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GEOLOGY

of

GRIGGS AND STEELE COUNTIES

by
John P. Bluemle
North Dakota Geological Survey
Grand Forks, North Dakota
1975

BULLETIN 64–PART 1
North Dakota Geological Survey
E. A. Noble, *State Geologist*

COUNTY GROUND WATER STUDIES 21–PART 1
North Dakota State Water Commission
Vernon Fahy, *Secretary and Chief Engineer*

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

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

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ABSTRACT

Griggs and Steele Counties, located at the eastern edge of the Williston basin, are underlain by 400 to 2,600 feet of Paleozoic and Mesozoic rocks that dip gently to the west. The Cretaceous Greenhorn, Carlile, Niobrara, and Pierre Formations lie directly beneath the glacial drift, and shale of the Pierre Formation is exposed in several places along the Sheyenne River. The Pleistocene Coleharbor Formation, which covers most of the area, consists mainly of glacial, fluvial, and lake sediment. The Coleharbor Formation averages 200 to 300 feet thick, but it is as much as 550 feet thick in some of the buried valleys. The Holocene Walsh Formation occurs in parts of the area, chiefly sloughs and river bottomland. It consists mainly of alluvial and eolian sediment.

Griggs County and the western two-thirds of Steele County are part of the Drift Prairie, which is characterized by flat to gently rolling topography that is rugged in areas of end moraines and intense ice thrusting, subdued on the ground moraine and outwash plains. Associated with these major landforms are numerous washboard moraines, drumlins, eskers, kames, meltwater trenches, and water-washed areas. The eastern third of Steele County is a nearly flat area covered by lake deposits of the glacial Lake Agassiz.

As the Late Wisconsinan glacier in eastern North Dakota thinned and receded eastward, it was increasingly affected by the topography over which it was flowing. This resulted in lobation of the glacier. Locally intense areas of thrusting developed within the lobate glacier, and large blocks of subglacial material were moved short distances. Large areas of Griggs County were washed by water flowing from the glacier, and in some areas gravel and sand were deposited. Continued withdrawal of the glacier resulted in ponding of melt water in parts of the two counties. These and other ponds tended to coalesce at lower and lower elevations, eventually forming Lake Agassiz, which flooded part of eastern Steele County.

INTRODUCTION

Purpose

This report is published by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, and the Water Management Districts of Griggs and Steele Counties. It is one of a series of county reports on groundwater resources. Reports on the groundwater basic data and the groundwater resources of Griggs and Steele Counties will be published separately.

The glacial deposits in Griggs and Steele Counties are described in detail. This information should be of value to anyone interested in the distribution of the geologic units that have potential as aquifers. Residents interested in learning more about the area and geologists concerned with the physical evidence supporting various geologic interpretations should find the report useful.

Parts of the report that deal with the origin of landforms and geologic history are largely my own interpretations of the events that led to the formation of the present landforms. These interpretations are intended for those interested in the geologic processes and sequences of events during Pleistocene time.

Methods of Study

LaVerne C. Rude and James C. Merritt mapped the geology of Griggs County during the 1964 and 1965 field seasons as part of their requirements for the master's degree at the University of North Dakota. I mapped Steele County during the 1969 field season and checked Rude's and Merritt's maps. Modifications necessary to adapt their maps to the map units used in this report were made at that time.

Data were plotted on aerial photographs at a scale of 1:24,000. U.S. Geological Survey topographic quadrangle maps, also at a scale of 1:24,000, were available for most of the area in time for the 1969 field season. These were used extensively in the final compilation of the map. All section line roads were traversed by automobile and the composition of sediments in road cuts and hand-augered holes was carefully recorded. A shovel and soil auger were used to obtain lithologic information in areas of poor exposures. The North Dakota State Water Commission provided rotary drilling equipment that was used during the 1970 and 1971 field seasons.

Previous Work

One of the earliest writers to discuss the geology of glacial Lake Agassiz in detail was Upham (1895), whose monograph is still a standard reference. Tyrrell (1896, 1914), Johnston (1916, 1921), Laird (1944), Nikiforoff (1947), and Rominger and Rutledge (1952) also discussed Lake Agassiz in some detail. Laird (1964) summarized the literature on Lake Agassiz. Several papers dealing with Lake Agassiz were presented at the 1966 conference on Environmental Studies of the Glacial Lake Agassiz Region. These were compiled into a single volume, *Life, Land and Water,* edited by W. J. Mayer-Oakes (1967).

Lemke and Colton (1958) summarized North Dakota Pleistocene geology and later published their *Preliminary Glacial Map of North Dakota* (Colton, Lemke, and Lindvall, 1963). A comprehensive study of the Paleozoic bedrock of eastern North Dakota (Ballard, 1963) includes the area covered in this report. Several geologic reports of the present county series are now available for the area near Griggs and Steele Counties. They include reports on Barnes, Stutsman, Eddy, Foster, Nelson, Walsh, Grand Forks, Traill, and Cass Counties. In addition, several circulars describing samples from exploratory oil wells have been published and various general studies of North Dakota bedrock have included all or parts of the two-county area.

Acknowledgments

I wish to acknowledge Mr. Joe Downey, U.S. Geological Survey, Bismarck, North Dakota, for supplying valuable testhole data and other information.

Regional Geology

Griggs and Steele Counties, in east-central North Dakota, have a combined area of approximately 1,424 miles (Griggs, 714; Steele, 710) in Townships 144-148 North, and Ranges 54-61 West. Griggs County and the western two-thirds of Steele County are located on the Drift Prairie, a gently undulating area covered mainly by glacial deposits (fig. 1). Eastern Steele County lies on the glacial Lake Agassiz plain, a nearly level area covered by glacial lake deposits. The drainage is directed generally southeastward and, except for eastern Steele County, the area is drained by the Sheyenne River. Eastern Steele County is drained by the east-flowing Goose and Elm Rivers and the south-flowing Maple River. All these rivers empty into the Red River of the North.

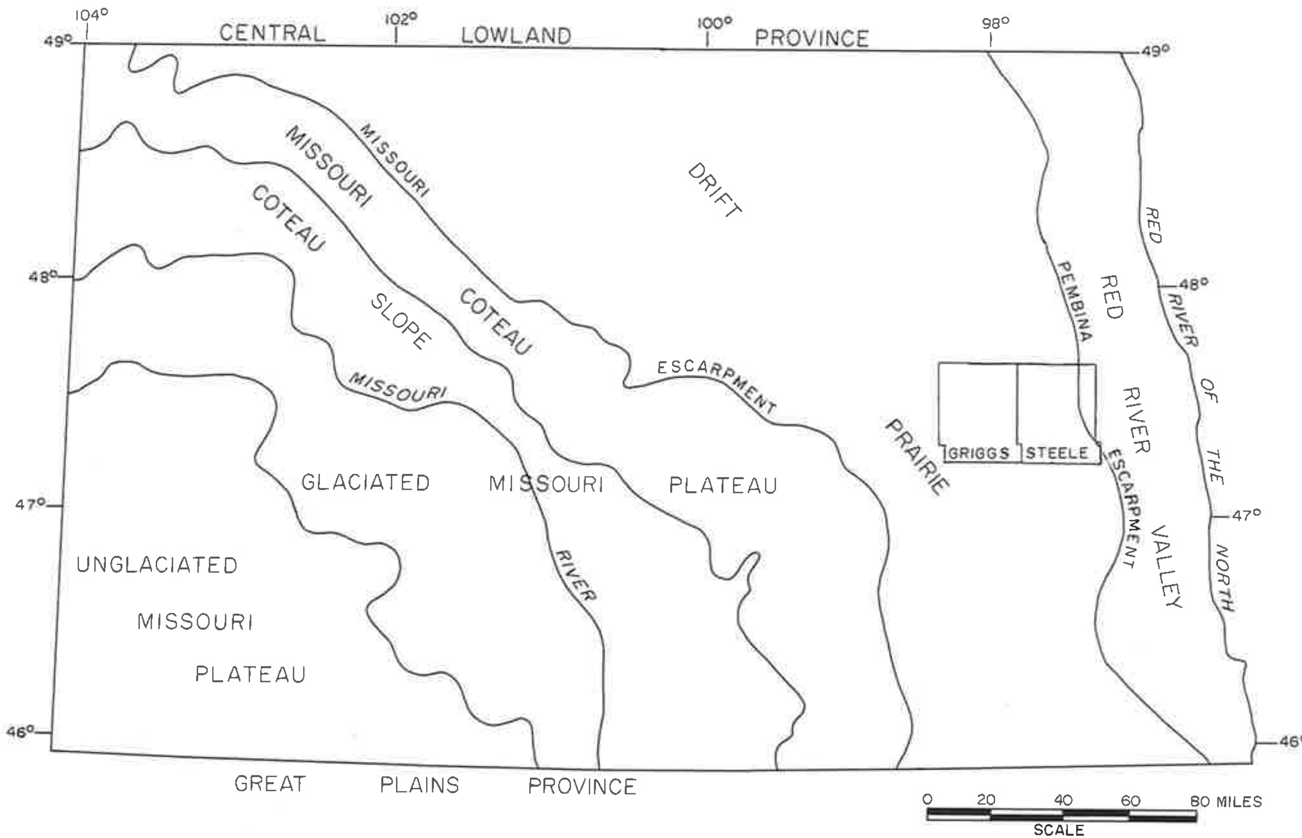


Figure 1. Physiographic and location map of Griggs and Steele Counties.

The two counties are situated on the eastern edge of the Williston basin, an intracratonic structural basin consisting of a thick sequence of sedimentary rocks. All the formations below the Coleharbor have a westerly regional dip and become thicker westward.

STRATIGRAPHY

General Statement

The ensuing discussion is mainly a description of the composition, sequence, and correlation of the geologic units that lie at and beneath the surface at the eastern margin of the Williston basin. Wherever possible, specific information on Griggs and Steele Counties is included. The description proceeds from the oldest known materials to the youngest (fig. 2). The younger, more easily accessible, geologic units are described in greater detail than are the older units. The landforms that occur at the surface over the two-county area are composed of the younger geologic materials, which were deposited mainly by glacial action. Considerable attention will be given to these landforms.

Precambrian Rocks

Precambrian basement rocks range in depth from about 1,000 feet in eastern Steele County to over 2,500 feet in western Griggs County. The distribution of the basement rocks in Griggs and Steele Counties and in nearby areas is shown on figure 3. In northwest Griggs County and southern Steele County the basement rocks are part of the Amphibole schist terrane, which consists of belts of low-grade schists or gneisses. The remainder of the two-county area, except for southwestern Griggs County, belongs to the Grand Forks plutonic terrane. These rocks are mainly massive granodiorites and granites with hypidiomorphic textures. Southwestern Griggs County is part of the Ramsey gneiss terrane, which consists of silicic rocks with a gneissic fabric.

Paleozoic Rocks

Paleozoic rocks range up to 1,200 feet thick in the northwest corner of Griggs County. They thin eastward and are absent in extreme southeastern Steele County. For purposes of discussion, the Paleozoic rocks can be subdivided into three sequences in Griggs and Steele

AGE		UNIT NAME	DESCRIPTION	THICKNESS IN FEET
Holocene	Tejas Sequence	Walsh Formation	Sand, silt, and clay	0-30
Quaternary	Tejas Sequence	Coleharbor Formation	Till, sand, gravel, silt, and clay	0-550
Tertiary				Absent
Cretaceous	Zuni Sequence	Pierre Formation	Shale	0-250
Cretaceous	Zuni Sequence	Niobrara Formation	Calcareous shale	0-160
Cretaceous	Zuni Sequence	Carlile Formation	Shale	0-200
Cretaceous	Zuni Sequence	Greenhorn Formation	Calcareous shale	80-150
Cretaceous	Zuni Sequence	Belle Fourche Formation	Shale	50-175
Cretaceous	Zuni Sequence	Mowry Formation	Shale	20-100
Cretaceous	Zuni Sequence	Newcastle Formation	Sandstone	60-120
Cretaceous	Zuni Sequence	Skull Creek Formation	Shale	40-100
Cretaceous	Zuni Sequence	Fall River-Lakota Interval	Sandstone and shale	50-200
Jurassic	Zuni Sequence			Absent
Triassic	Absaroka Sequence			Absent
Permian	Absaroka Sequence			Absent
Pennsylvanian	Absaroka Sequence			Absent
Mississippian	Kaskaskia Sequence	Bottineau Interval	Shale	0-50
Devonian	Kaskaskia Sequence	Duperow Formation	Dolomite and limestone	0-150
Devonian	Kaskaskia Sequence	Souris River Formation	Dolomite and limestone	0-70
Silurian	Tippecanoe Sequence	Stonewall Formation	Dolomite and limestone	0-50
Ordovician	Tippecanoe Sequence	Stony Mountain Formation	Dolomite and limestone	0-125
Ordovician	Tippecanoe Sequence	Red River Formation	Limestone and dolomite	0-560
Ordovician	Tippecanoe Sequence	Winnipeg Group	Calcareous shale, siltstone, and sandstone	0-220
Cambrian	Sauk Seq.	Deadwood Formation	Limestone, shale, and sandstone	0-50
Precambrian basement rocks			Schist, gneiss, and granite	—

Figure 2. Stratigraphic Column for Griggs and Steele Counties.

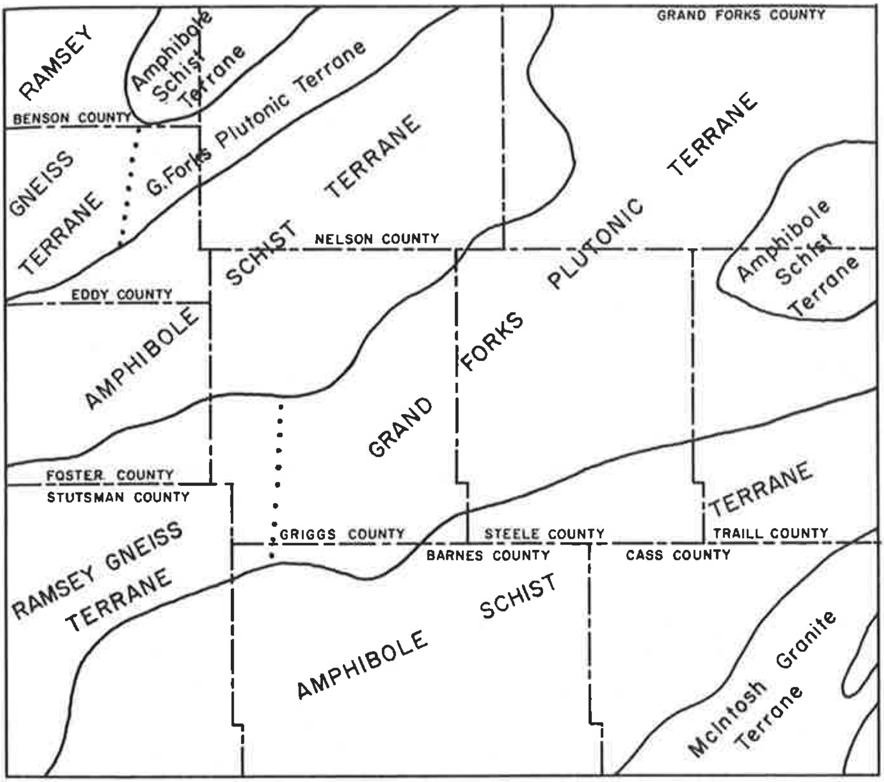


Figure 3. Geologic map of the basement rocks in the Griggs and Steele County area.

Counties. A sequence is defined as the preserved sedimentary rock record bounded by regional unconformities (Sloss, 1963). In ascending order, the sequences are the Sauk, Tippecanoe, and Kaskaskia. The Absaroka Sequence, which is present further west, is not represented in the two-county area.

Sauk Sequence

The Sauk Sequence is represented by the Deadwood Formation of Upper Cambrian to Lower Ordovician age. In Griggs County, the Deadwood Formation is an onlap depositional sequence with a basal sandstone overlain by shale and carbonate and then by another sandstone. It ranges in thickness from zero in the central part of Griggs County to about 50 feet at the Foster County line. It is absent in Steele County.

Tippecanoe Sequence

The Tippecanoe Sequence in the Williston basin followed a transgression of the seas from the south and east. It is represented in the two-county area by rocks of Middle Ordovician to Silurian age. The initial deposits of the Tippecanoe Sequence were the carbonate and clastic rocks of the Winnipeg Group. These were followed by carbonate, with minor amounts of evaporite, of the Red River, Stony Mountain, and Stonewall Formations. In Griggs and Steele Counties, rocks of the Tippecanoe Sequence range in thickness from zero in the southeast corner of Steele County to almost 1,000 feet in northwest Griggs County.

Kaskaskia Sequence

During deposition of the Kaskaskia Sequence, the Williston basin was slightly more tectonically negative than during deposition of the previous two sequences. Only the western edge of Griggs County has deposits of the Kaskaskia Sequence. The Devonian Souris River Formation, mainly gray dolomite and argillaceous limestone, is about 70 feet thick in northwestern Griggs County. The Devonian Duperow Formation carbonate and shale is as much as 150 feet thick in northwestern Griggs County. The Carrington Shale facies of the Bottineau Interval of Mississippian age consists of mottled red and green noncalcareous shale and is as much as 30 feet thick in southwestern Griggs County.

Mesozoic Rocks

Mesozoic rocks consist mainly of clastics that were deposited in widespread Jurassic and Cretaceous seas. These rocks range in thickness from about 400 feet in northeastern Steele County to about 1,400 feet in southwestern Griggs County. The Cretaceous Niobrara Formation is exposed at one locality in Steele County, and outcrops of the Cretaceous Pierre Formation occur along the Sheyenne River in a few other places. No other bedrock formations are exposed in the two counties.

Jurassic strata consist of reddish-brown siltstone, claystone, and fine-grained sandstone. Some redbed material was found at the base of the Fall River-Lakota interval in southeast Steele County, and Jurassic strata range up to about 100 feet thick in western Griggs County.

The lowermost Cretaceous rocks in Griggs and Steele Counties are the Fall River and Lakota Formations, which consist of pale red and light gray claystone and siltstone interbedded with fine-grained quartzose sandstone. These are overlain by interbedded gray shale and siltstone and fine- to coarse-grained quartzose sandstone. The Fall River-Lakota interval reaches a maximum thickness of about 200 feet in western Griggs County. The Skull Creek Formation, which overlies the Fall River Formation, is a medium- to dark-gray, silty and sandy shale that thins eastward due to both erosion and non-deposition. It is overlain by the Newcastle Formation, a medium-grained sandstone interbedded with some shale. It, in turn, is overlain by dark gray, bentonitic shale of the Mowry Formation. The Belle Fourche Formation, a dark-gray, flaky to massive, spongy shale, overlies the Mowry. The rest of the Cretaceous rocks consist of gray shale formations, some of which are calcareous, with some thin bentonitic layers. In ascending order, these formations include the Greenhorn, Carlile, Niobrara, and Pierre.

Niobrara Formation

A small exposure of Niobrara Formation shale occurs in a roadcut in northern Steele County (NE¼SE¼sec 36, T148N, R56W). In this exposure, the Niobrara sediment consists of a gray, calcareous, silty clay. Fish scales occur in the clay, which is compact but not strongly lithified.

Pierre Formation

Shale of the Pierre Formation is exposed along the walls of the Sheyenne River valley from the Nelson County line southward to about

10 miles southeast of Cooperstown. Unweathered, the Pierre Formation consists of medium gray, massive to fissile, noncalcareous shale and siltstone. Most of the exposures of the Pierre Formation along the Sheyenne River in Griggs County are highly weathered. Where weathered, the shale flakes and chips along distinct, but discontinuous, bedding planes. It is light gray and loose when dry; darker gray and cohesive due to included bentonite when wet. Bentonite beds are creamy to bluish white where unweathered, yellowish to light brown on exposed surfaces. Exposed surfaces on bentonitic zones tend to form a loose granular surface mulch (the so-called "popcorn" surface) as a result of wetting and drying or freezing and thawing. Limonite stains are common on fractures. Small iron concretions are abundant.

Quaternary Sediment

Coleharbor Formation

The Coleharbor Formation is exposed throughout Griggs and Steele Counties. It consists of glacial sediment and sediment related to glaciation; that is, beds and lenses of till, gravel, sand, silt, and clay with numerous boulders and cobbles. It has been divided into three main facies: till; sand and gravel; and silt and clay. The thickness of the Coleharbor Formation in Griggs and Steele Counties ranges from zero to more than 550 feet (fig. 4).

Till Facies

Till is a nonstratified mixture of sand, gravel, and boulders in a silt-clay matrix. In Griggs and Steele Counties, the till is commonly a stiff clay containing angular and rounded blocks of rock. The silt-clay fraction is olive gray to light gray where unoxidized, brownish to yellowish gray where oxidized. Color depends mainly on the depth and resultant intensity of oxidation. The thickness of the oxidized zone averages about 20 to 25 feet. The samples of till collected averaged about 10 percent gravel, 35 percent sand, 30 percent silt, and 25 percent clay. The mineralogy of the till of southern Griggs County is shown on table 1.

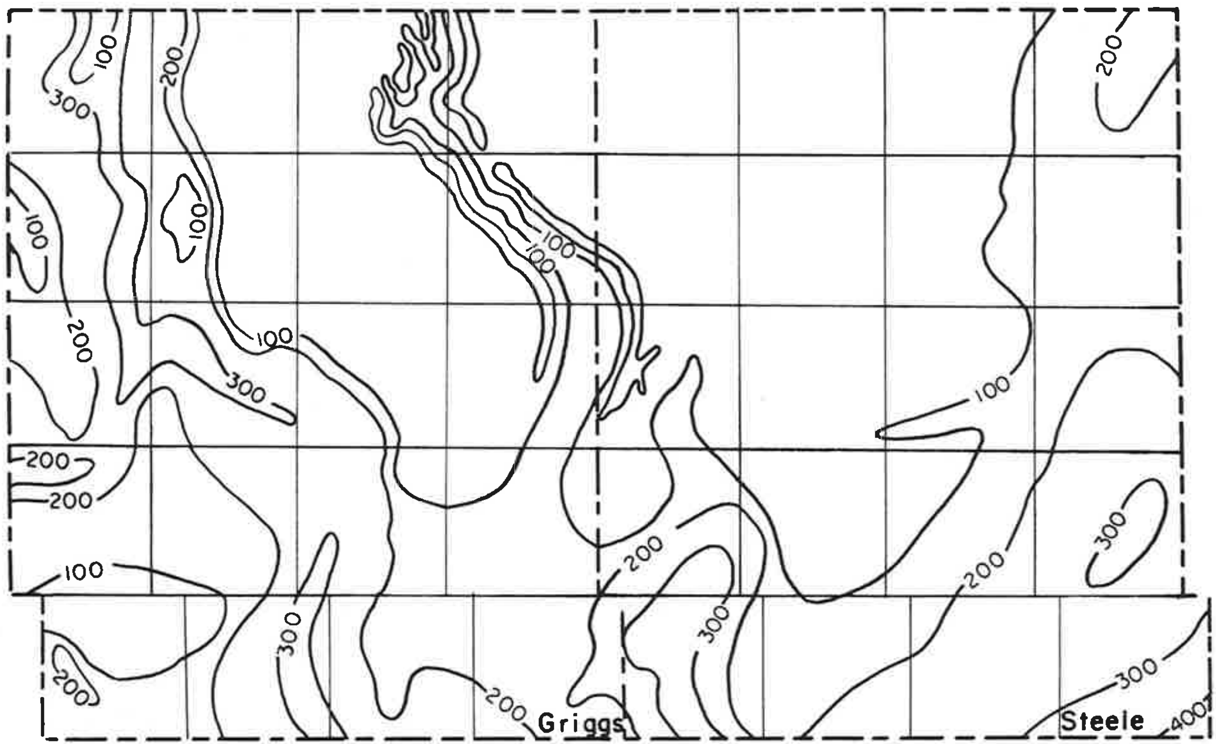


Figure 4. Isopach map of the Coleharbor Formation in Griggs and Steele Counties.

Table 1. *Generalized mineralogical composition of the silt-clay fraction of the till in southern Griggs County determined through X-ray diffraction analysis (Merritt, 1966).*

Mineral	Percentage
Quartz	21-49
Plagioclase	2- 6
K-Feldspar	1- 6
Dolomite	4-10
Calcite	4-15
Kaolinite	1- 2
Montmorillonite	12-21
Illite	9-18

The gravel fraction of the till averages about 37 percent shale, 35 percent carbonate, and 28 percent granitic and basic igneous rocks. The carbonate was derived from the Paleozoic carbonate sequences of southern Canada, the granitic and basic rocks from the Canadian Shield, and much of the shale was probably locally derived. The till is uncemented. Crude local jointing is common and gypsum crystals are commonly oriented parallel to the joint faces.

In a few deep excavations in southern Griggs and northern Barnes Counties, multiple horizons of till were observed. Although the tills of these several horizons were generally lithologically similar or even indistinguishable in most cases, in a few places the lower tills contained considerable amounts of lignite, which is not present in the surficial tills in Griggs and Steele Counties. Apparently the early ice that deposited these lower tills moved from a westerly direction, because the nearest lignite-bearing bedrock occurs about 50 miles to the west or 200 miles to the northwest in the Turtle Mountains.

Areas in which the till facies of the Coleharbor Formation are exposed are colored shades of green and designated "Ct" on plate 1. These areas are characterized by landforms composed mainly of glacial sediment, materials that were deposited directly from glacier ice.

Ground moraine.–Areas in which the Coleharbor Formation consists of lodgement deposits that were directly influenced by the base of the moving glacier as well as ablational materials that were lowered from upon and within the melting ice are designated Ct1 on plate 1. In most such areas, the ablational materials, which slid into place as mudflow deposits, probably account for most of the glacial sediment, and little lodgement material is present. In northern Griggs County, large blocks of shale from the Pierre Formation, commonly several tens of feet in diameter, and in some cases several hundred feet in diameter, are common constituents of the till. These blocks of material were transported short distances by the glacier.

In most places in Griggs and Steele Counties, the ground moraine is characterized by relatively smooth topography, gentle slopes, poorly integrated drainage, and relief averaging between 10 and 15 feet in a square mile. The surface is pitted by large numbers of nearly circular depressions averaging a few hundred feet across. Elevations on the ground moraine range from about 1,200 feet in eastern Steele County to about 1,500 feet in western Griggs County.

Low, linear ridges, either straight or arcuate in plan, that occur on the ground moraine in some areas, particularly in Steele County, are referred to as washboard moraine ridges. The long axes of these ridges parallel the former ice margin. Nielson (1969) studied the washboard moraines of northern Nelson County and concluded that they are remnant shear moraines that were deposited from a superglacial position. He stated that the shear moraines were formed by shearing of active ice over stagnant ice in marginal positions, forming debris-laden shear planes. The debris in the shear planes was then released by ablation, forming ice-cored shear moraines.

Narrow, streamlined lineations occur on the ground moraine in places, particularly in northern Griggs County. These lineations are drumlins and drumlinoid features that were formed by the moving glacier. Their long axes parallel the presumed direction of ice flow. Relief on such lineations is low and many are not apparent in the field, but they can be readily observed on air photos. In Griggs County, such lineations are most common in areas where till overlies fluvial or lacustrine deposits at relatively shallow depths (figs. 5 and 6). In most instances, the till thickness above these fluvial or lacustrine deposits is less than 5 feet. In areas where drumlins occur above thick till sequences, it appears that the most recently deposited till layer is quite thin.

Ground moraine that has been washed by wave action along the shores of glacial lakes is designated Ct1a on plate 1. One such area occurs in eastern Steele County at the edge of the Agassiz lake plain and another occurs in the Karnak area of southeastern Griggs County (T144N, R58W) (fig. 7). This second area was wave-washed by the waters of a glacial lake known as Lake Lanona, which also flooded part of northern Barnes County to the south (Willard, 1909; Kelly and Block, 1967; Bluemle, 1974). Patches of gravel and sand occur sporadically over the wave-washed ground moraine; beach ridges can be found in places along the shore of Lake Agassiz. Boulders are also more

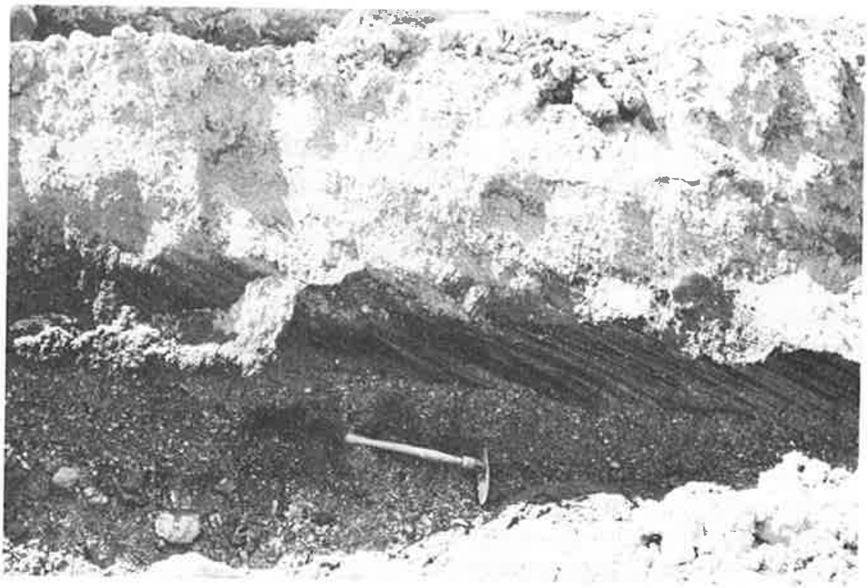


Figure 5. Sand and gravel overlain by till in section 8, T134N, R59W, about a mile south of the Griggs-Barnes County line. The gravel-till contact shown here occurs at a depth of about 14 feet. The overlying till contains considerable reworked gravel. Three separate horizons of till, separated by layers of fluvial sediment, occur in this excavation.

numerous than over areas of unwashed ground moraine, because wave action has removed the finer particles from the till, leaving the heavier rocks behind.

Areas of ground moraine that have been washed by running water are designated Ct1b on plate 1. Patches of sand and gravel occur in these areas, but till is the main lithology. Commonly, these washed areas grade to sand and gravel surfaces toward the source of the water that washed the area. Apparently, running water, which deposited most of its bedload of gravel in the Tolna-Pekin area of Nelson County,

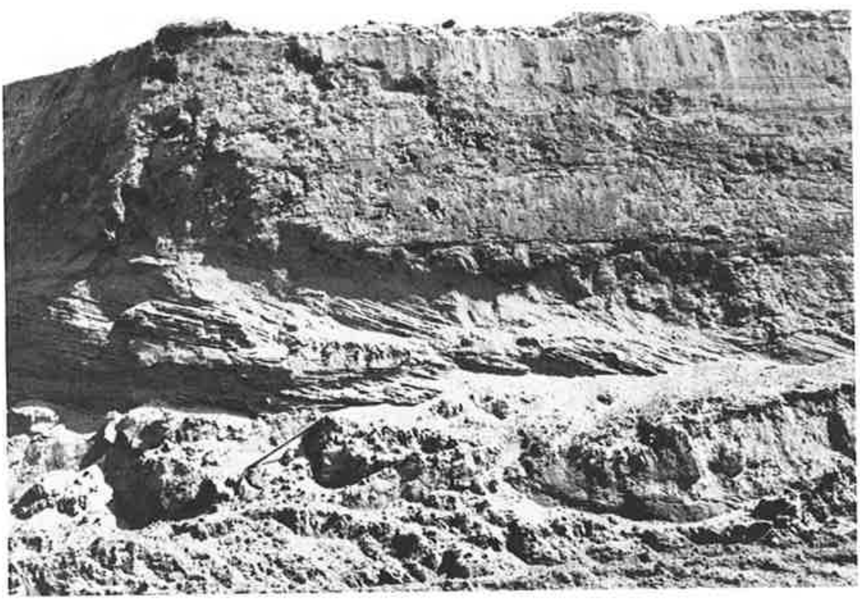


Figure 6. Silt over till over sand in northern Griggs County (sec 1, T147N, R60W). Till overlies outwash materials in a large area of northern Griggs and central and southern Nelson County. The uppermost silt, apparently a local lake deposit, can be seen in the upper right corner of the photo.

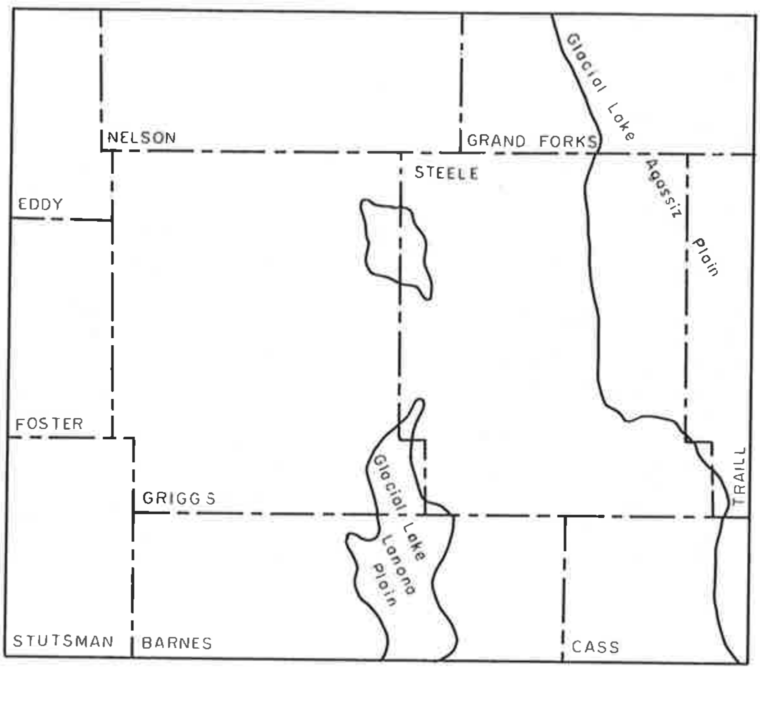


Figure 7. Index map of the lake plain areas. (Shows the location of Lake Lanona and Lake Agassiz.)

washed the till surface in Griggs County. Some of the washing apparently took place just prior to the entrenchment of the Sheyenne River in its valley.

Eroded till slopes.–Steep slopes of till occur along the Sheyenne River and Bald Hill Creek. These areas, designated Ct2 on plate 1, consist of deeply incised topography that was eroded by the streams and their tributaries. Relief ranges between 50 and 100 feet in a mile and drainage is integrated. In many places the slopes are partially covered by colluvial debris.

End moraines and ice-shoved blocks.–Glacial deposits that were deposited at the ice margin and materials consisting mainly of large blocks of shale or till that were moved as units by the ice, are designated Ct3 on plate 1 (also see figure 8). Most of these areas are mainly till with local concentrations of gravel and sand. Boulders are locally abundant. Although at least three areas that have traditionally been considered to be end moraines are found in the two-county area, it is likely that these features are largely the products of large-scale ice shoving (Bluemle, 1970). For purposes of discussion, these three features will be referred to as the Cooperstown, McHenry, and Binford end moraines. The designation "end moraine" should not be construed as a statement of how the features formed.

The Cooperstown end moraine consists of two segments in Griggs County, a five-mile-long ridge that ranges up to a mile wide in T147N, R60W, and a 15-mile-long ridge that ranges up to two miles wide in Tps144-146N, R59W. The northern segment has strong internal linearity (fig. 9), abundant surface boulders, and consists mainly of sandy, shaly till in most surface exposures. Inclusions of lake sediment up to a few tens of feet in diameter were found in highway cuts northwest of Lake Jessie. Pierre Formation shale is exposed in a roadcut in sec 27, T147N, R60W. Relief over the northern segment of the end moraine ranges to well over 100 feet in a mile locally. It is apparent that much of the material that makes up the Cooperstown end moraine in this area was moved by the glacier from the depression that is now occupied by Long Lake, Lake Jessie, and Lake Addie.

The southern segment of the Cooperstown end moraine in T145N, R59W, lacks internal linearity and is characterized instead by disintegration features that suggest glacial stagnation, although the features are neither so numerous nor so large as are the disintegration features on adjacent areas of dead-ice moraine. The end moraine in T144N, R59W, does have internal linearity, and disintegration features are less common.

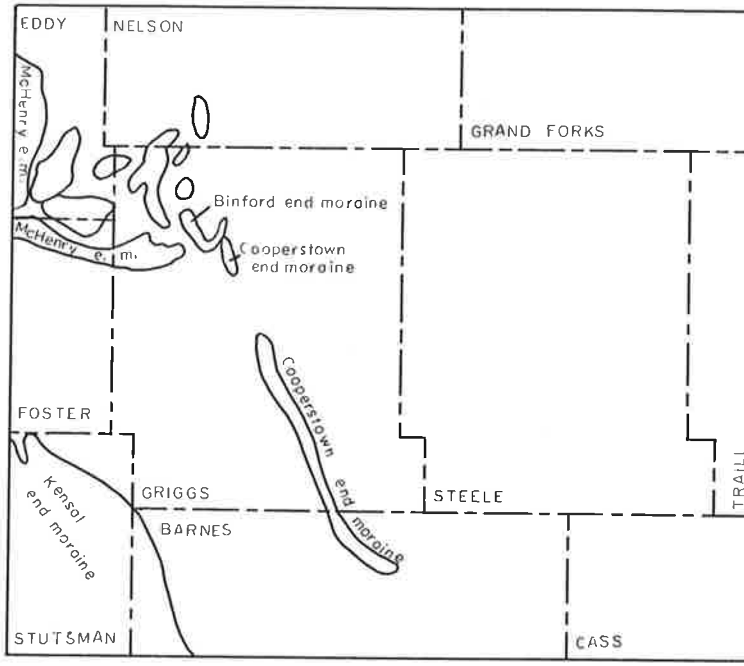


Figure 8. Index map of Griggs and Steele Counties showing areas of intensive ice shearing and end moraine development.

The McHenry end moraine in northwestern Griggs County (Tps 147-148N, Rs 60-61W) is discontinuous with many intervening areas of collapsed outwash deposits. Lithologies range from silty till to gravelly and sandy till, and it is difficult to accurately place the contact between the end moraine and the adjacent collapsed outwash. The internal linearity and irregular distribution of the hills that make up the McHenry end moraine strongly suggest that intensive thrusting and shearing were involved in the formation of the feature. The main force that emplaced the large blocks of material that make up the end moraine was from the northwest. Relief on the feature in Griggs County is as much as 200 feet locally.

The Binford end moraine (Tps 147-148N, R60W) is a 4-mile-long, loop-shaped ridge (fig. 10) with strong internal linearity and local relief of about 150 feet. Drumlinoid features behind the feature, along with

Figure 9. Cooperstown end moraine near Lake Addie (northeast part of photo). Secs 26 and 27, T147N, R60W. The highly ridged character of the feature in this area resulted from intensive shearing and thrusting at or near the ice margin. Much of the material that was thrust to the southwest came from the depression now occupied by Lake Addie.

Figure 10. Binford end moraine in T147N, R60W. View is from the north. This feature probably consists almost entirely of ice-thrust materials.

the internal linearity, reinforce the idea that the Binford end moraine consists almost entirely of ice-thrust materials. The Binford end moraine truncates the Cooperstown end moraine and is in turn truncated by the McHenry end moraine (pl. 1). The till of the Binford end moraine is silty, reflecting the fact that the ice that thrust it into place was moving over outwash and areas of proglacial lake sediment.

Dead-ice moraine.–An area of dead-ice moraine (Ct4 on plate 1) in central Griggs County is covered by materials that were deposited during the melting of stagnant glacial ice. Till present on the surface and within the stagnant ice slumped and slid into its present position when the ice melted. Mudflow deposits probably account for much of the material that makes up the dead-ice moraine. The dead-ice moraine of central Griggs County consists of about half till and half shaly, silty gravel and sand. Part of the area could best be described as collapsed outwash, but as it was impossible to break out the two units, it was all mapped as dead-ice moraine. Eskers composed mainly of shaly gravel and sand occur throughout the area. Many of the larger ones are shown on plate 1, but smaller ones were not mapped. Relief over areas of dead-ice moraine in Griggs County averages from 30 to 50 feet in a square mile.

Figure 11. Folded lake sediment, fine sand, and silt, within till in western Steele County (sec 33, T145N, R57W). The ice movement, which was southward (from the right), at this location, sheared material upward resulting in the folding.

An area of about 125 square miles in northeastern Griggs County and western Steele County has also been designated dead-ice moraine (pl. 1). It has elevations that range between 1,450 and 1,550 feet. Numerous ice-contact ridges of gravel and sand are present in places, particularly in the Sharon area. The Steele County dead-ice moraine is characterized by abundant depressions and stagnation features including several small elevated lake plains in T148N, R57W. The overall shape of the area is linear. Block (1965, p. 89) proposed the name Luverne end moraine for the area and designated the type area as the vicinity of Luverne, North Dakota, in southwest Steele County. Upham (1895, p. 158) also considered the area to be an end moraine and he referred to it as the "Eighth" or "Fergus Falls" moraine. In a summary of the Pleistocene geology of North Dakota, Lemke and Colton (1958, p. 5) correlated part of the area with the Cooperstown end moraine and they showed it as an end moraine on their later map of the state (Lemke, Colton, and Lindvall, 1963). Although the area may be related to the margin of the receding glacier, it is not typical of either ice marginal or ice-thrust glacial materials. The presence of abundant stagnation features indicates that the dead-ice moraine designation is more appropriate.

In general, the amount of superglacial and englacial material determines whether ground moraine or dead-ice moraine will form. Most of this material gets into the ice and to the glacier's surface, mainly near the glacier terminus, through the process of shearing (fig. 11). Shearing is an important process whenever the glacier experiences compressive flow, that is, whenever it moves uphill or over some sort of barrier. Irregular relief may result in compressive flow within the glacier. In the Steele County area, the edge of the Red River Valley could have acted as a barrier to the westward movement of the glacier, thereby initiating shearing and resulting in a slightly thicker accumulation of glacial sediment in the area shown as dead-ice moraine in Steele County.

Effect of pre-existing topography.--Preglacial topography covered by a veneer of till is designated Ct5 on plate 1. Relief in these areas in north-central Griggs County is as much as 150 feet in a square mile and drainage is well integrated. Till was deposited on hills of Pierre Formation shale in the same way as occurred in other areas of ground moraine. However, the till in these areas was too thin to form constructional topography, and the existing topography is due almost entirely to relief on the underlying shale surface, which, in turn, was shaped by intensive thrusting of large blocks of material by the glacier. It appears that the till veneer on top of the shale represents a short-lived advance of the ice over the area after the thrusting took place.

Mixed Till, Sand, and Silt Facies

A mixture of till, sand, and silt occurs over an area of about 45 square miles in southeastern Steele County and in an extensive area of Barnes, Cass, and Ransom Counties to the south. It is designated Ctg on plate 1 and consists of a rather silty till with inclusions of sand, gravel, and bedded silts. Bedding in the materials is commonly tilted, faulted, or contorted (figs. 12 and 13), although level and undisturbed bedding is also present, especially on hill tops. The till fraction of this facies is generally lighter in color than is other till in the two counties, due to the higher silt percentages.

Relief over the area designated Ctg in Steele County is between 10 and 20 feet in a mile and elevations range between 1,100 and 1,200 feet. The surface is relatively smooth, but numerous small depressions occur throughout the area. Apparently, the deposits formed when a proglacial lake flooded a discontinuous area of stagnant glacial ice (Bluemle, 1974). Silt was deposited in the lake, on top of stagnant ice where it was present, on till where stagnant ice was not present. Eventually, after the lake drained from the area and the stagnant ice

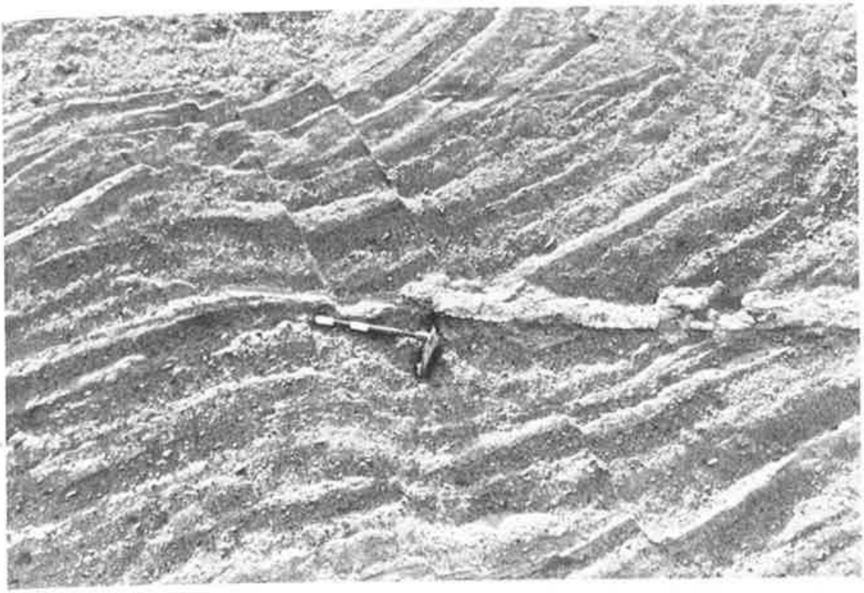


Figure 12. Faulting in sand of southeastern Steele County. Small structures such as this one are common in the area where fluvial and lacustrine sediments were deposited on top of stagnant glacial ice. Shovel is about 2½ feet long.

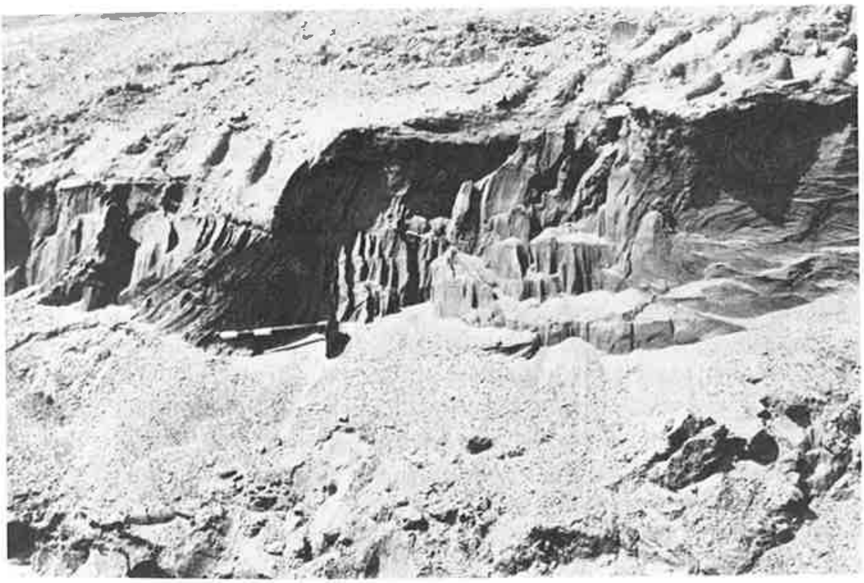


Figure 13. Slumped sand, apparently shore sediment, in southeastern Steele County in an area where a lake existed on top of stagnant ice.

melted, the lake deposits slumped down in places where they had been underlain by ice and remained horizontally bedded where stagnant ice had been absent. The lake deposits are thin and apparently the lake was short-lived.

Mixed Sandy Gravel, Gravelly Sand, and Silt Facies

A small area of complex lithologies, a mixture of sandy gravel, gravelly sand, and silt, occurs in secs. 25 and 36, T149N, R54W. It is designated Cts on plate 1. Sorting in the sand fraction is good and graded bedding is common. Relief over the area designated Cts in Steele County is generally less than 15 feet in a square mile. Elevations are near 1,150 feet. Apparently, these deposits formed along the shores of proglacial lakes that existed on top of stagnant ice (Bluemle, 1974). Melting of the ice during and after deposition of the shore deposits resulted in collapsed topography.

Sand and Gravel Facies

Gravel, gravelly sand, sand, silty sand, and sandy silt constitute a facies of the Coleharbor Formation that occurs throughout Griggs and Steele Counties. All areas colored shades of yellow or red with the designation "Cg" on plate 1 are characterized by landforms composed mainly of sand and gravel. Such areas are covered by materials that were deposited by fluvial and shoreline processes.

Glacial outwash.--Materials that were deposited by melt water flowing from the glaciers along with alluvial materials deposited by water derived from local precipitation during and immediately following glaciation are both designated Cg1 as they cannot be distinguished. Glacial outwash ranges from crudely sorted deposits near the end moraines to well sorted sand and gravel several miles in front of the end moraines. Included are materials on terraces along the major valleys, particularly the Sheyenne, and on the floors of melt water trenches where they are not covered by modern alluvium. Relief over areas of glacial outwash is generally less than 10 feet in a mile.

Outwash materials, otherwise similar to those designated Cg1, that were deposited on top of stagnant glacial ice are designated Cg2. Such materials collapsed when the stagnant ice melted and the gravel mixed with till deposits contained in the stagnant ice, resulting in siltier gravel. Minor folding and slumping of strata are common and can be observed in some gravel pits. These areas, mainly in central and northwestern Griggs County, have numerous depressions and rolling topography with local relief as high as 50 feet, although 10 to 25 feet in a mile is more

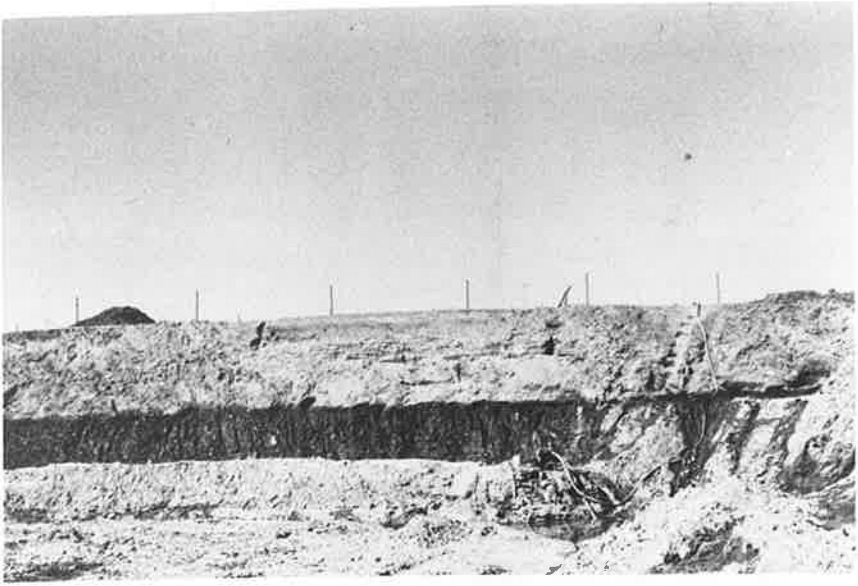


Figure 14. Outwash sand and gravel overlying till. Excavation is in central Griggs County in an area characterized by sand dune topography (sec 27, T146N, R60W). The water flows at the base of the gravel, wetting the underlying till, which is the dark zone. This wet till actually reaches the base of the excavation. The apparent dry band beneath the wet till is loose material in front of the excavation wall.

common. Thin outwash lies on top of till in parts of central Griggs County (fig. 14).

In western Griggs County, near Bald Hill Creek, the outwash occurs at two distinct levels that are apparently related to separate events. The upper level, which occurs at an elevation of about 1,470 feet, is graded to the McHenry end moraine, whereas the lower level, which occurs at about 1,450 feet, appears to be mainly an erosional surface that was cut from the upper outwash. The upper level probably once extended over the entire outwash area. The lower level appears to be graded to a more northerly source of water.

Melt water trenches.–Several melt water trenches that cross Griggs and Steele Counties were probably initiated as ice-marginal streams. In Steele County, many small trenches cross the ground moraine surface. These include the Maple and Goose Rivers, Beaver Creek, and Spring Creek. All of these valleys appear to mark successive positions of the receding ice-margin. Most of them have a single terrace level within the valley. In several places these small valleys make sharp bends to the east and an abandoned valley continues southward from the bend. The

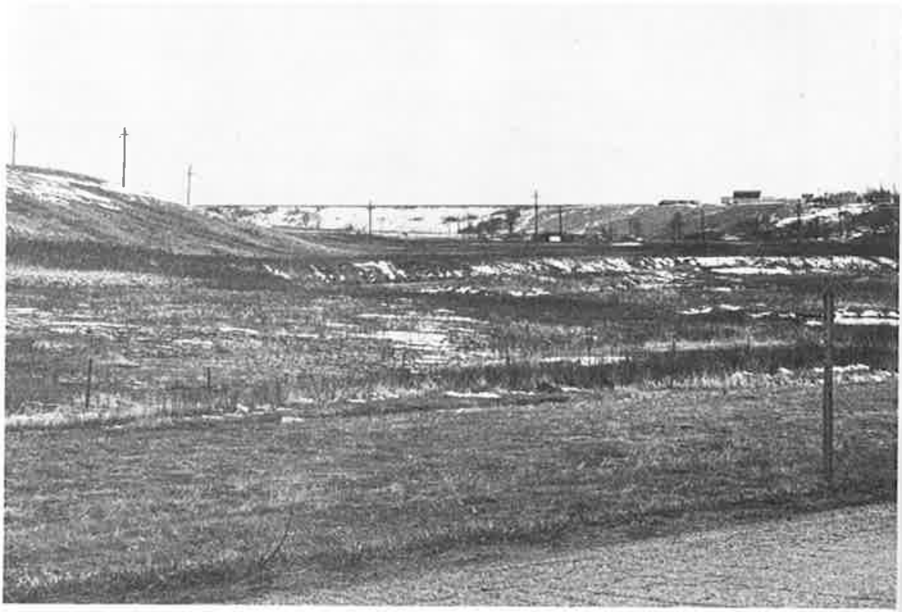


Figure 15. Bald Hill Creek melt water trench at Hannaford in Griggs County. View is to the south-southeast from the center of sec 5, T144N, R59W. Photo by James Merritt.

abandoned valleys commonly have floors at the same level as the terraces in the valleys that contain streams. In Griggs County, Bald Hill Creek and the Sheyenne River are the largest melt water trenches (figs. 15 and 16). They flow in trenches that may have been ice marginal at one time.

The largest melt water trench in the two-county area is the Sheyenne River valley. The trench was cut when Lake Souris drained into Lake Agassiz at the end of Wisconsinan time. Three terrace levels can be recognized in the Sheyenne River trench of Griggs County upstream from the bend in the valley in T147N, Rs57-58W. A fourth, low-level surface is probably mainly point bar deposits related to the modern floodplain. Downstream from the bend in the valley, three terrace levels are not present and only the low-level surface can be recognized.

The best developed and most extensive terrace level is about 50-70 feet above the present floodplain of the Sheyenne River. It is characterized by a covering of relatively high quality gravel. Numerous gravel pits produce from the terrace. Other terrace levels can be found

Figure 16. Sheyenne River valley in southern Griggs County. View is to the south from the north half of sec 11, T144N, R58W. Photo by James Merritt.

at 30-40 feet above the floodplain and at about 140 feet above the floodplain. Apparently, the highest terrace was formed when the route of the trench was first established. It lies only about 20 feet below the upland surface, which itself is highly washed and locally covered by gravel or sand.

Shore deposits.–Shore deposits, designated Cg3 on plate 1, cover the nearly flat, east-sloping areas of eastern Steele County (Tps144 and 145N, R55W), and individual beach ridges can be recognized in places. The shore deposits consist of gravelly sand and sandy gravel with some lenses of silt (figs. 17, 18, 19, and 20). Sorting in the gravel is good and graded bedding is common. A few beach ridges that occur in the area contain clean gravels, but these are generally less than 10 feet thick. Relief on beach ridges is generally less than 5 feet.

Deltaic deposits.–Deltaic sediments that were deposited by a large river of glacial melt water at its mouth where it entered Lake Agassiz are designated Cg4 on plate 1. An area of about three townships in eastern Steele County is shown as deltaic deposits. This area, a part of the Elk Valley delta, extends into Grand Forks and Traill Counties to the north and east. It is an area of fine sand and silt with coarse sand in a few places. The sandy deltaic sediment is generally less than 15 feet thick and overlies lake sediment. Vague to excellent horizontal bedding was observed in a few roadcuts. Most of the sediment appears to be of fluvial origin, but fluvial sediment interfingers with lake sediment in places. Relief is from 2 to 10 feet locally except near beach ridges where it is a little greater. The area slopes eastward at about 10 to 15 feet in a mile.

Ice-contact fluvial deposits.–Eskers and kames are composed of fluvial materials that were deposited in contact with the ice. Gravel and sand of such ice-contact deposits is mainly a poorly sorted material, rather dirty with a ratio of sand: silt + clay of 3:1. The shale content may be as high as 90 percent in many of the ice-contact deposits. Cobbles and boulders six inches and larger in diameter are common. Several thousand ice-contact features occur in the two counties, but most are too small to map. About 250 of them are shown in red on plate 1. Some of the larger ones are designated by the symbol Cg5, but many are too small for a letter designation.

The heaviest concentrations of linear ice-contact features is in the area of dead-ice moraine. Most of these are eskers that were deposited by streams flowing in channels or tunnels in the glacial ice. Many of the eskers in Griggs and Steele Counties have flat tops indicating they were deposited on the ground. Those with hummocky tops were deposited

Figure 17. Till on top of fine sand of the Herman Beach in eastern Steele County (sec 11, T146N, R55W). The till apparently slid onto the sand at this point. It does not ordinarily overlie the sand in nearby areas.

Figure 18. Sand in the Herman Beach in eastern Steele County (sec 11, T146N, R55W).

Figure 19. Herman Beach deposits in eastern Steele County (sec 11, T146N, R55W). The Agassiz lake plain is to the east (right).

Figure 20. Herman Beach deposits in eastern Steele County (sec 11, T146N, R55W). Notice the paleosol exposed in the cut.

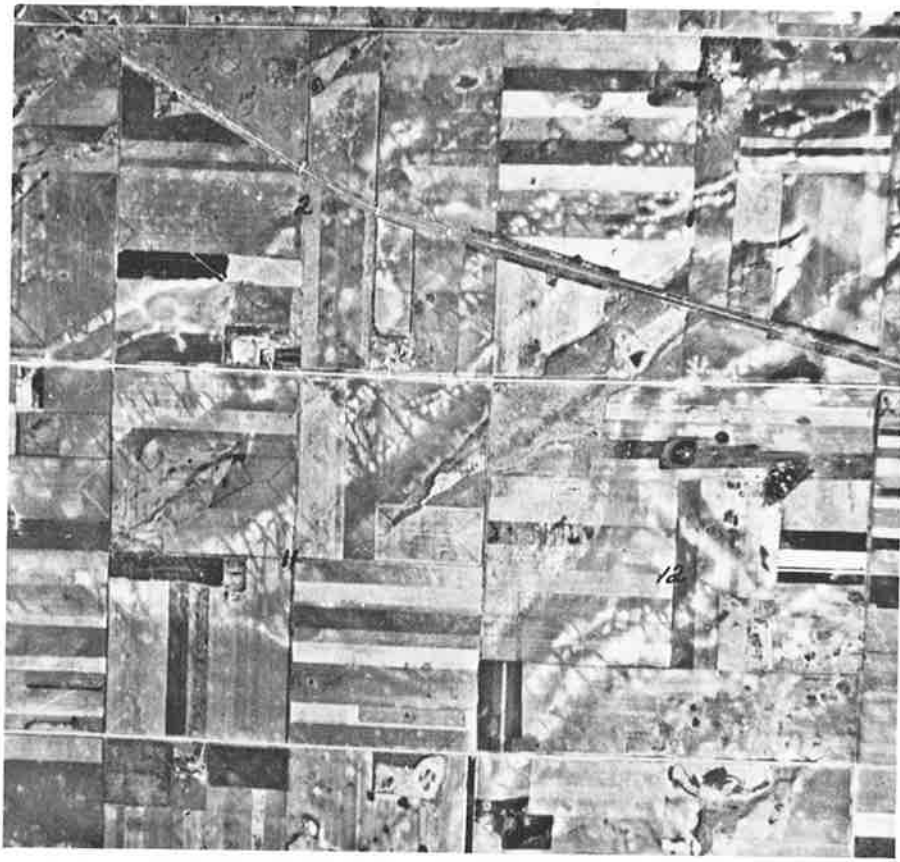


Figure 21. Air view of the network of eskers west of Hannaford, North Dakota (secs 1, 2, 11, and 12, T144N, R60W).

on ice and subsequently collapsed to a hummocky surface as the underlying ice melted. Surface boulders are abundant on most of the eskers. They were probably washed in by melt water flowing over the confined ice walls and concentrated there rather than being deposited as ablation debris from overlying ice. The large, branching esker (fig. 21) west of Hannaford (T144N, R60W) is an example of a superglacial esker. It rises about 40 feet above the surrounding countryside.

Conspicuous and prominent conical hills or mounds of washed glacial drift are known as kames. They were deposited in depressions in stagnant ice that subsequently melted, leaving the accumulated sediment, mainly gravel and sand, in the form of isolated or semi-isolated mounds. Unusually large numbers of small kames occur in T147N, R61W (fig. 22). Elsewhere, kames are more widely scattered.

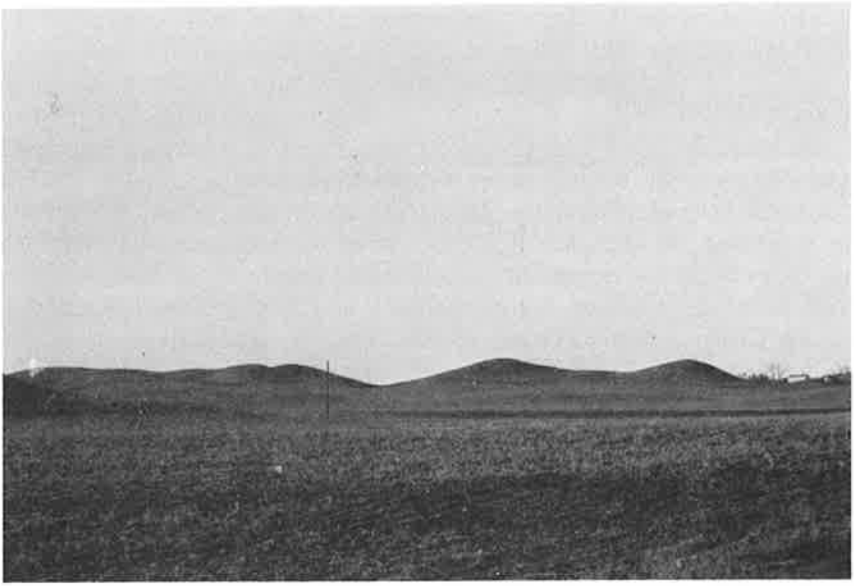
Silt and Clay Facies

A silty clay and clayey silt facies of the Coleharbor Formation occurs in several locations in Griggs and Steele Counties. These sediments were deposited in proglacial lakes. Flat areas of uneroded lake sediment are designated Cs1 on plate 1. A flat, boulder-free lake plain of bedded silt occurs in the southeast corner of T146N, R59W. It covers an area of about 3 square miles and is the largest glacial lake plain in Griggs County. Other similar areas of lake sediment occur in the Sharon area of Steele County and west of Colgate in Steele County. Most of these lake deposits are little more than a veneer of silt on top of till.

Other areas of lake sediment, essentially similar in lithology to those described above, but eroded so that relief is considerable in places, occur along the Goose River in Steele County and in certain places along the Sheyenne River in Griggs County. Such areas of eroded lake sediment are designated Cs2 on plate 1. The lake deposits of eastern Steele County underlie the deltaic sediments described previously; the lake deposits are exposed only where the deltaic sediments have been removed by erosion adjacent to the Goose River. Bedding is vague in most places, but excellent horizontal bedding was observed in a few places.

In secs 13, 14, 15, 23, and 24 of T147N, R58W, lake silt occurs in the Sheyenne River valley between the elevations of 1,360 and 1,430 feet, although the maximum exposure in any one place is about 50 feet. This lake deposit extends about a mile into Steele County and is apparently only a small remnant of what was once a considerably larger deposit. It formed when a lake was dammed in the Sheyenne River valley before the valley was a deep feature. The lake may have been a part of a proglacial lake that formed in Cass and Barnes Counties to the south as the glacier receded into the Red River Valley. Figure 23 shows lake sediment in southern Griggs County where strandlines indicate the existence of a fairly extensive lake at elevations as high as 1,440 feet. This is in the same elevation range as are the lake silts along the Sheyenne River in Griggs County.

Silt beds that were deposited in the northwest corner of Griggs County in proglacial lakes were overridden by the glacier. In a few places, this resulted in contorted bedding. Typically, the silt deposits of northwestern Griggs County have been incorporated as chunks into the overlying till deposits, which, as a result, are themselves exceptionally



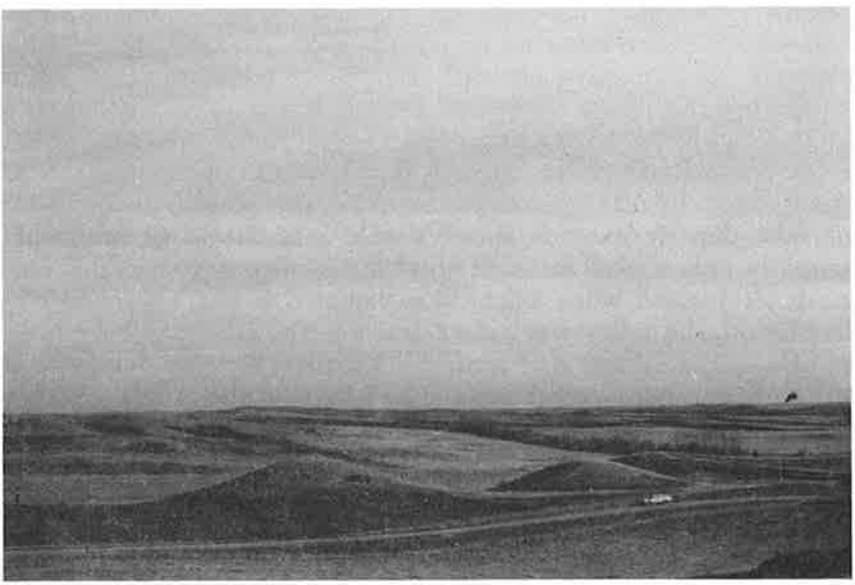


Figure 22. Kames in the area south of Mose in northwestern Griggs County (sec 9, T147N, R61W). Kames are unusually abundant in this area.

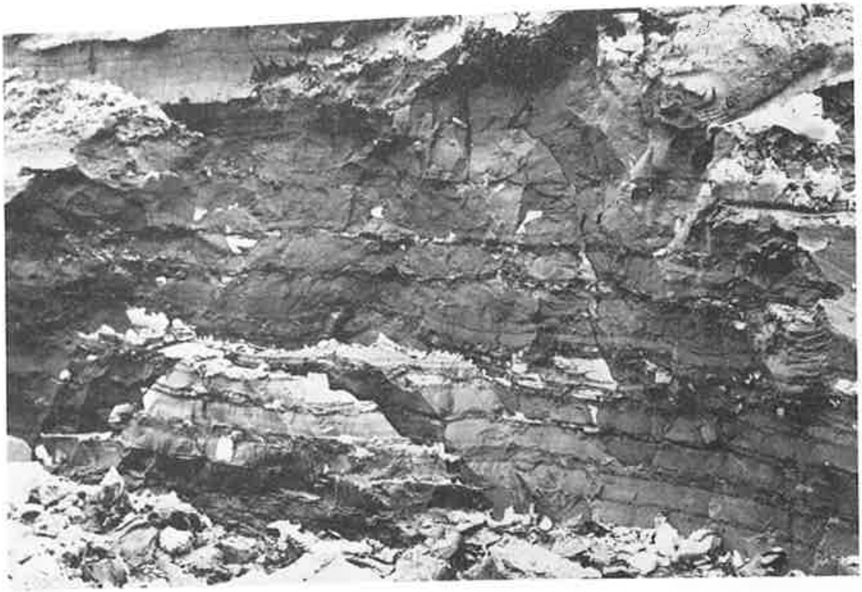


Figure 23. Lake sediment in southern Griggs County (sec 18, T145N, R58W). Layers of iron-stained, generally light brown, uniform silt about 4 inches thick are separated by thin bands of clay. The exposure is at a depth of about 20 feet. Forty feet of lake silt was exposed in the cut. At a depth of forty feet is a boulder-pavement lying on till.

silty. All the silt exposures are highly oxidized and colored shades of brown. These silt deposits were mapped as till because their most recent history involves redeposition by glacial processes.

Lake silt deposits overlain by till were found in several excavations in eastern Steele County (fig. 24). All of these silt deposits were located west of the Herman Beach suggesting that a fairly widespread lake may have covered the area before the formation of Lake Agassiz (Bluemle, 1974). As much as 25 feet of lake silt was observed in the area beneath till that occurs at the surface throughout that part of Steele County above the Agassiz lake plain. The buried silt deposit is much harder than typical Lake Agassiz silt and tends to be highly jointed.

Holocene Sediment

Walsh Formation

The Walsh Formation, which overlies the Coleharbor Formation and all other formations, includes a variety of clay, sand, silt, and gravel deposits. The Walsh Formation consists of materials that are of fluvial,

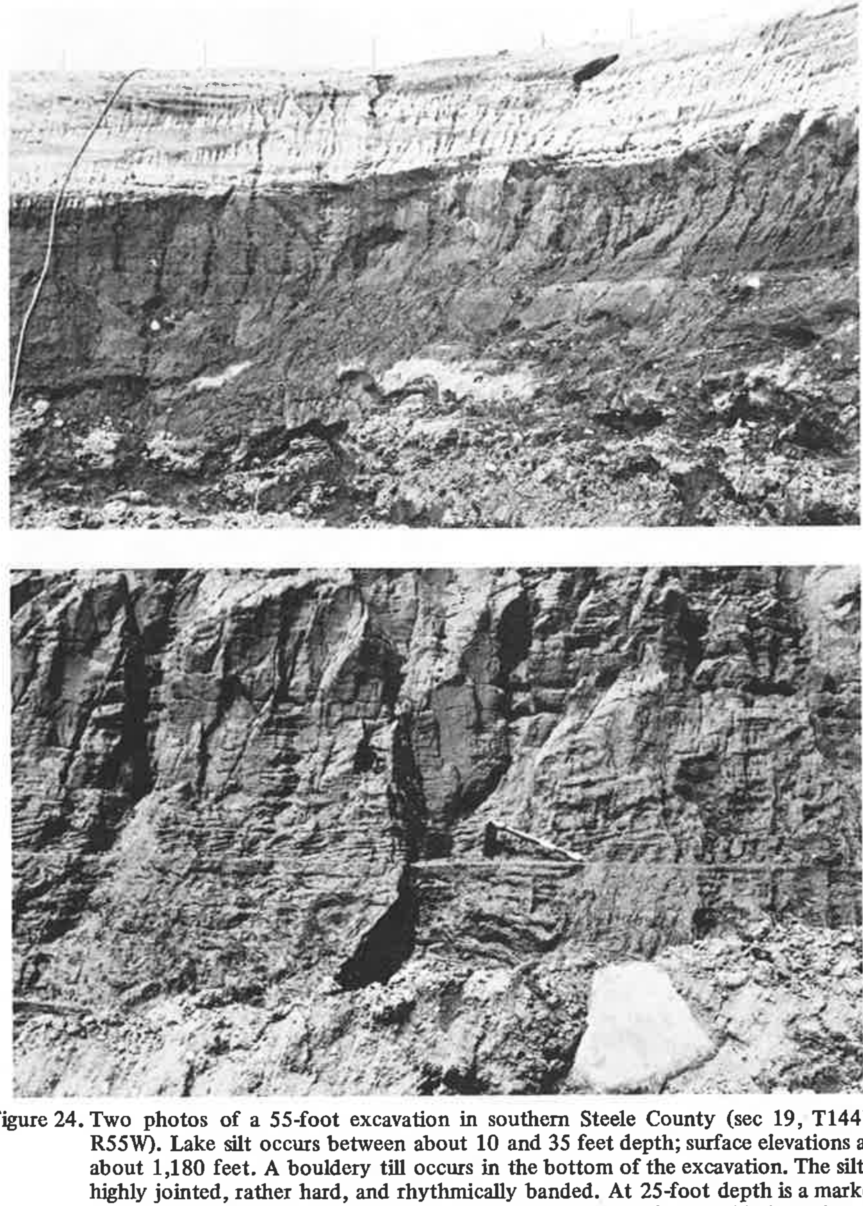


Figure 24. Two photos of a 55-foot excavation in southern Steele County (sec 19, T144N, R55W). Lake silt occurs between about 10 and 35 feet depth; surface elevations are about 1,180 feet. A bouldery till occurs in the bottom of the excavation. The silt is highly jointed, rather hard, and rhythmically banded. At 25-foot depth is a marked change in hardness that looks like an erosional break of some kind, perhaps a wave-cut surface. The silt beneath the break is considerably harder than that above. The upper photo shows the whole sequence; the lower shows a part of the silt unit with the ledge on the lower, harder silt.

lacustrine, eolian, mass-movement, or slopewash origin. It has a "dirty" appearance due to the presence of small (or large) amounts of included organic material. It differs in this respect from the Coleharbor Formation, which lacks organic materials and has a clean appearance.

The contact between the Walsh and Coleharbor Formations corresponds in most places to the Holocene-Pleistocene boundary. This boundary is dated at about 10,000 B.P. when grassland was replacing woodland in North Dakota and the rest of the Great Plains. As thick A-1 soil horizons began to develop over the area, materials eroded from these horizons provided the dispersed organic content of the Walsh Formation. The Walsh Formation has been divided into two main facies in Griggs and Steele Counties: clay, and interbedded sand, silt, and clay.

Clay Facies

The clay facies of the Walsh Formation consists of well sorted, dark gray to black organic clay to fine sand that ranges from a tough to a rather soft consistency. The materials are mainly uncemented. The clay facies consists of about 65 percent clay-sized particles, 25 percent silt-sized particles, and 10 percent sand (10 sieved samples). The mineralogy is predominantly calcareous montmorillonite with small amounts of quartz, feldspar, and shale among the larger grains. The clay is fine bedded (1 to 4 mm) and is confined to sloughs where it averages 1 to 3 feet thick. Most of the deposits are unleached and calcareous.

The deposits of the clay facies were brought to the sloughs through slopewash processes, and, to some extent, eolian processes, and redeposited by the pond water. Most of the clay deposits are characterized by flat topography with less than 1° slopes. They are represented on plate 1 by light gray areas and many are designated by the symbol Wc. Many are too small for a letter designation and many more are too small to show. Areas of the clay facies are most common in poorly drained areas, although drainage in the immediate areas of sloughs is partially integrated.

Interbedded Sand, Silt, and Clay Facies

The interbedded sand, silt, and clay facies of the Walsh Formation consists of river alluvium and windblown deposits. It is commonly slightly to moderately organic.

River alluvium.–The river alluvium, mainly floodplain deposits, consists of well sorted dark brown, gray, or black sand, sandy silt, clayey silt, or silty clay. Minor amounts of gravel occur. The materials are mainly uncemented, but, when dry, they can be quite hard. The river alluvium averages about 35 percent clay, 50 percent silt, and 15 percent sand (10 sieved samples). The mineralogy is essentially the same as that of the clay facies. The materials are characteristically thin bedded (1 to 4 mm). Shells, wood fragments, and bones are common, particularly in the alluvium of the Sheyenne River floodplain. The alluvial materials are commonly partially to well oxidized, unleached, and calcareous.

In Griggs and Steele Counties, alluvial materials, which are designated by the letter symbol Ws1 on plate 1, occur along all the perennial streams and many of the intermittent streams. The thickness is generally about two to three feet in the small valley bottoms but considerably more in the Sheyenne, Bald Hill, and Goose River valleys.

Windblown deposits.–Windblown materials, which are designated Ws2 on plate 1, occur mainly in western Griggs County. An average of less than 10 feet of windblown material occurs in association with areas of outwash sand and gravel of the Coleharbor Formation, which it overlies. Windblown deposits generally consist of nonstratified silt and fine sand. Vague horizontal color banding is discernable in a few exposures. Considerable black silt is common, particularly in the most recent deposits. Well sorted fine sand with frosted grains occurs in places, but it is not common. The relative percentages of sand, silt, and clay are not accurately known for the windblown deposits, but it is probable that the sand percentage is considerably higher than it is for the river alluvium and the clay percentage is lower. The windblown deposits are commonly well oxidized. Dune topography with local relief of less than 5 feet characterizes areas of windblown deposits. Areas of windblown deposits, too small to map, can be found throughout the two-county area, particularly where the underlying materials are sandy.

GEOLOGIC HISTORY DURING THE PLEISTOCENE

Topography on the Preglacial Surface

Prior to the earliest glaciation of Griggs and Steele Counties, streams flowed generally east and northward. Upland elevations over the area ranged between 1,400 and 1,500 feet in Griggs County and sloped eastward to less than 900 feet at the east edge of Steele County. A north-trending river in western Griggs County drained a large area to the west of the two-county area. This river was part of a river system, the trunk stream of which entered Canada from Towner County, northwest of Griggs and Steele Counties. Much of the eastern part of the two-county area was drained by the ancestral Red River, which also flowed northward.

Shale of the Cretaceous Pierre Formation was at the surface throughout Griggs County and on the western edge of Steele County (pl. 2). A four- to six-mile-wide strip of Cretaceous Niobrara Formation shale extended from north to south through Rs 56-57W of Steele County, and older Cretaceous shales covered the remainder of Steele County.

Pre-Wisconsinan Glacial History

Each time glaciers advanced southward over the area, they must have blocked the northward drainage in the Red River Valley, resulting in proglacial lakes. Buried lake silts found in excavations in eastern Steele County were probably deposited in such lakes. At one such site (sec 19, T144N, R55W), two till units were found separated by about 25 feet of lake sediment (fig. 24). The lowermost till is a bouldery clay that is sandy in places. Many of the boulders are extensively striated. The overlying silt is fairly uniform except for a marked change in hardness at about 10 feet from the base of the unit; the silt below the change is much harder than that above. The harder material also appeared to be slightly more contorted (flow structures) than that above. Near the base of the softer silt, a vertical joint pattern was apparent. Lying above the silt unit is a sandy, stony, soft, loose, and silty till. It appeared to be slightly stratified near the top.

At another site in central Steele County, two tills were found separated by about 6 feet of sand and gravel. The lower of the two tills is clayey, pebbly, hard and dense, and highly jointed. Most of the joint traces were horizontal and resembled bedding planes. The upper till is similar to the lower, but softer and unjointed.

Stratigraphic situations such as the two just mentioned suggest repeated episodes of glaciation. Several multiple till exposures were studied in the area to the north of Griggs and Steele Counties in 1964 (Bluemle, 1967a). These tills are separated by gravel horizons, boulder pavements, erosion surfaces, and buried soil profiles. Some of the lower tills are exceptionally hard, compact, and highly jointed, and stained by iron and manganese oxides. The presence of well developed erosion surfaces, buried oxidized zones, and buried soil profiles on top of the lower tills at several places points to their relatively ancient origin, perhaps pre-Wisconsinan in age.

In west central North Dakota, two possible pre-Wisconsinan drift units, the Dead Man and the Mercer drifts, were identified along Lake Sakakawea (Bluemle, 1971). At the present time, it is not possible to correlate either of these drift units with deposits suspected to be pre-Wisconsinan in Griggs and Steele Counties.

In Traill County, to the east of Steele County, Bluemle (1967b) reported two buried horizons of lake sediments. Hansen and Kume (1970) found evidence for four buried horizons of lake sediments in Grand Forks County, to the northeast of Steele County. Buried oxidized zones have been observed in several testholes in the Red River Valley, but not enough evidence is yet avialable to work out a detailed stratigraphic sequence for the glacial deposits of the area.

In summary, evidence exists that pre-Wisconsinan glaciations did occur in the Griggs-Steele County area. Detailed stratigraphic relationships are unclear and, until further data are available, nothing more than speculation about the ages of such glaciations is possible. All we can be certain of is that the uppermost drift horizon is Wisconsinan in age.

Wisconsinan Glacial History

Little is known about the early part of the Wisconsinan Epoch in Griggs and Steele Counties. Glacial drift of early Wisconsinan age occurs over much of central North Dakota west of the limit of late Wisconsinan drift, but in eastern North Dakota, early Wisconsinan drift has not been definitely identified. The discussion that follows deals mainly with the surficial geology of the area, the late Wisconsinan drift deposits.

The first part of the two-county area to become free of glacial ice for the last time was probably western Griggs County. Evidence for overridden lake deposits was found in northeastern Griggs County; apparently the late Wisconsinan glacier advanced over these proglacial lake deposits shortly before it deposited the McHenry end moraine. The many large, isolated hills and depressions in the area of the McHenry end moraine probably resulted from intense shearing and thrusting of subglacial materials while the ice margin stood near the area. The internal lineations of these blocks of material and the cross-cutting relationships suggest that the glacier flow direction shifted several times during readvances of a few miles each.

Figure 25 depicts conditions that may have existed when the ice margin was generally a short distance to the west of the two-county area. While it was in this position, the glacier deposited the Kensal end

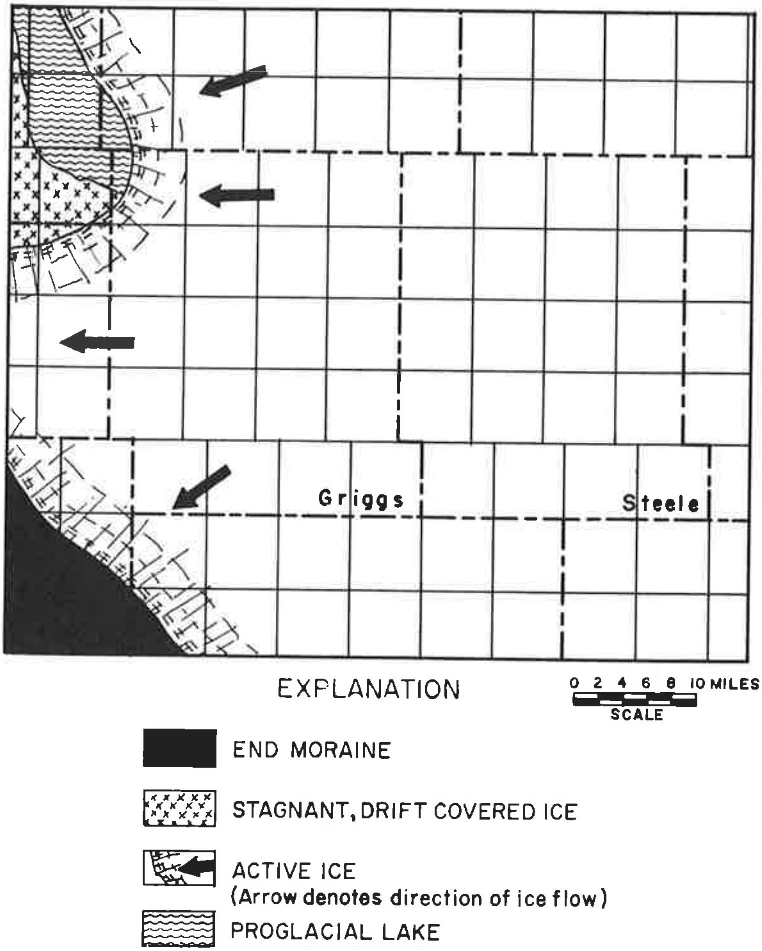


Figure 25. Diagram depicting conditions in the two-county area when the margin of the Late Wisconsinan glacier had receded to western Griggs County. The presence of lake silts in northwestern Griggs County indicates that a proglacial lake formed ahead of the receding glacier margin. The lake was somewhat larger at its maximum than shown here.

moraine in Stutsman, Barnes, and Foster Counties. As the glacier margin receded, western Griggs County gradually became free of ice. Apparently the ice margin receded to the position of the Cooperstown end moraine and once again the glacier thrust many large blocks of material distances ranging from a few hundred feet to a few miles. The Cooperstown end moraine in the Lake Jessie area and the Binford end moraine are examples of features that consist almost wholly of ice-thrust materials. Considerable outwash was deposited at about this time over west-central Griggs County (fig. 26). The same water that deposited the outwash sand and gravel also washed the till surface in some places in southwestern Griggs County; but, as the water flowed southward, it dropped its bedload, and little fluvial material was deposited in southern Griggs County.

As the glacier continued to waste, a portion of it stagnated in central Griggs County. This probably occurred because of the presence of a topographically high area of Cretaceous Pierre Formation shale northeast of the Cooperstown end moraine. It seems likely that this area of shale consists mainly of ice-thrust materials that were carried from a short distance to the north. Most shale exposures in the area have contorted bedding; many have almost vertical bedding. When the active glacier had thinned too much to override the bedrock high, or when the amount of thrust material became too great to allow continued southward movement of the glacier, a portion of the glacier stagnated (fig. 27). Melt water from the still active glacier to the northeast flowed over the stagnant ice, depositing large amounts of alluvial materials. In places, the drift-covered stagnant ice was too thick and stood too high to allow melt water streams to develop. Elsewhere, numerous streams flowed through the area, shifting course as the stagnant ice melted, depositing the gravel that now stands as ridges throughout the area. This explanation seems to best explain the general northeast-southwest trend of most of the gravel ridges.

Water became dammed in front of the ice margin in eastern Griggs County and northeastern Barnes County forming a series of lakes in a topographically low area through which the Sheyenne River melt water trench was later cut. At about the same time, the ice margin in northwestern Griggs County readvanced a few miles and deposited the McHenry end moraine (fig. 28).

The last significant ice marginal position of the late Wisconsinan glacier outside of the Red River Valley was in western Steele County (fig. 29). When the glacier margin receded to that position, it stagnated, resulting in the area of dead-ice moraine in western Steele County. Part of the area of stagnant ice was immediately flooded by proglacial melt

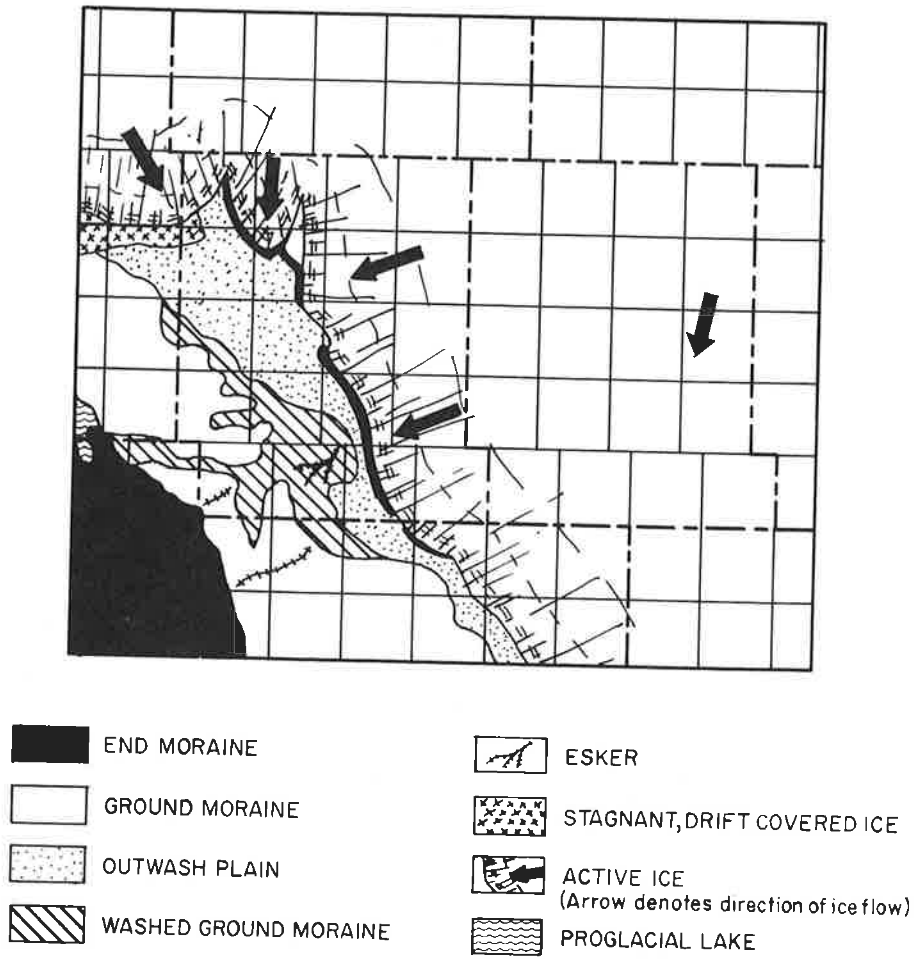
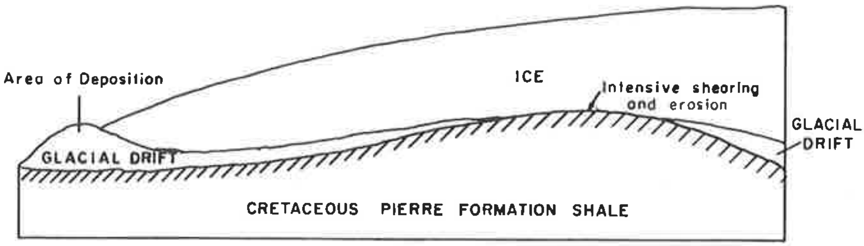


Figure 26. Conditions in the two-county area at about the time the Cooperstown end moraine was deposited. A readvance of the glacier on the north truncated the Cooperstown moraine, depositing the Binford moraine. Both these features consist largely of blocks of ice-thrust materials. Large amounts of melt water flowing from the melting glacier at this time deposited considerable outwash gravel in western Griggs County.



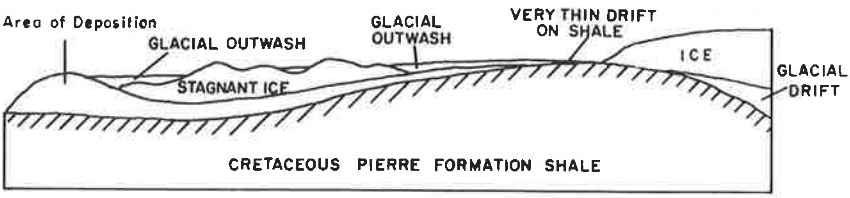


Figure 27. Active glacier depositing the Cooperstown end moraine. The ice is thick enough to flow over the high area of Pierre Formation shale (upper diagram). In the lower diagram, the active ice terminus is located behind the high area of Pierre shale and an area of stagnant ice remains between the Cooperstown end moraine and the area of high bedrock. Outwash from the active glacier terminus was deposited on lower areas of the stagnant ice.

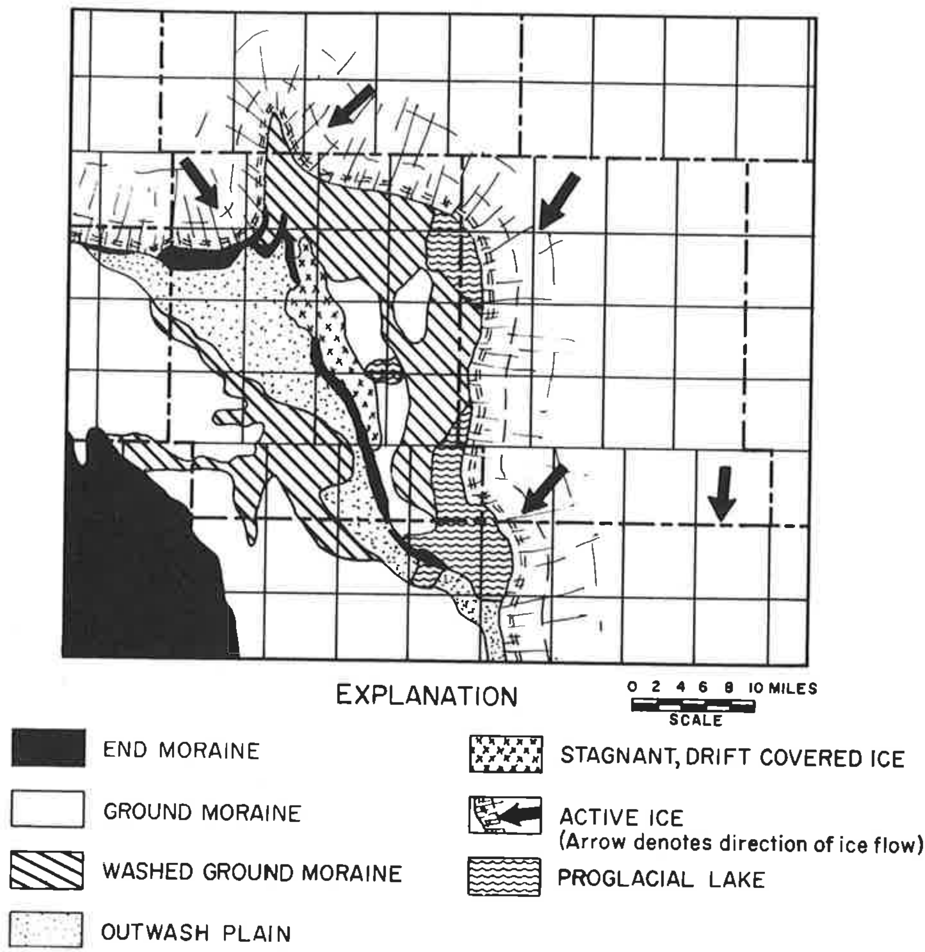


Figure 28. Glacier margin in western Steele County while the ice was still depositing the McHenry end moraine in northwestern Griggs County. Proglacial lakes formed in a valley that was to later develop into the Sheyenne River valley. One of these, at the Griggs-Steele-Barnes County junction, was Lake Lanona (see text).

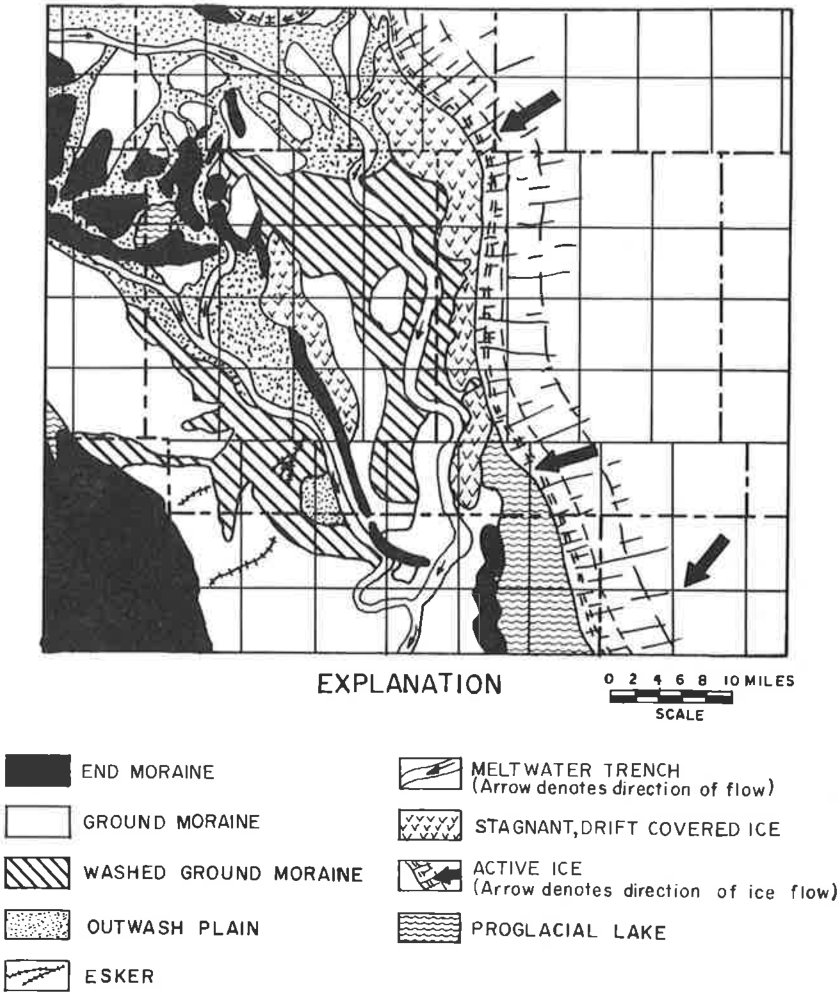


Figure 29. Diagram showing conditions when the active glacier margin receded from northern Griggs County. The Sheyenne River valley was established as a melt water trench at this time. The glacier stagnated in western Steele County as the active glacier from that time on was confined to the Red River Valley at this latitude. A proglacial lake flooded part of the stagnant ice in parts of southern Steele County and in a broad area to the south. This lake eventually expanded into Lake Agassiz as the water level dropped.

water in eastern Barnes and southern Steele Counties. As the glacier in the Red River Valley continued to recede, successively lower spillways were opened in southern North Dakota for the trapped melt water. The lake level dropped through four successively lower levels, 1,350; 1,300; 1,250; and 1,150, before reaching the Upper Herman level at 1,125 feet in eastern Steele and western Cass Counties. Throughout its existence at these higher levels, the lake existed, in part at least, on top of stagnant glacial ice. This superglacial lake occupied a total area of about 1,400 square miles, although this area was never under water all at the same time.

ECONOMIC GEOLOGY

Sand and Gravel

About 17 commercial sources of borrow material are located in Griggs and Steele Counties (information from North Dakota Highway Department Data). Most of these are rather small operations that operate only part time. Equipment is not currently located at many of the sites. In addition to the known commercial sites (locations of which are listed on the following page), a few hundred more possibilities for borrow material exist. They include all ice contact deposits, many of which are identified by red symbols on plate 1. Most of the gravels contain shale in amounts that range from a trace to 10 percent. A few aggregates contain shale in amounts up to 20 percent. The North Dakota Highway Department rejects any road material containing over 12 percent shale.

Table 1. *Commercial gravel sources in Griggs and Steele Counties.*

Location	Owner	Estimated Reserves in Cubic Yards
N½sec 2, T148N, R61W	Joel Goplen, Binford, ND	85,000
SW¼sec 2, T148N, R61W	Joel Goplen, Binford, ND	50,000
NW¼sec 30, T148N, R57W	Kate Wright, Sharon, ND	90,000
NW¼sec 33, T148N, R56W	Ed Nesheim, Sharon, ND	70,000
W½sec 31, T147N, R61W	Peter Dywad Pit	25,000+
E½sec 32, T147N, R61W	David Beardsley Estate Pit	Unknown
NE¼sec 9, T147N, R56W	Albert Gilbertson Pit	85,000
SW¼sec 27, T146N, R55W	State owned pit	Unknown
NW¼sec 32, T146N, R55W	Hans Gotfredson Pit	68,000
NE¼sec 21, T145N, R60W	L. O. Skjelset Pit	33,000
NW¼sec 22, T145N, R60W	Harold Brown Pit	Unknown
NW¼sec 5, T145N, R59W	Bruce Hazard Pit	45,000
SW¼sec 22, T145N, R59W	Perry Haaland Pit	56,000
NE¼sec 4, T144N, R60W	Gustave Sonju Pit	60,000
SE¼sec 21, T144N, R59W	Laura Fogderude Pit	148,000
NW¼sec 35, T144N, R56W	Randall Curry, Hope, ND	21,000
NE¼sec 35, T144N, R56W	W. R. Knox Pit	22,000

Hydrocarbons

As of July 1, 1974, seven exploratory oil wells had been drilled in Griggs and Steele Counties (6 in Griggs, 1 in Steele) and 44 stratigraphic tests had been completed (16 in Griggs, 28 in Steele). No production has yet been found. Interest continues in the area because of the presence of the Newcastle and other Cretaceous sands, which underlie the area. The Paleozoic formations that produce oil further west in North Dakota have porosity in Griggs and Steele Counties. The many possibilities for stratigraphic and structural traps along with shallow depths allowing easy and fast drilling should do much to promote exploration in the area.

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