a potential raw material for the manufacture of cement (Carlson, 1964). Included in this study was a prospect in the vicinity of Shawnee and McCanna (eastern edge of Tps. 151 and 152 N. and R. 56 W., and western edge of Tps. 151, 152, and 153 N., R. 55 W.). Test drilling and core analyses showed that a 20-foot thick "high-lime" zone was present at a depth of 50 feet or less in this area. This deposit covers an area a half mile wide and four miles long and contains about 55 million tons of reserves. The average calcium carbonate content of this "high-lime" zone is about 63 percent, not high enough to be suitable as a raw material for a Portland grade cement.

Limestone in the basal part of the Red River Formation is present in northeastern Grand Forks County at depths of about 200 feet. South of the city of Grand Forks, generally silty and sandy limestone is present within the Icebox Formation of the Winnipeg Group at depths of 200 to 250 feet. Both of these limestone beds are also present further west in Grand Forks County, but at progressively greater depths.

Clay

In western Grand Forks County along the Pembina escarpment bentonitic clay beds occur at the base of the Pierre Formation. This bentonitic clay is of a calcium and magnesium type and is better known as "Fuller's earth," a natural bleaching powder.

Outcrops of bentonitic clay occur in roadcuts and along the ravines in SW 1/4 SE 1/4 SW 1/4 sec. 4, T. 153 N., R. 56 W., SE 1/4 SE 1/4 SE 1/4 sec. 3, T. 152 N., R. 56 W., SW 1/4 SW 1/4 sec. 24, T. 152 N., R. 56 W., and SW 1/4 SW 1/4 NW 1/4 sec. 1, T. 151 N., R. 56 W. At this latter location (sec. 1) the cream-colored bentonite beds occur in a 5 1/2 foot interval interbedded with dark gray bentonitic shale. The thickness of individual bentonite beds range from less than an inch to six inches (see section description in Appendix A).

The bentonitic clays in Grand Forks County are not being utilized at the present time. The nearest bentonite mining operation is just north of the International line along the Pembina escarpment at Morden, Manitoba. This operation (O. E. Manz, personal communication) is in the same stratigraphic interval at the base of the Pierre Formation. The clay is being used for bleaching of mineral, vegetable, and animal oil and as a binder for taconite pelletizing. Tests show that the 8 to 14 feet of overburden on the bentonitic clay can be utilized as a light weight aggregate raw material.

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APPENDIX A

Detailed Descriptions of Surface Sections

Section GF-1. SW 1/4 SW 1/4 NW 1/4 sec. 1, T. 151 N., R. 56 W.
Moraine Township Section.
East roadcut, north side of valley wall.

	Feet	Inches
Pleistocene-		
10. Glacial till, light-brownish-gray to olive-gray, clayey; many gray shale pebbles on the weathered surface.	11	0
Cretaceous-Pierre Formation		
9. Shale, olive-gray, slightly plastic, breaks into large flakes; some manganese staining on the bedding planes; a few manganese concretions.	1	9
8. Shale, light-olive gray, blocky, mottled by manganese coating and contains manganese concretions; vertical fractures.	3	0
7. Shale, dark gray, thin bedded, soapy feel, blocky, fractured.	1	8
6. Bentonitic clay, light-yellowish-gray.		0.5
5. Shale, dark gray, as above; contains traces of light-yellowish-gray bentonitic clay, jarosite concretions, and gypsum crystals.	1	10
4. Clay and ironoxide layer, reddish-brown; gypsum crystals.		0.5

	Feet	Inches
3. Bentonitic clay, light-yellowish-gray to light-medium-gray, soapy feel; alternating beds of light-yellowish-gray and light-medium-gray 0.5 to 1 inch thick; breaks readily when dry.	1	8
Cretaceous - Niobrara Formation		
2. Clay and ironoxide layer, brown; on surface as nodules.		0.3
1. Marlstone and shale, light-brownish-gray to light-yellowish-brown, massive, chalky appearance. Base covered.	4	5
Total	25	5.3

Section GF-2 SW 1/4 SW 1/4 sec. 24, T. 152 N., R. 56 W.
Shawnee Section.
East roadcut, north side of valley wall.

	Feet	Inches
Pleistocene-		
10. Glacial till, olive-gray, silty, many gray shale pebbles on the weathered surface.	14	0
Cretaceous-Pierre Formation		
9. Shale, medium-to dark-gray, flaky, soapy feel; thin interbeds of light-yellowish-gray bentonite.	1	10
8. Bentonitic clay, light-yellowish-gray and light-medium-gray.		6
7. Shale, dark-gray, same as unit 9.	1	0
Cretaceous-Niobrara Formation		
6. Clay and ironoxide layer, brown; gypsum crystals.		2.5
5. Shale, calcareous, light-brownish-gray to light-yellowish-brown, blocky, massive, fractured; gypsum crystals, ironoxide, and yellow jarosite.	4	0
4. Bentonitic clay, light-yellowish-gray.		2.5
3. Shale, calcareous, light-yellowish-gray, blocky.	2	6
2. Covered interval.	33	
1. Marlstone, light-medium-gray, fractured, blocky, jointed, flecks of white calcite, chalky appearance. Stream bed.	2	0
Total	59	3

Section GF-3. SW 1/4 NE 1/4 sec. 6, T. 152 N., R. 56 W.
Niagara Section.
North bank, southeast side of bluff.

	Feet	Inches
Pleistocene-		
8. Glacial till, light-brownish-gray, oxidized.	6	6
Cretaceous-Pierre Formation		
7. Shale, olive-to dark-gray, very thin bedded; manganese-coated limestone concretions. Weathered.	20	10
6. Bentonitic clay, light-yellowish-green.		3.4
5. Shale, dark-gray to black, thin bedded; contains calcite prisms of *Inoceramus* sp.	9	6
4. Bentonitic clay, light-yellowish-green.	1	1.2
3. Shale and claystone, medium-gray to olive-gray, thin to thick bedded; contains calcite prisms and molds of *Inoceramus* sp.	6	6
2. Bentonitic clay, light-yellowish-green.		1
1. Shale, dark greenish-gray to black, thin bedded; contains manganese covered limestone concretions. Covered interval to stream bed.	8	1
Total	52	10.5

Section GF-4. NE 1/4 sec. 23, T. 152 N., R. 56 W.
Whiskey Creek Section.
West roadcut, south valley wall.

	Feet	Inches
Pleistocene-		
4. Glacial till, light-brownish-gray, oxidized, large cobbles and boulders common.	4	0
Cretaceous-Niobrara Formation		
3. Marlstone, light-yellowish-gray to light-gray, containing white flecks of calcite; occasional lighter-colored horizontal bands; weathered surface has alligator skin texture.	6	10
2. Marlstone, as above, oyster zone; clusters of shells and shell fragments of small (less than 0.5 inch) fossil oysters, *Crassostrea congesta* (Conrad), common.		3
1. Marlstone, as in unit 3; vertical joints, filled with sulphate salts and calcite. Base covered.	10	0
Total	23	1

APPENDIX B

Summary of Petroleum Exploratory Wells

N. D. G. S. Well Number	29	580	1356	1415	3191	3204	4122
N. D. G. S. Circular Number		108	178	200			
Location	35-152-51	15-151-53	24-152-54	22-152-54	5-153-52	17-152-51	26-149-55
Date Drilled	1951	1954	1957	1957	1962	1962	1966
Elevation, Ground Level	844	939.5	963	1015	840	837	1154
Total Depth	2051	898	1062	1150	802	558	598
Mechanical Log-Depth to Formation tops in feet	none (lithologic)			none (lithologic)			
Cretaceous - Greenhorn							259
Belle Fouche							340
Newcastle - Skull Creek		155	252	310			466
Fall River - Lakota		268	306	390	160	98	588
Ordovician Red River		483	500	625	244	251	
Winnipeg - Roughlock		670	840	970	610	373	
Winnipeg-Icebox		711	880		653	412	
Winnipeg - Black Island		887	1049		783	548	
Precambrian	440	895	1061		802	550	

TABLE 2.

Characteristics of the three areas of the Agassiz Lake Plain district in Grand Forks County

	Elk Valley Area	Arvilla Slope Area	Manvel Lowland Area
Drainage	Integrated Coarse texture Dendritic pattern	Integrated Medium texture Rectangular pattern	Integrated to poorly integrated Medium to coarse texture Dendritic pattern
Streams	Perennial Intermittent	Intermittent Perennial	Intermittent Perennial
Dominant Topography and Local Relief	Outwash plain 0 to 5 feet Delta-Lake plain 0 to 5 feet End moraine 40 to 75 feet Beach ridges 5 to 15 feet Beach scarps 15 to 35 feet	Beach ridges 5 to 20 feet Beach scarp 5 to 15 feet Ground moraine 0 to 5 feet Lake plain 0 to 5 feet	Lake plain 0 to 3 feet Lineations
Slope Relief	5 feet per mile 80 feet per mile 50 feet per mile	40 feet per mile 20 feet per mile 10 feet per mile	10 feet per mile 5 feet per mile Level
Slope	Level, sloping, very gently sloping 0°, 1° to 5°, less than 1°	Nearly level to very gently sloping Less than 1°	Level 0°
Surface	Sand and gravel Silty clay and clay	Sand and gravel Till	Silty clay Clay
Lithology	Till Sand and gravel	Silty clay and clay	Silt
Drift Thickness	10 to 340 feet	150 to 450 feet	100 to 375 feet

TABLE 3

Characteristics of the strandline deposits in Grand Forks County

Strandline	Elevation	Characteristics in Grand Forks County
Upper Herman	1140-1165	From T. 152 N., R. 55 W. and south the deposits are low and long, narrow, somewhat discontinuous ridges of coarse sand and gravel from 3 to 12 feet thick; the sand and gravel generally contains many shale pebbles. North of T. 152 N., R. 55 W., the deposits are low, isolated gravelly sand ridges less than 10 feet thick; a scarp marks much of the base of the strandline.
Lower Herman	1125-1140	From T. 150 N., R. 55 W. and south the deposits are very low, long narrow ridges of coarse sand, usually less than 3 feet thick. North of T. 150 N., R. 54 W., the deposits are in long, broad ridges of sand and gravelly sand usually less than 5 feet thick.
Norcross	1085-1115	From T. 151 N., R. 54 W., and south the deposits are a few isolated ridges of sand and gravelly sand in an area of wind blown deposits. North of T. 151 N., R. 54 W., the deposits are in a broad band of coarse sand in low sand ridges; and generally marked by scarps and washed zones of sand. The deposits are generally about 5 to 10 feet thick.
Tintah	1030-1075	From T. 154 N., R. 55 W., northern Grand Forks County, and south the sand deposits of this strandline are mostly a washed zone on an eastward facing scarp; there are also a few isolated, very low ridges of coarse sand. The scarp becomes lower southward and disappears in T. 149 N., R. 53 W.
Campbell	990-1010	From T. 154 N., R. 55 W. to T. 149 N., R. 52 W., the deposits are in obvious ridges of

TABLE 3 (cont.-)

Strandline	Elevation	Characteristics in Grand Forks County
		gravel, gravelly sand, and coarse sand; the ridges are usually less than 15 feet thick, but are up to 30 feet thick in secs. 29 and 32, T. 150 N., R. 52 W. The gravel and sand are missing in a few places where the strandline is marked by a scarp on till; the scarp is 15 to 20 feet high.
McCauleyville	970-994	From T. 154 N., R. 55 W., to T. 149 N., R. 52 W., the deposits are in an obvious, almost continuous ridge of coarse sand, gravelly sand, and gravel generally 5 to 10 feet thick, but up to 15 feet thick in T. 149 N., R. 52 W., where the ridge is prominent.
Blanchard	940-961	From T. 154 N., R. 54 W., to T. 150 N., R. 52 W., the deposits are in three sets, but sometimes two, of narrow, low, discontinuous sand and gravelly sand ridges generally from 2 to 8 feet thick and not more than 12 feet thick. From T. 150 N., R. 52 W., and south to T. 149 N., R. 51 W., the deposits are low, discontinuous mounds of sand and gravelly sand less than 5 feet thick.
Hillsboro	925-940	From T. 154 N., R. 54 W., south to T. 149 N., R. 51 W., the deposits are generally in two sets of long, narrow gravelly sand and sand ridges that are discontinuous; thickness of the deposits is from 3 to 7 feet. In T. 149 N., R. 51 W., the deposits are in a series of short, very narrow ridges of sandy gravel that are up to 8 feet thick.
Emerado	895-904	A low scarp and associated fine sand bar in T. 154 N., and south of there a set of narrow, long discontinuous gravelly sand and sand ridges that are offset slightly to

TABLE 3 (cont.-)

Strandline	Elevation	Characteristics in Grand Forks County
		form an overlapping pattern in Tps. 150 and 151 N., R. 52 W. Thickness is as much as 7 feet.
Ojata	865-870 and 875-880	Two strandlines (No. 1 and No. 2) that are mostly low scarps and very discontinuous, low narrow ridges of fine sand; the deposits occasionally are sandy gravel; and deposits are 2 to 4 feet thick. The coarser materials of the very low beach ridges are either reworked ice-contact deposits or sandy lake deposits over till.