# GEOLOGY

# of

# TOWNER COUNTY, NORTH DAKOTA

by
John P. Bluemle
North Dakota Geological Survey
Grand Forks, North Dakota
1984

BULLETIN 79–PART I
North Dakota Geological Survey
Don L. Halvorson, *State Geologist*

COUNTY GROUNDWATER STUDIES 36–PART I
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

Prepared by the North Dakota Geological Survey
in cooperation with the U.S. Geological Survey,
North Dakota State Water Commission,
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# ABSTRACT

Towner County, located on the eastern edge of the Williston Basin, is underlain by 3,500 to 4,500 feet of Paleozoic and Mesozoic rocks that dip to the west-southwest toward the center of the basin about 200 miles to the southwest. The Cretaceous Pierre Formation shale underlies glacial sediment everywhere in the county. Pleistocene Coleharbor Group glacial deposits which cover the entire area, average about 150 feet thick, reaching a maximum thickness of about 600 feet in a buried preglacial valley that transects the county from south to north.

A total of five formations consisting of glacial deposits, mainly till, are recognized within the Coleharbor Group in Towner County. These formations, which represent separate advances of glacial ice, are mainly of Wisconsinan age. Additional, older till units are buried beneath the five formally named formations, but their ages are not known; presumably they are pre-Wisconsinan.

Towner County is located on the Glaciated Plains, an area of undulating to flat topography. Most of the county is characterized by low-relief collapsed glacial topography. A prominent esker extends across the county from north to south. The southern part of Towner County was part of glacial Lake Cando and is covered by silt and wind-blown sand.

## REGIONAL SETTING

Towner County, in northern North Dakota, covers 1,044 square miles in Townships 157-164 North and Ranges 65-68 West. It is located between 98° 58' 45" West Longitude on the east and 99° 31' 31" West Longitude on the west and between 48° 22' 13" North Latitude on the south and 49° North Latitude (the U.S.-Canadian International boundary) on the north (fig. 1).

The surface deposits in Towner County consist entirely of Pleistocene sediments of Late Wisconsinan age laid down on deposits of earlier glaciations or on bedrock of Cretaceous age (Pierre Formation shale). The slope on the preglacial bedrock topography is northward. The dip of the Cretaceous and older rocks is toward the southwest, reflecting the position of the county on the eastern flank of the Williston Basin, an intracratonic basin, the center of which is in western North Dakota.

Towner County lies entirely within the Glaciated Plains (Drift Prairie) just east of the Turtle Mountains. It is characterized mainly by undulating to gently rolling glacial sediment (till) except for the flat plain of glacial Lake Cando in the south and a strip of glaciofluvial and ice-contact gravel and sand that extends from north to south through the approximate center of the county. Relief is highest near the ice-contact ridges in the central part of the county and near some of the larger coulees that have been eroded into the till plain in the northwest part of the county. In most places, relief is low with slopes ranging between 1° and 3°. Elevations range from less than 1,450 feet on the glacial Lake Cando plain in the southeast to about 1,775 feet in parts of northwestern Towner County just east of the Turtle Mountains.

## METHODS OF STUDY

Field mapping was done during the summer of 1982. Stereoscopic pair photo coverage (scale 1:20,000), and topographic sheets of the 7.5-minute series (scale 1:24,000), were available for the entire county. Both the photos and topographic sheets were used in compiling the geologic map. Lithologic information was otained mainly from road cut or road ditch exposures or through the use of a 5-foot hand auger. Additional information was obtained through test-hole drilling (about 35,000 feet of test hole were drilled during the current study) by the North Dakota State Water Commission. Information on subsurface stratigraphy was obtained from files of the North Dakota Geological Survey oil exploration tests.

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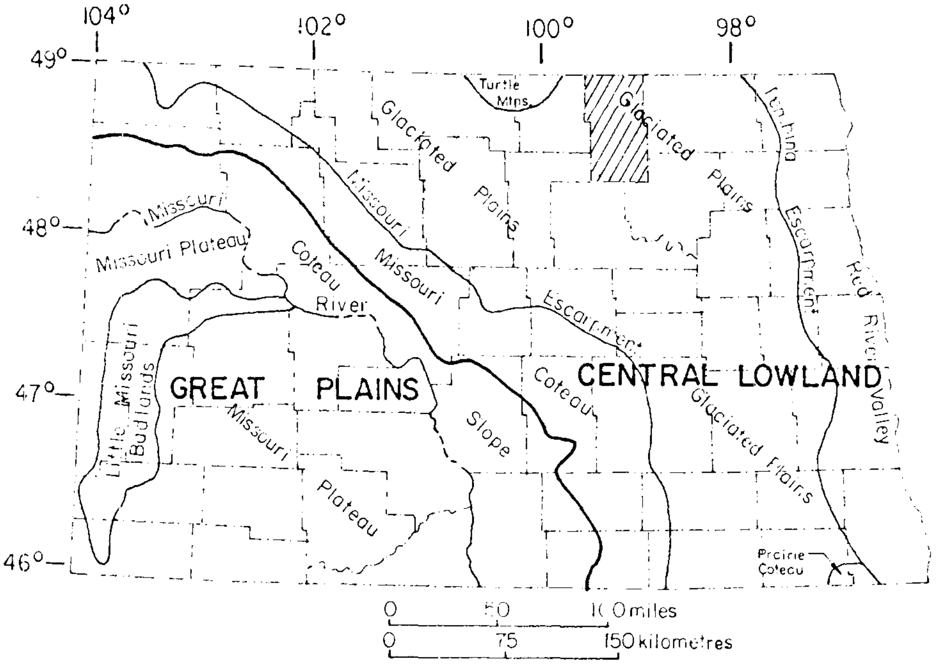

Figure 1. Physiographic map of North Dakota showing the location of Towner County.

## ACKNOWLEDGMENTS

I gratefully acknowledge Howard Hobbs, who, in the course of completing a Ph.D. dissertation at the University of North Dakota, developed a stratigraphic framework to serve as a basis for understanding the Pleistocene history of northeastern North Dakota. Hobbs collected surface samples and studied core samples of the glacial sediments, analyzed textures, and determined proportions of crystalline, carbonate, and shale grains in the samples he obtained. He recognized several discrete formations of glacial origin in the Towner County area. The part of this report dealing with stratigraphic correlation of till units is based largely on Hobbs' work.

## STRATIGRAPHY

### General Statement

As much as 4,600 feet of Paleozoic and Mesozoic sedimentary rocks lie on the Precambrian basement in Towner County. The discussion that follows is mainly a description of the composi-

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tion, sequence, and correlation of the geologic units that lie at and immediately beneath the surface in Towner County. The description proceeds from the oldest known materials, which are discussed briefly, to the younger materials which, because they are more easily accessible, are described in much greater detail than are the older units. All of the landforms that occur at the surface in Towner County are composed of Pleistocene materials, which were deposited mainly by glacial action. The emphasis of this report will be on the configuration and origin of the landforms.

## Precambrian Rocks

A total of seven wells have penetrated Precambrian rocks in Towner County. The Precambrian surface in Towner County ranges from a depth of about 3,700 feet in the east to about 4,600 feet in the west. It slopes west-southwestward at about 33 feet per mile in the northern part of the county and about 43 feet per mile in the southern part. Elevations on the Precambrian surface range from 2,200 feet below sea level in northeasternmost Towner County to slightly more than 3,000 feet below sea level in the southwest corner of the county.

Samples of cuttings from the wells that have penetrated Precambrian rocks in Towner County were examined by E. G. Lidiak, whose findings have not been published. Lidiak named several rock type "terranes" in North Dakota. Most of Towner County is part of his Towner granite terrane, which extends from the Canadian border to south-central North Dakota. The remainder of the county is included in Lidiak's Ramsey gneiss terrane. Generally the Precambrian rocks of Towner County are granite, granodiorite, and gneiss. The granite is medium to coarse grained with most cuttings consisting of individual grains. The samples are generally fresh. Quartz, microcline, and normally zoned plagioclase are the essential minerals in the samples of granite. Two wells penetrated gneiss, which Lidiak characterized as almandine amphibolite facies.

## Paleozoic Rocks

Paleozoic rocks range in thickness from about 2,300 feet in northwestern Towner County to about 1,800 feet in the southeastern corner of the county. At least part of the variation in thickness was caused by episodes of erosion that resulted in unconformities. For purposes of discussion, it is convenient to divide the stratigraphic section into sequences, a sequence being the preserved sedimentary record bounded by major regional unconformities. Paleozoic sequences recognized in Towner County are the Sauk, Tippecanoe, and Kaskaskia.

### Sauk Sequence

All the rocks of the Sauk Sequence are included in the Deadwood Formation, which consists of interbedded clastics and carbonates. Based on test holes in adjacent counties, about 15 feet of Deadwood sediments may occur in southwesternmost Towner County, although the Deadwood Formation was not recognized in any of the test holes in the county.

### Tippecanoe Sequence

Rocks of the Tippecanoe Sequence range in thickness from about 1,000 feet to 1,200 feet in Towner County. The relatively uniform thickness reflects stable conditions during deposition of these rocks and a location where the depositional thickness of all the formations, except the Interlake Formation, have been preserved. The Tippecanoe Sequence began with clastics of the Winnipeg Group, followed by carbonates and minor evaporites of the Red River, Stony Mountain, and Interlake Formations.

### Kaskaskia Sequence

Rocks of the Kaskaskia Sequence range in thickness from about 750 feet to 1,150 feet, east to west. The Devonian rocks are mostly carbonates with minor amounts of evaporites and shales. They thin southeastward, primarily because of depositional thinning, but also as a result of unconformities between Mississippian and Devonian rocks as well as within the Devonian rocks. The only Mississippian rocks that occur in Towner County are the lower Lodgepole and Bakken Formations. These rocks are primarily carbonates with some anhydrite. Their erosional edge extends generally north to south across Towner County, and they are present only in the northwestern and southern parts of the county.

The Devonian and Mississippian rocks in Towner County were eroded during post-Mississippian time. Erosion of the Paleozoic rocks resulted in two or more broad, southwest-trending valleys through which rivers apparently flowed from the Canadian Shield area northwest of Towner County southwestward into the Williston Basin during some part of Late Mississippian, Pennsylvanian, and Permian time (Anderson, 1974). One of these broad valleys crosses central Towner County. Relief in the valley, which is in excess of 500 feet east of Towner County, is compensated for by a markedly thickened section of Jurassic and, to a lesser extent, Triassic sediments.

## Mesozoic Rocks

Mesozoic rocks are mainly fine-grained clastics that range in thickness from about 1,600 feet in northeastern Towner County to about 2,400 feet along the western edge of the county. These rocks are divided into two sequences, the Absaroka and the Zuni (fig. 2).

### Absaroka Sequence

The Triassic Spearfish Formation is the only remnant of the Absaroka Sequence in Towner County. No Pennsylvanian or Permian rocks occur in the county. The Spearfish Formation consists of red beds that range in thickness from about 80 to 90 feet in central Towner County to an erosional edge to both the north and south.

### Zuni Sequence

The Zuni Sequence includes rocks of Jurassic and Cretaceous age which reach a combined total thickness ranging from about 1,600 feet in the northeast to about 2,400 feet in the southwest. The Jurassic rocks, which consist mainly of shale with some fine-grained sandstone and lesser amounts of carbonates and gypsum, range from about 250 feet thick in the northeastern corner of the county to about 650 feet in the southwest. Jurassic sediments thicken in a broad, northeast-southwest trending valley (post-Mississippian to Triassic age) carved into the pre-Mesozoic surface.

Cretaceous rocks in Towner County range from about 1,300 feet thick in the east to about 1,750 feet in the southwest. The lower Cretaceous Inyan Kara clastics unconformably overlie the Jurassic section in all but the southwestern quarter of Towner County where marine shale overlies the Jurassic. The Cretaceous section above the Inyan Kara is mainly gray, marine shale except for some sandy zones, the most notable of which is the Newcastle Formation, which is present in southwestern Towner County. The Cretaceous shales are mainly noncalcareous, except for the Greenhorn and Niobrara, and they contain isolated bentonitic layers. The upper surface of the Pierre Formation is an unconformity overlain everywhere by sediment of the Quaternary Coleharbor Group (fig. 3). The Pierre Formation is not exposed anywhere in Towner County.

## Pleistocene Sediment

All the sediment related to glacial deposition in Towner County, that is, all the materials that were deposited by the glacial ice and by flowing and ponded water associated with the ice, are collectively referred to as the Coleharbor Group. Sediment of the Coleharbor Group is exposed throughout the county and ranges up to over 500 feet thick a few miles southwest of Rock Lake (fig. 4). It consists of three main textural

| AGE | | UNIT NAME | DESCRIPTION | THICKNESS (feet) |
|---|---|---|---|---|
| Holocene | TEJAS | OAHE FORMATION | Sand, silt, and clay | 0- 20 |
| Quaternary | | COLEHARBOR GROUP | Till, sand, gravel, silt, and clay | 5-600 |
| Cretaceous | ZUNI | PIERRE FORMATION | Shale | 500-700 |
| | | NIOBRARA FORMATION | Calcareous shale | 175-225 |
| | | CARLILE FORMATION | Shale | 175-230 |
| | | GREENHORN FORMATION | Calcareous shale | 110-140 |
| | | BELLE FOURCHE FORMATION | Shale | 120-135 |
| | | MOWRY FORMATION | Shale | 35-100 |
| | | NEWCASTLE FORMATION | Sandy silt | 0- 45 |
| | | SKULL CREEK FORMATION | Shale | 25-110 |
| | | INYAN KARA FORMATION | Sandstone and shale | 0-120 |
| Jurassic | | UNDIFFERENTIATED | Shale, sandstone, carbonates, and gypsum | 250-650 |
| Triassic | ABSAROKA | SPEARFISH | Siltstone and sandstone | 0- 80 |
| Permian | | | (absent in Towner County) | ---- |
| Pennsylvanian | | | | |
| Mississippian | KASKASKIA | MADISON GROUP | Carbonates and shale | 0-250 |
| | | BAKKEN FORMATION | Siltstone and shale | 0- 15 |
| Devonian | | THREE FORKS FORMATION | Shale, siltstone, and dolomite | 0- 50 |
| | | BIRDBEAR FORMATION | Limestone | 0- 85 |
| | | DUPEROW FORMATION | Dolomite and limestone | 200-370 |
| | | SOURIS RIVER FORMATION | Dolomite and limestone | 160-240 |
| | | DAWSON BAY FORMATION | Dolomite and limestone | 95-220 |
| | | PRAIRIE FORMATION | Halite | 20- 45 |
| | | WINNIPEGOSIS FORMATION | Limestone and dolomite | 40-100 |
| Silurian | TIPPECANOE | INTERLAKE FORMATION | Dolomite | 125-240 |
| | | STONEWALL FORMATION | Dolomite and limestone | 60- 80 |
| Ordovician | | STONY MOUNTAIN FORMATION | Dolomite, limestone, and shale | 120-135 |
| | | RED RIVER FORMATION | Limestone | 540-565 |
| | | WINNIPEG GROUP | Siltstone, sandstone, and shale | 165-190 |
| Cambrian | SAUK | DEADWOOD FORMATION | Limestone, dolomite, shale, and sand | 0- 15 |
| Precambrian basement rocks | | | | |

Figure 2. Stratigraphic column for Towner County.

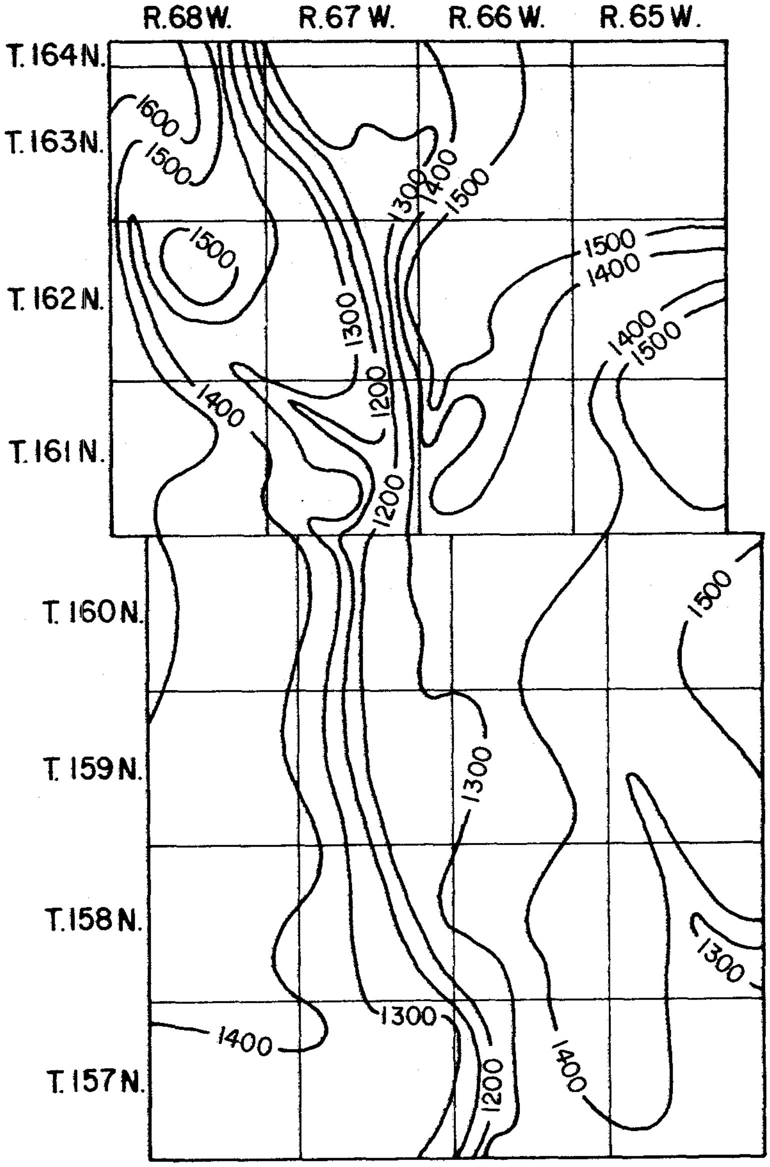

Figure 3. Subglacial topography of Towner County. Map is adapted from Randich and Kuzniar (in preparation). Elevations are given in feet. The Cretaceous Pierre Formation subcrops beneath the glacial sediment cover everywhere except for some small, scattered areas in the westernmost part of the county where the Cretaceous Fox Hills Formation lies on the Pierre Formation.

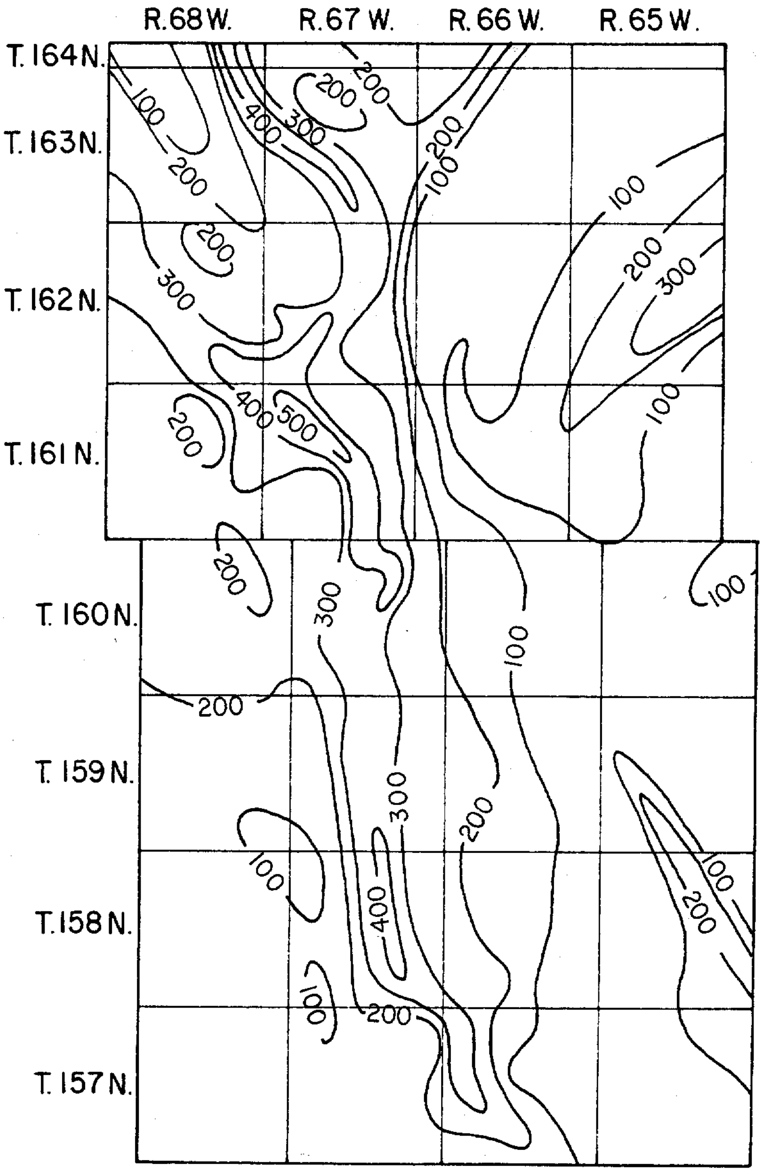

Figure 4. Thickness of glacial sediment in Towner County. Thicknesses are given in feet.

facies: glacial sediment (till); silt and clay; and sand and gravel.

## Till Facies

The till of the Coleharbor Group found at and near the surface in Towner County (map units Qccg, Qccu, Qct, Qcer, and Qcew on pl. 1) is typically a mixture of varying proportions of clay, silt, sand, pebbles, cobbles, and boulder-sized particles. The matrix, composed mostly of silt- and clay-sized particles is, in oxidized exposures, generally pale to dark yellowish brown in color. It tends to be slightly darker when it is moist. Fresh, unoxidized samples of till, taken during test-hole drilling, are medium to dark olive gray, tight, cohesive, and sometimes brittle. Some samples from deep holes are extremely hard material. The depth of oxidation of the surface till throughout Towner County ranges from about 10 to 35 feet.

The till found near the surface is mostly poorly indurated, and it may be weakly jointed, but it has no other structure such as bedding or sorting. It is, however, typically quite silty, and small chunks of lake silt are found in many places, especially in southwestern Towner County. The probable reason for this is that, because preglacial and interglacial drainage was northward, the advancing glaciers tended to cause ponding of runoff and meltwater as they advanced. When the glaciers overrode the ponded areas, they picked up the silt and clay that had been deposited in the water and incorporated it into the till.

### Stratigraphic Correlation of Till Units

The Coleharbor Group has been subdivided into a large number of informal units and formal formations by various geologists. Such subdivisions are usually based on studies of identifiable till units. Some of these units are apparently regionally correlatable, but others seem to have local extent at best. No attempt was made during the present study to unravel the till stratigraphy of Towner County. However, a study of the glacial stratigraphy of northeastern North Dakota by Howard Hobbs included all of Towner County. Hobbs, whose work has not been published, recognized seven lithostratigraphic units (formations) in northeastern North Dakota and correlated them over much of the area. He also recognized several additional units, which he could not correlate and which he did not name. Hobbs differentiated and correlated the various formations primarily by the proportion of crystalline (igneous and metamorphic rock fragments), carbonate, and shale grains in the coarse-sand fraction (1 to 2 mm) of the till. Table 1 lists the formations recognized by Hobbs in northeastern North

TABLE 1.--Texture and Coarse-sand Lithology of Glacial Sediments (Till) in the Area of Study

| Formation | Sand | Silt | Clay | Crystalline | Carbonate | Shale |
|---|---|---|---|---|---|---|
| *Hansboro Formation | 28 | 38 | 34 | 50 | 27 | 23 |
| Falconer Formation | 29 | 33 | 38 | 42 | 34 | 24 |
| *Dahlen Formation | 29 | 44 | 27 | 26 | 19 | 55 |
| *Gardar Formation | 32 | 42 | 26 | 10 | 8 | 82 |
| *Vang Formation | 34 | 35 | 31 | 40 | 25 | 35 |
| Tiber Formation | 27 | 38 | 35 | 21 | 28 | 51 |
| *Cando Formation | 35 | 41 | 24 | 25 | 16 | 59 |

* Recognized in Towner County.

Texture figures are percentages of total sand, silt, and clay, excluding gravel. Coarse-sand lithology figures are percentages of total crystalline, carbonate, and shale, excluding miscellaneous grains. Figures are area-weighted medians--considerable variation from the median exists in all formations.

Dakota. Of the seven formations recognized by Hobbs, five--the Cando, Vang, Gardar, Dahlen, and Hansboro--were recognized in Towner County.

Generally, Hobbs' test holes were about 150 feet deep or shallower. In much of northeastern North Dakota, a 150-foot hole is deep enough to penetrate the entire thickness of glacial sediment, but in parts of Towner County, as in the deep valley that extends from north to south through the county (fig. 3) the glacial sediment is over 300 feet thick and as much as 500 feet thick. It was possible to correlate short distances, generally less than a mile, from several of Hobbs' test holes to holes drilled for the present study. The till stratigraphy worked out by Hobbs correlates closely with the till stratigraphy observed in the upper parts of several deep test holes drilled for the present study. In many of these deeper holes, an extremely diverse and complex succession of till units exists below the lowest units that were identified by Hobbs (generally, the Cando Formation, which must be either early or pre-Wisconsinan, was the lowermost formation Hobbs identified in Towner County). It is likely that the older (pre-Wisconsinan) till units were preserved best in valleys, such as the deep one in Towner County, and removed by erosion on the uplands. For this reason, Hobbs was not able to extend his studies to the older units.

### Cando Formation

The stratigraphically lowest glacial unit Hobbs was able to correlate throughout northeastern North Dakota was the Cando Formation. According to Hobbs, who named the Cando Formation for the town of Cando in Towner County, the formation is composed of till, stratified sediment (silt, sand, and gravel), and shale breccia. Till of the Cando Formation is olive gray where unoxidized and buff to olive brown where oxidized. The shale content of the coarse sand generally ranges from 55 percent to 65 percent. The normalized crystalline ratio generally ranges from 0.55 to 0.70, indicating that crystalline grains generally outnumber carbonate grains in the coarse sand fraction.

The Cando Formation rests in some places on shale of the Cretaceous Pierre Formation and in other places on older, unnamed glacial sediments. It is directly overlain by the Vang Formation in three locations studied by Hobbs, and it is overlain by an unnamed unit directly under the Vang Formation in one place. The Cando Formation is also overlain by the Gardar and Dahlen Formations in several places.

The Cando Formation is widely preserved in the subsurface in Towner County. In a test hole located in sec 27, T158N, R66W, about a mile east of Cando, 5 feet of till of the Cando Formation overlies 34 feet of shale breccia of the Cando Formation over shale of the Pierre Formation, and underlies stratified sediment and till of the Gardar Formation. It is exposed at the surface in several places near the Little South Pembina River in Cavalier County, and it has been found sporadically at other locations. The till portion of the Cando Formation is generally less than 20 feet thick; too little is known to make any further generalizations.

The Cando Formation can be differentiated from the Hansboro and Vang Formations by its greater abundance of shale, from the Tiber Formation (which does not occur in Towner County) by its lesser abundance of carbonate grains, and from the Gardar Formation by its lesser abundance of shale. The Dahlen Formation contains less shale than the Cando Formation in Towner County. Thus, the Cando Formation can be distinguished from the Dahlen Formation, apart from its stratigraphic position, only by a study of the distribution of shale abundance in the Dahlen Formation.

The age of the Cando Formation is unknown, and it has not been correlated beyond the area studied by Hobbs.

### Vang Formation

The Vang Formation overlies the Cando Formation in much of Towner County. At its type section in eastern Cavalier County near Vang, the Vang Formation is composed of till that is sandy, buff where oxidized, and light gray where unoxidized. Pebbles and cobbles of crystalline rocks are abundant. At other locations, the till of the Vang Formation is not as sandy, but it has the same general appearance. Coarse sand in the till contains little shale (from 25% to 45%). Crystalline grains are considerably more common than carbonate grains; the normalized crystalline ratio generally ranges from 0.60 to 0.75. A cobble and boulder accumulation occurs at the top of the Vang Formation at its type section in Cavalier County.

The Vang Formation directly overlies shale of the Pierre Formation in six places that Hobbs observed it. It overlies the Cando and Tiber Formations in three places each, and it overlies uncorrelated sediments in four places. The Vang Formation is not directly overlain by the Hansboro or Falconer Formation at any known location.

The Vang Formation occurs sporadically over northeastern North Dakota. It ranges from about 20 to 35 feet thick over most of Towner County, but near Churchs Ferry, 40 feet of till of the Vang Formation overlies 110 feet of stratified gravel and sand of the Vang Formation.

Till of the Vang Formation can be distinguished from till of the Dahlen, Gardar, Tiber, and Cando Formations by its lesser shale content and from the Hansboro Formation by its greater shale content and stratigraphic position.

The Vang Formation contains till and, locally, large amounts of gravel and sand. The glacier that deposited the till of the Vang Formation advanced from the east and northeast, bringing abundant crystalline sand from the Canadian Shield.

The age of the Vang Formation is not known. It is correlated with a layer of glacial sediment exposed in the Sheyenne River trench and with the Marcoux Formation in northwestern Minnesota (Harris, Moran, and Clayton, 1974). The Vang Formation is generally thought to be equivalent to Units B and C of Salomon (1975).

### Gardar Formation

The Gardar Formation (Salomon, 1975) generally rests on older glacial sediments in the Red River Valley and in Towner County, and on shale bedrock along the Pembina Escarpment and in much of Cavalier County. In places, the Gardar Formation rests on a soled boulder pavement at the top of an older layer of glacial sediment. The Gardar Formation contains a soled boulder pavement at its base in some places where it rests on the Pierre Formation. The Gardar Formation occurs sporadically at the surface, but it is generally overlain by the Dahlen Formation, where it commonly contains a soled cobble and boulder pavement at its top.

Till of the Gardar Formation is olive brown where oxidized and olive gray where unoxidized. It is generally strongly jointed and stained by oxides of iron and manganese. Shale fragments are abundant; the shale content of the coarse sand generally ranges from 60 percent to 90 percent with extreme values of 38 percent and 95 percent. Crystalline grains are generally more common than carbonate grains. The normalized crystalline ratio generally ranges from 0.50 to 0.75.

Along the base of the Pembina Escarpment, the Gardar Formation can be divided into an upper and a lower member. The lower member can be distinguished by its shale content, which is generally 10 percent to 15 percent less than the upper member. The upper member forms the full thickness of the Gardar Formation outside of Hobbs' study area, and is equivalent to the Gardar of Salomon (1975). The lower member is equivalent to Salomon's Unit A. In places, the upper member is absent, and the lower member is recognized by its lower shale content relative to nearby samples of the upper member.

The Gardar Formation is extensively distributed over Hobbs' study area, but it is absent in several broad areas. The Gardar Formation is much more commonly found than any older formation, which indicates a period of considerable erosion before the deposition of the Gardar Formation. The thickness of the Gardar Formation is variable, but some generalizations can be made. Till of the Gardar Formation is generally less than 15 feet thick over the Glaciated Plains and the Pembina Escarpment and from 40 to over 100 feet thick at the base of the Pembina Escarpment in the Red River Valley, particularly in the southern part of Hobbs' study area.

Till of the Gardar Formation can be differentiated from till of any other formation by its abundant shale. Although some samples of till of the Gardar Formation contain less abundant shale than some samples of till of other formations, till of the Gardar Formation contains more shale than till of any other formation at the same location. Shale abundance is different from place to place in each formation; the general pattern is a strong decrease eastward from the Pembina Escarpment and a small, variable decrease westward from the Pembina Escarpment.

The Gardar Formation is composed of glacial sediment and some stratified gravel and sand. The ice that deposited the glacial sediment of the Gardar Formation advanced from the northwest, as indicated by striations on soled boulders beneath its base.

The age of the Gardar Formation is unknown, but like all the underlying formations, it is older than Late Wisconsinan.

The Gardar Formation may have been deposited during the Napoleon Glaciation (Moran et al., 1976) and Clayton (1966) has suggested that the Napoleon Glaciation was Early Wisconsinan. The Gardar Formation is correlated with glacial sediment exposed along the Sheyenne River Trench between Lisbon and Fort Ransom, and with the St. Hilaire Formation in northwestern Minnesota (Harris et al., 1974) on the basis of shale abundance.

### Dahlen Formation

The Dahlen Formation (Salomon, 1975) in most places rests on till of the Gardar Formation. Where the Gardar Formation is absent, the Dahlen Formation rests on shale bedrock or on older glacial sediments. A soled boulder pavement is commonly observed at the top of the Gardar Formation or older formations overlain by till of the Dahlen Formation. A boulder pavement is commonly present at the base of the formation where it overlies shale bedrock. Striations on the boulders are generally aligned northwest-southeast. The Dahlen Formation is overlain by the Falconer Formation in parts of the Red River Valley, and in some places it is separated from the Falconer Formation by laminated lake sediment of the Wyler Formation (Harris et al., 1974). In parts of the western Glaciated Plains, the Dahlen Formation is overlain by till of the Hansboro Formation.

Till of the Dahlen Formation is generally light brown where it is oxidized and medium to olive gray where it is unoxidized. It tends to be soft and friable to a depth of several feet below the surface and hard and blocky below. Iron- and manganese-oxide stains are common in areas where till of the Dahlen Formation contains abundant shale. The shale content of the coarse sand of the till generally ranges from 40 percent to 80 percent, an uncommonly broad range. Crystalline grains are more common than carbonate grains in the coarse sand; the normalized crystalline ratio generally ranges from 0.55 to 0.65.

The Dahlen Formation is widely distributed over Hobbs' study area. The till of the formation is generally from 25 to 40 feet thick in the Towner County area and 5 to 15 feet thick along the Pembina Escarpment. In the Red River Valley, till of the Dahlen Formation ranges from 15 to 50 feet thick. In places where the formation is especially thin, the boulder pavement beneath may be at the surface or covered by only a thin soil. Generally, where till of the Dahlen Formation forms the surface sediment, the formation is thickest where the surface hummocks are highest, and is thin in areas of flat topography.

Till of the Dahlen Formation can be distinguished from till of the Vang, Falconer, and Hansboro Formations by its greater abundance of shale, from till of the Gardar Formation by its lesser abundance of shale, and from till of the Tiber Formation by its greater abundance of crystalline grains relative to carbonate grains. Till of the Dahlen Formation can be distinguished from till of the Cando Formation by stratigraphic position and the distribution of shale abundance in the Dahlen Formation.

The Dahlen Formation consists of glacial sediment and a small amount of fluvial and lacustrine sediment. The glacier that deposited the till of the Dahlen Formation in Towner County advanced from the northwest, as indicated by striations on the boulder pavements, alignment of drumlins, and alignment of washboard moraines.

The Dahlen Formation includes the deposits of the main Late Wisconsinan glaciation, which has been called the Lostwood Glaciation by Clayton (1972). The Dahlen Formation extends well to the south of Hobbs' study area and it is exposed along the Sheyenne River Trench. It is correlated with the upper part of the Red Lake Falls Formation (Harris et al., 1974) on the basis of shale content, but not with the lower part of the Red Lake Falls Formation, which contains very little shale and was probably derived from a northeastern rather than northwestern source.

### Hansboro Formation

The Hansboro Formation rests directly on the Dahlen Formation. No formation has been observed overlying the Hansboro Formation. According to Hobbs, who named the Hansboro Formation for the town of Hansboro in northern Towner County, the formation is composed of till and stratified sediment. Till of the Hansboro Formation is similar in appearance to till of the Dahlen Formation. It is buff where oxidized, light gray where unoxidized, generally fissile, and it lacks iron-stained joints. The shale content of the till is sparse, ranging from 17 percent to 27 percent in the coarse-sand fraction studied by Hobbs. Crystalline sand grains are considerably more common than carbonate grains; the normalized crystalline ratio ranges from 0.62 to 0.69. The Hansboro Formation can be distinguished from the Cando, Tiber, Vang, Dahlen, and Gardar Formations by the lesser abundance of shale in the till fraction.

The Hansboro Formation occurs widely over Towner County. Its boundaries are poorly defined because not enough data are available. Where it occurs, the till portion of the Hansboro Formation is less than 15 feet thick. The total thickness of the Hansboro Formation ranges up to about 50 feet thick in some test holes.

The age of the Hansboro Formation is unknown, but it is younger than the underlying Dahlen Formation. It was probably deposited during a readvance of the retreating Late Wisconsinan glacier. This readvance may have corresponded to the readvance that deposited the Falconer Formation farther east. It is also possible that the readvance of the Hansboro Formation was a reactivation of stagnant ice from the glacier which had earlier deposited the Dahlen Formation. This would explain why the eastern edge of the Hansboro Formation does not correspond to any presently known ice-marginal position.

## Silt and Clay Facies

### Surface Deposits

Deposits of silt and clay are found at the surface in several places in Towner County (Qcof, Qcoh, and Qos), and they are widespread in the southeastern part of the county, mainly southeast of Cando (pl. 1). The deposits of glacial Lake Cando cover most of T157N, Rs66 and 67W and parts of T158N, Rs66 and 67W. Elevations on the lake plain range from about 1,450 feet in the south to over 1,470 feet in the north and west. The lake sediments in southeastern Towner County are fine grained, tending toward clay in many places, but banded with lenses of fine sand in other places. They are commonly oxidized to yellowish-orange colors to depths as great as 15 feet. Beneath the oxidized zone they are olive gray in color, with considerable amounts of gypsum crystals. In places where clay predominates, the lake sediment is quite hard and cohesive. The glacial Lake Cando deposits are about 20 to 22 feet thick in most places in southeastern Towner County where they most commonly overlie fluvial sand or gravel. In places where the sand or gravel is absent, they overlie till, and in these places the silt and clay deposits of glacial Lake Cando are generally thinner, reflecting relief on the pre-lake till surface. In parts of T157-158N, R65W, lake sediments are absent and, although the till surface is flat like the remainder of the lake plain in this area, it is bouldery, apparently a wave-worn plain.

Areas of Holocene Oahe Formation silt and clay are found on the floors of sloughs throughout Towner County. Although several hundred small areas of Oahe Formation silt and clay (Qos) occur in the county, especially in association with the areas of Qccu in the east, only a few of the larger areas are shown on the geologic map (pl. 1). The silt and clay of the sloughs consists of 10 to 20 feet of tough, black clay, silty clay, and clayey silt. Several percent of included organic material gives it its black color.

### Buried Deposits

Several discrete, buried layers of silt and clay were identified during test drilling in Towner County. These buried layers of lake sediment occur within reasonably well-defined depth ranges and at relatively uniform elevations, making it possible to correlate them over broad areas within the county. Although many additional test holes throughout the county penetrated isolated layers of silt and clay, most of these layers were less than 10 feet thick, and most of them could not be correlated with the stratigraphy in nearby test holes. The correlatable silt layers, on the other hand, generally extended over several townships.

The deepest, buried silt horizon occurs in two areas (fig. 5). Basal elevations on this horizon range from about 1,240 feet to as high as 1,296 feet. Identified in nine locations, this deeply buried deposit ranges from about 20 feet to as much as 150 feet thick, but it is generally between 40 and 60 feet thick. It is likely, however, that the thickest silt deposits are actually composites of two or more separate events, because it was not possible to differentiate the discrete units where they were not separated by either till or gravel layers. This deepest silt horizon is typically olive gray to dark gray, although in at least one test hole in sec 17, T161N, R67W, it was brownish gray and may have been at least partly oxidized.

In four of the nine test holes that penetrated the lowermost silt horizon, the silt lies directly on Cretaceous Pierre Formation shale. It lies on 30 to 50 feet of fluvial sediment in three holes and, in the remaining two holes, it lies on 135 and 236 feet of interbedded sand, gravel, and till.

In most of the test holes, the deepest silt horizon contains considerable lignite debris in interbedded sandy zones. The presence of lignite shows that the water supplied to the lake in which the silt was deposited had a western source.

The next lower silt horizon occurs at elevations generally about 100 feet above the deepest one. Basal elevations range from about 1,325 feet to as high as 1,360 feet and the silt horizon ranges up to 60 feet thick. This silt deposit was identified in at least 18 test holes; and similar probable lake deposits, consisting of clay or fine sand, were identified at the same interval in several additional test holes, but these are not included on figure 6.

The test holes that penetrated the second lowest silt horizon are located mainly in southern Towner County and generally along the eastern edge of the deep valley that crosses the county from south to north. This may suggest that the lake in which the silt was deposited was dammed by ice on the west. The second-lowest silt horizon also contains considerable detrital lignite, indicating that drainage into the proglacial lake in which the silt was deposited was from the southwest. In several of the test holes that penetrated the second silt, the sediment is brownish in color, suggesting that the material was at least partly oxidized.

The uppermost widespread buried silt horizon occurs about 100 feet above the second one, with basal elevations of about 1,420 feet. It is as thick as 104 feet in at least one place (fig. 7), but averages about 30 to 40 feet thick. Like the two deeper buried silt horizons, this third one is at least partly oxidized in several test holes. This silt horizon is buried beneath more

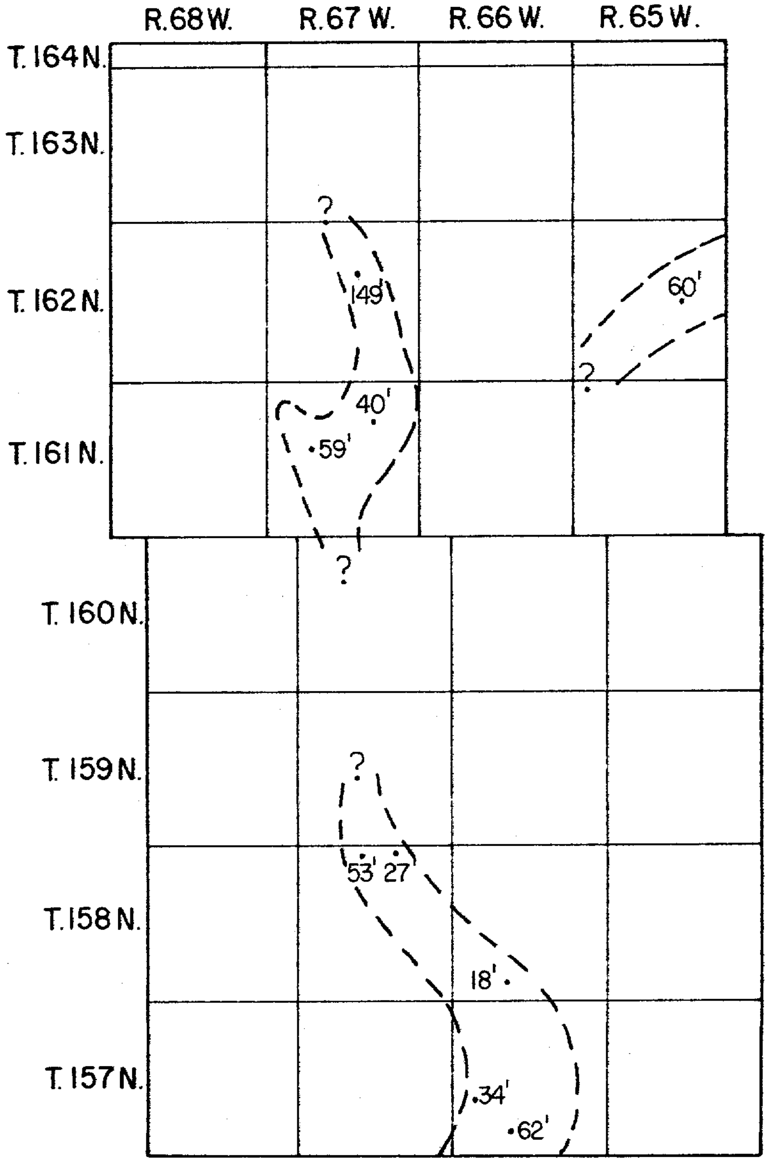

Figure 5. Thickness of the lowermost silt horizon in Towner County. Thicknesses are given in feet. Dashed lines show the probable maximum extent of the deposit, which appears to have been confined mainly to the deep valley that crossed the county from south to north (fig. 3).

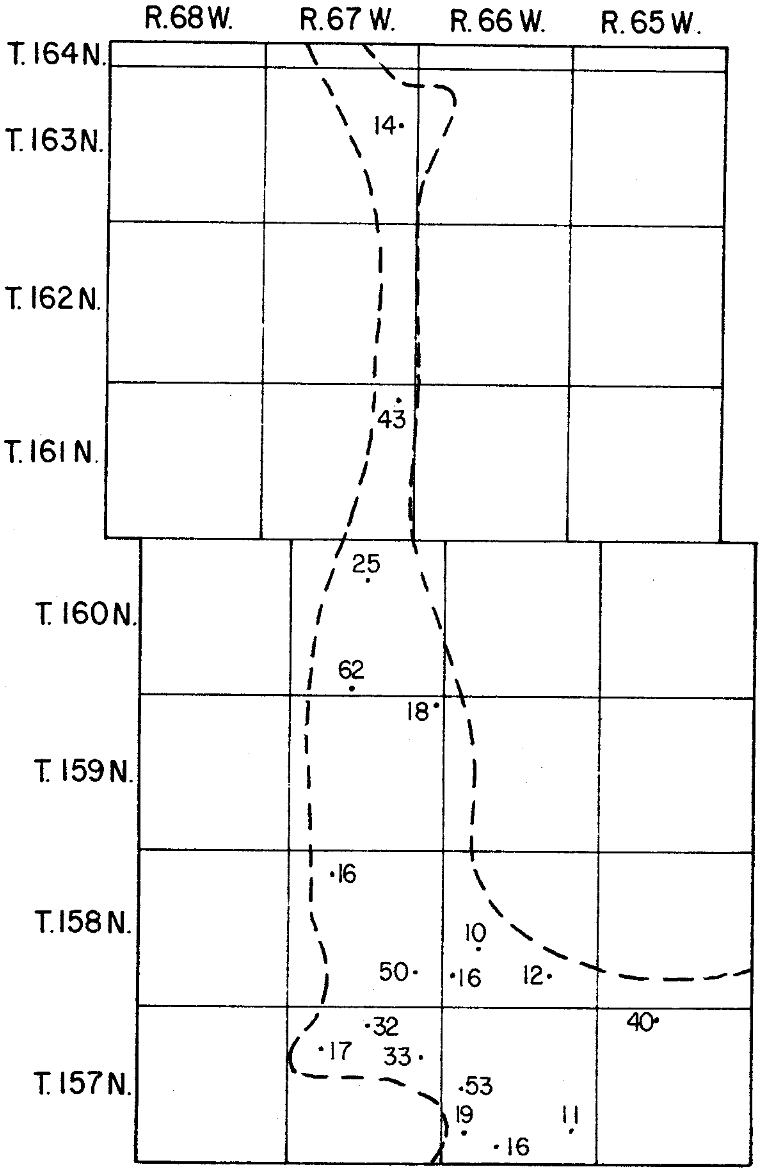

Figure 6. Distribution and thickness of the second-deepest silt horizon in Towner County. Thicknesses are given in feet. Maximum probable extent of the lake in which the silt was deposited is shown by dashed line.

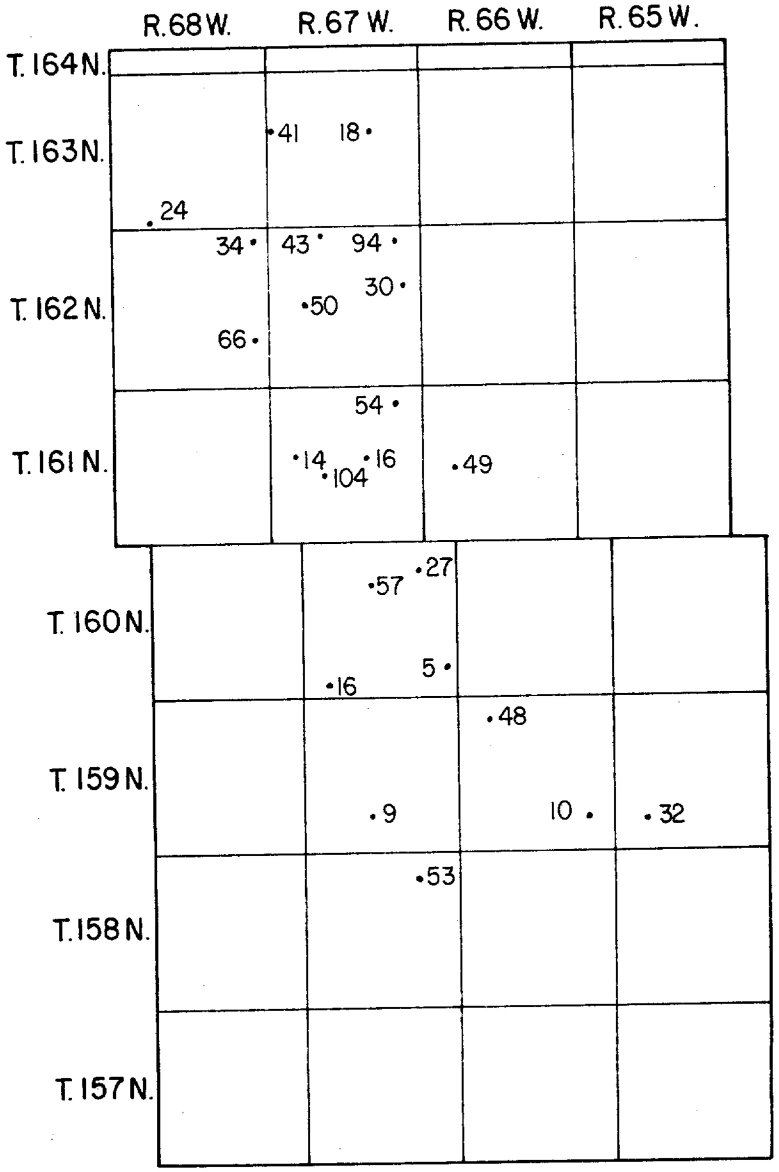

Figure 7. Distribution and thickness of the third silt horizon in Towner County. Thicknesses are given in feet.

than 100 feet of fluvial or glacial sediment in most places. It occurs within the same elevation range as the surface silt of glacial Lake Cando in southeastern Towner County.

Finally, another higher buried silt horizon was noted in three locations in northwestern Towner County. This buried silt horizon ranges from 24 to 72 feet thick, and it is buried beneath 60 to 135 feet of glacial sediment. It occurs at elevations above 1,550 feet.

### Age of the Buried Silt Deposits

The uppermost buried silt horizon lies beneath (in some cases considerably beneath) the till of the Cando Formation. Although the age of the Cando Formation is not known, it can be inferred from its relationship to younger till units that it is probably not younger than Early Wisconsinan, and it may be pre-Wisconsinan in age. Consequently, it is probable that all of the buried silt horizons are older than Early Wisconsinan.

## Sand and Gravel Facies

### Surface Deposits

Deposits of sand and gravel are most common in a 1- to 4-mile-wide zone that extends from the Canadian boundary southward past Rock Lake to an area a few miles east of Cando. Within this zone, flat-bedded, shaly, iron-stained gravel (Qcrf on pl. 1) commonly underlies nearly flat topography. Along with the flat areas within this zone are less extensive areas of similar shaly gravel commonly with collapsed or otherwise contorted bedding (areas of Qcrh on pl. 1). A prominent esker ridge is also associated with the areas of Qcrf and Qcrh. This esker, which is discussed in more detail elsewhere in this report, also consists of extremely shaly gravel that generally has slumped and contorted bedding.

Many small ice-contact ridges are present in the eastern part of the county associated with areas designated Qccu (pl. 1). Many of these ridges are covered by 1 or 2 feet of till, a result of overriding by a glacier, but in places the gravel of the ridges is exposed. Where it could be observed, the gravel consists mainly of extremely shaly material, composed of as much as 80 or 90 percent shale cobbles and pebbles, all apparently derived from the relatively shallow Pierre Formation in the area.

In parts of T158N, Rs65 and 66W, discontinuous areas of fine, wind-blown sand (Qou) overlie the northernmost deposits of glacial Lake Cando and the southernmost fluvial sands deposited by streams that flowed into the lake. This sand is silty and appears to be interbedded in some places with lake sediment.

### Buried Deposits

An extensive deposit of gravel and sand occurs beneath the surface in Towner County in a 6- to 8-mile-wide zone that extends southward, mainly through R67W, from the Canadian boundary to the southern edge of the county and beyond (figs. 8 and 9). This gravel deposit, which is nearly 300 feet thick in places in Towner County, is part of the Spiritwood Aquifer System (Randich and Kuzniar, in preparation), an extensive and complex aquifer developed in a series of preglacial and glacial diversion valleys that extend southward into South Dakota (Armstrong, 1982). The gravel of the Spiritwood Aquifer System occurs in several discrete horizons, each of which apparently relates to specific fluvial events of preglacial, glacial, or intraglacial age. The stratigraphy of these gravel horizons is described in detail by Randich and Kuzniar (in preparation). For the purposes of the present study, the total aggregate thickness of the gravel content of the glaciofluvial sediments has been calculated (fig. 8). The sand and gravel content of the glacial sediment has also been calculated and expressed as a percentage of the total bedrock overburden thickness (fig. 9).

# GEOMORPHOLOGY

## General Description

The modern landscape in Towner County is the surface that was formed by the Wisconsinan glacier that covered the area, by streams carrying water from the nearby melting glacial ice, and by the glacial Lake Cando, which flooded the southeastern part of the county when the glacier melted. During postglacial time, streams carved valleys into the till plain in northwestern Towner County and eolian processes slightly modified the glacial Lake Cando plain.

The landforms of Towner County apparently formed largely during the final melting of the glacier from the area, although it is likely that some of the overall configurations, especially in the northeast, formed during slightly earlier events and the modern topography there may be a result of modified (veneered) features. The main glacier melted from the area east of the Turtle Mountains about 12,000 years ago (Clayton, Moran, and Bluemle, 1980). It stagnated in some areas, especially over eastern Towner County in the area designated as Qccu on the geologic map (pl. 1).

Relief over most of Towner County is low. It may exceed 75 feet locally along some of the gullies such as Armourdale Coulee, Big Coulee, and Hidden Island Coulee, all in the northwestern part of the county. The flattest areas are the glacial Lake

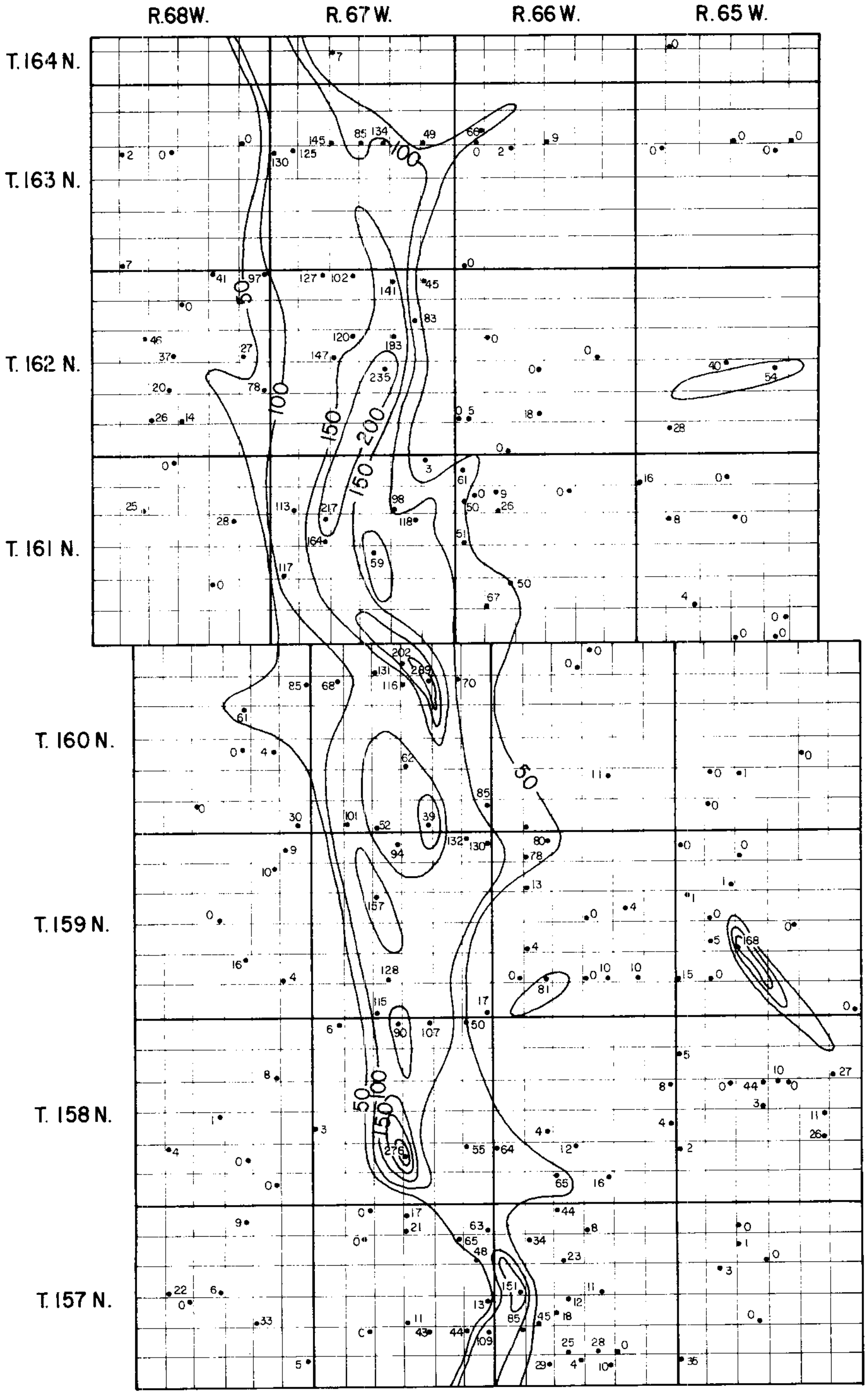

Figure 8. Total footage of gravel and sand penetrated in test holes in Towner County. Contour interval is 50 feet.

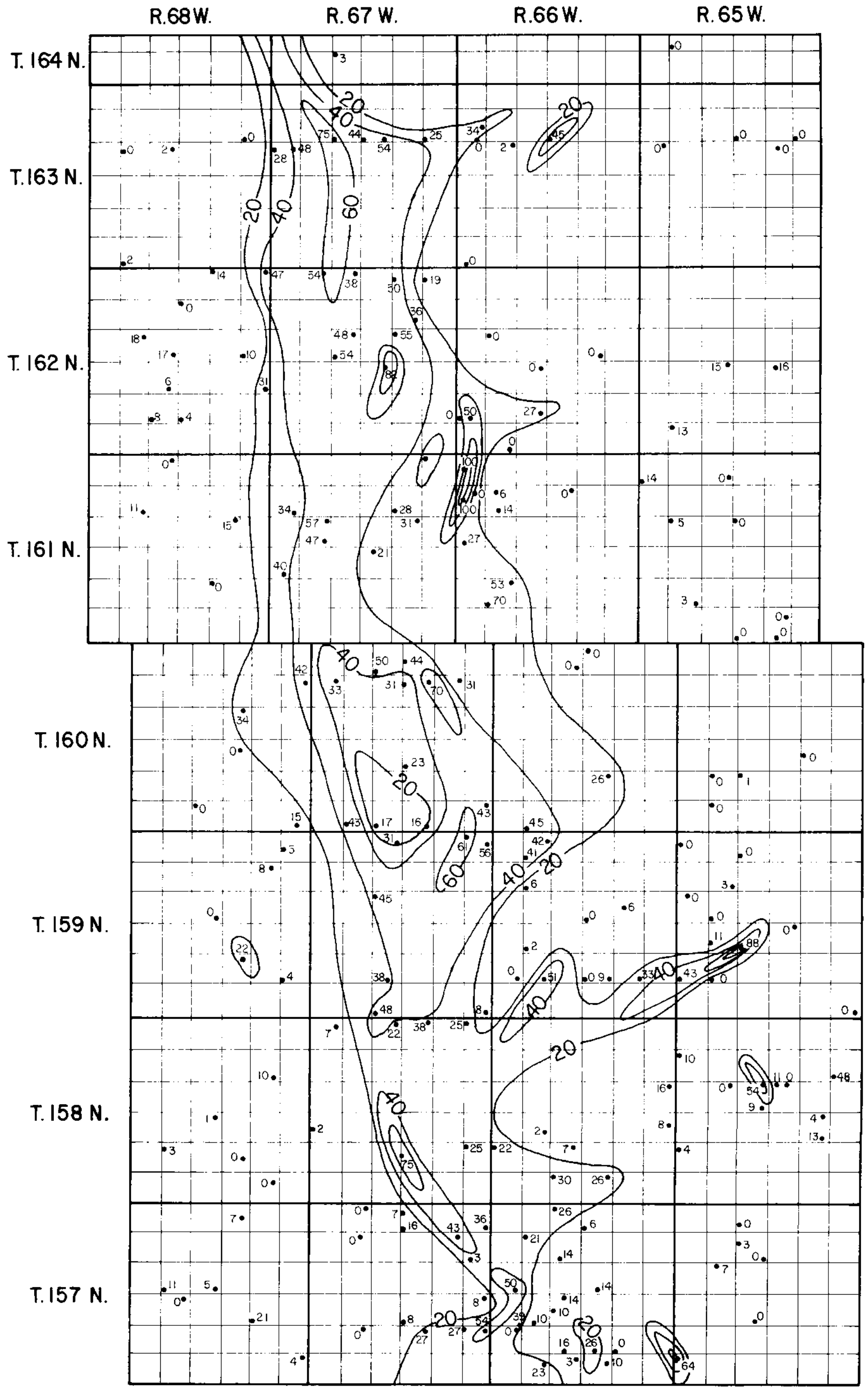

Figure 9. Percentage of gravel and sand in the glacial sediment in Towner County. Contour interval is 20 percent.

Cando plain in the southeast, some of the washed plains (Qcew and Qcer on pl. 1) in the central and southwestern areas, and the fluvial plain south of Rock Lake (Qcrf on pl. 1). Surface elevations rise from about 1,450 feet on the glacial Lake Cando plain to about 1,775 feet in northwestern Towner County.

## Glacial Landforms

### Collapsed Glacial Topography

Hilly and hummocky glacial topography results from the lateral movement of supraglacial sediment as it subsides (collapses, is let down, or slides to lower elevations in the form of mudflows) when the underlying ice melts out from under it (Clayton, 1967; Clayton and Moran, 1974; Clayton, Moran, and Bluemle, 1980). Although this is the generally accepted explanation for the origin of hummocky glacial topography, two alternatives have been suggested. Stalker (1960) suggested that hummocks resulted from the squeezing of subglacial fluvial and lacustrine sediment that lacks evidence of ever having been under a glacier. Bik (1967) suggested that hummocks resulted from the movement of sediment during the growth and decay of permafrost; he considered them to be relict pingos. However, in North Dakota, hummocks were generally formed at a time when paleoecologic evidence indicates a climate too warm for permafrost, and hummocks are generally absent in North Dakota in areas known to have had permafrost (Clayton, Moran, and Bluemle, 1980).

On the geologic map of Towner County (pl. 1), the collapsed glacial topography (Qccg, Qccu) is subdivided on the basis of its most conspicuous variables: slope angles, overall relief, presence or absence of ring-shaped hummocks, and presence or absence of transverse ridges.

Collapsed glacial topography is the most widespread glacial landform in Towner County. The undulating areas (Qccu) have slightly greater relief than do the gently rolling areas (Qccg). Relief over the broad areas of undulating collapsed glacial topography in eastern Towner County (east of the town of Rock Lake) range from about 10 to 20 feet locally and drainage over this area is essentially non-existent. Elevations are generally less than 1,600 feet and slope down to the west.

Relief over the area of undulating collapsed glacial topography in western Towner County (west of the town of Rock Lake) is generally 5 to 15 feet locally, except near the numerous gullies where it may exceed 25 feet. This area slopes eastward at about 20 to 25 feet in a mile and is bounded by a 20- to 25-foot, east-facing scarp that extends southward from the Hansboro area to the Rock Lake area. Collapsed gravel deposits occur east of the scarp. A number of small, east-trending valleys help to drain this area much better than the area to the east. Small washboards transect the undulating collapsed glacial topography in southwestern Towner County (pl. 1). The intersecting pattern of washboards in Tps.157-158N, R68W suggests a cross-cutting glacier margin relationship. The last event involved an east-flowing glacier overriding part of southwestern Towner County.

The area of undulating collapsed glacial topography east of Rock Lake is characterized by intricate topography with closely spaced small hills and sloughs, and large numbers of ridges, which are small eskers covered by a veneer of till. The mudflow material probably slid onto the eskers when the stagnant ice in the area melted. No apparent evidence was seen for glacial readvance that might otherwise account for the till cover on the eskers. The surface of the area is typically quite bouldery. Undulating collapsed glacial topography that occurs west of Rock Lake is also covered mainly by bouldery till that is quite gravelly in places. The topography is less intricate, with fewer sloughs and hills spaced more widely than in the eastern area.

### Ice-thrust Topography

A 10-square-mile area in northeastern Towner County is interpreted as ice-thrust topography (Qct on pl. 1). Relief in the area is about 50 feet locally. Large, low hills and intervening slough-filled depressions characterize the area in contrast to the intricate topography to the southwest. A northwest-southeast linearity is apparent on air photographs and, in places, individual hills appear to be associated with source depressions from which they may have been derived by ice-thrusting (Bluemle, 1970; 1982). Sandy till is the most common surface material. In places, the till has an unusually reddish color, perhaps a result of the sand fraction, which consists of large percentages of iron-rich shale that has been oxidized.

### Water-worn Till Surfaces

In places, the till surface in Towner County has been washed by running water (Qcer on pl. 1) and by wave action along the northwestern shore of glacial Lake Cando (Qcew on pl. 1). These washed till surfaces are flat, with small amounts of associated gravel and bouldery surfaces in some places.

The most extensive water-worn till surface occurs through central Towner County, between Rock Lake and Egeland. This bouldery surface grades into outwash gravel in places. It must have formed after the large esker to the west of it was deposited. The water that washed the surface flowed southward, away from the melting active glacier and toward the glacial Lake Cando.

Figure 10. Armourdale Coulee in northwestern Towner County. View to the east over sec 1, T162N, R68W from the area of the dam. This is one of the deeper coulees carved from the till plain in western Towner County.

### Slopewash-eroded Till Slopes

Gullies such as Hidden Island Coulee and Armourdale Coulee in western Towner County have steep, eroded slopes cut in till (Qcci on pl. 1) (fig. 10). Relief is as much as 50 feet locally. These gullies grade both downstream and upstream to more gentle valleys with smooth, uneroded slopes. The eroded slopes grade downstream into colluvial or fluvial material in some instances. At the point where Armourdale Coulee ends, for example, an ice-contact ridge begins, presumably marking the location where the water flowing out the coulee issued onto stagnant glacial ice. The water flowed southward from this point, on or along the edge of the ice, forming the complex esker system found in central Towner County (pl. 1).

Some of the coulees are "beaded," much broader in some places than in others. This may indicate they were cut in part when discontinuous stagnant ice still underlay the area.

## Lacustrine Landforms

### Offshore to Nearshore Lake Plain

An area of about three townships in southeastern Towner County is part of the glacial Lake Cando plain (Qcof on pl. 1).

Elevations range between 1,450 and 1,460 feet, rising slightly to the north. Most of the local relief, which is less than 3 feet in most places, is the result of modification of the surface by wind. In some places southeast of Cando a few miles, minor relief on the lake plain has resulted from the action of toads (Bufo hemiphrys), which have built low mounds up to 3 feet higher than surrounding areas. These mounds are apparent on airphotos as light spots or "freckles" (see discussion of similar toad-disturbed areas in Deal, 1971).

The glacial Lake Cando plain is underlain in the relatively lower areas (below about 1,460 feet) by 10 to 20 feet of tough clay with lenses of silt and abundant secondary gypsum. The clay is oxidized to yellowish-brown hues. In relatively higher areas (1,460 to 1,465 feet) silty to sandy lake sediment is common. The sand fraction of the sediment increases northward and grades into mainly sand in T158N, Rs65-66W. This is presumably a delta-like area that represents the location where a stream or streams emptied into the lake.

No shore features were noted in association with the glacial Lake Cando plain in Towner County. Rather, the lake sediments lie on till, the contact between the till and the lake sediments being quite indistinct and ragged (in spite of the solid contact line shown on plate 1).

In T157N, Rs66-67W, a two-mile-wide area of collapsed lake deposits occurs (Qcoh on pl. 1). Elevations range between 1,470 and 1,500 feet with flat areas averaging about 1,475 feet. Many small knobs and hummocks and some large potholes (up to a square mile) occur. The overall topography is quite irregular. Bedded silt and clay occurs everywhere within this area of collapsed lake deposits except on the esker just west of U.S. Highway 281, where gravel is found. Gypsum crystals are abundant in the lake sediment.

## Modern Ponds and Sloughs

Only a few of the larger modern ponds and sloughs are shown on plate 1. The larger, perennial lakes such as Rock Lake and Snyder Lake, occur in the north-south sag associated with the underlying buried bedrock valley. These lakes are fresh, and charged with water from the underlying aquifer. They are underlain by gravel and sand. At the present time (1983), the aquifer is losing water to the lakes which are at high levels and flooding nearby farm land.

Most of the sloughs and intermittent lakes (Qos) that occur throughout the county are underlain by slough sediment on top of glacial till. These lakes, especially those at lower elevations, are mainly brackish. In those intermittent lakes that are not interconnected with the aquifer referred to earlier, the water level is controlled largely by the level of the water table under the adjacent hillslopes. Surface runoff from adjacent hillslopes during rains and spring thaws contributes considerable water to these lakes, but the sustaining supply during the rest of the year is from groundwater seepage. This concept has been treated in more detail by Clayton (1972). For this reason, these lakes may dry up during periods of prolonged drought.

The most common sediment found in intermittent lakes and sloughs is a black to brown, dense, plastic clay that has a relatively high organic content.

## Fluvial Landforms

### River Flood Plains

The largest area of glacial outwash and associated fluvial material occurs in central Towner County, extending southward from T161N, R66W to T158N, Rs65-66W (Qcrf on pl. 1). This area is surfaced mainly by shaly gravel, although patches of bouldery till are found in places. The gravel is apparently not much more than 10 feet thick in any location and, in places, small areas of till occur within the area mapped as gravel (pl. 1). The sand is interbedded with thin layers of lake silt in some exposures. A smaller, flat area of gravel occurs in T163N, Rs66-67W (pl. 1). This gravel deposit is also quite thin.

Areas of collapsed river flood plains (Qcrh on pl. 1) are present in a 1- to 2-mile-wide zone that extends from north to south through the county. This area of collapsed fluvial deposits is, in most places, closely associated with a prominent esker that lies within it or along its edge. The gravel found in the unit is shaly, interlayered with silt and clay in places, and otherwise of poor quality (figs. 11 and 12).

Through much of its extent, the collapsed gravel lies in front (east of) an east-facing scarp that is typically 25 to 30 feet high. It appears that the scarp marks the western extent of a stagnant glacier upon which fluvial material was deposited from the uplands to the west.

### Eskers

The hundreds of small esker ridges in eastern Towner County have been discussed briefly in the part of this report dealing with "Collapsed Glacial Topography." As already noted, most of these 15- to 20-foot-high ridges are less than a mile long, although several dozen of them are more than two miles long (pl. 1). These small eskers are mainly veneered with till, interpreted as being mudflow sediment.

The most prominent esker in Towner County occurs as several segments trending mainly north-south through the central part of the county. The esker is best developed in

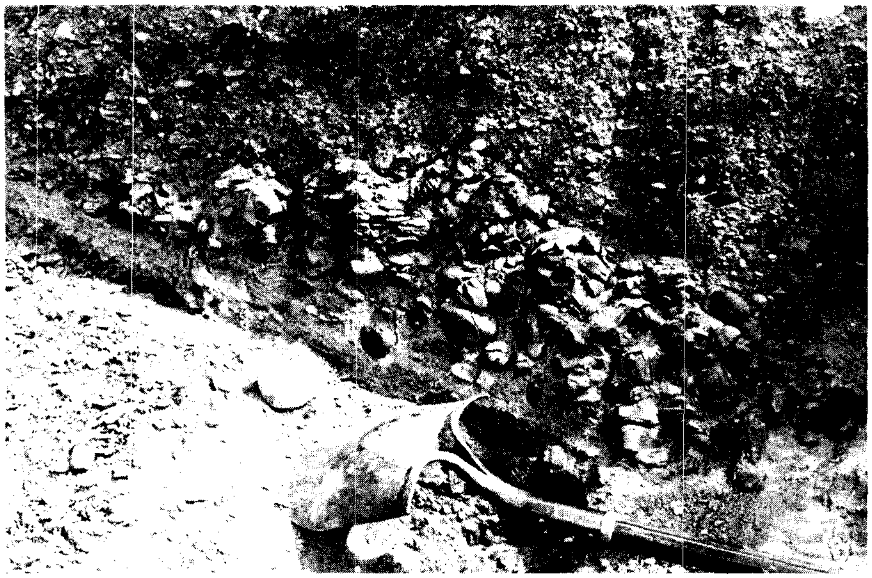

Figure 11. Coarse gravel at Snyder Lake in central Towner County (sec 18, T160N, R66W). Most of the cobbles are shale. This is part of an extensive, ice-contact deposit that trends from north to south through central Towner County.

Figure 12. Same exposure as shown on figure 11.

T159N, R66W where it consists of multiple, parallel ridges about 40 to 45 feet high and about 500 feet across. Several gravel pits are operating in the ridge in this location and gravel pits are located in other places in the ridge as well (fig. 13). The gravel in the esker is coarse with fist-sized cobbles of shale, suggesting that the source was nearby.

The extensive esker complex just described is closely associated with the area of collapsed river flood plain discussed above. It must have formed when a stagnant glacier covered most of eastern Towner County, its western edge parallel to the esker, perhaps only a short distance west of the esker. The esker ends about two miles north of Cando, but two prominent eskers about 3 miles south of Cando may represent a continuation of the same esker system. Possibly, the gap in the esker near Cando was caused by wave erosion in the glacial Lake Cando, because an arm of the lake plain extends northwestward through the gap.

### Eolian Landforms

Thin, discontinuous deposits of wind-blown sand are found in some places in association with the area of river flood-plain material. Recognizable dunal topography is uncommon, although some low dunes occur in T158N, Rs65-66W (Qou on pl. 1).

## SYNOPSIS OF QUATERNARY HISTORY

The Precambrian, Paleozoic, and Mesozoic history of Towner County is summarized earlier in this report, in the section dealing with stratigraphy. During early Tertiary time, it is possible that some marine sediments were deposited in the Cannonball sea--Cannonball Formation sediments are present on the Turtle Mountains--but it seems likely that, during most of Tertiary time, the area was emergent and subjected to erosion. This erosion removed large amounts of late Cretaceous and possibly early Tertiary sediment, presumably transporting it northward to Hudson Bay. The late Tertiary landscape that resulted was carved largely from Pierre Formation shale. Scattered remnants of Fox Hills Formation sandstone remained in western Towner County and, farther west, a large outlier of Cretaceous Hell Creek and Paleocene Cannonball sediments formed a broad upland or mesa in the area that is now the Turtle Mountains.

In Towner County, the late Tertiary landscape was dominated by a broad, deep valley through which a river flowed from south to north, entering the county from the south and leaving at the Canadian border. Apparently, this river was the trunk stream that drained most of western and central North

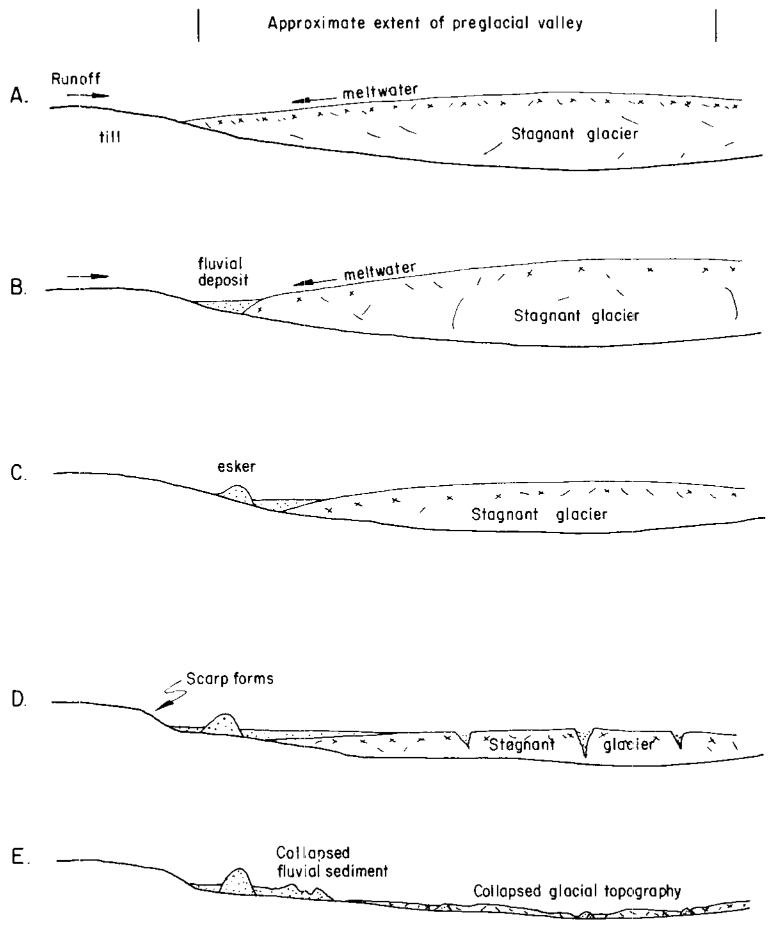

Figure 13. Five-step, west-east, schematic diagram through central Towner County in the Snyder Lake area. The lowland in the eastern half of the county was filled with a stagnant glacier in Late Wisconsinan time (A). A drainage way developed between the western edge of the glacier and the upland to the west as the ice melted (B). At the same time, debris tended to accumulate on the surface of the melting ice. When the ice continued to melt, the gravel and sand that had been deposited in this drainageway was left standing as an esker (C). With continued melting of the glacier, water flowing along the ice margin carved a scarp against the upland and deposited additional gravel and sand at somewhat lower elevations, some of it on top of areas of the stagnant glacier (D). Small streams in the melting, stagnant glacier to the east resulted in eskers forming in that area. The resulting topography is depicted by cross-section E: a prominent esker just east of a till scarp, parallel areas of flat, uncollapsed fluvial sediment adjacent to areas of collapsed fluvial sediment, and an area of collapsed glacial topography to the east that has numerous small, till-covered eskers.

Dakota. Its tributaries included the preglacial Knife, Heart, and Cannonball Rivers (Bluemle, 1972; 1983). The north-trending river valley was approximately 400, or perhaps 500 feet deep, and probably 10 to 15 miles wide.

When the earliest glaciers advanced across southern Manitoba and eastern North Dakota, all north-flowing rivers were dammed and lakes formed in their valleys, ahead of the advancing glaciers. Similarly, when the glaciers receded, lakes developed south of the receding glaciers. To the east, in the Red River Valley, glacial Lake Agassiz formed at the edge of the glacier during retreat of the Late Wisconsinan glacier. In Towner County, glacial Lake Cando formed south of the receding glacier at about the same time. However, these lakes, which left a layer of silt and clay that is today exposed at the land surface, were not the only ones that existed during Pleistocene time; each time a glacier advanced, and later when it receded, a lake formed. The records of many of these earlier lakes are now buried, the silts interbedded with glacial and fluvial sediments that were deposited during the several times the area was glaciated.

The pre-Wisconsinan glacial history has not been worked out in any detail. Randich and Kuzniar (in preparation) have constructed a series of cross sections across the broad preglacial valley in Towner County. These cross sections include numerous test holes which penetrate multiple layers of buried lake deposits interbedded with layers of gravel or till, indicating multiple glaciations and proglacial lakes.

At least some of the early proglacial lakes that formed south of the glacier overflowed southeastward, carving a series of prominent meltwater trenches southward across eastern North Dakota (fig. 14). The most important of these has usually been referred to as the Spiritwood Aquifer System. The northernmost end of the portion of the aquifer system that was formed by diverted water is located in southeastern Towner County. From that point it trends southeastward through Ramsey County, thence generally southward by way of various buried meltwater trenches; at least two routes lead to the Red River Valley.

It is possible that, after some of the earlier glaciers receded from the area, during the interglacial periods, drainage was reestablished northward through the old valley. The valley was not nearly completely filled with glacial or glacial-related sediment after the earlier advances. It was only after it had been overridden by glaciers several times that the preglacial valley became almost completely filled. Even today, a broad lowland corresponds to the course of the preglacial valley. It has not been determined when the drainage was finally permanently diverted away from its northerly direction.

The Late Wisconsinan glacier flowed southeastward into Towner County over the Turtle Mountains. As the glacier

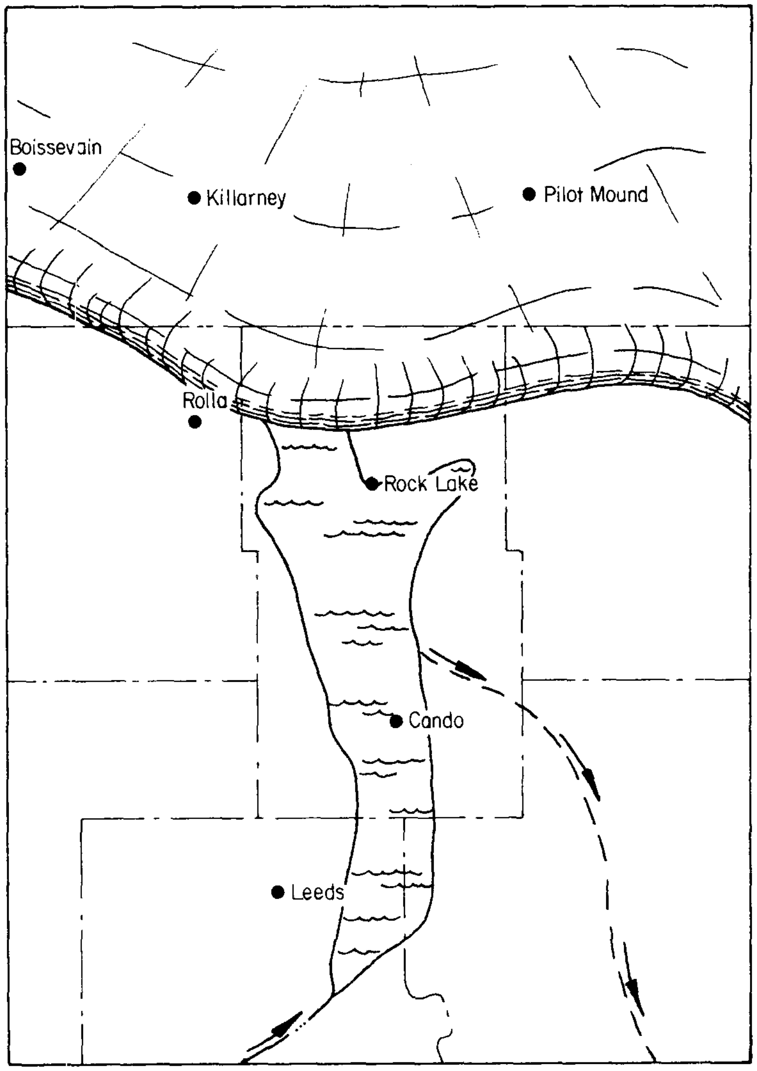

Figure 14. Pre-Wisconsinan or early Wisconsinan time. When early glaciers advanced southward across Towner County, they blocked the northward drainage, causing proglacial lakes to flood the major river valley that extends through the central part of the county. The three buried silt horizons that have been identified indicate that proglacial lakes formed at least that often; evidence for additional lakes may have been removed by glacial and interglacial erosion. When the lakes overflowed, they carved a deep, narrow trench southeastward into Ramsey County and beyond. Evidence for early glaciations has been identified only in the deep valley.

wasted and became thinner, the ice on the Turtle Mountains became isolated from the main body of the glacier and stagnated. The Turtle Mountains rise 600 to 800 feet above the surrounding area and glacial ice only 200 or 300 feet thick will flow under its own weight, so even after the ice on the Turtle Mountains stagnated, glacial flow continued on either side of the Turtle Mountains (Bluemle, 1966; Deal, 1971). The part of the glacier that flowed around the west side of the Turtle Mountains has been designated the Souris Lobe and the part that flowed around the east side was the Leeds Lobe (Lemke and Colton, 1958). The two lobes merged south of the Turtle Mountains (fig. 15), forming a single moving mass of nearly stagnant ice in the lee of the Turtle Mountains in Rolette County (Deal, 1971). The ice immediately south of the Turtle Mountains continued to flow as long as the thickness and movement of the surrounding ice permitted it to do so.

With continued melting of the glacier, an ice-free corridor opened between the Souris and Leeds Lobes. Apparently, the Souris Lobe remained somewhat more vigorous than the Leeds Lobe for a slightly longer period of time. For this reason, it tended to expand and apparently readvanced into the corridor (figs. 16 and 17), perhaps as far east as southwesternmost Towner County where northeast-southwest trending washboard ridges (Tps157-158N, R68W) truncate the more numerous northwest-southeast trending washboard ridges (pl. 1). However, evidence for such readvance of the Souris Lobe is not conclusive. Such local readvance from the west and northwest might have occurred slightly after or at about the same time as the active Leeds Lobe glacier in Towner County receded to the eastern part of the county or even shortly after it had melted from the county.

It seems likely that the glacial ice ceased to be active in much of Towner County over a relatively short period of time. That is, the glacier stagnated over much of the area all at once. Evidence for active ice margins and deposition by actively moving glacial ice is largely absent from the area. Late during the last deglaciation of Towner County, the western half of the county was relatively free of ice, or at least covered only by discontinuous stagnant ice, at the same time that the lower land to the east was still covered by a relatively more continuous layer of ice (fig. 18). The ice to the east had, however, probably stagnated and was no longer actively flowing. Runoff water from the ice melting on the uplands to the west, and possibly from the still-active Souris Lobe to the west, along with local precipitation, flowed eastward, away from the Turtle Mountains, until it reached the edge of the stagnant glacier in eastern Towner County. The runoff was then diverted southward along the edge of the stagnant glacier (fig. 18). It also flowed onto the stagnant glacier and then southward, forming the numerous

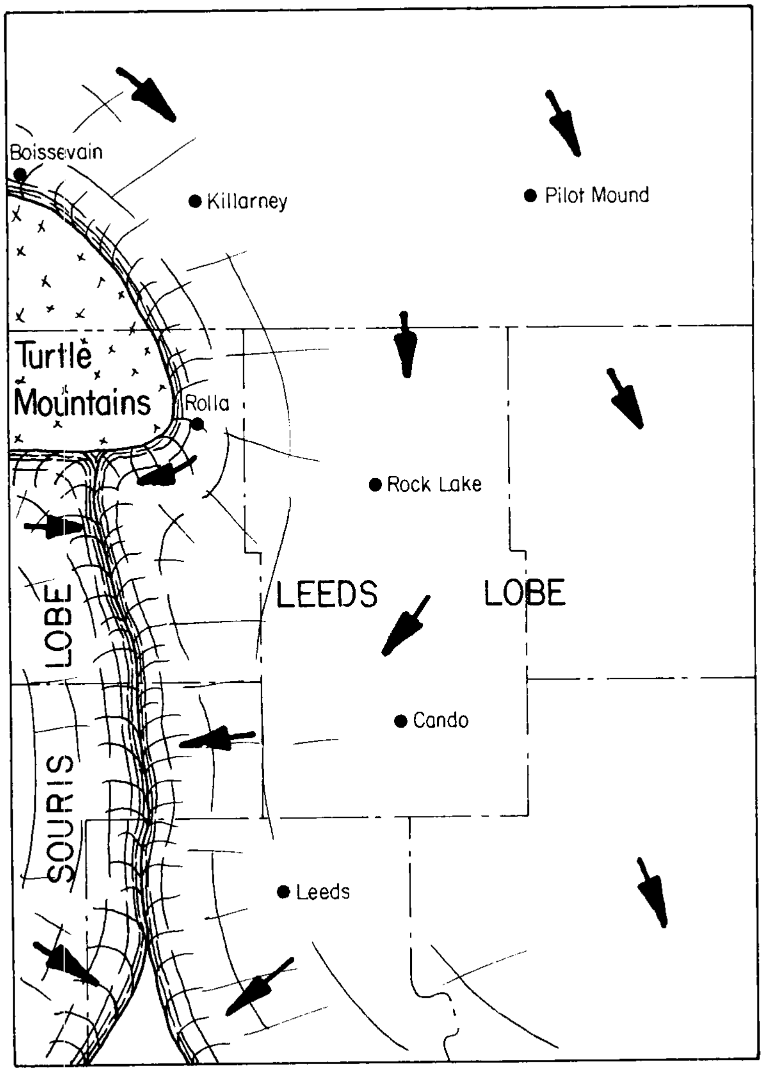

Figure 15. Early stage in the deglaciation of Towner County in Late Wisconsinan time. Towner County was glaciated at the end of Wisconsinan time by ice of the Leeds Lobe, which flowed around the east side of the Turtle Mountains (earlier the glacier had flowed directly over the Turtle Mountains and Towner County). The ice-flow directions shown on the above map represent the movement of the ice in Late Wisconsinan time after the glacier had stagnated over the Turtle Mountains.

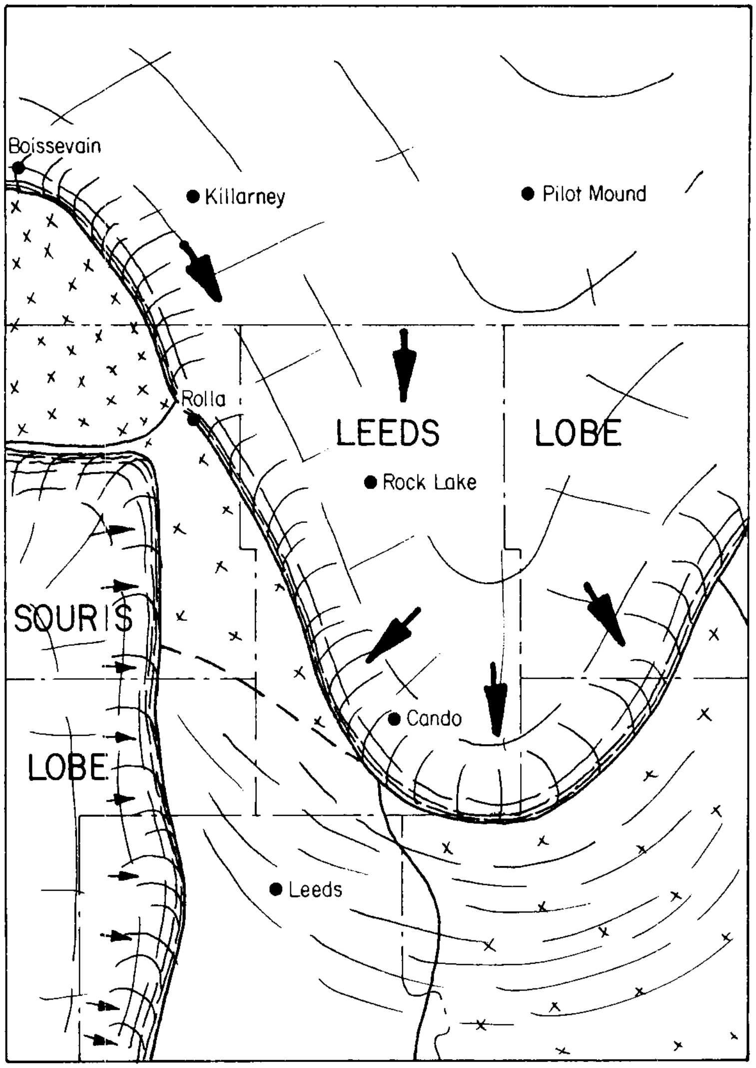

Figure 16. Deglaciation of southwestern Towner County. The first part of Towner County that was deglaciated at the end of Wisconsinan time was the southwestern corner. An ice-free corridor opened southeast of the Turtle Mountains between the receding Leeds and Souris Lobes, although some areas of stagnant glacial ice probably remained in the ice-free area. Widely spaced x's (southeastern part of the map area) represent discontinuous and probably thin stagnant glacial ice. At about this time, too, intense glacial thrusting took place along the margin of the Souris Lobe.

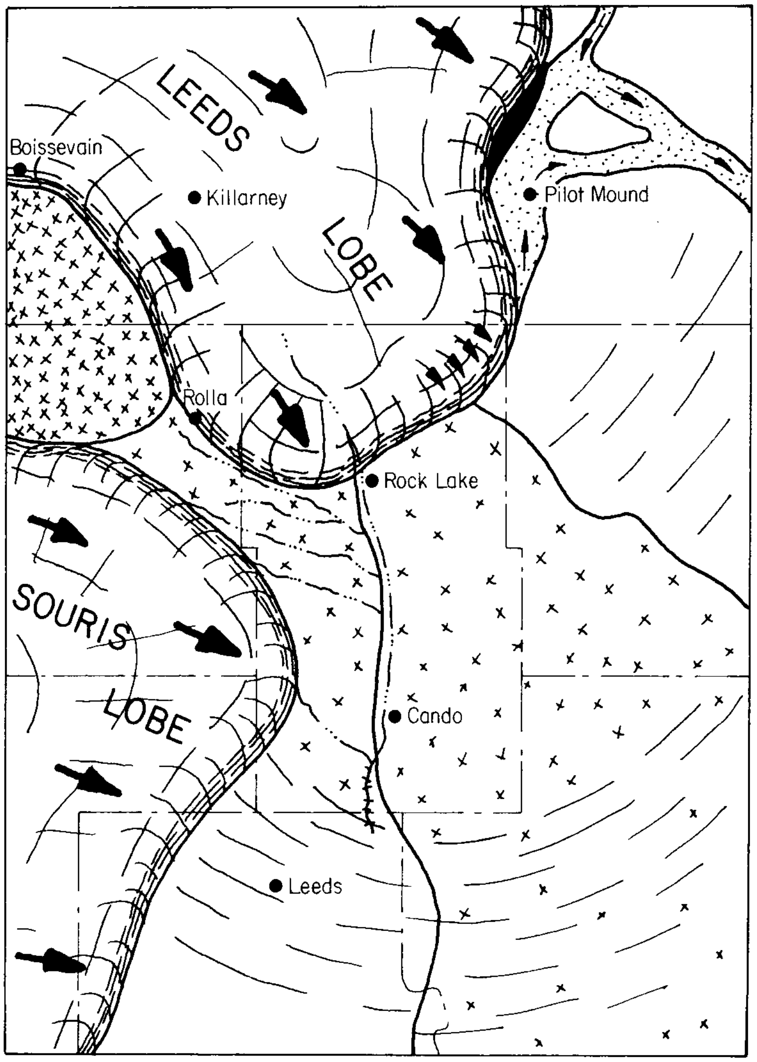

Figure 17. Readvance of the Souris Lobe. As the Leeds Lobe continued to recede, minor readvance occurred along the margin of the Souris Lobe, which may have advanced into southwestern Towner County. The only evidence for such readvance in Towner County is an area of apparently truncated washboard moraine topography (see text). An extensive area of stagnant glacial ice remained over eastern Towner County when the Leeds Lobe receded.

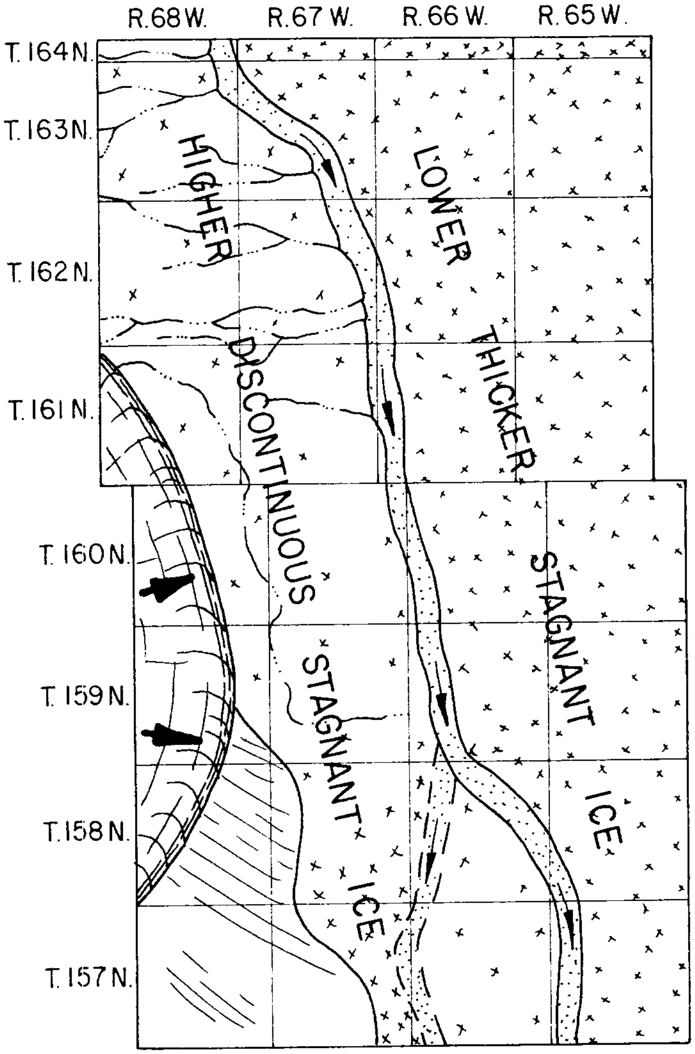

Figure 18. Last stage in deglaciation of Towner County. The lower land in eastern Towner County was covered by a more continuous and thicker layer of stagnant glacial ice than was the higher land to the west. Runoff from the west flowed as far as the edge of the stagnant glacier, then was diverted southward along the edge of the stagnant glacier.

small ice-contact ridges that can be seen in the area today (pl. 1).

The most important ice-contact feature in Towner County is a prominent, discontinuous esker complex, an ice-contact ridge, that extends southward from near Hansboro, past Rock Lake and Snyder Lake to just north of Cando.

During its earliest stages, the ice-contact ridge was probably mainly an esker stream, but as the glacier continued to melt, it evolved into more of a kame terrace, the stream flowing at a slightly lower level on solid ground, but abutting against the western edge of the stagnant ice front (fig. 13). During its earliest stage, the ice-contact stream flowed southward past Cando into Benson County, as evidenced by a segment of a prominent esker south of Cando. The stream may then have shifted course, flowing southeastward into Ramsey County, forming the esker in secs 17, 20, 29, and 32, T157N, R65W. At the time the stream flowed in contact with the ice, forming what is now the esker ridge, the proglacial Lake Cando had not yet begun to form in Towner County.

At about this time, local ponding occurred west of the stagnant glacier in some places. East of Hansboro and Armourdale (Tps162 and 163N, R67W) streams flowing eastward issued either into small proglacial lakes or into lakes that existed at least partly on top of stagnant ice. These streams deposited fans of sand and gravel at their mouths (mainly Qcrh on pl. 1). The two best examples of such fans are the ones in secs 11, 12, 13, and 24, T162N, R67W and in secs 21, 22, 27, 34, and 35, T163N, R67W. These fan deposits constitute one of the best gravel supplies found in Towner County.

As the stagnant glacier in eastern Towner County continued to melt, proglacial Lake Cando flooded southern Towner County and parts of northernmost Ramsey and Benson Counties (fig. 19). During its early stages, considerable fine sand and silt were delivered to the lake by the same south-flowing stream complex that had earlier formed the ice-contact features already described. By this time, the streams were flowing on solid ground, depositing discontinuous fluvial sediments in the area between Rock Lake and Cando, but probably mainly eroding the till surface over which they flowed. The load of fluvial sediment was dumped in the north end of the lake south of Egeland, probably as a density-current fan in a small "delta" in Tps158-159N, Rs65 and 66.

## ECONOMIC GEOLOGY

### Hydrocarbons

A total of 12 holes have been drilled in Towner County in search of oil and gas. Of these 12 test holes, seven were

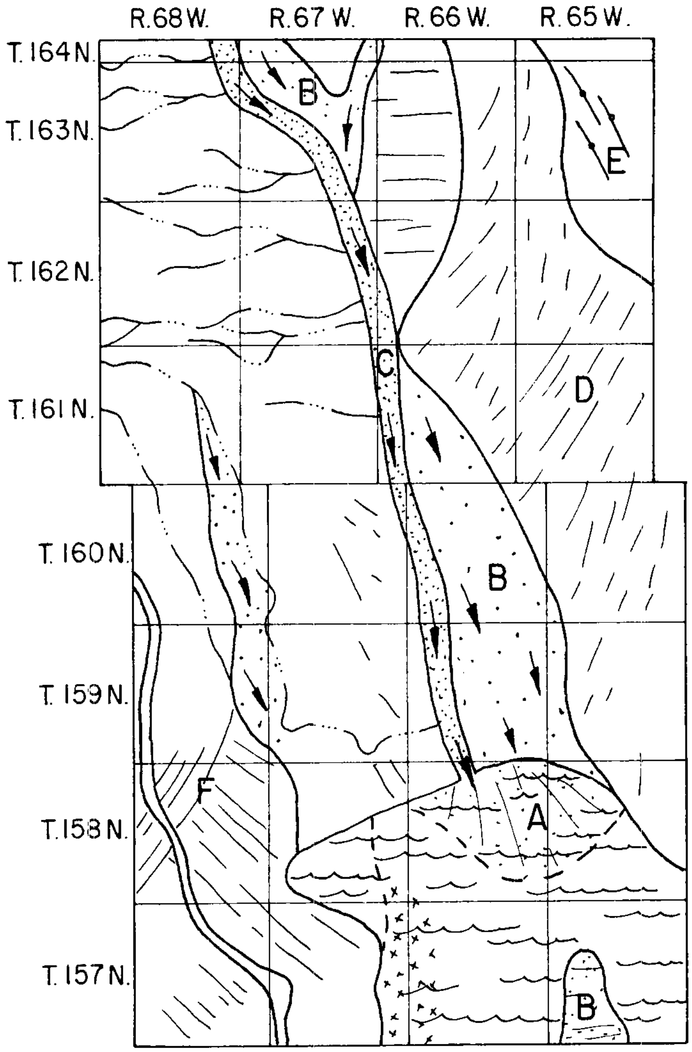

Figure 19. Formation of glacial Lake Cando. By the time glacial Lake Cando flooded southeastern Towner County, most of the stagnant ice there had already melted. However, the lake did flood an area of stagnant ice along its western edge (x-pattern). When this ice melted, the overlying lake sediments collapsed and became slumped and contorted. Streams from the north carried sand and silt to the northern part of the lake, resulting in a delta-like deposit (A). Other landforms depicted on the above map include water-worn till surfaces (B–the widely spaced dot pattern); gravel and sand (C–the closely spaced dot pattern); collapsed glacial topography with abundant eskers (D–area in eastern part of the county); ice-thrust topography (E); and an area of washboards with cross-cutting relationships (F).

drilled through the entire stratigraphic section into Precambrian rocks, and 10 (including the seven Precambrian tests) were drilled as deep as Devonian. One of the wells bottomed in the Cretaceous Inyan Kara Formation and one bottomed in Mississippian rocks. None of the wildcat wells was successful; no oil shows were reported from any of the wells.

## Sand and Gravel

Reported sand and gravel production in Towner County for the past six years (1977 to 1982) has averaged 49,000 cubic yards annually, ranging between 40,000 and 60,000 yards a year. Nearly all of this gravel was taken from ice-contact fluvial deposits. About 80 percent of the reported production was from a pit in sec 18, T157N, R66W. This pit is operated by Miller Gravel and Ready Mix, Inc. of Cando.

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