GEOLOGY

of

CAVALIER AND PEMBINA COUNTIES

by
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North Dakota Geological Survey
Grand Forks, North Dakota
1975

BULLETIN 62–PART 1
North Dakota Geological Survey
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COUNTY GROUNDWATER STUDIES 20–PART 1
North Dakota State Water Commission
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Prepared by the North Dakota Geological Survey
in cooperation with the U.S. Geological Survey,
North Dakota State Water Commission,
Cavalier County Water Management District,
and the Pembina County Board of Commissioners

Printed by Kaye's, Inc., Fargo, North Dakota

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INTRODUCTION

Purpose and Scope

Geologic mapping of Cavalier and Pembina Counties was undertaken by the North Dakota Geological Survey as part of a statewide groundwater program. This study was made in cooperation with the United States Geological Survey, the North Dakota State Water Commission, and the County Commissioners of Cavalier and Pembina Counties. The results are published in three parts: Part I, which describes the geology; Part II, which gives the basic hydrologic data; and Part III, which evaluates the groundwater resources.

The objects of Part I are: (1) to provide a map of the surface geology, (2) to describe the economic and engineering characteristics of the surface geology, and (3) to acquaint the residents of Cavalier and Pembina Counties with their geologic environment.

Methods of Study

Mapping of the two-county area was begun late in the summer of 1968 and was completed during the summer of 1970. Lithologic information was obtained from roadcuts along county roads; or where roadcuts were not sufficient to reveal the nature of the sediments present, shallow hand auger holes were dug. A truck-mounted power auger was used to obtain deeper lithologic information. Rotary drilling, under the supervision of the U. S. Geological Survey provided deep test-hole information. In addition, logs are available from exploratory oil-well tests and from Porter and O'Brien, consulting engineers for the U.S. Air Force.

The geologic information obtained was plotted on aerial photographs which were available for the entire two-county area and on topographic maps where coverage was available. The final geologic map uses a North Dakota Highway Department county road map as a base at a scale of 1:126,000.

Regional Geography and Geology

Nearly all of Cavalier County lies within the physiographic district of the Drift Prairie (fig. 1). The Drift Prairie is gently rolling to

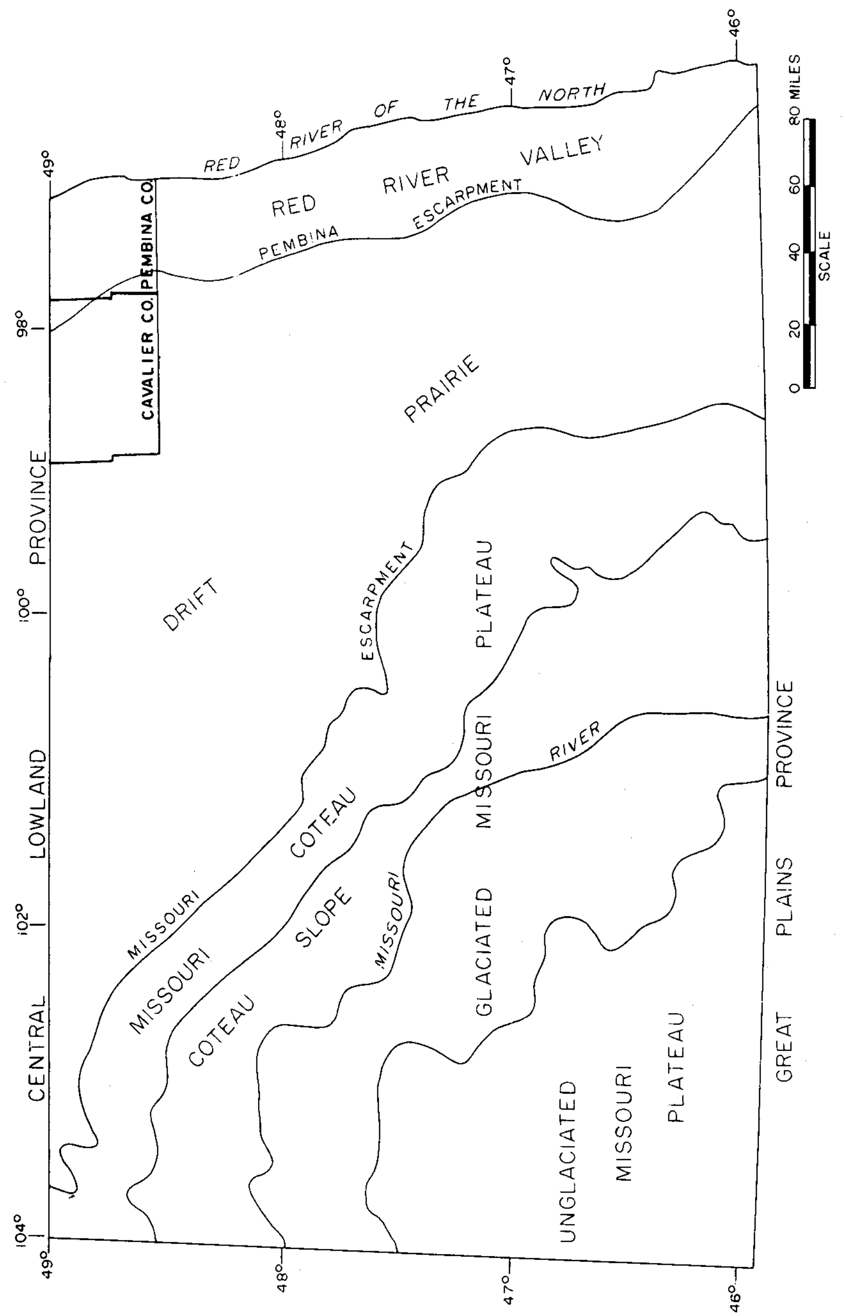

Figure 1. Index map showing location of Cavalier and Pembina Counties and the physiographic units of North Dakota.

undulating and is underlain by sediments deposited by glaciers. Elevations in the county range from 1620 feet in the western part, to less than 1200 feet in the northeastern part of the county. Drainage is poorly developed, and the streams that are present generally flow in former channels which carried water from the melting glaciers. The Pembina Escarpment, along the eastern edge of Cavalier County, marks the eastern edge of the Drift Prairie. To the east of this escarpment is the Red River Valley.

Pembina County lies entirely within the physiographic district of the Red River Valley, the basin of glacial Lake Agassiz. The area is nearly level, except in the west, where most of the beaches and the Pembina Delta are located. Elevations in the beach and delta area range between 800 and 1,200 feet. The elevation of the lake plain ranges from 900 feet in the west to about 750 feet in the vicinity of the Red River of the North. The development of natural surface drainage in the lake basin is not much further advanced than that of the Drift Prairie, although three major rivers cross the area.

The two counties are on the eastern edge of the Williston basin. The bedrock, underlying the glacial deposits, consists mostly of marine shale and sand of Cretaceous and Jurassic age (pls. 3 and 4). In some areas of eastern Pembina County, preglacial erosion was so extensive that Precambrian rocks lie immediately below the glacial sediments. All the rock units except the glacial sediments have a regional dip to the west or southwest and thicken in that direction.

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Pre-Quaternary Stratigraphy

Information on rocks present below the Quaternary deposits in the Cavalier-Pembina area is based largely on logs of oil-test borings. These logs are on file with the North Dakota Geological Survey in Grand Forks.

Rocks of three formations outcrop in the Cavalier and Pembina Counties area. The rest of the older rocks have been described on the basis of well cuttings and electric-log characteristics. Carlson and Anderson (1965) have divided the stratigraphic column of North Dakota into sequences (Sloss, 1963), (fig. 2). A summary of each sequence, from oldest to youngest, in the Cavalier-Pembina area is given below.

SEQUENCE	SYSTEM	GROUP OR FORMATION		DOMINANT LITHOLOGY
TEJAS	TERTIARY	COLEHARBOR GROUP		Glacial Drift
		WHITE RIVER		Clay, Sand, and Limestone*†
		GOLDEN VALLEY		Clay, Sand, and Silt*†
		FORT UNION GROUP	TONGUE RIVER	Shale, Sandstone, and Lignite*†
			CANNONBALL	Marine Sandstone and Shale*†
			LUDLOW	Sandstone, Shale, and Lignite*†
ZUNI	CRETACEOUS	HELL CREEK		Sandstone, Shale, and Lignite*†
		MONTANA GROUP	FOX HILLS	Marine Sandstone*†
			PIERRE	Shale
		COLORADO GROUP	NIOBRARA	Shale, Calcareous
			CARLILE	Shale
			GREENHORN	Shale, Calcareous
			BELLE FOURCHE	Shale
		DAKOTA GROUP	MOWRY	Shale
			NEWCASTLE	Sandstone
			SKULL CREEK	Shale
			FALL RIVER	Sandstone and Shale
			LAKOTA	Sandstone and Shale
	JURASSIC	MORRISON		Shale, Clay
		SUNDANCE		Shale, green and brown, and Sandstone
		PIPER		Limestone, Anhydrite, Salt, and red Shale
ABSAROKA	TRIASSIC	SPEARFISH		Siltstone, Salt, and Sandstone*
	PERMIAN	MINNEKAHTA		Limestone*†
		OPECHE		Shale, Siltstone, and Salt*†
	PENNSYLVANIAN	MINNELUSA		Sandstone and Dolomite*†
		AMSDEN		Interbedded Dolomite, Limestone, Shale, and Sandstone*†
KASKASKIA	MISSISSIPPIAN	BIG SNOWY GROUP	HEATH	Shale, Sandstone, and Limestone*
			OTTER	
			KIBBEY	
		MADISON		Interbedded Limestone and Evaporites*
				Limestone*
	DEVONIAN	BAKKEN		Siltstone and Shale*
		THREE FORKS		Shale, Siltstone, and Dolomite*
		BIRDBEAR		Limestone*
		DUPEROW		Interbedded Dolomite and Limestone*
		SOURIS RIVER		Interbedded Dolomite and Limestone*
		DAWSON BAY		Dolomite and Limestone*
		PRAIRIE		Halite*
		WINNIPEGOSIS		Limestone and Dolomite*
TIPPECANOE	SILURIAN	INTERLAKE		Dolomite
	ORDOVICIAN	STONEWALL		Dolomite and Limestone
		STONY MOUNTAIN FORMATION	GUNTON MEMBER	Limestone and Dolomite
			STOUGHTON MEMBER	Argillaceous Limestone
		RED RIVER		Limestone and Dolomite
		WINNIPEG GROUP	ROUGHLOCK	Calcareous Shale and Siltstone
			ICEBOX	Shale
			BLACK ISLAND	Sandstone
SAUK	CAMBRIAN	DEADWOOD		Limestone, Shale, and Sandstone*†

*Not present in Pembina County
†Not present in Cavalier County

Figure 2. Stratigraphic column of North Dakota. Heavy dashed lines represent major regional unconformities. Modified from Carlson and Anderson, 1966, p. 1835.

Tippecanoe Sequence

The oldest rocks in the Tippecanoe Sequence that are present in Cavalier and Pembina Counties are included in the Winnipeg Group of Ordovician age. This group contains marine shale, limestone, and sandstone. Limestone and dolomite are the primary rock types that make up the Red River, Stony Mountain, and Stonewall Formations, which are also Ordovician in age. The youngest rocks in the Tippecanoe Sequence belong to the Silurian Interlake Formation, which is largely composed of dolomite.

Kaskaskia Sequence

Rocks of Devonian and Mississippian age are part of the Kaskaskia Sequence. Limestone and dolomite are the primary rock types of the Devonian Formations, which include the Winnipegosis, Prairie, Dawson Bay, Souris River, Duperow, and Birdbear Formations. Mississippian age rocks are primarily limestone and dolomite of the Bottineau Interval (Madison Formation).

The Kaskaskia Sequence is present only in Cavalier County.

Absaroka Sequence

The Triassic Spearfish Formation is the only formation in the Absaroka Sequence that is present in the two-county area. This formation consists largely of siltstone and sandstone and some evaporites and is present only in Cavalier County.

Zuni Sequence

The Zuni Sequence contains a total of 13 formations which range in age from Jurassic to Cretaceous. The Jurassic rocks, which include the Gypsum Spring, Piper, Sundance, and Morrison Formations, consist of limestone, shale, and sandstone, and minor amounts of gypsum. Cretaceous rocks in Cavalier and Pembina Counties are largely shale and sandstone. These rocks are included in the Dakota Group, and the Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations. The Carlile, Niobrara, and Pierre Formations are all exposed at the surface in the Cavalier-Pembina area (pls. 1 and 2).

Carlile Formation (Unit 26)

The Carlile Formation is a soft, black, marine shale and contains discontinuous pale yellow to reddish-brown limonite stringers. Large ellipsoidal concretions commonly occur within this shale. The shale is generally non-calcareous, contains abundant selenite, and in fresh samples has an oily odor. Fish scales are commonly found in the shale.

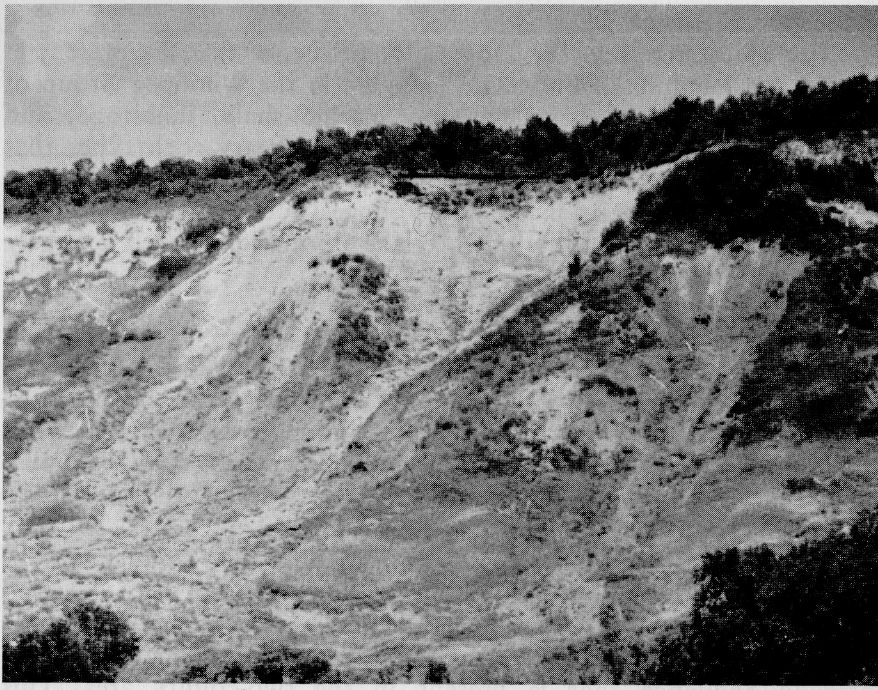

Figure 3. The Carlile and Niobrara Formations are extensively exposed along Pembina River Valley. The soft black shale of the Carlile Formation tends to slump while Niobrara Formation forms nearly vertical cliffs with almost no vegetation. (Loc: sec 34, T163N, R57W)

The Carlile Formation is exposed all along the Pembina River Valley (fig. 3). It tends to slump easily, and massive slump blocks are evident near the base of the valley walls. The best exposure of this formation is in the NE¼sec 33, T163N, R57W. A section of shale, about 100 feet thick is exposed here, and is the lowest stratigraphic exposure in North Dakota. Other exposures occur in the SE¼SW¼sec 3, T162N, R57W, roadcuts in sec 10, T163N, R57W, and secs 33 and 34, T164N, R57W.

Niobrara Formation (Unit 25)

The Niobrara Formation conformably overlies the Carlile Formation (fig. 3). About 150 feet of Niobrara shale and marlstone is exposed in the Cavalier-Pembina area and consists of two members. The upper member is a yellowish tan, marly shale, which forms conspicuous cliffs. The lower member of the Niobrara Formation is a light gray shale with white specks. The upper member is massive and jointed whereas the lower member is fissile. Both members are calcareous. Fossils are common in this formation; oyster shells have been found in sec 7, T161N, R56W, and sec 30, T163N, R58W.

The Niobrara Formation is extensively exposed along the Pembina River Valley and along the lower three miles of the Little North Pembina River. The lower member of the Niobrara Formation is best exposed in the valley of the Little South Pembina River, in the middle of sec 19, T162N, R57W. Here the upper member is missing, and the lower member of the Pierre Formation lies directly on the lower member of the Niobrara. The upper member of the Niobrara is exposed in roadcuts in the Pembina Escarpment just above the level of the Lake Agassiz plain in the area just west of Gardar to the west of Mountain. There are also several exposures in roadcuts northwest of Walhalla which cross over the escarpment.

Pierre Formation (Units 23 and 24)

Conformably overlying the Niobrara Formation is the Pierre Formation, also of Cretaceous age. The Pierre Formation has been divided into four stratigraphic units, from bottom to top, the Pembina Member, Gregory Member, DeGrey Member, and Odanah Member (Gill and Cobban, 1965). The four members have been grouped into two units on plates 1 and 2. The upper unit consists of the Odanah and DeGrey Members (fig. 4), and the lower unit consists of the Gregory (fig. 5) and Pembina Members (fig. 6).

The combined thickness of the Odanah and DeGrey Members is about 180 feet, although at any one outcrop the exposure will generally be less than 150 feet. Both members are predominantly hard, siliceous, gray shale. Thin bentonite beds are present in both members, but the DeGrey is much more bentonitic than the Odanah Member. The upper two members are highly fractured and jointed, but they form conspicuous cliffs because of their hardness. Iron and manganese concretions are common. Reddish-brown and purple stains are common on weathered surfaces and joints. The Odanah Member weathers into distinct plates or flakes.

The Gregory and Pembina Members make up the lower unit of the Pierre Formation. Both are highly bentonitic and tend to slump easily when exposed. The Gregory Member is a gray bentonite-rich shale that weathers with a characteristic popcorn-like surface. The Pembina Member is a soft, black, bentonitic shale, which may be confused with the black shale of the Carlile Formation. The Pembina Member can be distinguished by its stratigraphic position, overlying the Niobrara Formation, while the Carlile Formation underlies the Niobrara. The

Figure 4. The upper unit of the Pierre Formation is a blocky, hard, siliceous gray shale. This unit forms conspicuous nearly vertical cliffs. (Loc: Borrow pit in sec 19, T161N, R57W)

Carlile Formation contains discontinuous limonite bands, whereas the Pembina Member contains continuous yellowish brown bentonite bands. The fish scales, which are common in the Carlile, are rare in the Pembina Member.

Both the Gregory and Pembina Members are noncalcareous, and both contain iron concretions. The base of the Pembina Member, which occurs at an elevation of about 1,270 feet, is marked by conspicuous yellowish bentonite beds.

The Pierre Formation is the most widely exposed bedrock unit in Cavalier and Pembina Counties. A nearly complete section is exposed on the north side of North Dakota Highway 5 in sec 24, T161N, R57W. Some of the best exposures are along the North Branch Park River near Milton. Other good exposures are along the Little North Pembina River, the Little South Pembina River, and the South Branch Park River. Numerous pits in the upper unit of the Pierre have been quarried for secondary road surfacing material. Gill and Cobban (1965) have reported on the paleontology of the Pierre Formation.

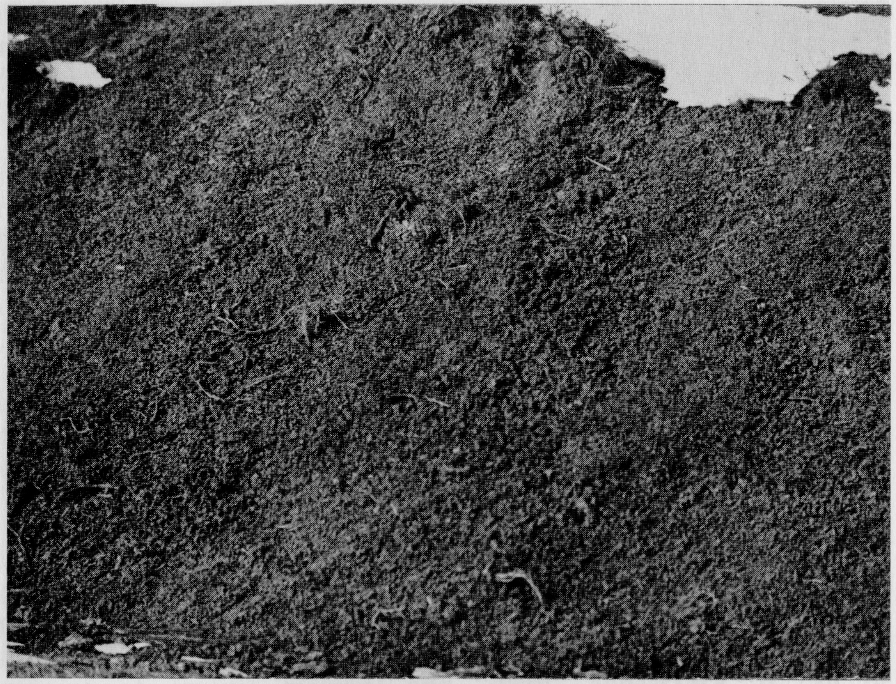

Figure 5. The Gregory Member of the lower unit of the Pierre Formation is a bentonite-rich shale that weathers with a characteristic popcorn-like surface. (Loc: sec 36, T164N, R58W)

Tejas Sequence

The Tejas Sequence consists of the Coleharbor Group and Walsh Formation in Cavalier and Pembina Counties.

Coleharbor Group

The Coleharbor Group (originally defined as a formation by Bluemle, 1971) is largely till, which is a homogeneous mixture of various proportions of sand, silt, clay, pebbles, cobbles, and boulders. The matrix, which is mostly silt and clay, is usually yellowish-brown to brownish-gray when oxidized and light olive gray when unoxidized. The coarser materials are generally angular to subrounded and consist of carbonate rock, igneous and metamorphic rock, and shale. The till is poorly indurated to nonindurated, may exhibit jointing in outcrops, but has no other structure, such as bedding or sorting. The Coleharbor Group also includes a laminated clay and silt facies, and a sand and gravel facies. The sand and gravel deposits associated with either these clays and silts or till exhibit various degrees of sorting and bedding.

Figure 6. Yellowish-brown bentonite beds are conspicuous in the Pembina Member of the Pierre Formation. (Loc: sec 31, T163N, R57W)

The Coleharbor Group in Cavalier County is nearly all till that was deposited as a result of glaciation during the Pleistocene Epoch. In this county, Bluemle (1967) reported multiple till sheets separated by outwash, boulder pavements, erosion surfaces, or buried soil profiles. Several test holes in the western part of the county have revealed the presence of more than one till sheet. A power auger hole in SE¼SE¼SE¼sec 36, T160N, R64W, shows evidence of at least two till sheets. The sequence here is 21 feet of slightly sandy, shaly, oxidized till, underlain by 14 feet of unoxidized till, and then, at a depth of 35 feet, a very stony, oxidized till. Underlying the Coleharbor Group in Cavalier County is the Pierre Formation.

The Coleharbor Group in Pembina County contains three facies: till facies, sand and gravel facies, and clay and silt facies. As in Cavalier County there are several till sheets in the subsurface. The stratigraphy of these till units has only recently been studied, and undoubtedly several glacial advances during the Pleistocene Epoch were involved in the deposition of these tills. Preliminary results of the stratigraphy of these tills is given in appendix A. Sand and gravel deposits, some of which may have originated as glacial outwash, are interbedded with these tills. Plates 2 and 4 show the subsurface geology in Pembina County.

Overlying the till in Pembina County is a clay that may locally exceed 130 feet. This clay is laminated to massive, highly plastic, light to dark gray and contains abundant soft carbonate pebbles and nodules. It grades laterally westward into sand and gravel, which is topographically higher than the clay. It is easily distinguished from the underlying till and from overlying laminated silty clay described below. This clay unit will be hereafter referred to as the Walhalla clay.

The Walhalla clay is overlain by laminated, yellowish-brown to brownish-gray, calcareous silty clay, which is the surface unit in much of eastern Pembina County. In western Pembina County this upper silty clay is overlain by fine sand or well sorted, bedded sand and gravel.

Walsh Formation

The Walsh Formation (Bluemle, 1973, p. 33) consists mostly of silt and clay and lesser amounts of sand and gravel. It overlies the Coleharbor Group. This formation is composed of sediments that have fluvial, eolian, or colluvial origins. It can best be recognized by its high content of organic material and "dirty" appearance. It can be differentiated from other similar appearing sediments by its stratigraphic position above the Coleharbor Group.

The Walsh Formation in Cavalier and Pembina Counties is of limited extent. Its distribution is shown on plates 1 and 2.

Surficial Geology

The sediments that make up the surface deposits are included in four major categories on the basis of origin: (1) glacial, (2) lacustrine, (3) fluvial, and (4) eolian.

In the following discussion the various surficial units have been assigned numbers which are keyed to the geologic maps (pls. 1 and 2) supplied with this report. The primary function of using numbered units is for easy reference to the map.

Glacial Deposits

Most of the surficial deposits in Cavalier County are there because of direct deposition of sediments by glaciers which occupied much of North Dakota as late as 13,000 years ago. Glacial deposits are at the surface only in the southwestern corner of Pembina County.

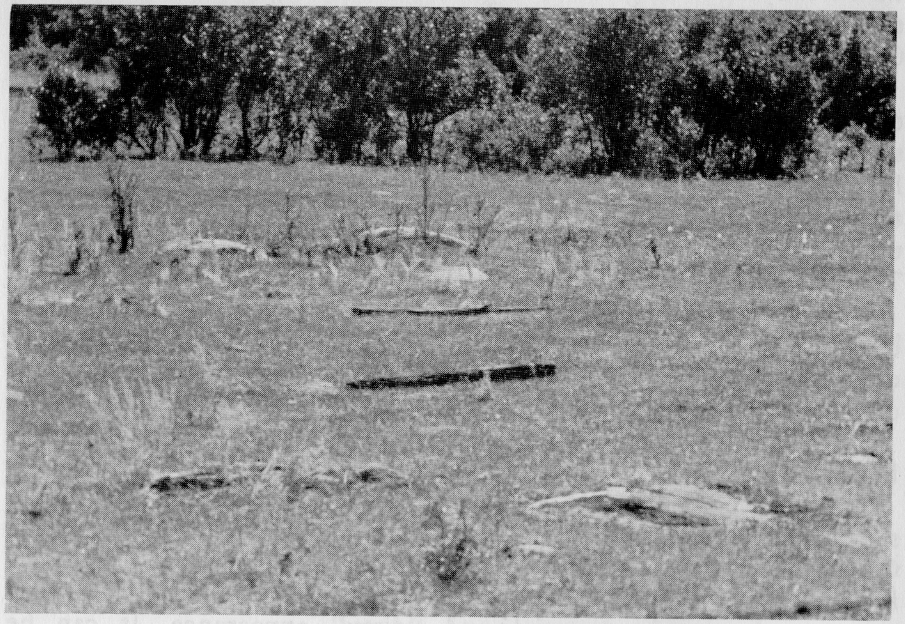

Figure 7. The bouldery surface character of this unit is a result of washing away of the finer sediments by wave action of glacial Lake Agassiz. (Loc: sec 21, T159N, R56W)

Till is the predominant facies in this group of deposits. Other facies, such as sand and gravel, in the form of eskers, are also included with the glacial deposits, although they were not deposited directly by glacial action.

Map units 16, 17, 18, 19, 20, 21, and 22 all represent till units that are lithologically quite similar. The differentiation of one from another is primarily on the basis of their morphologic characteristics. In contrast, the map units shown in Pembina County (units 1-15) represent a distinction based mostly on lithologic differences.

Unit 16

Approximately 25 square miles in southwestern Pembina County is mapped as unit 16. This unit represents a clay-rich till that is extremely stony and exhibits a large concentration of boulders and cobbles at the surface (fig. 7). The surface on this till unit is nearly flat to gently undulating. Several northwest trending ridges of sand and gravel also are present on the surface. A prominent scarp (Campbell

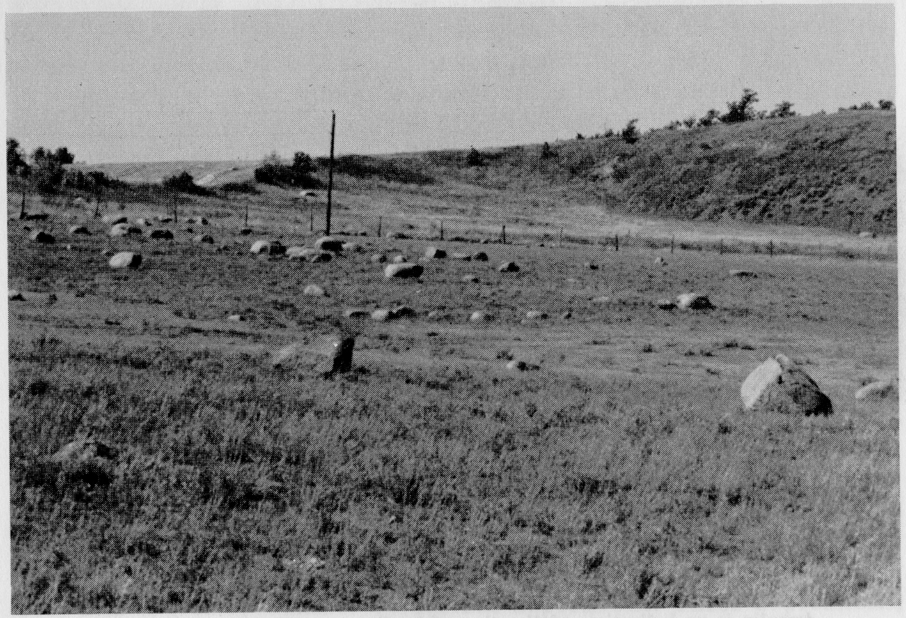

Figure 8. The lag concentrate of boulders on the till represented by unit 10 was left behind as erosion was initiated by wave action of Lake Agassiz and continued by streams flowing across the area as the lake receded. (Loc: sec 31, T164N, R57W)

Scarp) also trending northwest, traverses across this unit at an elevation between 1,000 and 1,025 feet.

This unit is a till that has been washed by wave action of glacial Lake Agassiz. The sand and gravel ridges are strandlines of Lake Agassiz. The Campbell Scarp is a wave-cut bluff that was formed during a relatively long period of time during which the lake stood at this level.

Unit 17

A thin mantle of till overlying the lower unit of the Pierre Formation (fig. 8) occurs in northeastern Cavalier County. This unit covers 15 square miles in area. It is shown as unit 17 on plate 1. Included with this till are minor amounts of sand and gravel and a lag concentrate of boulders. Local relief may be as much as 50 feet here, although the topography is generally undulating.

Unit 17 represents an eroded till. Erosion was initiated by wave action of Lake Agassiz and continued by streams flowing across the area after the lake receded.

Figure 9. A long linear ridge north of Langdon. The northwest-southeast orientation of this drumlin is an indication of direction of ice flow over Cavalier County. (Loc: secs 4 and 12, T161N, R60W)

Unit 18

Much of the eastern half of Cavalier County is underlain by a stony, silty till (unit 17). Boulders are common and cobbles are abundant. The clay-silt-sand fraction of the till is oxidized to yellowish-brown at the surface, and it is olive gray where unoxidized at depth. The boulders, cobbles, and larger pebbles are composed of limestone, dolomite, shale, granite, and metamorphic rocks. Lignite fragments are common, particularly in the sand-size fraction. Topographically, the area underlain by this till unit is gently undulating to nearly flat. Relief ranges from 5 to 15 feet; however, it is commonly less than 10 feet. Local relief may exceed 40 feet in areas where long linear ridges occur. Surface depressions, which are evident as ponds or sloughs, are rare, and surface drainage is poorly developed.

The long, linear ridges mentioned above are found in two "sets" in Cavalier County. One set is 2 to 3 miles north of Langdon (fig. 9), whereas the other set is 4 to 5 miles south of Milton, near the county line. Ridges such as these were first recognized as drumlins by Lemke (1958).

A hole drilled near the northern end of a drumlin in SE¼SW¼sec 26, T162N, R60W, north of Langdon, encountered 16 feet of sandy, pebbly till over weathered shale. At this point the drumlin was less than 16 feet high, so this drumlin is composed primarily of till. In another drumlin, in the SE¼SW¼sec 1, T161N, R60W, weathered shale was encountered at a depth of 15.5 feet, well above the level of the surrounding till plain, showing this drumlin to be bedrock cored.

The till represented by unit 18 was deposited by glacial ice that moved from a northwesterly direction. In most of the area underlain by this till, the bedrock is less than 50 feet from the surface (pl. 5). The morphologic characteristics of this till unit appear to be controlled by the original bedrock surface. That is to say, that except in cases where bedrock valleys have been filled with till, the present-day surface probably closely reflects the bedrock surface.

Unit 19

Map unit 19 represents a stony loam of glacial origin with minor amounts of sand and gravel. The differentiation of this unit from the till shown as unit 18 is based on somewhat higher local relief (10 to 20 feet) and a greater number of surface depressions. These depressions, which manifest themselves as ponds or sloughs, are easily recognized on aerial photographs and usually number more than 10 but fewer than 30 per square mile. Eskers (fig. 10) which are sinuous ridges of stratified sand and gravel, are more abundant than in the area shown by unit 18, although most are too small to be shown on the geologic map (pl. 1). Disintegration ridges and trenches are common, particularly in the western part of this till unit. Streams are rare and surface drainage is largely nonintegrated.

Aerial photographs show a series of straight to arcuate low ridges in unit 19. The most conspicuous of these occur in the uplands between the Pembina River Valley and the Little South Pembina River Valley. There are also occasional occurrences of these ridges in the north-central section of Cavalier County. The ridges have been called washboard moraines and are interpreted to indicate successive positions of a wasting ice margin. The ridges are perpendicular to the direction of flow of the ice. On the uplands between the Pembina River and the Little South Pembina River, the drift is thin, and minor stream valleys and gullies, which are tributary to larger Pembina River systems, are parallel to the ridges.

Figure 10. Eskers are sinuous ridges of sand and gravel which may be covered by a thin veneer of till. These can be local sources of low grade sand and gravel supply. (Loc: sec 10, T160N, R60W)

The thickness of drift in unit 19 is generally somewhat greater than in unit 18 (pls. 1 and 5). The higher local relief and greater number of depressions present in this unit may be related to the greater thickness of this material. The morphologic characteristics of the drift in unit 18 are largely influenced by the bedrock; whereas, the surficial characteristics of unit 19 are largely independent of bedrock control. The till of unit 19 may represent deposits of an inactive ice sheet with the characteristics of the surface being due to ablation of the ice.

Unit 20

Unit 20 represents a till unit which exhibits hummocky topography with local relief that ranges from 10 to 35 feet. This unit occurs throughout southwestern Cavalier County, and isolated patches occur north of Nekoma, east of Hannah, and southeast of Maida. The till is generally olive-brown to olive-gray silty clay loam. Disintegration features are abundant throughout, though they are generally too small to show on the geologic map. Eskers are also abundant. At least 30 undrained depressions per square mile occur throughout unit 20. Drainage is nonintegrated or poorly integrated.

Unit 20 includes deposits of a stagnant ice mass. This mass of ice probably broke off from the retreating glacier and slowly wasted. Because of the great amount of debris covering such a surface, melting was slow and uneven. A hummocky area with an abundance of disintegration features has been the result.

Unit 21

An area of 80 square miles in northwestern Cavalier County is shown as unit 21. The sediments in this area are till, locally very sandy, which is overlain in places by 1 to 2 feet of poorly sorted sand and gravel. A lag concentrate of boulders is common and many of these boulders exceed 5 feet in diameter. The topography is nearly flat to undulating and local relief is generally less than 5 feet. Though surface streams are rare, the great extent to which the sloughs are connected provides avenues for surface water drainage.

Except in the areas where the slough network is present, the drift is quite thin (pls. 1 and 5). The till in unit 21, as the till in unit 18, has surface characteristics that seem to be a reflection of the underlying bedrock characteristics. The thin veneer of sand and gravel overlying the till was deposited by northward flowing streams washing over the area.

Unit 22

In Cavalier County, there are many long linear depressions in which the dominant lithology is till. Locally this unit, which is mapped as unit 22, also contains clayey sand and gravel. The till is generally less than 10 feet thick, and may be underlain by shale-rich sand and gravel that is generally less than 3 feet thick.

These linear depressions, shown by unit 22, represent former meltwater channels which were overridden by the last glaciation. The organic clays, mapped as unit 6, also occur in these channels, particularly in the northwestern part of Cavalier County. Small intermittent streams occupy some of these old channels. Most water movement, however, is restricted to underflow in the buried sand and gravel.

Lacustrine Deposits

Lacustrine deposits include all materials that were deposited in lakes. The texture of these deposits can range from coarse gravel to clay, depending mainly on sediment source and how far from shore the deposition took place. In general, the farther from the shore, the finer the material that is deposited. Depth of water is also a factor in determining the size and amount of material that will be deposited in any given area.

Nearly all of Pembina County and the extreme northeastern part of Cavalier County were covered by a lake during the latter part of the Wisconsinan Age of the Pleistocene Epoch. This lake, which occupied parts of Manitoba, Ontario, Saskatchewan, North Dakota, Minnesota, and the extreme northeastern corner of South Dakota, was Lake Agassiz, named after Louis Agassiz, a Swiss zoologist who was one of the first to publicize the existence and effects of continental glaciation. The sediments deposited in Lake Agassiz in Pembina and Cavalier Counties are shown by units 7 through 13 on plate 2.

Unit 7

The clayey silt that covers most of the eastern half of Pembina County is shown as unit 7. The color of this clayey silt is yellowish-brown near the surface and becomes light gray with depth. Pebbles are not common in this sediment; however, they are locally present. Gypsum crystals are also common and are the result of calcium concentration of discharging groundwater. The thickness of this clayey silt ranges from 26 feet, just northwest of Cavalier, to about 5 feet at Hamilton. Varves, a series of alternating light and dark beds, are a diagnostic feature of this deposit. The darker beds are finer grained than the lighter ones.

The surface expression of this silty clay is nearly flat to gently undulating. The unit has a regional slope eastward toward the Red River. Elevations range from nearly 900 feet near Cavalier to about 790 feet at Drayton, giving a slope of less than 5 feet per mile. A complex network of drainage ditches is necessary to adequately drain the land allowing its use for agricultural purposes.

Aerial photographs of the area mapped as unit 7 show numerous lineations traversing this clayey silt unit (fig. 11). Most of these trend northwest-southeast, while a few trend northeast-southwest. Where these lineations cross each other, the northwest lineations cut across the northeast ones. In that part of unit 7 east of unit 11, these lineations are not mapped both because of the complexity of their pattern and because they have been somewhat obscured by flooding and farming practices.

Several theories have been proposed to explain the origin of these lineations. Johnston (1916) thought they were due to unusual tundra or permafrost conditions. There is no evidence, however, that such

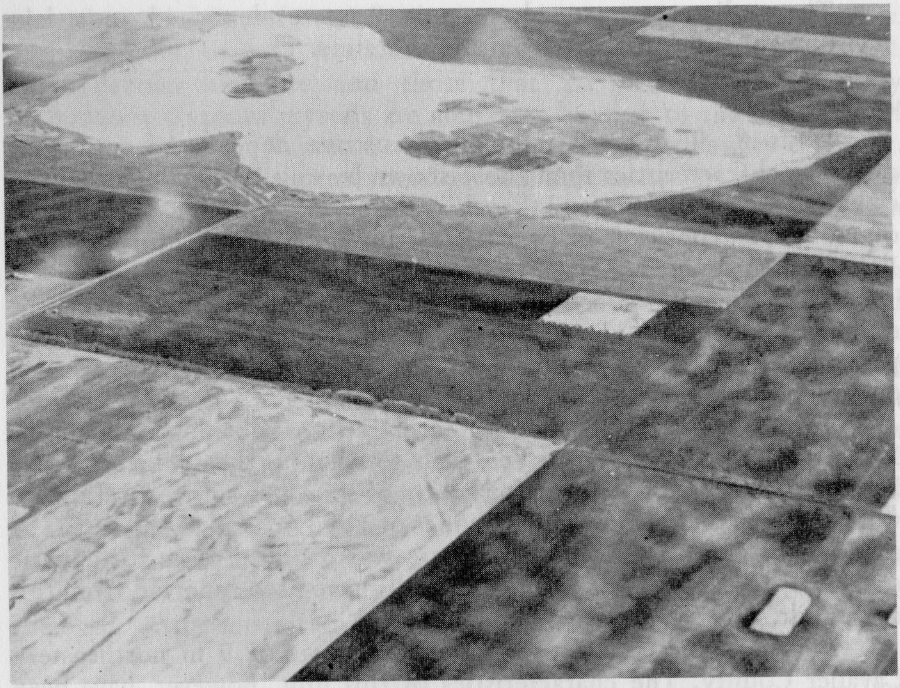

Figure 11. An aerial view of the Lake Agassiz plain in eastern Pembina County. The lineations are the result of floating ice dragging on the bottom in the shallow parts of Lake Agassiz.

conditions ever existed in the Red River Valley (Mollard, 1957). Another theory attributed these lineations to normal processes of wave action and running water (Nikiforoff, 1952). Mollard (1957) and Elson (1961) thought the lineations to be a reflection of fracture patterns in the underlying bedrock. Colton (1958) thought that these lineations are ridges formed by the soft lake sediments being squeezed up into cracks in overlying lake ice. He suggests that in the later stages of Lake Agassiz, the water was shallow and froze all the way to the bottom in the cold seasons. The weight of the overlying ice on the lake bottom would tend to force the soft sediments upward into any existing cracks.

Clayton, and others (1965), proposed another theory which best explains some of the characteristics of those lineations that the other theories do not. During spring break-up, floating ice would drag bottom in the shallow parts of Lake Agassiz. The prevailing winds moved these ice blocks which grooved the soft bottom sediments. The lineations, then, show the prevailing wind directions and the subsequent changes in those directions.

The sediments mapped as unit 7 were deposited in a lake environment some distance from any shoreline.

Units 8, 9, 10

Units 8, 9, and 10 represent lacustrine deposits of somewhat different characteristics than those shown by unit 7. Although they are essentially similar deposits, they have been differentiated on the basis of mode of deposition or processes acting upon these sediments after Lake Agassiz drained.

The sediments shown as unit 8 are somewhat sandier than the sediments shown by unit 7. This sandier unit is mapped in the western part of Pembina County and is bordered on three sides by beach and delta deposits.

This sandy, clayey silt is interpreted to be a lagoon deposit. Longshore currents flowing parallel to the northeast face of the Pembina Delta resulted in the formation of spits and bars separating the water behind them from the remainder of Lake Agassiz to the east. The shallow, quiet water environment here was an ideal place for aquatic organisms to survive. Snail and clam shells have been reported from this clayey silt.

Another sandy, clayey silt is mapped as unit 9 in northeastern Cavalier County. The characteristics of this unit, however, have been altered by alluviation and groundwater discharge. Sand from the beach and delta deposits bordering the western side of this unit has been transported by colluvial and alluvial action onto the lake plain. A high water table and springs seeping from the base of the Campbell Scarp made this into a wetlands area and is the reason for differentiating this unit from unit 7.

The lacustrine deposits represented by unit 10 are found in two isolated areas in Cavalier County. One of these deposits is located in secs 3, 10, and 15, T160N, R60W, south of Langdon. The other deposit is north of Mt. Carmel in sec 4, T163N, R60W. In the lake deposit that is south of Langdon, the laminated clay and silt is at least 5 feet thick. A prominent till rim surrounds this lake deposit.

Both of the deposits shown as unit 10 are lakes that were formed on the glacial ice that covered Cavalier County, or near its margin. The till rim surrounding the lake sediment south of Langdon indicates that this was an ice-walled lake (Clayton and Cherry, 1967).

Unit 11

About 100 square miles of eastern Pembina County is shown as unit 11 on plate 2. This unit extends from just west of Drayton north

to within 2½ miles of Pembina. At its widest point, it is 6 miles across. Lithologically, unit 11 is similar to unit 7, but it is somewhat more silty. Pebbles are rare and those that are present are primarily carbonates. Gypsum crystals are abundant because of the discharge of saline groundwater. Varves are also characteristic of this silty clay unit.

The topographic expression on this unit is nearly flat to gently undulating. The regional slope is eastward, and elevations range from 805 feet to 795 feet.

The ice-drag lineations, discussed previously, are also abundant in this unit. The lineations are better preserved here than in unit 2 and may be largely due to less farming activity.

The soils in this unit are highly saline, and is the primary reason for differentiating it from unit 7. These saline soils are the result of discharging saline groundwater. Paleozoic carbonates, which is the bedrock in this part of Pembina County, contain highly mineralized water. This water, plus the water from the overlying glacial drift, is being discharged to the surface in this area.

The depositional environment of this silty clay, as shown by unit 11 is the same as the deposits of unit 7. Subsequent geologic events are the basis for the separation of the two units.

Unit 12

Unit 12 is mapped in the central region of Pembina County and trends northwest into the extreme northeastern corner of Cavalier County. The lithology of this unit varies from clayey silt to medium-grained sand. The texture, however, is predominantly very fine sand and silt, which is highly oxidized and crumbles easily where clay content is low. Colors of this sediment are generally yellowish-brown or reddish-brown to yellowish-gray. This silt unit ranges in thickness from about 8 feet to 20 feet north of Walhalla. In the southern part of the county where this silt occurs, thicknesses often exceed 15 feet, as southeast of Hensel.

Topography on the sediment mapped as unit 12 ranges from nearly flat to gently undulating. The regional slope is eastward but the gradients are somewhat steeper than those on units 7 through 11. Elevations range from a high of 960 feet southeast of Walhalla to 814 feet south of St. Thomas.

A series of sub-parallel ridges that trend northwest occur on this silt unit. These ridges, which extend from the Canadian border to within 2 miles of Cavalier, represent beaches that formed along the shore of Lake Agassiz. They occur at elevations between 890 and 900 feet. The thickness of the beach sediment does not exceed 10 feet, and is generally closer to 5 feet.

Aerial photographs of this unit show the existence of hundreds of small meandering stream channels. These streams began to flow over the area during the recession of Lake Agassiz. The channels have since been filled in, probably as a result of aggradation during the Holocene.

The environment of deposition of this silt unit is substantially different from those sediments shown as units 7 and 8. Unit 12 represents a near-shore environment in which the depth of water was quite shallow. Wave action was more active here and allowed only the coarser materials to settle out. The finer silts and clays were carried farther out into the lake. The low beaches present in the surface show that there were at least temporary stillstands of the lake during its gradual withdrawal.

Unit 13

About 160 square miles of western Pembina County and 17 square miles of northeastern Cavalier County are mapped as units 13 and 14. The sediments shown as unit 14 have the same lithology as those of unit 13, but their origin and morphology are substantially different. Unit 14 is discussed under the section dealing with fluvial deposits.

The sediment of unit 13 is primarily a yellowish-brown, fine to medium, well sorted sand. Grain size is highly variable, though, and ranges from silt to coarse gravel. In a few places this unit is similar to unit 4, consisting of reddish-yellowish-brown to greenish-gray very-fine sand to silt. The beach ridges in this unit are composed of moderately well sorted sand and gravel.

Overall thickness of the sediments shown by unit 13 ranges from less than 6 feet east of Hensel to over 50 feet southeast of Walhalla. The beach ridges themselves vary from only a few feet to more than 20 feet thick. The thickest beach gravels occur in the vicinity of Akra and form an arcuate pattern around deposits shown by units 15 and 8.

Topographically the area shown as unit 13 is gentle and rolling. The surface is nearly flat to gently undulating. Along the eastern part of the unit the ground surface is nearly flat. Surface elevation in the vicinities of Cavalier and Hensel is about 890 feet. South of Walhalla, and near Mountain, the elevation ranges from over 1100 to around 1000 feet.

The sand and gravel deposits shown as unit 13 were formed in nearshore and offshore environments of Lake Agassiz. Here wave action was the dominant factor in producing the landforms seen today. The activity of the waves tended to remove silt and clay, which were carried

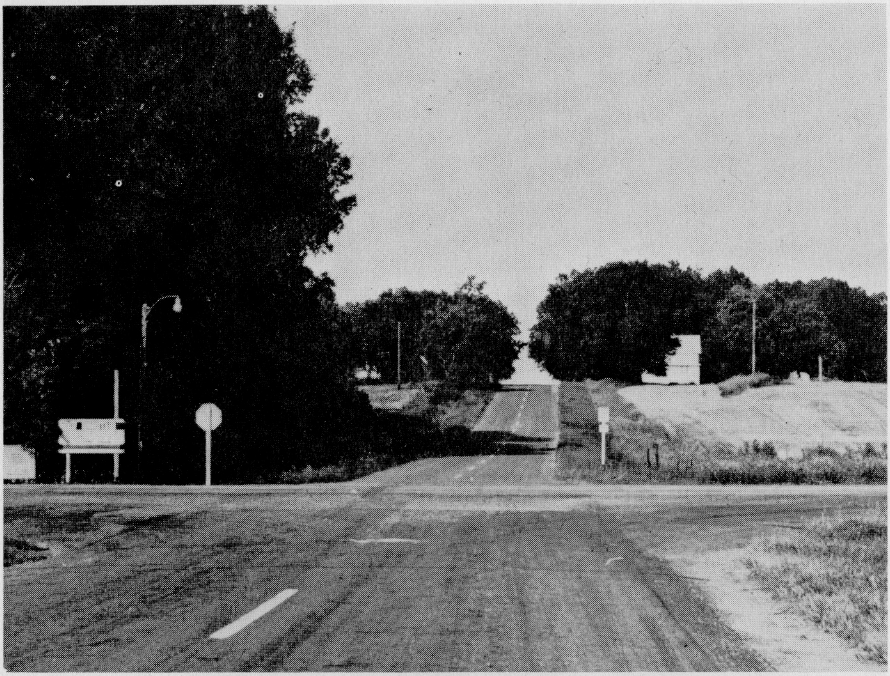

Figure 12. The Campbell scarp at Mountain, North Dakota. This wave cut bluff is the longest and most continuous of all the strandlines of Lake Agassiz. (Loc: sec 16, T160N, R56W)

lakeward. The sand and gravel were reworked in this near-shore environment and were deposited as extensive beaches.

The former shorelines of Lake Agassiz that are represented by these beaches have been named and correlated in other parts of the Red River Valley (Upham, 1896; Baker, 1967; Bluemle, 1967; Klausing, 1968; Hansen and Kume, 1970). These correlations are based on relative position and assume that all strandlines formed when Lake Agassiz receded for the last time are still present. In this report most of the strandlines in Pembina County have not been named because of the doubts about the validity of the methods used in correlating strandlines.

Near the western edge of the area shown by unit 13 in Pembina County, two scarps occur. One, the Campbell Scarp (fig. 12), extends northward from the Walsh County line to Mountain. In the vicinity of Mountain, this scarp disappears but appears again 3 miles south of Leyden. From there it extends northwest, past Walhalla, into Cavalier County, and on across the Canadian border. The other scarp, the

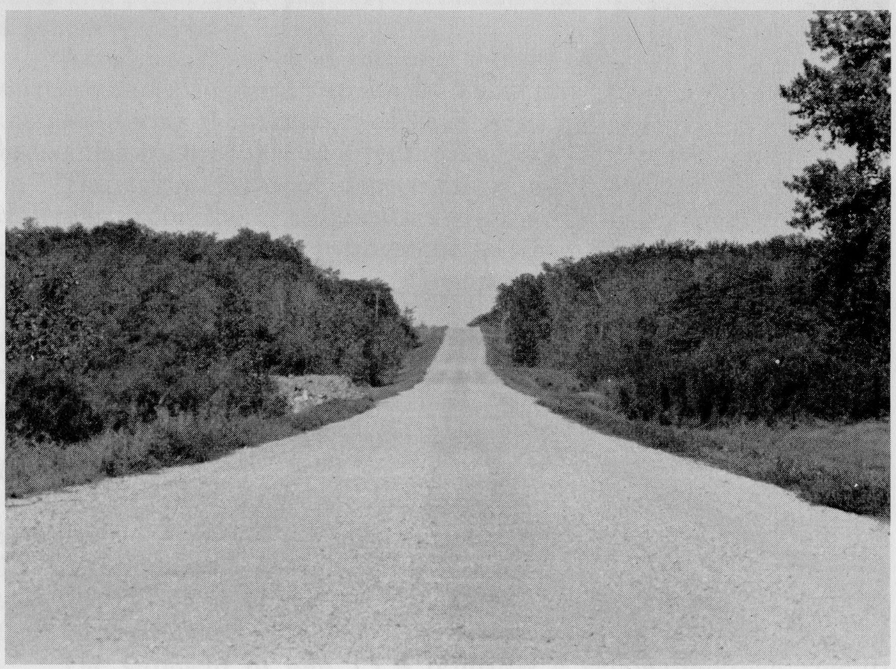

Figure 13. The Norcross Scarp is similar in origin to that of the Campbell Scarp. However, it represents a higher level of Lake Agassiz. (Loc: secs 28 and 33, T159N, R56W)

Norcross Scarp (fig. 13), is located in T159N, R56W, in the southwestern corner of Pembina County. It extends north from the Walsh County line to the vicinity of Gardar. Northward from here the scarp is absent, probably as the result of erosion following the final drop of Lake Agassiz.

These scarps are wave-cut bluffs formed during periods at which Lake Agassiz stood at these two levels. The Campbell and Norcross strandlines represent stillstands of the lake level possibly over long periods of time.

The Campbell Scarp, which is at elevations between 1025 and 1050 feet in Pembina County, is traceable throughout the Red River Valley. This scarp is readily recognizable on both the western and eastern sides of the lake plain in North Dakota, Minnesota, and Manitoba.

Fluvial Deposits

In Pembina and Cavalier Counties, fluvial deposits include alluvial sand and gravel deposited by glacial meltwater streams as well as the

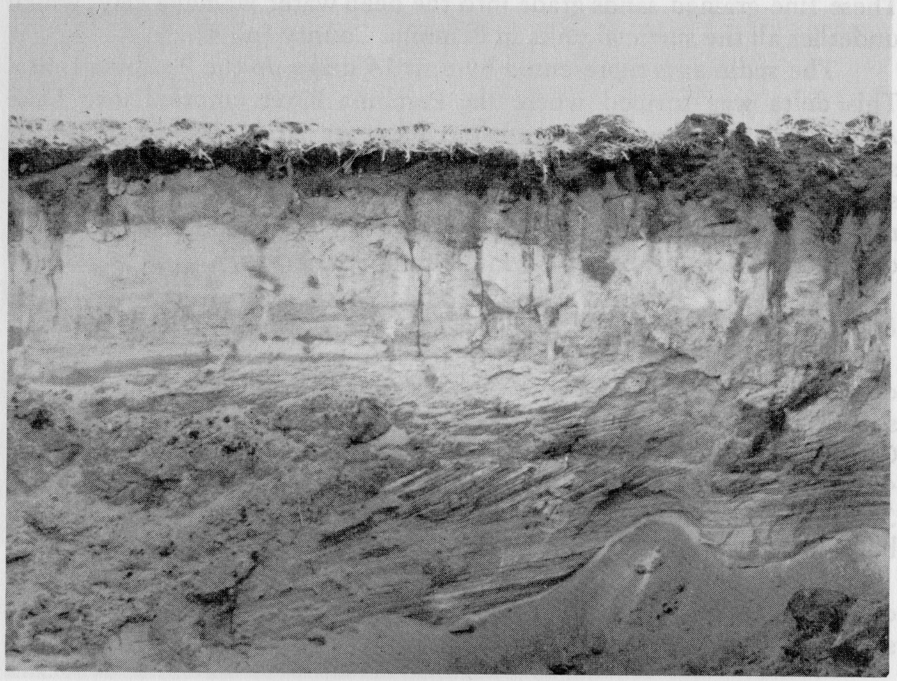

Figure 14. Roadcut along North Dakota Highway 32 showing well sorted cross-bedded sands in the Pembina Delta. (Loc: sec 32, T163N, R56W)

fine-grained sediments being deposited by the modern streams. The Pembina Delta is a result of stream carried sediments being deposited near the margin of Lake Agassiz.

Unit 14

The sediments of unit 14 are very similar to those of unit 13. The dominant lithology of unit 14 is coarse, shaly sand in the west grading to somewhat finer and cleaner sand towards the east. Very few cuts exist in this unit, but where they exist on the eastern side, well sorted, cross-bedded sands are exposed (fig. 14). The sediments exhibit poorer sorting on the western side of the unit. Surface topography on these sediments is nearly flat to rolling and elevations range between 1100 and 1250 feet. Based on numerous testholes in the area, the sediments represented by unit 14 range in thickness from 80 to 170 feet in the north to 15 feet in the south.

This unit is underlain by shale gravel and coarse sand, which becomes finer grained and more clayey eastward, into the lake basin.

These fine-grained sands grade into the deep water Walhalla clay, which underlies all the surficial units in Pembina County (pl. 4).

The sediments represented by unit 14 make up the Pembina Delta. This delta was formed where the Pembina River emptied into Lake Agassiz. Although sediments of a delta are of multiple origin, the sediments shown by unit 14 are primarily of fluvial origin. The well sorted cross-bedded sand near the eastern edge of the delta has been reworked by shoreline processes. The steep northeastern face of the delta is the foreset face as well as the Campbell Scarp.

Unit 1

In Cavalier County, the sediment that is shown as unit 1 is largely clay and silt to fine sand that locally contains sand and gravel. These sediments are restricted to narrow stream valley bottoms in Cavalier County and in Pembina County, the floodplain of the Pembina River to 4 miles east of Neche. From the reach extending downstream from sec 3, T163N, R56W, the floodplain of the Pembina River is characterized by numerous meander scars and cutoff meanders.

The sediments shown as unit 1 is alluvium deposited in river channels that range in thickness from less than a foot in the smaller stream valleys to greater than 50 feet, east of Walhalla.

Unit 2

The sediments shown as unit 2 on plates 1 and 2 range in texture from fine sand to silt and clay. The surface expression of this unit is a low nearly flat to gently undulating plain that slopes gently eastward toward the Red River. The thickness of these sediments may exceed 20 feet near the Pembina, Tongue, and North Branch Park Rivers, but thin rapidly away from them.

The alluvial sediments shown as unit 2 are overbank deposits which were deposited during high flood stages of the Pembina, Tongue, and Red Rivers.

A topographic feature known as Horgan Ridge (fig. 15) extends across unit 2. This feature extends from the southwestern quarter of sec 17, T163N, R55W, and winds its way 8 miles eastward into the northwest quarter of sec 17, T163N, R53W. On the basis of several power-auger borings, this ridge is underlain by as much as 10 feet of silt and clay of units 1 and 7 which rests on 20 to 50 feet of fine sand and silt which is in turn underlain by Walhalla clay. Horgan Ridge is interpreted to be an old channel deposit of the Pembina River. Figure 16 shows a way in which a compaction ridge may be formed. Similar

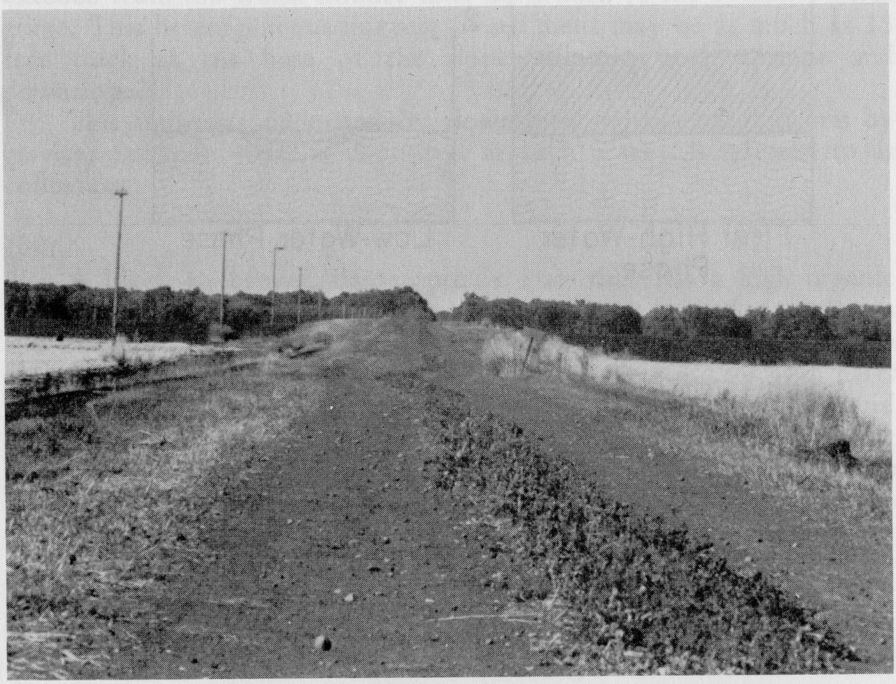

Figure 15. Horgan Ridge extends for approximately 8 miles in an east-west direction and is the topographic expression of an old channel of the Pembina River. (Loc: secs 17 and 18, T163N, R54W)

features occur in Traill County (Bluemle, 1967) and Cass County (Klausing, 1968).

Unit 3

The sediments shown by unit 3 are mapped on terrace remnants in sec 32, T163N, R56W, and cover little more than one-fourth of a square mile. These sediments are composed largely of clay and silt with minor amounts of coarse sand and gravel. Topographically, the surface on these sediments forms a flat plain that slopes gently northwestward towards the Pembina River. These terrace remnants lie above an elevation of 1000 feet, which is 40 feet above the present floodplain.

The sediments that make up these terrace remnants indicate a higher stage of flow of the Pembina River as it drained into Lake Agassiz. This unit was probably formed at about the same time as the sediments of map unit 4.

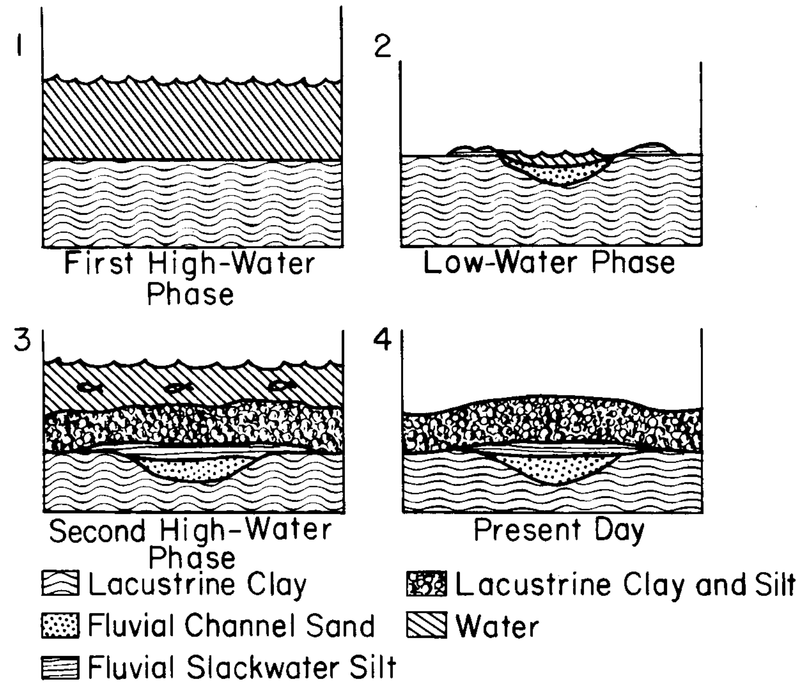

Figure 16. Steps in the formation of a compaction ridge such as Horgan Ridge.

Unit 4

The coarse sand and gravel sediments found along the steep valley walls in the Pembina River gorge are shown as unit 4. This sand and gravel is moderately to poorly sorted and has a very high shale content. Minor amounts of silt and clay are also present. This unit is restricted to the steep valley walls along the Little South Pembina River from sec 22, T162N, R57W, to within 2 miles south of Walhalla. It is also found in the Pembina River Valley from sec 24, T163N, R57W, to within a half mile of Walhalla.

This sand and gravel unit was deposited during a higher stage of the Pembina River system as it drained into Lake Agassiz. The coarse texture of these sediments indicates a much higher discharge for this river than is present now in the Pembina River system.

Unit 5

Unit 5 represents a mixture of clay, sand, gravel, shale, and till. This unit is generally a poorly sorted, very dense and compact deposit. It is restricted to a narrow band as much as 1½ miles in width that

extends from the Walsh County line, northward to the Pembina River gorge. This heterogeneous mixture of sediment may be as much as 15 feet thick at the base of the slope, thinning both upslope and downslope.

This unit was deposited by downslope movement of debris by gravity. Sediment that is deposited in such a way is referred to as colluvium.

Unit 6

A black to brown, dense, plastic clay that has a high organic content is shown as unit 6. This unit is found in undrained depressions and in the linear meltwater channels (unit 22) in Cavalier County. Two such organic clay deposits are also found in Pembina County, in parts of secs 22 and 23, T160N, R55W, and in parts of secs 21, 22, 27, and 28, T162N, R55W. Because of poor surface discharge these organic clays and silts have been concentrated in low, undrained depressions as pond and slough deposits. Deposition of this unit probably began in the early Holocene.

Eolian Deposits

Sediments transported and deposited as a result of wind action are classified as eolian. Sand dunes are commonly the result of such wind action.

Unit 15

Unit 15 represents sediment composed of fine sand that is well sorted consisting primarily of quartz and feldspar, with minor amounts of shale and lignite fragments. The greatest areal extent of this unit is 20 square miles and overlies much of the eastern half of the Pembina Delta. There are isolated sandy areas just south of Icelandic State Park west of Cavalier, northeast of Hensel, and one mile south of Cavalier.

Topography on the sediment mapped as unit 15 is rolling to hilly. Local relief may exceed 40 feet, although it is generally less than 20 feet. Thickness of this sediment may be greater than 50 feet in the Pembina Delta area.

Unit 15 represents sand dunes (fig. 17) which had as their source Pembina Delta and beach sands. Formation of the dunes probably began shortly after the Walhalla clay was deposited in the Lake Agassiz basin. Dune formation continued then through the Late Wisconsinan and into early Holocene. The abundant vegetation on these dunes indicates that they have been stable for a long period of time.

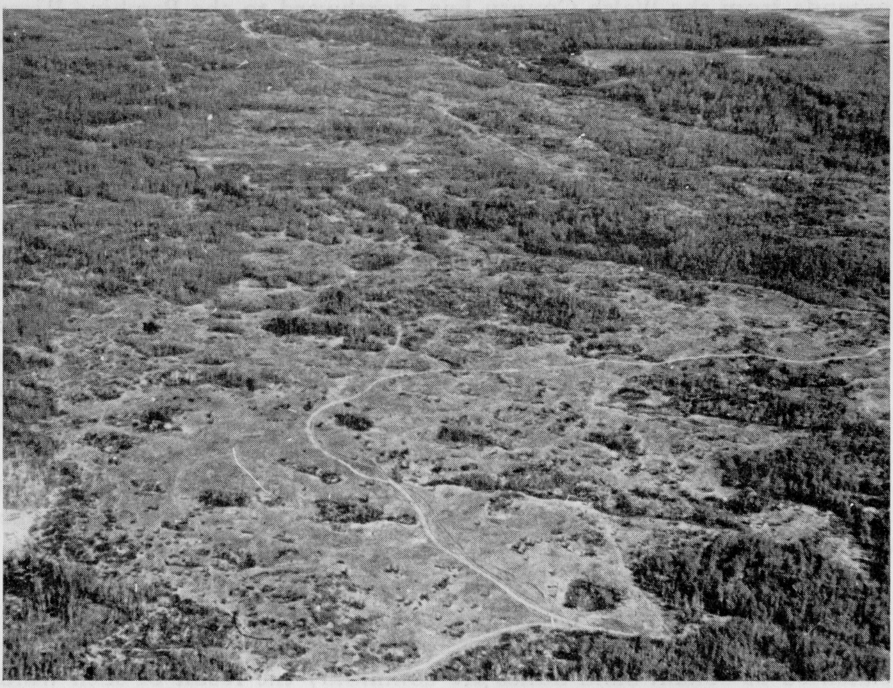

Figure 17. Aerial view of sand dunes on the eastern half of the Pembina Delta. The abundant vegetation indicates that these dunes have been stable for a long period of time. View is to the north.

Synopsis of Geologic History

Preglacial History

Rocks of Precambrian age in Pembina and Cavalier Counties consist primarily of granite and amphibolite. Little is known of their geologic history. Since the close of the Precambrian, the preglacial history of Cavalier and Pembina Counties has been largely a series of marine transgressions and regressions. Because of the position of these counties on the northeast flank of the Williston basin much of the Paleozoic sedimentary record which may have been present in this area was removed during times when the seas were absent from this area.

The oldest sedimentary rocks represent a marine transgressive sequence during which sedimentation was essentially uniform and continuous. Deposition began in the Middle Ordovician (Winnipeg Formation) and continued to Early or Middle Silurian (Interlake Formation). A period of erosion followed which developed a major unconformity on the Interlake Formation.

During the Middle Devonian, seas again transgressed the area, and cyclical carbonate deposition occurred in Cavalier County. Most of the Devonian and any Mississippian rocks which may have been present in these counties were removed by pre-Jurassic erosion.

Devonian rocks are overlain by mainly clastic sediments of Triassic age in southwestern Cavalier County. In other areas they are overlain by rocks of Middle Jurassic age.

A time of marine transgression began in the Middle Jurassic and deposition was essentially uniform through Cretaceous time in Cavalier and Pembina Counties. Near the end of the Cretaceous, the seas receded westward, with the Pierre Formation marking the end of marine deposition in the two counties. Since deposition of the Cretaceous sediments, erosion has been the dominant geologic process in Cavalier and Pembina Counties.

Glacial History

Cavalier and Pembina Counties have been glaciated several times during the Pleistocene. Bluemle (1967) has reported the presence of multiple till deposits in Cavalier County. Stratigraphic study of this area of northeastern North Dakota has been advanced only enough to permit preliminary correlation of the till units, although their age relationships are unknown at present (app. A).

The surficial till units described in Cavalier County are all Late Wisconsinan in age and are all probably the result of the same ice advance. The glacier that covered Cavalier and Pembina Counties and deposited the surficial till in Cavalier County may have advanced into the area as early as 25,000 years ago.

About 13,000 B.P. the ice margin began melting northward, exposing a drainage divide in northeastern South Dakota. Lake Agassiz was ponded behind this divide, by the highlands to the east and west, and probably by the ice to the north (Moran, 1972). This first stage of Lake Agassiz probably did not advance into Pembina County. About 12,800 B.P. ice readvanced southward into the Red River Valley. As the margins of this ice sheet retreated northward, the waters of Lake Agassiz spread northward.

In Pembina County, Lake Agassiz was bordered on the west by the Pembina escarpment. During this first stage of the lake in Pembina County, the Walhalla clay was deposited. At the same time, the Pembina River, which had been flowing southward along the base of the escarpment, now discharged directly into Lake Agassiz and deposition of the Pembina Delta began. Beach formation also began along the shorelines of Lake Agassiz. About 12,200 B.P. the level of

Lake Agassiz dropped to Campbell level as a result of drainage through the Minnesota River Valley. The lake stood at this level for about 1,000 years. During this stage, the northeast-facing slope of the Pembina Delta was steepened by wave action. Longshore currents caused the formation of large spit deposits south of the delta and east of Mountain. These spits cut off part of the lake, forming a lagoon, shown as unit 8 (pl. 2).

About 11,000 B.P. ice had retreated into Ontario, and Lake Agassiz drained eastward into Lake Superior. During this low water period much of the surface of the Walhalla clay was exposed. A drainage network was established across the exposed lake floor (Moran, et al, 1971), and the sand in Horgan Ridge was deposited by the Pembina River.

About 10,000 B.P. the drainage into Lake Superior was blocked and the lake was refilled to the Campbell level. The upper laminated clay and silt (unit 7), which is the surface sediment over much of Pembina County, was deposited. The lower strandlines, below the Campbell level, were formed during this phase.

This last phase of Lake Agassiz lasted until about 9,000 B.P. (Elson, 1967). The eastern outlets into Lake Superior were again opened as a result of ice retreat, and Lake Agassiz drained from North Dakota for the last time.

Postglacial History

Since the end of glaciation in Cavalier and Pembina Counties, rivers established their present courses, probably flowing over much the same course as when the Walhalla clay was exposed. Deposition of the Walsh Formation began with the close of the glacial epoch, and continues through today.

GEOLOGY FOR PLANNING

Introduction

The previous section has dealt largely with the type and distribution of the various geologic units in Cavalier and Pembina Counties. This section deals primarily with the application of the geologic knowledge gained during this study to three categories: (1) economic resources potential, (2) general construction conditions, (3) geologic factors affecting suitability of sites for sanitary landfills. A fourth area of concern in this geologic study was evaluation of the

groundwater resources of the two-county area. Part III of this report discusses in detail the groundwater resources of Cavalier and Pembina Counties.

Plates 6-11 and their accompanying explanations summarize the geology in the three categories listed above.

Economic Resources Potential (Plates 6 and 7)

Sand and Gravel

Sand and gravel is probably the most important mineral deposit in Cavalier and Pembina Counties. The sand and gravel is used primarily for concrete aggregate and road surfacing. Of the two counties, Pembina County is much more important as a sand and gravel producer than is Cavalier County.

In Pembina County, the sand and gravel is largely limited to areas of beach deposits of Lake Agassiz. The major gravel pits are found in an old spit west of Cavalier and on top of the Pembina Delta, south of Walhalla. Sand, especially in the delta area, is relatively clean (i.e., shale free) and of uniform size.

The sand and gravel deposits in Cavalier County are largely ice-contact features such as eskers. These materials have very limited application because of their high shale content.

Clay and Shale

At the turn of the century the Mayo Brick Plant, west of Walhalla, used the Carlile shale as raw material in the manufacture of bricks (Barry and Melsted, 1908). This clay has a high sulfur content and fuses at a low temperature. The resulting black brick contains unburned sulfur that causes bloating of brick. However, the Carlile shale might be adequate for drain tile, hollow brick, and pressed brick (Laird, 1956).

The lower two members of the Pierre Formation, particularly the Pembina Member, are rich in Fuller's earth, which has been used as a clarifying agent for oils, as a bleaching clay, in drilling mud, and as a filler. It is highly absorbent, which makes it desirable for many of the uses listed above. In Cavalier and Pembina Counties, the Fuller's earth does not appear to be abundant enough, nor of high enough quality to make commercial extraction feasible. However, the absorbent properties of this clay are such that relatively impure materials may still have limited application, such as in kitty litter or garage floor cleaners (O. E. Manz, oral communication).

Cement Rock

In the early 1900's, a cement plant operated near Concrete, using shale of the Niobrara Formation as raw material. The low quality of this natural cement and poor market factors led to the demise of this operation within a few years (Laird, 1956).

The Niobrara Formation has since been investigated as a raw material for Portland cement. It was found that there is a zone in this formation that may be suitable if a beneficiation treatment or blending material were available (Carlson, 1964). However, at present it does not appear to be economically feasible.

The Ordovician Red River Formation, which is primarily limestone, has also been studied as a possible raw material for Portland cement (Anderson and Haraldson, 1969). At depths of 487 to 505 feet in northern Pembina County, a high calcium, low magnesium zone is present. This zone is a possibility for further study.

Petroleum

About two dozen oil exploration holes have been drilled in Cavalier and Pembina Counties. To date there has been little evidence of petroleum resources in this area.

Other Minerals

In 1969, two holes were drilled in Pembina County to investigate the source of a magnetic anomaly. One test hole was near Akra and the other was near Hensel. It was believed that this magnetic anomaly was the result of a concentration of iron ore which might be economically recoverable. Although iron-rich deposits were found, the deposit was too poor to justify development.

A gypsum-dolomite exploration program was conducted in Pembina County in 1966. No appreciable gypsum deposits were found, and dolomite was found at depth too great to be economically recoverable (North Dakota Geol. Survey open file report).

General Construction Conditions (Plates 8 and 9)

Any planned construction should take into account: (1) groundwater conditions, (2) topography, and (3) the nature of the foundation materials. Plates 8 and 9 summarize the various geologic units in Cavalier and Pembina Counties in light of the above conditions. Also included are estimates on permeability, compressibility, and bearing strength. Comments relating to any special problems that may be encountered are also included. In some cases, depth to bedrock may be of importance in construction planning. The map showing drift thickness (pl. 5) is useful in this respect.

It should be pointed out that plates 8 and 9 are only general and actual conditions may be quite different than those predicted. However, the information provided on these plates may be useful during the planning phase and early phase of construction.

Suitability for Landfill Sites (Plates 10 and 11)

Of prime importance in the proper disposal of wastes is the prevention of contamination of local groundwater. There are a number of factors involved in choosing a site for waste disposal: (1) nature and type of refuse, (2) the type of contaminants produced as a result of decay, and (3) the possible harmful effects to health as a result of the contaminants produced. These factors can be dealt with best by engineers and health officials. There are, however, geologic and hydrogeologic factors that also need to be considered.

In choosing a sanitary landfill site on the basis of geologic conditions some of the factors are: (1) type of earth materials in which a sanitary landfill site is to be located, (2) permeability of these earth materials, (3) position of the watertable, and (4) direction of groundwater movement. The first factor can be rather easily determined by simple on-site inspection or with the aid of a geologic map. Permeability of materials differs with the material. Clay generally has very low permeability and sand is very permeable. The uniformity of a deposit also affects permeability. Till, for example, usually has low permeability, but if it contains numerous sand and gravel lenses it may not be satisfactory. Shale is a very uniform material and itself has low permeability. However, over most of Cavalier County and parts of Pembina County, the upper tens of feet of the Pierre Formation is highly fractured. Because of this highly fractured nature of the shale, it is considered highly permeable. The thickness of sediments overlying the shale then becomes an important consideration in selecting a landfill site (pl. 5).

The last two factors, watertable position and direction of groundwater movement, are somewhat more difficult to ascertain. Ideally, the watertable should be below the bottom of the landfill. However, in both counties the watertable is generally within 10 feet of surface over most of the area. Groundwater moves from areas of high pressure to areas of low pressure; that is, it moves from areas of a high watertable position to areas with a low watertable position. Generally, though not always, the watertable reflects the surface topography and groundwater moves from high areas to low areas. The movement of groundwater in Cavalier and Pembina Counties generally follows the topography.

Plates 10 and 11 summarize the geologic units in the two counties on the basis of suitability for locating a sanitary landfill in them. This is only a general summary of the conditions that might be encountered. Selection of a specific site should include detailed on-site investigation.

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APPENDIX A

Pleistocene Stratigraphy of Cavalier and Pembina Counties and Adjacent Areas

by
Nena L. Salomon

Introduction

Glacial sediment of northeastern North Dakota has been differentiated into nine lithostratigraphic units on the basis of outcrop characteristics, lithology of the very coarse sand, and texture. In this report, each unit is described and, where possible, correlated with units outside northeastern North Dakota. Two units, the Gardar Formation and the Dahlen Formation, are herein named. An interpretation of the glacial history of northeastern North Dakota and northwestern Minnesota is presented.

Methods of Study

In an area of about 2,000 square miles, 80 outcrops and 28 testholes were described and sampled (fig. 1). The percentage of sand, silt, and clay was determined using the standard sieve-pipette analysis procedures employed by the North Dakota Geological Survey (Moran, in preparation). The lithology of the very coarse sand (1 mm to 2 mm) was determined by examining the sand grains under a binocular microscope. Each sand sample was divided into four lithologic groups: crystalline grains (igneous and metamorphic rock types), carbonate grains (limestone and dolomite), shale, and a minor amount of miscellaneous rock types. About 350 grains were counted in each sample. The lithology of the very coarse sand and texture of sampled outcrops and testholes in Cavalier and Pembina Counties are listed in appendix B. Descriptions of outcrops and testholes in these counties are found in appendix C.

Definitions

Certain terms and concepts that are used in this report have restricted meanings and are defined here. The term "pebble-loam" is defined as sediment composed of nearly equal amounts of sand, silt, and clay that contains pebbles, cobbles, and boulders. Pebble-loam is the descriptive equivalent of the term "till." In the area studied the genetic equivalent of pebble-loam is glacial sediment. The word "till" is not used in this report because of its combined descriptive and genetic definition. The lithostratigraphic units discussed in this report consist of widespread continuous beds of pebble-loam containing discontinuous lenses of stratified sediment. The boundaries of the lithostratigraphic units are defined in the following manner. Discontinuous lenses of sediment (stratified sand, gravel, silt, or clay) underlying a continuous bed of pebble-loam are considered to be part of the overlying unit; for example, see the interval from 92 feet to 110 feet in testhole 4220 (app. C). Discontinuous lenses of sediment overlying continuous beds of pebble-loam and underlying a continuous bed of sediment other than pebble-loam are considered to be part of the underlying unit; for example, see the interval from 118 feet to 150 feet in testhole 5940 (app. C). A cobble and boulder accumulation is considered to be part of the underlying unit, unless the underlying unit does not consist of pebble-loam, or pebble-loam overlying the accumulation occurs amidst and beneath the cobbles and boulders. In these two examples, the accumulation is considered to be part of the overlying unit.

Lithostratigraphy

Unit D

Description.—Unit D consists of pebble-loam and a minor amount of stratified sediment. The unbedded, compact pebble-loam contains abundant carbonate and crystalline pebbles. Testhole samples are olive gray (5Y 5/1).* The lithology of the very coarse sand and texture are the criteria for recognizing the pebble-loam of unit D (table 1). Shale content of the very coarse sand generally ranges from 15% to 25%.** The texture of the sediment is clay loam.***

Contacts.—In the three testholes in which unit D was recognized, this unit directly overlies bedrock. In one testhole, pebble-loam of unit D directly underlies about 5 feet of laminated, silty clay of unit C. In two testholes, pebble-loam of unit D directly underlies pebble-loam of unit B.

Extent and thickness.—Unit D occurs in three of twenty-six testholes in Pembina, Walsh, and Grand Forks Counties. This unit occurs at the base of the Pembina Escarpment, a north trending shale scarp in northeastern North Dakota. The regional extent of this unit is unknown. The thickness of this unit ranges from 10 feet to 40 feet.

*Munsell Soil Color Chart.
**This range=mean ±1 standard deviation.
***U.S. Soil Survey Manual, Agricultural Handbook No. 18

Table 1. *Textural and lithologic characteristics of formations in Cavalier and Pembina Counties and adjacent areas.*

Formation	Texture(%) (Sd-St-Cl)**	Coarse Sand Lithology(%) (Cy-Cb-Sh)***	Number of Samples
*Falconer	31-45-24	38-31-31	46
*Dahlen	35-45-20	32-21-47	102
*Gardar	34-42-24	13-10-77	76
Lower Red Lake Falls	43-39-18	44-54-2	6
Unit 1	29-54-17	33-65-2	3
Unit A	35-36-29	21-17-62	31
Unit B	36-38-26	26-20-54	19
Unit C	30-27-43	30-28-42	6
Unit D	35-29-36	37-48-15	1

*Formations outcropping in northeastern North Dakota.
**Sd=Sand, St=Silt, Cl=Clay.
***Cy=Crystalline, Cb=Carbonate, Sh=Shale.

Differentiation.—Pebble-loam of unit D contains fewer shale fragments (very coarse sand, 1 mm to 2 mm) than pebble-loam of units C, B, and A and the Gardar and Dahlen Formations. Pebble-loam of unit D contains more shale fragments than pebble-loam of unit 1 or the lower part of the Red Lake Falls Formation. Pebble-loam of unit D is more clayey than pebble-loam of the Falconer Formation.

Origin.—Unit D consists primarily of glacial sediment and minor amounts of interbedded fluvial and lacustrine sediment.

Age and correlation.—The age of unit D is not known. This unit has not been correlated with formations outside northeastern North Dakota.

Unit C

Description.—Unit C consists of pebble-loam and a minor amount of stratified sediment. The unbedded, compact pebble-loam is olive

gray (5Y 5/1) in color and contains abundant carbonate and shale pebbles. Sand lithology and texture are the criteria for recognizing the pebble-loam of unit C (table 1). Shale content of the very coarse sand generally ranges from 35% to 45%. The texture of the sediment is clay or clay loam.

Contacts.—In one of the four testholes in which unit C was recognized, about 5 feet of laminated, silty clay of unit C directly overlies pebble-loam of unit D. In the remaining testholes, unit C directly overlies bedrock. In three testholes, pebble-loam of unit C directly underlies 10 feet of sand and gravel of unit B or the Dahlen Formation. In one testhole, pebble-loam of unit C directly underlies pebble-loam of unit A.

Extent and thickness.—Unit C occurs in four of twenty-six testholes in the area studied. This unit occurs at the base of the Pembina Escarpment and its regional extent is unknown. The thickness of this unit ranges from 30 to 40 feet.

Differentiation.—Pebble-loam of unit C contains fewer shale fragments than pebble-loam of unit B, unit A, or the Gardar Formation. Pebble-loam of unit C generally contains fewer shale fragments and is more clayey than pebble-loam of the Dahlen Formation. Pebble-loam of unit C contains more shale fragments than pebble-loam of unit D, unit 1, the lower part of the Red Lake Falls Formation, or the Falconer Formation. Pebble-loam of unit C generally contains more shale fragments and is more clayey than pebble-loam of the Falconer Formation.

Origin.—Unit C consists of glacial sediment and a minor amount of fluvial and lacustrine sediment.

Age and correlation.—The age of unit C is unknown. This unit has not been correlated with formations outside northeastern North Dakota.

Unit B

Description.—Unit B consists of pebble-loam that contains abundant carbonate and shale pebbles and a minor amount of stratified sediment. Testhole samples are olive gray (5Y 5/1). Sand lithology and texture are the criteria for recognizing the pebble-loam of this unit (table 1). Shale content of the very coarse sand generally ranges from 50% to 60% and is always less than the shale content of the overlying pebble-loam of unit A. The texture of the sediment is clay or clay loam.

Contacts.—In four of nine testholes, unit B directly overlies units D or C. In five testholes, unit B directly overlies bedrock. In six of nine testholes, pebble-loam of unit B directly underlies pebble-loam of unit

A. In three testholes, pebble-loam of unit B directly underlies about 5 feet of sand and gravel or laminated, silty clay of unit A.

Extent and thickness.—Unit B occurs in nine of twenty-six testholes in Pembina, Walsh, and Grand Forks Counties. This unit occurs at the base of the Pembina Escarpment and its regional extent is unknown. The thickness of this unit ranges from 35 feet to 70 feet.

Differentiation.—Pebble-loam of unit B contains more shale fragments than pebble-loam of unit D, unit C, unit 1, the lower part of the Red Lake Falls Formation, or the Falconer Formation. Pebble-loam of unit B contains fewer shale fragments than pebble-loam of unit A or the Gardar Formation and is more clayey than pebble-loam of the Dahlen Formation.

Origin.—Unit B consists of glacial sediment and a minor amount of fluvial and lacustrine sediment.

Age and correlation.—The age of unit B is unknown. This unit has not been correlated with formations outside northeastern North Dakota.

Unit A

Description.—Unit A consists of pebble-loam and a minor amount of stratified sediment. The unbedded, compact, blocky pebble-loam contains abundant shale pebbles and a minor amount of lignite. Testhole samples are olive gray (5Y 5/1), and outcrop color is dark gray to dark brown. Sand lithology and texture are the criteria for recognizing the pebble-loam of unit A (table 1). The texture of the sediment is clay, clay loam, or loam. Pebble-loam of unit A contains numerous boulders and cobbles (Downey, 1971; Hutchinson, 1973), shale blocks as thick as 20 feet, and inclusions of pebble-loam of unit B.

Contacts.—In eight of the thirteen testholes in which unit A was recognized, pebble-loam of unit A directly overlies either pebble-loam of unit C or unit B. In three testholes, about 5 feet of sand and gravel or laminated, silty clay of unit A directly overlies pebble-loam of unit B. In two testholes, unit A directly overlies bedrock. In eleven of thirteen testholes, pebble-loam of unit A directly underlies pebble-loam of the Gardar Formation. In one testhole, pebble-loam of unit A directly underlies about 10 feet of laminated, silty clay of the Wylie Formation. In one testhole, pebble-loam of unit A is the surface sediment.

Extent and thickness.—Unit A occurs in thirteen of twenty-six testholes in Pembina, Walsh, and Grand Forks Counties and outcrops in eastern Cavalier County. Thickness of this unit ranges from 20 feet to

122 feet. It is thickest along the base of the Pembina Escarpment in Grand Forks and Walsh Counties and thins north and east of this area.

Differentiation.—Pebble-loam of unit A contains more shale fragments than pebble-loam of any other unit, except the Gardar Formation. In outcrops, pebble-loam of unit A is difficult to distinguish from pebble-loam of the Gardar Formation. Pebble-loam of unit A is generally darker and in places contains fewer shale pebbles than pebble-loam of the Gardar Formation.

Origin.—Unit A consists of glacial sediment and a minor amount of fluvial and lacustrine sediment.

Age and correlation.—The age of unit A is not known. This unit is correlated with the St. Hilaire Formation of eastern Grand Forks County and northwestern Minnesota (Harris and others, 1974). Pebble-loam in both units contain shale pebbles and a minor amount of lignite. In outcrops, this pebble-loam is darker than the pebble-loam of overlying and underlying units.

Unit 1

Description.—Unit 1 consists of pebble-loam and a minor amount of stratified sediment. The unbedded, compact pebble-loam contains abundant carbonate pebbles. Testhole samples are olive gray (5Y 5/1). Sand lithology and texture are the criteria for recognizing the pebble-loam of unit 1 (table 1). Shale content of the very coarse sand is generally less than 1%. The texture of the sediment is clay loam, loam, or silty loam.

Contacts.—In two of three testholes, unit 1 directly overlies bedrock. In the remaining testhole, the base of unit 1 was not reached. In two testholes, pebble-loam of unit 1 directly underlies pebble-loam of the lower part of the Red Lake Falls Formation. In the other testhole, pebble-loam of unit 1 directly underlies about 5 feet of sand and gravel of the lower part of the Red Lake Falls Formation.

Extent and thickness.—Unit 1 occurs in three of twenty-six testholes in the study area. This unit occurs in the eastern half of Pembina and Walsh Counties and its regional extent is unknown. Thickness of unit 1 ranges from 20 feet to 30 feet.

Differentiation.—Pebble-loam of unit 1 contains fewer shale fragments than pebble-loam of any other unit. In addition pebble-loam of unit 1 contains more carbonate fragments than pebble-loam of the lower part of the Red Lake Falls or the Falconer Formations.

Origin.—Unit 1 consists primarily of glacial sediment and minor amounts of interbedded fluvial and lacustrine sediment.

Age and correlation.—The age and correlation of unit 1 is unknown.

Lower Part of the Red Lake Falls Formation

Description.—The lower part of the Red Lake Falls Formation (Harris and others, 1974) of northeastern North Dakota consists of pebble-loam and a minor amount of stratified sediment. The unbedded, blocky pebble-loam contains abundant carbonate pebbles. In outcrops in northwestern Minnesota, the pebble-loam is compact and blocky and contains iron and manganese stained joints. Testhole samples are olive gray (5Y 5/1). Sand lithology and texture are the criteria for recognizing the pebble-loam of the lower part of the Red Lake Falls Formation. Shale content of the very coarse sand is generally less than 5%. The texture of the sediment is loam.

Contacts.—In two of seven testholes, in which the lower part of the Red Lake Falls Formation was recognized, pebble-loam of this formation directly overlies pebble-loam of unit 1. In one testhole, about 5 feet of sand and gravel of the lower part of the Red Lake Falls Formation directly overlies pebble-loam of unit 1. In one testhole, the lower part of the Red Lake Falls Formation directly overlies bedrock. In the remaining testholes, the base of the Red Lake Falls Formation was not reached. In four of seven testholes, pebble-loam of the lower part of the Red Lake Falls Formation directly underlies laminated, silty clay of the Wylie Formation. In two testholes, pebble-loam of the lower part of the Red Lake Falls Formation directly underlies pebble-loam of the Dahlen Formation. In one testhole, pebble-loam of the lower part of the Red Lake Falls Formation directly underlies about 5 feet of sand and gravel of the Falconer Formation. The lateral contact between pebble-loam of the lower part of the Red Lake Falls Formation and pebble-loam of the Gardar Formation has not been observed. In Grand Forks County, these formations have been traced to within 2 miles of one another (Moran, personal communication).

Extent and thickness.—The lower part of the Red Lake Falls Formation occurs in seven of twenty-six testholes in the eastern part of the study area. This formation also occurs in northwestern Minnesota. Thickness of this unit ranges from 10 feet to 60 feet.

Differentiation.—Pebble-loam of the lower part of the Red Lake Falls Formation contains fewer shale fragments than pebble-loam of all other units except unit 1. Pebble-loam of the lower part of the Red Lake Falls Formation contains fewer carbonate fragments and is sandier than pebble-loam of unit 1.

Origin.—The lower part of the Red Lake Falls Formation consists of glacial sediment and a minor amount of fluvial and lacustrine sediment.

Age and correlation.—The lower part of the Red Lake Falls Formation is correlated with the Granite Falls Formation of southwestern Minnesota (Matsch, 1971) and the Gardar Formation. Pebble-loam in these formations is compact and blocky and contains iron and manganese stained joints. Carbonate pebbles are very abundant and few shale pebbles occur within the pebble-loam of the Granite Falls Formation and the lower part of the Red Lake Falls Formation. The difference in lithology in the pebble-loam of the lower part of the Red Lake Falls Formation and the Gardar Formation is a result of different source areas. The lower part of the Red Lake Falls Formation contains material derived from Ordovician limestone and dolomite, and the Gardar Formation contains material derived from Cretaceous shale. The Dahlen Formation directly overlies both these formations.

The lower part of the Red Lake Falls Formation was probably deposited during Early Wisconsinan time. Radiocarbon dates from southwestern Minnesota in sediment of the Granite Falls Formation (Matsch, 1971) indicate that this sediment was deposited before 34,000 B.P.

Gardar Formation

Source of name.—The village of Gardar, Pembina County, North Dakota.

Type area.—Eastern Cavalier County and western Pembina County.

Type section.—Gardar Section (No. 30), SE¼NE¼SE¼sec 16, T159N, R56W; a river cut on the south side of the North Branch of the Park River.

Reference sections.—Road Cut (No. 974), SE¼SE¼sec 15, T160N, R56W. Testhole 2582, NW¼NW¼NW¼sec 11, T154N, R55W.

Description.—The Gardar Formation consists of pebble-loam and a minor amount of stratified sediment. The unbedded, compact, blocky pebble-loam contains abundant shale pebbles (70% to 90%). At some outcrops, where the Gardar Formation is at the surface, the formation consists of soft, fissile pebble-loam, less than 5 feet thick, that grades downward to compact, blocky pebble-loam. In some outcrops, where the Gardar Formation is not at the surface, the upper part of the formation is strongly oxidized. Iron and manganese stained joints occur throughout the pebble-loam. Testhole samples are olive gray (5Y 5/1), and outcrop color ranges from olive gray to yellowish brown. Outcrop characteristics, sand lithology, and texture are the criteria for recognizing the pebble-loam of the Gardar Formation (table 1). Shale content of the very coarse sand generally ranges from 70% to 80%. The texture of the sediment is clay, clay loam, or loam.

Contacts.—In nine of ten testholes, the Gardar Formation directly overlies unit A. In one testhole, the Gardar Formation directly overlies bedrock. In outcrops, sand and gravel of the Gardar Formation directly overlie pebble-loam of unit A. In eight of ten testholes, pebble-loam of the Gardar Formation directly underlies pebble-loam of the Dahlen Formation. In one testhole, pebble-loam of the Gardar Formation directly underlies laminated, silty clay of the Wylie Formation. In one testhole, pebble-loam of the Gardar Formation is the surface sediment. In many outcrops, a boulder acccumulation separates pebble-loam of the Gardar Formation from pebble-loam of the Dahlen Formation. This boulder accumulation occurs as either a boulder lag of the Dahlen Formation or a striated boulder pavement of the Gardar Formation. In other outcrops, pebble-loam of the Gardar Formation directly underlies stratified sand and gravel of the Dahlen Formation. In some areas of eastern Cavalier County, the Gardar Formation is exposed at the surface. The lateral contact between pebble-loam of the Gardar Formation and pebble-loam of the lower Red Lake Falls Formation has not been observed. In Grand Forks County these formations have been traced to within 2 miles of one another (Moran, personal communication).

Extent and thickness.—The Gardar Formation occurs in ten of twenty-six testholes and outcrops throughout the study area. It outcrops as far west as Lena, Manitoba, and as far south as Ft. Ransom, North Dakota. Thickness ranges from 5 feet to 80 feet, and the base is seldom exposed in outcrops. The maximum thickness occurs at the base of the Pembina Escarpment.

Differentiation.—Pebble-loam of the Gardar Formation contains more shale fragments (very coarse sand) than pebble-loam of any other unit. In outcrops, pebble-loam of the Gardar Formation may contain more shale pebbles than pebble-loam of unit A. The blocky pebble-loam of the Gardar Formation contains iron and manganese stained joints and more shale pebbles than the fissile pebble-loam of the Dahlen or Falconer Formations which do not contain iron and manganese stained joints.

Origin.—The Gardar Formation consists of glacial sediment and a minor amount of fluvial and lacustrine sediment.

Age and correlation.—The Gardar Formation is correlated with the Minnedosa Formation of Manitoba (Klassen, 1969) and the Floral Formation of Saskatchewan (Christiansen, 1968). The pebble-loam in these formations is compact and blocky and contains iron and manganese stained joints. An extensive boulder pavement occurs at the top of these formations. The Gardar Formation is correlated with the lower part of the Red Lake Falls Formation (Harris and others, 1974) and the Granite Falls Formation (Matsch, 1971). Reasons for these correlations were previously discussed in the section on the lower part of the Red Lake Falls Formation.

The Gardar Formation is believed to be Early Wisconsinan in age on the basis of radiocarbon dates in sediment of the Granite Falls and Floral Formations. In Saskatchewan, radiocarbon dates in sediment of the Floral Formation (Christiansen, 1968) indicate that this sediment was deposited before 40,000 B.P.

Dahlen Formation

Source of name.—The village of Dahlen, Nelson County, North Dakota.

Type area.—Western Grand Forks County.

Type section.—Forest River Cut I (No. 518), NE¼SE¼NE¼sec 10, T154N, R55W; a river cut on south side of Forest River.

Reference sections.—Forest River Cut II (No. 516), NW¼SE¼NE¼sec 5, T145N, R55W; a river cut on south side of Forest River. Testhole 2582, NW¼NW¼NW¼sec 11, T154N, R55W.

Description.—The Dahlen Formation consists of pebble-loam and a minor amount of stratified sediment. The soft, fissile pebble-loam contains many shale pebbles (40% to 60%). Near the base of outcrops where the Dahlen Formation is thick, the soft, fissile pebble-loam grades into compact, blocky pebble-loam. In outcrops where the Dahlen Formation overlies shale, the number of shale pebbles in the pebble-loam gradually increase downward. This increase generally occurs within the lower one-third of the pebble-loam. Testhole samples are olive gray (5Y 5/1), and outcrop color ranges from olive gray to light yellowish brown. Outcrop characteristics, sand lithology, and texture are the criteria for recognizing the pebble-loam of the Dahlen Formation (table 1). Shale content of the very coarse sand generally ranges from 40% to 60%. The texture of the sediment is clay loam, silty clay loam, silty loam, or loam.

Contacts.—In eleven of fifteen testholes, the Dahlen Formation directly overlies the Gardar Formation. In one testhole, about 15 feet of sand and gravel of the Dahlen Formation overlies pebble-loam of unit C. In one testhole, the Dahlen Formation rests on bedrock. In the remaining testholes, the base of the Dahlen Formation was not reached.

In many outcrops, pebble-loam of the Dahlen Formation and pebble-loam of the Gardar Formation are separated by a boulder lag of the Dahlen Formation or a striated boulder pavement of the Gardar Formation. Striations on the boulder pavement indicate a northwest-southeast flow direction. In other outcrops, stratified sand and gravel of the Dahlen Formation directly overlies pebble-loam of the Gardar Formation. In western Grand Forks County, the Dahlen Formation generally overlies bedrock. In this area, the base of the Dahlen Formation commonly consists of a boulder lag, but stratified sand and gravel and laminated, silty clay also occur at the base of this formation. In six of fifteen testholes, pebble-loam of the Dahlen Formation directly underlies pebble-loam of the Falconer Formation. In two testholes, pebble-loam of the Dahlen Formation directly underlies sand and gravel of the Falconer Formation. The thickness of this sand and gravel is 10 feet and 50 feet. In six testholes, pebble-loam of the Dahlen Formation directly underlies laminated, silty clay of the Wylie Formation. In one testhole, pebble-loam of the Dahlen Formation directly underlies poorly laminated clay that has been informally called "Walhalla Clay" (Arndt, this report). In outcrops, the contact between pebble-loam of the Dahlen Formation and the overlying laminated, silty clay of the Wylie Formation is generally sharp.

Extent and thickness.—The Dahlen Formation occurs in fifteen of twenty-six testholes in Pembina, Walsh, and Grand Forks Counties and outcrops in Cavalier, Pembina, Walsh, Grand Forks, and Steele Counties. This formation outcrops as far west as Lena, Manitoba, and as far south as Ft. Ransom, North Dakota. Sediment of the Dahlen Formation is exposed at the surface throughout most of eastern North Dakota. Thickness ranges from 2 feet to 40 feet. The maximum thickness occurs at the base of the Pembina Escarpment.

Differentiation.—Pebble-loam of the Dahlen Formation contains more shale fragments than pebble-loam of unit D, unit C, unit 1, lower part of the Red Lake Falls Formation, or the Falconer Formation. Pebble-loam of the Dahlen Formation contains fewer shale fragments than pebble-loam of unit B, unit A, or the Gardar Formation. In outcrops, fissile pebble-loam of the Dahlen Formation contains fewer shale pebbles (4 mm to 64 mm) than blocky pebble-loam of the Gardar Formation or unit A. Pebble-loam of the Dahlen Formation is very similar to pebble-loam of the Falconer Formation, particularly near the outer boundary of the Falconer Formation, which is marked by the Edinburg Moraine. In most outcrops, pebble-loam of the Dahlen Formation contains more shale pebbles than pebble-loam of the Falconer Formation. In other outcrops, pebble-loam of both formations look alike, and the only method to differentiate the two is by the presence of the Wylie Formation or extensive stratified sand and gravel between the two formations.

Origin.—The Dahlen Formation consists of glacial sediment and a minor amount of fluvial and lacustrine sediment.

Age and correlation.—The Dahlen Formation is correlated with the upper part of the Red Lake Falls Formation of northwestern Minnesota (Harris and others, 1974), the New Ulm Formation of southwestern Minnesota (Matsch, 1971), the Lennard Formation of Manitoba (Klassen, 1969), and the Battleford Formation of Saskatchewan (Christiansen, 1968). The pebble-loam in these formations is soft and fissile. A boulder accumulation generally occurs at the base of these formations. Shale pebbles are common in pebble-loam of the Dahlen, upper part of the Red Lake Falls, and New Ulm Formations.

The Dahlen Formation is Late Wisconsinan in age. Radiocarbon dates in Saskatchewan (Christiansen, 1968) and Iowa (Ruhe, 1969) under formations correlated with the Dahlen Formation indicate that the glacial sediment of the Dahlen Formation was deposited after 20,000 B.P.

Wylie Formation

Description.—The Wylie Formation (Harris and others, 1974) consists of laminated silt and clay that contains no pebbles. Testhole samples are olive gray and outcrop color varies from olive gray to yellowish brown. In outcrops, near the base of the formation, dark, thick clay beds predominate and gradually thin upwards until light silt layers predominate.

Contacts.—In twelve of thirteen testholes, silty clay of the Wylie Formation directly overlies pebble-loam of the Gardar, lower part of the Red Lake Falls, and Dahlen Formations. In one testhole, the Wylie Formation rests on bedrock. In outcrops, the contact is sharp between silt and clay of the Wylie Formation and pebble-loam of the Dahlen Formation. In ten of thirteen testholes, silty clay of the Wylie Formation directly underlies pebble-loam of the Falconer Formation. In three testholes, silty clay of the Wylie Formation directly underlies clay of the "Walhalla Clay," which is differentiated from the Wylie Formation on the basis of electric log characteristics. In outcrops, the silt and clay of the Wylie Formation is interbedded with the overlying pebble-loam of the Falconer Formation.

Extent and thickness.—The Wylie Formation occurs in thirteen of twenty-six testholes in the study area and outcrops in Grand Forks

County. This formation occurs in the Red River Valley of North Dakota and Minnesota. The outer boundary of the Wylie Formation and the Falconer Formation is the Edinburg Moraine. The thickness of the Wylie Formation ranges from 2 feet to 10 feet.

Differentiation.—The Wylie Formation consists of laminated silt and clay, and all other units consist predominantly of unbedded pebble-loam.

Origin.—The Wylie Formation consists of off-shore lacustrine sediment.

Age and correlation.—The sediment of the Wylie Formation was deposited following the deposition of the glacial sediment of the Dahlen Formation (after 20,000 B.P.) and preceding the deposition of the glacial sediment of the Falconer Formation (before 13,500 B.P.). The Wylie Formation has not been correlated with formations outside the Red River Valley of North Dakota and Minnesota.

Falconer Formation

The Falconer Formation was named by Harris and others (1974) from testholes in the Grand Forks area. This formation has been traced in the subsurface to exposures along the Edinburg Moraine in Grand Forks and Walsh Counties. The pebble-loam of the Falconer Formation in these exposures is much sandier and contains more shale than the pebble-loam in the type area. The Forest River Cut I (No. 518, NE¼SE¼NE¼sec 10, T154N, R55W) is here designated as an additional reference section for the Falconer Formation.

Description.—The Falconer Formation consists of pebble-loam and stratified sediment. The unbedded, soft, fissile pebble-loam contains many carbonate and shale pebbles (40% to 60%). In eastern Pembina, Walsh, and Grand Forks Counties, carbonate pebbles predominate. In western Pembina, Walsh, and Grand Forks Counties, along the Edinburg Moraine, shale pebbles predominate. Testhole samples are olive gray (5Y 5/1), and outcrop color ranges from olive gray to light yellowish brown. Outcrop characteristics, sand lithology, and texture are the criteria for recognizing the pebble-loam of the Falconer Formation (table 1). Shale content of the very coarse sand generally ranges from 10% to 40%. The texture of this sediment is clay loam, silty clay loam, silty loam, or loam.

Contacts.—In eight of eighteen testholes, pebble-loam of the Falconer Formation directly overlies silty clay of the Wylie Formation. In six testholes, pebble-loam of the Falconer Formation directly overlies pebble-loam of the Dahlen Formation. In four testholes, sand and gravel, ranging in thickness from 10 feet to 50 feet, of the Falconer Formation directly overlies either pebble-loam of the Gardar, lower part of the Red Lake Falls, or Dahlen Formations. In outcrops, pebble-loam of the Falconer Formation is interbedded with the underlying silt and clay of the Wylie Formation. In fifteen of eighteen testholes, the Falconer Formation directly underlies clay of the "Walhalla Clay." In three testholes, pebble-loam of the Falconer Formation is exposed at the surface.

Extent and thickness.—The Falconer Formation occurs in eighteen of twenty-six testholes and outcrops in the study area. This formation occurs throughout the Red River Valley of North Dakota and Minnesota. In North Dakota, the outer limit of the formation is marked by the Edinburg Moraine. Thickness of the Falconer Formation ranges from 5 feet to 100 feet; maximum thickness occurs along the Edinburg Moraine.

Differentiation.—Pebble-loam of the Falconer Formation contains fewer shale fragments than pebble-loam of unit C, unit B, unit A, the Gardar Formation, or the Dahlen Formation. Pebble-loam of the Falconer Formation is more silty than pebble-loam of unit D. Pebble-loam of the Falconer Formation contains fewer carbonate fragments than pebble-loam of unit 1 or the lower part of the Red Lake Falls Formation. In outcrops, fissile pebble-loam of the Falconer Formation contains fewer shale pebbles than the blocky pebble-loam of the Gardar Formation or unit A. Pebble-loam of the Falconer Formation, near the Edinburg Moraine, is difficult to distinguish from pebble-loam of the Dahlen Formation. The two formations can be differentiated by the occurrence of the Wylie Formation or extensive stratified drift between them.

Origin.—The Falconer Formation consists of glacial sediment and a significant amount of fluvial sediment.

Age and correlation.—The Falconer Formation was deposited before 13,500 B.P., based on radiocarbon dates in North Dakota (Moran and others, 1974). The Falconer Formation is laterally equivalent to the Huot Formation in northwestern Minnesota and eastern Grand Forks County (Harris and others, 1974). Generally both units overlie the Wylie Formation. The outer limit of the Falconer and Huot Formations is marked by the Edinburg Moraine.

History

At least nine glacial advances occurred in northeastern North Dakota and northwestern Minnesota during Pleistocene time. Erosion, varying in degree and duration, followed each glacial advance.

The pebble-loam of unit D was deposited during a glacial advance from the northeast. The time of this advance is unknown. The minor amount of shale within this sediment suggests a northeast source area, since exposures of shale occur only north and west of the area in which unit D occurs. Erosion, following this advance, removed most of the sediment of unit D from the area studied.

During a glacial advance from the north or northwest, the pebble-loam of unit C was deposited. The age of this advance is not known. The large amount of shale in this sediment suggests a north or northwest source area, since exposures of shale occur only north and west of the area in which unit C occurs. Following this advance, erosion removed most of the sediment of unit C from the study area.

The pebble-loam of unit B was deposited during a glacial advance from the north or northwest. The time of this advance is unknown. A north or northwest source area is suggested by the large amount of shale in this sediment. Exposures of shale occur only north and west of where unit B occurs. Minor erosion followed this glacial advance. As a result, unit B is thick and traceable in the subsurface of the area studied.

The pebble-loam of unit A and the St. Hilaire Formation was deposited during a glacial advance from the northwest. The age of this advance is not known. The large amount of shale in this sediment suggests a northwest source area, since extensive exposures of shale occur only northwest and west of the area in which unit A and the St. Hilaire Formation occur. Along the Pembina Escarpment, the shale content in pebble-loam of unit A averages around 60% and progressively decreases to 30% in pebble-loam of the St. Hilaire Formation in northwestern Minnesota. This change is a reflection of a change in bedrock. About halfway between these two areas, the bedrock changes from shale to limestone, dolomite, and sandstone.

During a glacial advance from the north, the pebble-loam of unit 1 was deposited. The time of this advance is unknown. The large amount of carbonates in this sediment suggests a northern source area, since extensive exposures of limestone and dolomite occur only north of the area in which unit 1 occurs. The scarcity of shale in the sediment suggests a north or northeast source area, since exposures of shale occur only northwest and west of the area in which unit 1 occurs.

Following this advance, extensive erosion removed the fine material from pebble-loam at the surface, and boulders accumulated. These boulders were reworked and occur as a boulder pavement or lag, which locally underlies pebble-loam of the Gardar Formation and generally underlies pebble-loam of the lower part of the Red Lake Falls

Formation. Erosion also exposed large areas of bedrock. As a result, pebble-loam of the Gardar Formation, which was deposited after this period of erosion, contains large amounts of shale. In most outcrops where the base of the Gardar Formation is exposed this formation directly overlies shale. Erosion removed most of the sediment of unit 1, thus explaining its limited occurrence. In one testhole, in Walsh County, the upper five feet of unit A is extremely weathered and this unit is directly overlain by the Gardar Formation. In one outcrop, in Stutsman County, a weathered zone occurs in pebble-loam that underlies the Gardar Formation. This weathered zone is thicker and more intense than the Holocene weathering zone at the top of this site. Based on boulder accumulation, abundant bedrock in pebble-loam of the Gardar Formation, and intensity of weathering, a long period of erosion preceded the deposition of the Gardar and the lower part of the Red Lake Falls Formations.

During a glacial advance from the north, the pebble-loam of the Gardar and the lower part of the Red Lake Falls Formations was deposited. This advance occurred before 40,000 B.P. (Christiansen, 1968), probably during Early Wisconsinan time. An advance from the north is suggested by the abrupt change in lithology from abundant shale in pebble-loam of the Gardar Formation to abundant limestone and dolomite in pebble-loam of the lower part of the Red Lake Falls Formation. This change is a result of the change in bedrock from shale to sandstone, limestone, and dolomite. The advance of the glacier paralleled the boundary of the bedrock change, which trends north. As a result, only a minor amount of shale occurs in the pebble-loam east of the shale boundary and only a minor amount of limestone and dolomite occurs in the pebble-loam west of the boundary.

Erosion followed this glacial advance and produced a boulder accumulation. This widespread boulder accumulation, from Saskatchewan to southwestern Minnesota, occurs at the base of the Battleford, Lennard, Dahlen, and New Ulm Formations. Bedrock was not extensively exposed by erosion, and as a result, the Dahlen Formation, which was deposited after this period of erosion, does not contain a great abundance of shale. In one outcrop, a weathered zone occurs in pebble-loam of the Gardar Formation and directly underlies the Dahlen Formation. The thickness and intensity of this weathered zone appears to be less than the thickness and intensity of the weathered zone that developed before the deposition of the Gardar Formation. Based on the boulder accumulation, the amount of bedrock in pebble-loam of the Dahlen Formation, and a weak weathered zone, an extensive period of erosion preceded the deposition of the Dahlen

Formation and the upper part of the Red Lake Falls Formation. This period of erosion was probably not as intense as the period of erosion which pre-dated deposition of the Gardar and the lower part of the Red Lake Falls Formations.

The pebble-loam of the Dahlen and the upper part of the Red Lake Falls Formations was deposited during a glacial advance from the northwest. This advance occurred before 20,000 B.P. on the basis of radiocarbon dates in Saskatchewan (Christiansen, 1968) and Iowa (Ruhe, 1969; 201, 212). An advance from the northwest is indicated by washboard moraines, drumlins, and flutings that occur throughout eastern North Dakota. Striations on the boulder pavement underlying the Dahlen Formation indicate a northwest-southeast flow direction. An advance from the northwest is also suggested by the shale in pebble-loam of the upper part of the Red Lake Falls Formation, since shale only outcrops northwest and west of the area in which this formation occurs.

The glacier stagnated following this advance. In the Red River Valley, several lakes formed in depressions bordered by stagnating ice and bedrock highs. One such lake, in northeastern North Dakota and northwestern Minnesota, was Lake Climax (Moran and Clayton, in preparation), which was confined by stagnating ice and the Pembina Escarpment. The Wylie Formation consists of off-shore sediment that was deposited in Lake Climax.

After the deposition of the sediment of the Wylie Formation, the glacier readvanced. During this minor readvance, pebble-loam of the Falconer and Huot Formations was deposited. This readvance occurred before 13,500 B.P. on the basis of radiocarbon dates in North Dakota (Moran and Clayton, in preparation). The outer limit of this advance is marked by the Edinburg Moraine.

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APPENDIX B
Basic Data for Outcrops and Testholes in Cavalier and Pembina Counties

Testhole† or Outcrop Number	Unit*	Texture(%) (Sd-St-Cl)**	Coarse Sand Lithology(%) (Cy-Cb-Sh)***
2582†	1	38-49-13	35-19-46
	1	39-45-16	39-18-43
	1	37-47-16	42-18-40
	2	34-44-22	35-18-46
	2	36-44-20	34-15-51
	2	32-47-21	31-17-52
	3	29-56-15	10-8-82
	3	32-51-17	10-8-82
	3	34-62-4	12-12-75
	3	36-44-20	18-11-71
516	2	36-49-15	29-21-50
	2	36-50-14	27-16-57
518	1	36-43-21	31-24-45
	1	17-46-37	36-19-49
	2	36-49-15	33-19-49
	2	33-52-15	30-18-52
35	3	34-44-22	7-6-87
	3	34-47-19	4-7-89
	3	36-42-22	4-4-92
972	3	39-49-11	14-8-78
970	3	45-42-11	15-7-78
969	3	38-47-15	17-12-71
967	3	36-48-16	22-11-67
	3	34-34-22	18-9-72
3568†	1	27-61-12	41-49-9
	1	24-53-23	43-41-16
	1	20-68-12	44-45-10
	1	26-58-16	37-50-13
	1	23-56-21	42-42-16
4220†	2	20-38-42	24-19-57
	2	32-34-34	13-29-58
	8	28-28-44	27-29-43
	8	27-30-43	26-32-42
	9	30-28-42	41-32-27
4216†	6	31-34-35	21-19-58
	6	31-36-33	19-18-63
	6	35-33-32	22-12-66
	7	34-29-37	24-23-53
	7	37-31-32	22-20-57
	7	36-25-39	21-21-58
	9	27-33-40	28-48-24
	9	25-42-33	31-42-27
	9	27-32-41	32-49-19

*1=Falconer, 2=Dahlen, 3=Gardar, 4=Lower Red Lake Falls, 5=Unit 1, 6=Unit A, 7=Unit B, 8=Unit C, 9=Unit D.
**Sd=Sand, St=Silt, Cl=Clay.
***Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX B—Continued

Testhole† or Outcrop Number	Unit*	Texture(%) (Sd-St-Cl)**	Coarse Sand Lithology(%) (Cy-Cb-Sh)***
	9	25-37-35	38-43-18
	9	28-35-36	35-48-17
975	3	35-43-22	6-3-91
974	3	42-46-12	9-3-88
	3	43-47-10	11-3-85
5943†	1	36-51-13	49-46-5
	1	35-53-12	50-48-2
	1	32-56-12	43-55-1
	4	33-36-31	46-51-3
	4	36-41-24	46-53-1
	4	39-41-20	38-60-2
	4	44-43-13	44-54-2
	5	33-34-28	33-66-1
5940†	1	43-53-4	41-59-0
	1	36-57-7	37-61-2
	1	36-53-11	37-55-8
	1	32-53-15	35-58-7
	4	42-40-18	37-56-7
	4	42-36-20	44-53-2
	4	38-35-27	41-48-11
5946†	1	32-50-18	22-20-57
	1	31-47-22	36-60-4
	1	25-50-25	38-56-6
	4	47-49-4	45-51-4
	4	48-36-16	44-54-2
	5	33-47-20	27-72-1
	5	36-45-19	30-68-2
5947†	1	36-48-16	44-51-5
	1	34-52-14	50-46-4
	1	34-53-13	41-55-4
	1	34-56-10	44-49-7
	1	27-60-13	50-14-9
	1	30-50-20	45-51-4
	6	21-51-28	24-16-60
	6	19-43-38	18-21-61
	6	32-30-38	25-25-50
	7	37-39-24	23-26-51
	7	33-35-32	24-27-49
	8	36-43-21	28-30-42
	8	35-43-22	31-39-30
	8	23-51-26	24-30-46
3566†	1	31-61-8	47-47-5
	2	33-60-7	31-22-47
	2	35-60-5	12-23-65

*1=Falconer, 2=Dahlen, 3=Gardar, 4=Lower Red Lake Falls, 5=Unit 1, 6=Unit A, 7=Unit B, 8=Unit C, 9=Unit D.
**Sd=Sand, St=Silt, Cl=Clay.
***Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX B–Continued

Testhole† or Outcrop Number	Unit*	Texture(%) (Sd-St-Cl)**	Coarse Sand Lithology(%) (Cy-Cb-Sh)***
	3	39-50-11	13-13-74
	3	49-47-13	19-18-73
976	3	36-47-17	9-4-87
984	3	42-43-15	10-4-86
	6	36-45-19	21-12-67
985	3	30-40-30	17-11-72
	6	37-39-24	27-9-62
3870	1	30-56-14	44-32-24
	1	36-49-15	44-28-28
	1	35-51-14	44-31-25
	2	30-51-19	33-12-55
	2	21-58-21	25-15-60
	2	32-42-21	20-17-63
978	1	18-48-33	52-26-12
979	3	36-46-17	15-9-77
	3	45-45-10	17-10-73
980	3	35-47-17	15-10-75
982	2	54-30-16	30-23-47
	2	48-36-16	32-16-52
986	2	39-44-17	31-13-15
	3	35-47-17	18-7-74
	3	39-41-20	24-10-65

*1=Falconer, 2=Dahlen, 3=Gardar, 4=Lower Red Lake Falls, 5=Unit 1, 6=Unit A, 7=Unit B, 8=Unit C, 9=Unit D.
**Sd=Sand, St=Silt, Cl=Clay.
***Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX C
Description of Outcrops and Testholes in Cavalier and Pembina Counties

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology(%) (Cy-Cb-Sh)**
154-55-5-adb	516	0-55	Stratified sand and gravel.		
		55-75	Alternating layers of silt and clay; lower 5' contains thick layers of dark brown clay alternating with thin layers of light brown silt; clay layers gradually thin upwards; upper 10' contains light brown silt (Wylie Fm.).		
		75-95	Pebble-loam, compact, abundant shale pebbles (Dahlen Fm.).	36-51-13	28-19-53
154-55-10-ada	518	0-9	Interbedded sand and silt.		
		9-10	Organic rich silt.		
		10-15	Sandy silt, very well sorted, contorted, and involuted bedding near top.		
		15-21	Sand, medium-grained, poorly sorted, large-scale, trough-shaped crossbedding.		
		21-26	Sand, coarse-grained, well sorted.		
		26-39	Sand, medium-grained, moderate to well sorted, small-scale crossbedding.		
		39-79	Pebble-loam, compact, fissile to massive, olive gray, silt and sand lenses, abundant shale pebbles (Falconer Fm.).	36-44-20	34-22-44
		79-83	Silt, laminated, brown pebble-loam interbedded with silt in upper 2'; upper boundary of this unit is the top of the uppermost continuous silt layer (Wylie Fm.).		
		83-89	Pebble-loam, compact, olive gray, abundant shale pebbles, sand lenses (Dahlen Fm.).	34-51-15	31-18-51
154-55-11-bbb	2582†	0-20	Medium to coarse grained sand, abundant shale grains.		

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX C—Continued

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology(%) (Cy-Cb-Sh)**
154-55-11-bbb		20-64	Pebble-loam, olive gray (5Y 5/1) (Falconer Fm.).	39-45-16	38-19-43
		64-70	Laminated silty clay, olive gray (5Y 6/1) (Wylie Fm.).		
		70-97	Pebble-loam, lenses of sand and gravel, olive gray (5Y 5/1) (Dahlen Fm.).	34-44-22	33-17-50
		97-104	Sand, poorly sorted (Dahlen Fm.).		
		104-160	Pebble-loam, lenses of poorly sorted sand and gravel, olive gray (5Y 5/1) (Gardar Fm.).	34-51-15	12-10-78
		160-212	Pebble-loam, lenses of sand and gravel, olive gray (5Y 5/1) (Unit A).	40-45-15	24-12-64
		212-240	Sand and gravel, poorly sorted, abundant shale (Unit A).		
		240-302	Poor samples, abundant sand and gravel, some pebble-loam.		
		302-315	Shale, bentonitic, light gray (Greenhorn Fm.).		
159-56-16-dad	35	0-3	Organic rich silt.		
		3-6	Boulder lag, gravel with abundant carbonates (Gardar Fm.).		
		6-11	Pebble-loam, friable, sand, silt, and gravel lenses, very abundant shale pebbles (Gardar Fm.).		
		11-21	Pebble-loam, blocky, iron-stained joints, very abundant shale pebbles (Gardar Fm.).	35-45-20	5-5-90
159-57-5-ab	972	0-9	Friable pebble-loam, abundant shale pebbles (Gardar Fm.).	39-50-11	14-8-78
		9-10	Stratified sand and silt (Gardar Fm.).		
		10+	Gray, fissile shale (Pierre Fm.).		
159-57-5-ab	970	0-8	Blocky, pebble-loam, abundant shale pebbles (Gardar Fm.)	45-43-12	15-7-78
		8+	Stratified sand and gravel (Gardar Fm.).		
159-58-21-cc	969	0-10	Blocky pebble-loam, abundant shale pebbles (Gardar Fm.).	38-47-15	17-12-71

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX C—Continued

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology(%) (Cy-Cb-Sh)**
159-58-33-bb	967	0-3	Pebble-loam, abundant shale pebbles (decreasing upwards) (Gardar Fm.).	36-48-16	22-11-67
		3-8	Flat-bedded, reddish brown sand and gravel, contorted along upper contact (Gardar Fm.).		
		8+	Blocky pebble-loam, abundant shale pebbles (Gardar Fm.).	34-34-32	18-9-73
160-54-18-baa	3568†	0-10	Fine sand, mostly quartz.		
		10-44	Laminated silty clay, olive gray (5Y 6/2).		
		44-172	Laminated clay, calcareous white specks, olive gray (5Y 5/1) ("Walhalla Clay").		
		172-196	Pebble-loam, pebbles: Cb>Cy>Sh, olive gray (5Y 5/1) (Falconer Fm.).	25-58-17	41-46-13
		196-220	No samples.		
		220-380	Layers of quartz sand and shale (Dakota Group).		
		380-420	Reddish brown shale (Jur. undiff.).		
160-56-24-aaa	4220†	0-25	Laminated, silty clay, olive gray (5Y 6/2, 6/3) ("Walhalla Clay").		
		25-80	Laminated clay, calcareous white specks, olive gray (5Y 6/1) ("Walhalla Clay").		
		80-92	Pebble-loam, pebbles: Sh≅Cb>Cy, olive gray (5Y 5/1) (Dahlen Fm.).	26-36-38	18-24-58
		92-110	Sandy, clayey, gravel, pebbles: Cb>Cy>Sh (Dahlen Fm.).		
		110-132	Pebble-loam, silt lens, pebbles: Cb>Cy = Sh, olive gray (5Y 5/1) (Unit C).	28-29-43	26-31-43
		132-144	Pebble-loam, pebbles: Cb>Cy>>Sh,*** olive gray (5Y 5/1) (Unit D).	30-28-42	41-42-27
		144-200	Calcareous, white-speckled shale, gray (5Y 4/1) (Belle Fourche Fm.).		

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.
*** >> represents very much greater than.

APPENDIX C—Continued

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology(%) (Cy-Cb-Sh)**
160-56-34-ccc	4216†	0-25	Pebble-loam, pebbles: Cb > Cy > Sh, gypsum and lignite fragments, olive gray (5Y 5/1, 6/1) (Unit A).	33-34-33	21-16-63
		25-60	Pebble-loam, few pebbles, sand lens, gray (5Y 5/1) (Unit B).	36-28-36	22-22-56
		60-100	Pebble-loam, pebbles: Cb > Cy > Sh, olive gray (5Y 5/1) (Unit C).	27-36-37	33-46-21
		100-112	Calcareous, dark gray, waxy shale (Carlile Fm.).		
		112-120	Massive waxy shale, dark gray (2.5Y 5/0) (Greenhorn Fm.).		
160-57-14-cc	975	0-15	Blocky pebble-loam, abundant shale pebbles, yellowish brown (Gardar Fm.).	35-43-22	6-3-91
		15-17	Boulder lag, sand and gravel (Gardar Fm.).		
		17+	Gray fissile shale (Pierre Fm.).		
160-57-15-dd	974	0-4	Friable pebble-loam, abundant shale pebbles, yellowish brown (Gardar Fm.).	35-45-20	10-2-88
		4-5	Stratified sand and gravel (Gardar Fm.).		
		5+	Blocky pebble-loam, abundant shale pebbles, yellowish brown (Gardar Fm.).	43-46-11	10-3-87
161-52-24-dad	5943†	0-15	Laminated, silty clay, light gray (2.5Y 7/2) ("Walhalla Clay").		
		15-150	Laminated clay, white calcareous specks, olive gray (5Y 5/1, 6/1) ("Walhalla Clay").		
		150-159	Clayey gravel, mostly carbonate rocks (Falconer Fm.).		
		159-172	Pebble-loam, pebbles: Cb > Cy, olive gray (5Y 5/1) (Falconer Fm.).	34-54-12	47-50-3
		172-183	Clayey gravel, mostly carbonate rocks (Falconer Fm.).		
		183-186	Carbonate boulders and cobbles (Falconer Fm.).		
		186-240	Pebble-loam, pebbles: Cb > Cy, olive gray (5Y 5/1, 6/1) (Red Lake Falls Fm.).	39-41-20	43-55-2

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX C—Continued

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology(%) (Cy-Cb-Sh)**
		240-263	Pebble-loam, pebbles: Cb >> Cy,*** olive gray (5Y 5/1) (Unit 1).	33-34-28	32-65-1
		263-280	Yellowish gray dolostone (Ord. undiff.).		
161-53-25-bba	5940†	0-12	Laminated, silty clay, light gray (2.5Y 7/2) ("Walhalla Clay").		
		12-118	Laminated clay, white calcareous specks, olive gray (5Y 5/1) ("Walhalla Clay").		
		118-150	Moderately sorted sand, mostly quartz (Falconer Fm.).		
		150-210	Pebble-loam, pebbles: Cb > Cy, olive gray (5Y 5/1) (Falconer Fm.).	36-55-9	37-59-4
		210-225	Laminated, silty clay (Wylie Fm.).		
		225-266	Pebble-loam, pebbles: Cb ≅ Cy, olive gray (5Y 6/1) (Red Lake Falls Fm.).	41-37-22	41-52-7
		266-280	Reddish brown shale (Jur. undiff.).		
161-53-33-ddd	5946†	0-15	Laminated, silty clay, light gray (2.5Y 7/2) ("Walhalla Clay").		
		15-150	Laminated clay, white calcareous specks, olive gray (5Y 5/1) ("Walhalla Clay").		
		150-170	Pebble-loam, pebbles: Cb > Cy, olive gray (5Y 5/1) (Falconer Fm.).	29-49-22	36-59-4
		170-180	Laminated, silty clay, olive gray (5Y 5/1) (Wylie Fm.).		
		180-195	Pebble-loam, pebbles: Cb >> Cy,*** olive gray (5Y 5/1) (Red Lake Falls Fm.).	48-42-10	44-53-3
		195-200	Sandy gravel, mostly carbonate pebbles (Red Lake Falls Fm.).		
		200-230	Pebble-loam, pebbles: Cb >> Cy,*** olive gray (5Y 6/1) (Unit 1).	34-46-20	28-69-2
		230-260	Sand, silt, clay, poor samples (Dakota Group).		
		260-280	Micaceous shale, olive gray (5Y 5/1) (Dakota Group).		

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.
*** >> represents very much greater than.

APPENDIX C—Continued

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology (%) (Cy-Cb-Sh)**
161-54-24-ddd	5947†	0-24	Laminated, silty clay ("Walhalla Clay").		
		24-140	Laminated clay, white calcareous specks, olive gray (5Y 5/1) ("Walhalla Clay").		
		140-185	Pebble-loam, pebbles: Cb>Cy>Sh, olive gray (5Y 6/1) (Falconer Fm.).	32-53-15	46-49-5
		185-198	Laminated, silty clay, olive gray (5Y 5/1) (Wylie Fm.).		
		198-246	Pebble-loam, pebbles: Sh > Cb > Cy, few gypsum fragments, olive gray (5Y 6/1) (Unit A).	24-42-34	21-19-60
		246-265	Pebble-loam, pebbles: Cb ≅ Sh>Cy, olive gray (5Y 6/1) (Unit B).	35-37-28	24-26-50
		265-302	Pebble-loam, pebbles: Cb>Cy>Sh, olive gray (5Y 5/1) (Unit C).	31-46-23	28-33-39
		302-320	Greenish-gray shale, light gray mottling (Dakota Group).		
161-55-18-bbb	3566	0-33	Laminated, silty clay, light gray (5Y 6/2) ("Walhalla Clay").		
		33-175	Laminated clay, calcareous white specks, olive gray (5Y 6/1) ("Walhalla Clay").		
		175-186	Pebble-loam, pebbles: Cb>Cy>Sh, olive gray (5Y 6/1) (Falconer Fm.).	31-61-8	47-48-5
		186-200	Pebble-loam, pebbles: Sh>Cb ≅ Cy, olive gray (5Y 6/1) (Dahlen Fm.).	33-60-7	22-22-56
		200-216	Pebble-loam, pebbles: Sh>Cb ≅ Cy, olive gray (5Y 6/1) (Gardar Fm.).	40-48-12	17-11-72
		216-240	Micaceous shale, dark gray (5Y 4/1) (Belle Fourche Fm.).		
161-57-33-ba	976	0-8	Friable pebble-loam, abundant shale pebbles (Gardar Fm.).	36-47-17	9-4-87
		8-9	Boulder lag, Cb≈Cy (Gardar Fm.).		
		9+	Gray fissile shale (Pierre Fm.).		

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX C—Continued

Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology (%) (Cy-Cb-Sh)**
162-58-7-cb	984	0-4	Pebble-loam, abundant shale pebbles, sand and gravel lens (Gardar Fm.).	42-43-15	10-4-86
		4-15(?)	Blocky pebble-loam, pebbles: Sh ≅ Cb ≅ Cy, dark brown (Unit A?).	36-45-19	21-12-67
		15(?)+	Gray, fissile shale (Pierre Fm.).		
162-58-21-da	985	0-8	Friable pebble-loam that becomes blockier downward, abundant shale pebbles, yellowish brown to olive gray (Gardar Fm.).	30-41-19	16-10-74
		8-11	Flat-bedded sand and gravel, some pebble-loam inclusions (Gardar Fm.).		
		11+	Blocky pebble-loam, pebbles: Sh>Cb>Cy (Unit A).	37-39-24	28-9-63
163-56-24-ada	3870†	0-20	Sandy silt ("Walhalla Clay").		
		20-85	Sand and gravel, abundant shale pebbles ("Walhalla Clay").		
		85-130	Laminated, silty clay, calcareous white specks, olive gray (5Y 6/1) ("Walhalla Clay").		
		130-186	Pebble-loam, abundant shale and carbonate pebbles, few gypsum fragments, olive gray (5Y 6/1) (Falconer Fm.).	34-52-20	26-15-59
		186-194	Laminated, silty clay, olive gray (5Y 6/1) (Wylie Fm.).		
		194-218	Pebble-loam, abundant shale and carbonate pebbles, olive gray (5Y 5/1) (Dahlen Fm.).	28-52-21	26-15-59
		218-260	Micaceous shale, dark gray (5Y 4/1) (Belle Fourche Fm.).		
		260-300	Well sorted, quartz sand (Dakota Group).		
163-57-29-ab	978	0-8	Friable pebble-loam, abundant carbonate pebbles (Falconer Fm.).	18-48-33	62-25-10
		8+	Gray fissile shale (Pierre Fm.).		
163-58-20-da	979	0-3	Friable pebble-loam, abundant shale pebbles (Gardar Fm.).		

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.

APPENDIX C—Continued

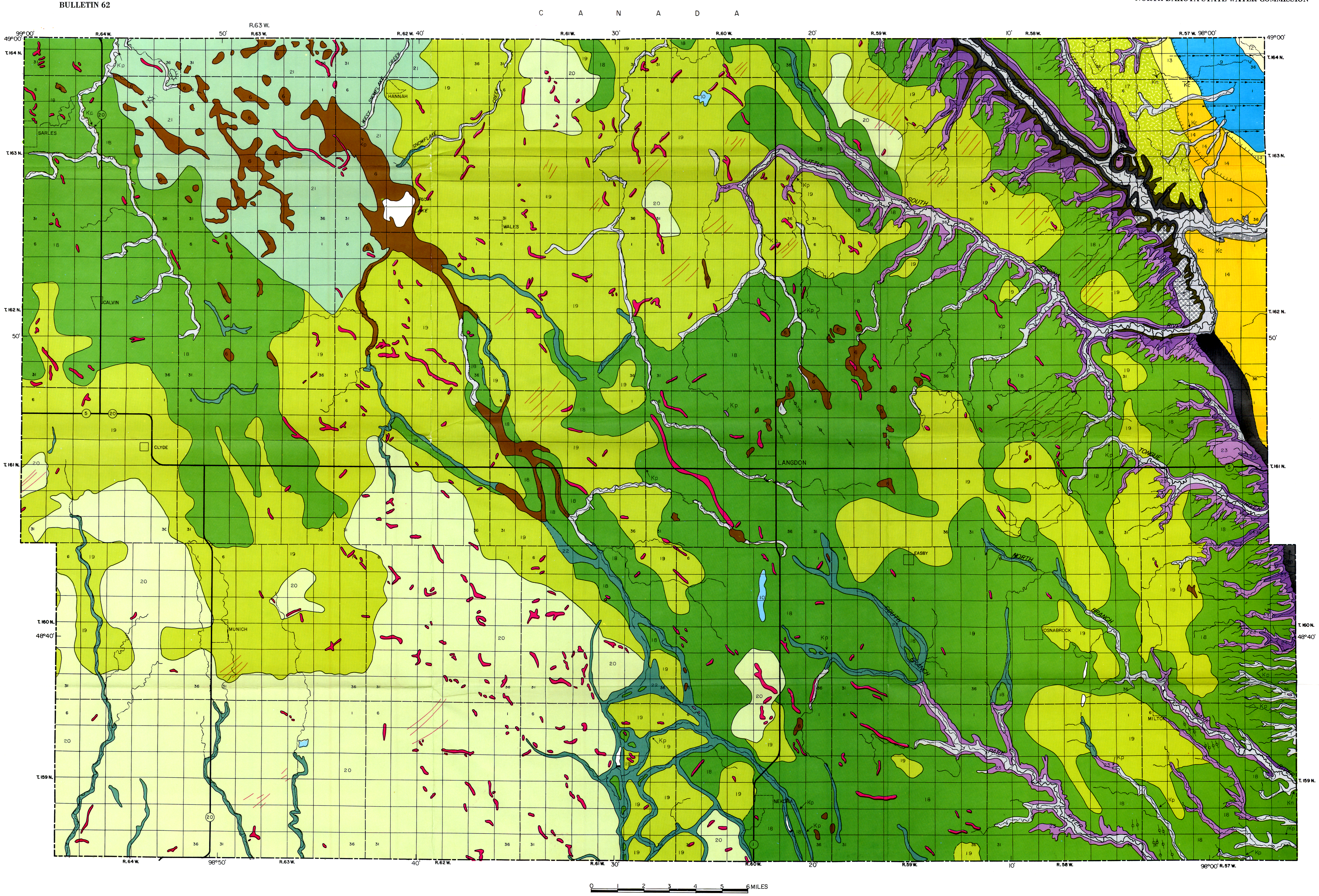
Location	Testhole† or Outcrop Number	Depth from Surface (ft.)	Lithologic Description	Texture(%) (Sd-St-Cl)*	Coarse Sand Lithology(%) (Cy-Cb-Sh)**
		3-4	Sand and gravel, laminated silt, some iron staining (Gardar Fm.).	36-46-17	15-9-77
		4-9	Blocky pebble-loam, abundant shale pebbles (Gardar Fm.).	45-45-10	17-10-73
		9+	Gray, fissile shale (Pierre Fm.).		
163-59-13-aa	980	0-10(?)	Friable pebble-loam, abundant shale pebbles (Gardar Fm.).	38-45-17	15-10-75
		10(?)+	Gray shale (Pierre Fm.).		
163-60-13-dc	982	0-8	Friable pebble-loam, pebbles: Sh>Cy>Cb (Dahlen Fm.).	51-33-16	31-20-49
		8+	Gray shale (Pierre Fm.).		
163-64-22-ba	986	0-4	Friable pebble-loam, pebbles: Sh>Cy>Cb, yellowish brown (Dahlen Fm.).	39-44-17	32-19-54
		4-5	Boulder pavement.		
		5+	Blocky pebble-loam, abundant shale pebbles, olive gray (Gardar Fm.).	38-44-18	21-9-70

*Sd=Sand, St=Silt, Cl=Clay.
**Cy=Crystalline, Cb=Carbonate, Sh=Shale.

PART 1 PLATE 1
COUNTY GROUND-WATER STUDIES 20
BULLETIN 62

PLATE 1. - GEOLOGY OF CAVALIER COUNTY

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION



MAP UNITS

Unit	Lithostratigraphic Unit	Description	Topography	Origin
1	**Walsh Formation** Sand and silt facies	Generally gray to black bedding is horizontal although vague; organic fragments common.	Flat to gently sloping	Modern river overbank sediment; some river-channel sediment.
2	**Walsh Formation** Sand and silt facies	Light to very dark gray; bedding obscure; thins rapidly away from rivers.	Flat to gently rolling	Modern river overbank sediment.
3	**Walsh Formation** Sand and silt facies	Clay and silt underlain by sand and gravel; cross-bedded; moderately sorted.	Flat to nearly flat	Pre-modern river overbank sediment; some river-channel sediment.
4	**Walsh Formation** Sand and silt facies	Mostly sand and gravel; large.	Steep slopes	Sediments deposited by the Pembina River during a time of very high discharge.
5	**Walsh Formation** Gravel facies	Heterogenous mixture of sand silt clay and gravel; poorly sorted; generally dense and compact.	Moderate to steep slopes	Slopewash and creep sediment.
6	**Walsh Formation** Clay facies	Vague bedding; dark brown to black.	Flat	Slough and pond sediment.
7	**Coleharbor Group** Silt and clay facies	Laminated; yellowish-brown to light gray.	Nearly flat to gently undulating	Offshore sediment of Lake Agassiz.
8	**Coleharbor Group** Silt and clay facies	Laminated to massive yellowish-brown; snail and clam shells present.	Nearly flat to gently undulating	Offshore sediment of a lagoon near Lake Agassiz; the area containing this sediment was cut off from the rest of the lake by longshore bars and spits.
9	**Coleharbor Group** Silt and clay facies	Laminated; yellowish-brown to light gray locally overlain by thin veneer of clayey sand.	Nearly flat to gently undulating	Offshore sediment of Lake Agassiz modified by postdepositional processes such as slopewash and groundwater discharge.
10	**Coleharbor Group** Silt and clay facies	Laminated; dark gray to black; snail shells present.	Nearly flat	Sediment deposited in lakes whose basins were enclosed by ice.
11	**Coleharbor Group** Silt and clay facies	Laminated; yellowish-brown to light gray; gypsum crystals abundant.	Nearly flat to gently undulating	Saline offshore sediment of Lake Agassiz; salinity is a result of groundwater discharge from underlying Paleozoic and Pleistocene sediments.
12	**Coleharbor Group** Silt and clay facies Sand and gravel facies	Mostly silt and very fine sand; yellowish-brown to light-brown; bedding not apparent.	Nearly flat to gently undulating	Near-shore or shallow-water sediment of Lake Agassiz.
13	**Coleharbor Group** Sand and gravel facies Silt and clay facies	Mostly sand and gravel; well sorted; distinct cross-bedding; gravel is generally found in linear ridges.	Rolling to undulating	Shoreline, near-shore, and offshore sediments of Lake Agassiz.
14	**Coleharbor Group** Sand and gravel facies	Mostly medium to coarse sand; moderately to well sorted; grades from shaly sand in the west to clean sand in the east.	Rolling to hummocky	Near-shore and fluvial sediments that make up the Pembina Delta.
15	**Coleharbor Group** Sand and gravel facies	Fine sand; well sorted.	Rolling to hilly	Wind-blown sediments of sand dunes.
16	**Coleharbor Group** Sand and gravel facies Stony loam facies	Pebbly, silty, clay loam overlain by thin discontinuous bodies of sand and gravel; locally thin veneer of laminated silt and clay; surface boulders abundant locally.	Nearly flat to undulating	Glacial sediment (till) modified by wave action of Lake Agassiz.
17	**Coleharbor Group** Stony loam facies **Pierre Formation and Niobrara Formation**	Pebbly, silty, clay loam; generally thin; overlying Cretaceous Pierre and Niobrara Formations; locally minor amounts of sand and gravel; bedrock commonly exposed; abundant surface concentrations of boulders.	Hilly to undulating	Eroded glacial sediment (till) overlying lower Pierre and Niobrara Formations.
18	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; minor amounts clay, sand, and gravel; generally yellowish-brown to olive gray; few sloughs and depressions; occassional surface ridges of stratified sand and gravel (eskers) although most are too small to be shown on the map.	Nearly flat to gently undulating; local relief 5 to 15 feet	Glacial sediment (till).
19	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; discontinuous lenses of sand and gravel at depth; surface sand and gravel ridges (eskers) may be covered by thin veneers of silty clay loam; generally yellowish-brown to olive gray; abundant sloughs and depressions.	Gently undulating; local relief 10 to 20 feet	Glacial sediment (till).
20	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; discontinuous lenses of sand and gravel with depth; surface sand and gravel ridges (eskers) abundant although most are too small to be shown on the map; abundant sloughs and depressions generally in excess of 30 per square mile	Undulating to hummocky; local relief 10 to 35 feet	Glacial sediment (till) deposited from stagnant ice mass.
21	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; minor amounts of sand and gravel; discontinuous lenses of sand and gravel with depth; locally may be overlain by 1 to 2 feet of poorly sorted sand; lag concentrate of boulders very common.	Flat to undulating; local relief less than 5 feet	Glacial sediment (till).
22	**Coleharbor Group** Stony loam facies Sand and gravel facies	Pebbly, silty, clay loam; locally sand and gravel; may be underlain by shaly sand and gravel that is generally less than 5 feet thick.	Flat to gently undulating	Glacial sediment (till) deposited in former glacial meltwater channels.
23	**Pierre Formation** Upper Member	Shale; gray, hard, siliceous non-calcareous; thin beds of yellow clay; iron and manganese concretions; fractures easily; weathers into distinct chips and flakes.	Steep slopes	Marine offshore sediment.
24	**Pierre Formation** Lower Member	Shale; dark gray to black; soft; abundant yellow clay beds; upper portion weathers into a distinctive "popcornlike" surface; slumps easily.	Moderate slopes	Marine offshore sediment.
25	**Niobrara Formation**	Shale; yellowish-tan to light gray; calcareous; upper yellowish member is jointed and fossils are common; lower gray member is speckled and has fissile structure.	Steep slopes	Marine offshore sediment.
26	**Carlile Formation**	Shale; black; soft; discontinuous limonite stringers; large ellipsoidal concretions common; generally non-calcareous; abundant gypsum crystals; fish scales common; slumps easily.	Moderate to steep slopes	Marine offshore sediment.

Map units 2, 7, 8, 15, and 16 are not included in Cavalier County

MISCELLANEOUS SYMBOLS

- Eskers
- Geologic Contacts
- Inferred Geologic Contacts
- Ponds and Lakes
- Beach Ridges
- Ice-drag Marks
- Washboard Moraines
- Drumlins
- Scarp
- Compaction Ridge
- Kp Cretaceous Pierre Formation Outcrop
- Kn Cretaceous Niobrara Formation Outcrop
- Kc Cretaceous Carlile Formation Outcrop
- (32) North Dakota State Road
- (I-29) United States Road

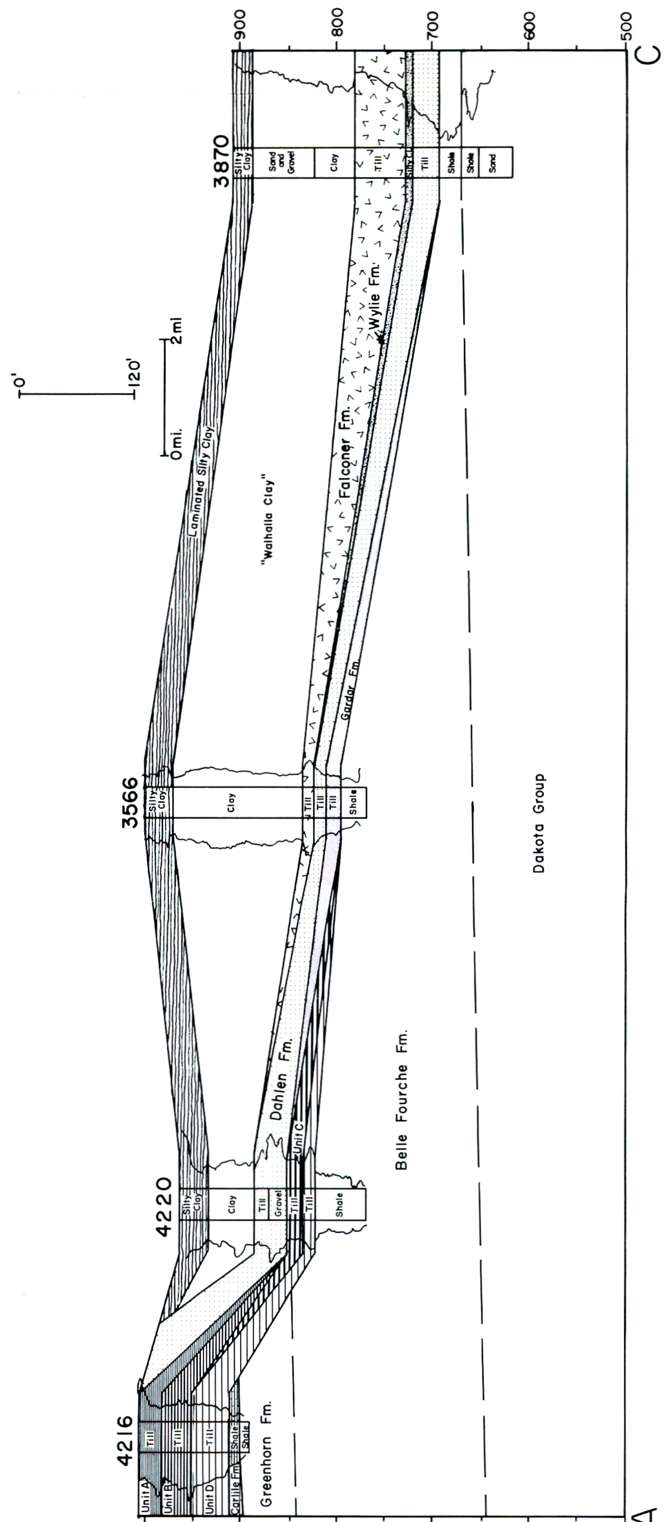
STRATIGRAPHIC UNITS

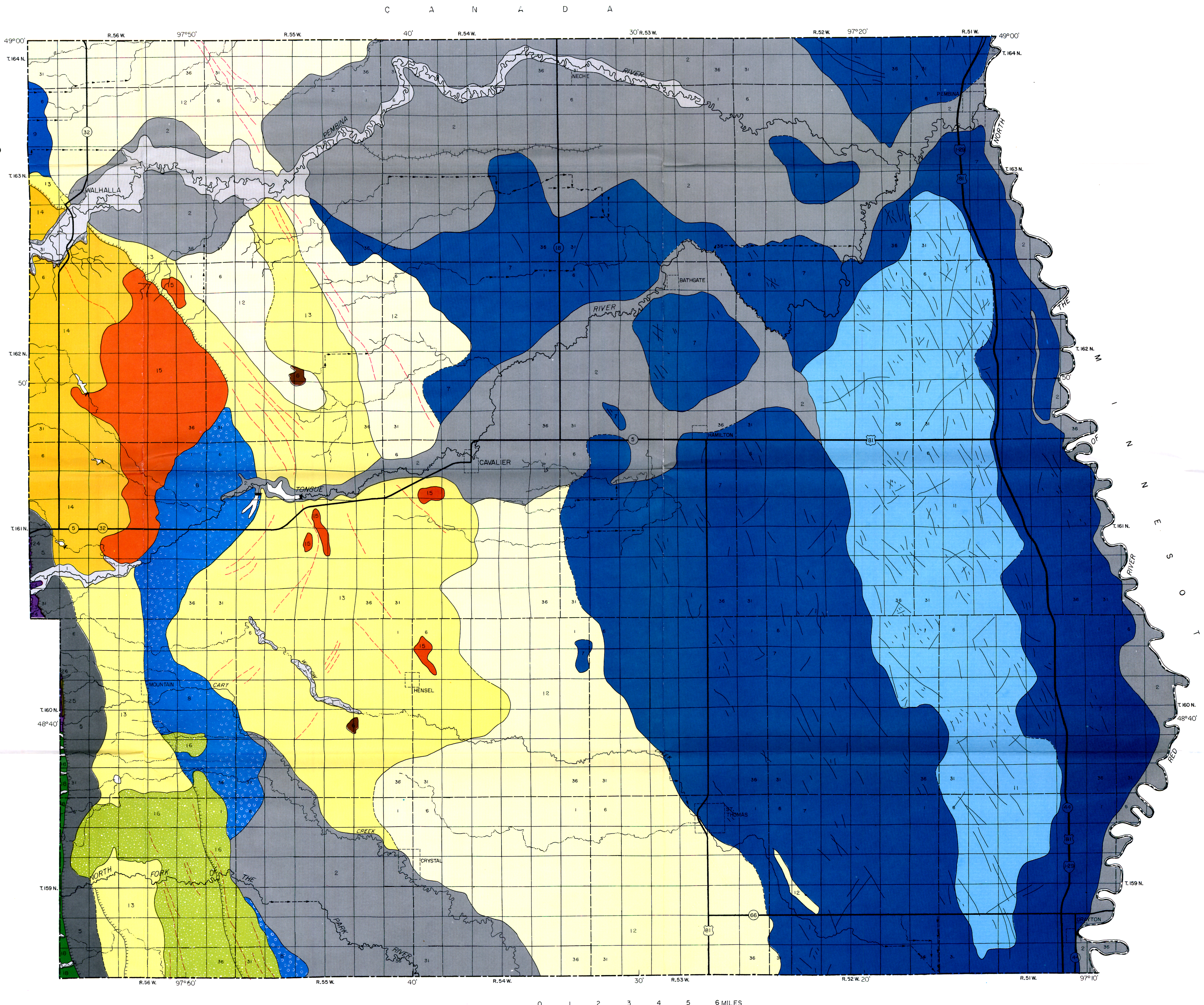
Sequence	System	Epoch	Formation or Group		Description	Map Units
Tejas Sequence	Quaternary System	Holocene Epoch	WALSH FORMATION	Clay Facies	Clay; dark brown to black; dispersed organic material; bedding planes difficult to recognize; Swamp, slough and pond sediment	6
				Sand and Silt Facies	Silty clay, clayey silt, sandy silt; dark brown-gray-black; vague horizontal bedding; wood, shells, and bone fragments present; River sediment deposited along river valleys and floodplains.	1, 2, 3, 4
				Gravel Facies	Gravel, sand, silt, clay; poorly sorted to nonsorted; lithology and texture variable; commonly found along fronts of steep slopes; Deposited by slopewash, slumping, sliding, and earth creep.	5
		Pleistocene Epoch	COLEHARBOR GROUP	Stony Loam Facies	Homogenous mixture of clay, silt, sand, pebbles, cobbles, and boulders in various proportions, non-structified; poorly sorted; Glacial sediment.	16, 17, 18, 19, 20, 21, 22
				Sand and Gravel Facies	Gravel, gravelly sand, sand, silty sand, sandy silt, vague to distinct bedding; well sorted to poorly sorted; Most deposited by rivers during glacial times; some deposited on beaches and in near-shore environments; some deposited by wind.	12, 13, 14, 15, 16, 22
				Silt and Clay Facies	Clay, silty clay, clayey silt, silt, and some very fine sand; generally laminated but may be nonbedded; Deposited in lakes.	7, 8, 9, 10, 11, 12, 13, 16
Zuni Sequence	Cretaceous System		PIERRE FORMATION	Upper Member	Shale; gray; hard; siliceous; jointed; iron-stained; thin yellow clay bands near base; Marine offshore sediment.	23
				Lower Member	Shale; gray to black; calcareous in upper part; abundant yellow clay bands throughout, may be several inches to two feet thick; slumps easily; Marine offshore sediment.	17, 24
			NIOBRARA FORMATION		Shale, tan in upper part; light gray and speckled in lower part; highly calcareous; blocky structure in upper part; fissile structure in lower part; fossiliferous; Marine offshore sediment.	17, 25
			CARLILE FORMATION		Shale; black, non-calcareous; abundant fish scales; slumps easily; Marine offshore sediment.	26

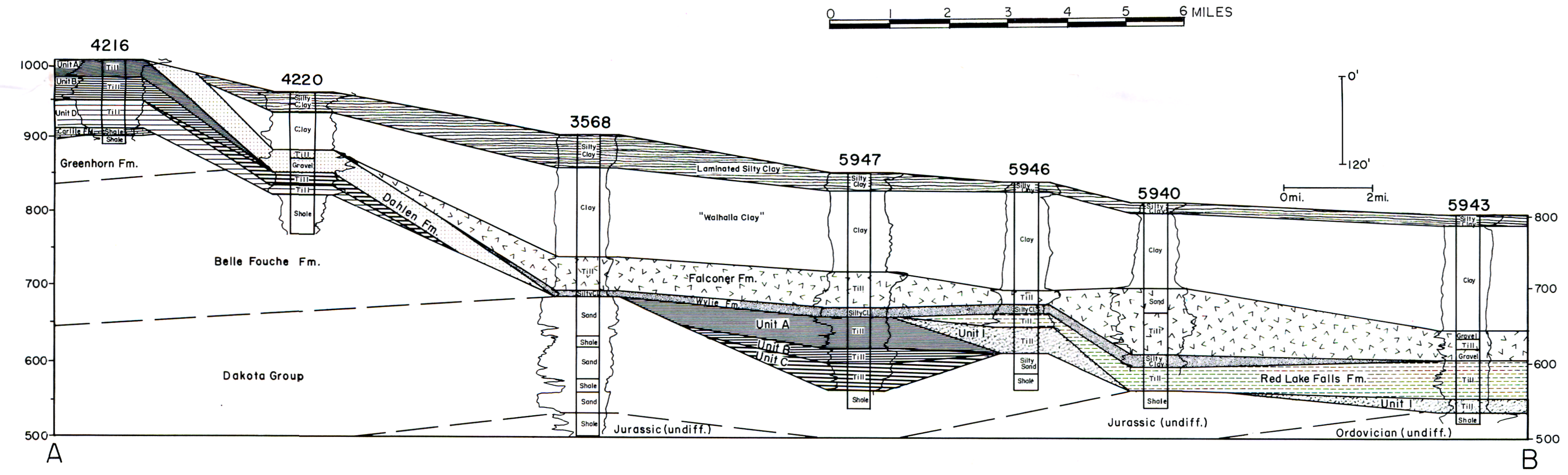
PART 1 PLATE 2
COUNTY GROUND-WATER STUDIES 20
BULLETIN 62

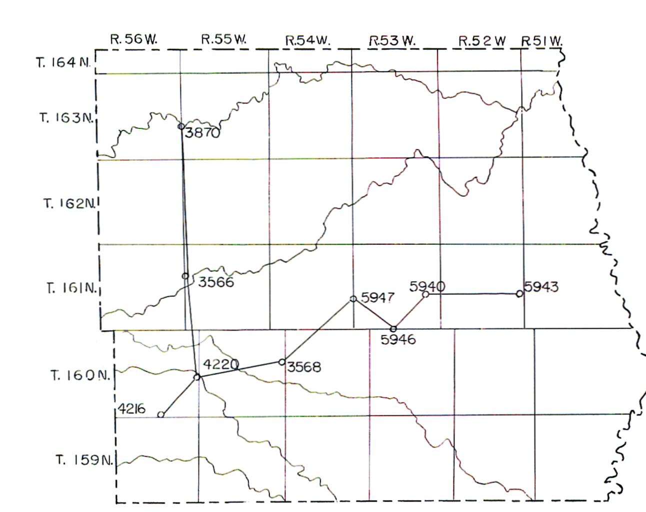
PLATE 2. - GEOLOGY OF PEMBINA COUNTY

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION









STRATIGRAPHIC UNITS

Sequence	System	Epoch	Formation or Group		Description	Map Units
Tejas Sequence	Quaternary System	Holocene Epoch	WALSH FORMATION	Clay Facies	Clay; dark brown to black; dispersed organic material; bedding planes difficult to recognize; Swamp, slough and pond sediment	6
				Sand and Silt Facies	Silty clay, clayey silt, sandy silt; dark brown-gray-black; vague horizontal bedding; wood, shells, and bone fragments present; River sediment deposited along river valleys and floodplains.	1, 2, 3, 4
				Gravel Facies	Gravel, sand, silt, clay; poorly sorted to nonsorted; lithology and texture variable; commonly found along fronts of steep slopes; Deposited by slopewash, slumping, sliding, and earth creep.	5
		Pleistocene Epoch	COLEHARBOR GROUP	Stony Loam Facies	Homogenous mixture of clay, silt, sand, pebbles, cobbles, and boulders in various proportions, non-structified; poorly sorted; Glacial sediment.	16, 17, 18, 19, 20, 21, 22
				Sand and Gravel Facies	Gravel, gravelly sand, sand, silty sand, sandy silt, vague to distinct bedding; well sorted to poorly sorted; Most deposited by rivers during glacial times; some deposited on beaches and in near-shore environments; some deposited by wind.	12, 13, 14, 15, 16, 22
				Silt and Clay Facies	Clay, silty clay, clayey silt, silt, and some very fine sand; generally laminated but may be nonbedded; Deposited in lakes.	7, 8, 9, 10, 11, 12, 13, 16
Zuni Sequence	Cretaceous System		PIERRE FORMATION	Upper Member	Shale; gray; hard; siliceous; jointed; iron-stained; thin yellow clay bands near base; Marine offshore sediment.	23
				Lower Member	Shale; gray to black; calcareous in upper part; abundant yellow clay bands throughout, may be several inches to two feet thick; slumps easily; Marine offshore sediment.	17, 24
			NIOBRARA FORMATION		Shale, tan in upper part; light gray and speckled in lower part; highly calcareous; blocky structure in upper part; fissile structure in lower part; fossiliferous; Marine offshore sediment.	17, 25
			CARLILE FORMATION		Shale; black, non-calcareous; abundant fish scales; slumps easily; Marine offshore sediment.	26

MAP UNITS

Unit	Lithostratigraphic Unit	Description	Topography	Origin
1	**Walsh Formation** Sand and silt facies	Generally gray to black bedding is horizontal although vague; organic fragments common.	Flat to gently sloping	Modern river overbank sediment; some river-channel sediment.
2	**Walsh Formation** Sand and silt facies	Light to very dark gray; bedding obscure; thins rapidly away from rivers.	Flat to gently rolling	Modern river overbank sediment.
3	**Walsh Formation** Sand and silt facies	Clay and silt underlain by sand and gravel; cross-bedded; moderately sorted.	Flat to nearly flat	Pre-modern river overbank sediment; some river-channel sediment.
4	**Walsh Formation** Sand and silt facies	Mostly sand and gravel; large.	Steep slopes	Sediments deposited by the Pembina River during a time of very high discharge.
5	**Walsh Formation** Gravel facies	Heterogenous mixture of sand silt clay and gravel; poorly sorted; generally dense and compact.	Moderate to steep slopes	Slopewash and creep sediment.
6	**Walsh Formation** Clay facies	Vague bedding; dark brown to black.	Flat	Slough and pond sediment.
7	**Coleharbor Group** Silt and clay facies	Laminated; yellowish-brown to light gray.	Nearly flat to gently undulating	Offshore sediment of Lake Agassiz.
8	**Coleharbor Group** Silt and clay facies	Laminated to massive yellowish-brown; snail and clam shells present.	Nearly flat to gently undulating	Offshore sediment of a lagoon near Lake Agassiz; the area containing this sediment was cut off from the rest of the lake by longshore bars and spits.
9	**Coleharbor Group** Silt and clay facies	Laminated; yellowish-brown to light gray locally overlain by thin veneer of clayey sand.	Nearly flat to gently undulating	Offshore sediment of Lake Agassiz modified by postdepositional processes such as slopewash and groundwater discharge.
10	**Coleharbor Group** Silt and clay facies	Laminated; dark gray to black; snail shells present.	Nearly flat	Sediment deposited in lakes whose basins were enclosed by ice.
11	**Coleharbor Group** Silt and clay facies	Laminated; yellowish-brown to light gray; gypsum crystals abundant.	Nearly flat to gently undulating	Saline offshore sediment of Lake Agassiz; salinity is a result of groundwater discharge from underlying Paleozoic and Pleistocene sediments.
12	**Coleharbor Group** Silt and clay facies Sand and gravel facies	Mostly silt and very fine sand; yellowish-brown to light-brown; bedding not apparent.	Nearly flat to gently undulating	Near-shore or shallow-water sediment of Lake Agassiz.
13	**Coleharbor Group** Sand and gravel facies Silt and clay facies	Mostly sand and gravel; well sorted; distinct cross-bedding; gravel is generally found in linear ridges.	Rolling to undulating	Shoreline, near-shore, and offshore sediments of Lake Agassiz.
14	**Coleharbor Group** Sand and gravel facies	Mostly medium to coarse sand; moderately to well sorted; grades from shaly sand in the west to clean sand in the east.	Rolling to hummocky	Near-shore and fluvial sediments that make up the Pembina Delta.
15	**Coleharbor Group** Sand and gravel facies	Fine sand; well sorted.	Rolling to hilly	Wind-blown sediments of sand dunes.
16	**Coleharbor Group** Sand and gravel facies Stony loam facies	Pebbly, silty, clay loam overlain by thin discontinuous bodies of sand and gravel; locally thin veneer of laminated silt and clay; surface boulders abundant locally.	Nearly flat to undulating	Glacial sediment (till) modified by wave action of Lake Agassiz.
17	**Coleharbor Group** Stony loam facies **Pierre Formation and Niobrara Formation**	Pebbly, silty, clay loam; generally thin; overlying Cretaceous Pierre and Niobrara Formations; locally minor amounts of sand and gravel; bedrock commonly exposed; abundant surface concentrations of boulders.	Hilly to undulating	Eroded glacial sediment (till) overlying lower Pierre and Niobrara Formations.
18	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; minor amounts clay, sand, and gravel; generally yellowish-brown to olive gray; few sloughs and depressions; occassional surface ridges of stratified sand and gravel (eskers) although most are too small to be shown on the map.	Nearly flat to gently undulating; local relief 5 to 15 feet	Glacial sediment (till).
19	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; discontinuous lenses of sand and gravel at depth; surface sand and gravel ridges (eskers) may be covered by thin veneers of silty clay loam; generally yellowish-brown to olive gray; abundant sloughs and depressions.	Gently undulating; local relief 10 to 20 feet	Glacial sediment (till).
20	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; discontinuous lenses of sand and gravel with depth; surface sand and gravel ridges (eskers) abundant although most are too small to be shown on the map; abundant sloughs and depressions generally in excess of 30 per square mile	Undulating to hummocky; local relief 10 to 35 feet	Glacial sediment (till) deposited from stagnant ice mass.
21	**Coleharbor Group** Stony loam facies	Pebbly, silty, clay loam; minor amounts of sand and gravel; discontinuous lenses of sand and gravel with depth; locally may be overlain by 1 to 2 feet of poorly sorted sand; lag concentrate of boulders very common.	Flat to undulating; local relief less than 5 feet	Glacial sediment (till).
22	**Coleharbor Group** Stony loam facies Sand and gravel facies	Pebbly, silty, clay loam; locally sand and gravel; may be underlain by shaly sand and gravel that is generally less than 5 feet thick.	Flat to gently undulating	Glacial sediment (till) deposited in former glacial meltwater channels.
23	**Pierre Formation** Upper Member	Shale; gray, hard, siliceous non-calcareous; thin beds of yellow clay; iron and manganese concretions; fractures easily; weathers into distinct chips and flakes.	Steep slopes	Marine offshore sediment.
24	**Pierre Formation** Lower Member	Shale; dark gray to black; soft; abundant yellow clay beds; upper portion weathers into a distinctive "popcornlike" surface; slumps easily.	Moderate slopes	Marine offshore sediment.
25	**Niobrara Formation**	Shale; yellowish-tan to light gray; calcareous; upper yellowish member is jointed and fossils are common; lower gray member is speckled and has fissile structure.	Steep slopes	Marine offshore sediment.
26	**Carlile Formation**	Shale; black; soft; discontinuous limonite stringers; large ellipsoidal concretions common; generally non-calcareous; abundant gypsum crystals; fish scales common; slumps easily.	Moderate to steep slopes	Marine offshore sediment.

Map units 3, 10, 17, 19, 20, 21, 22, and 26 are not included in Pembina County

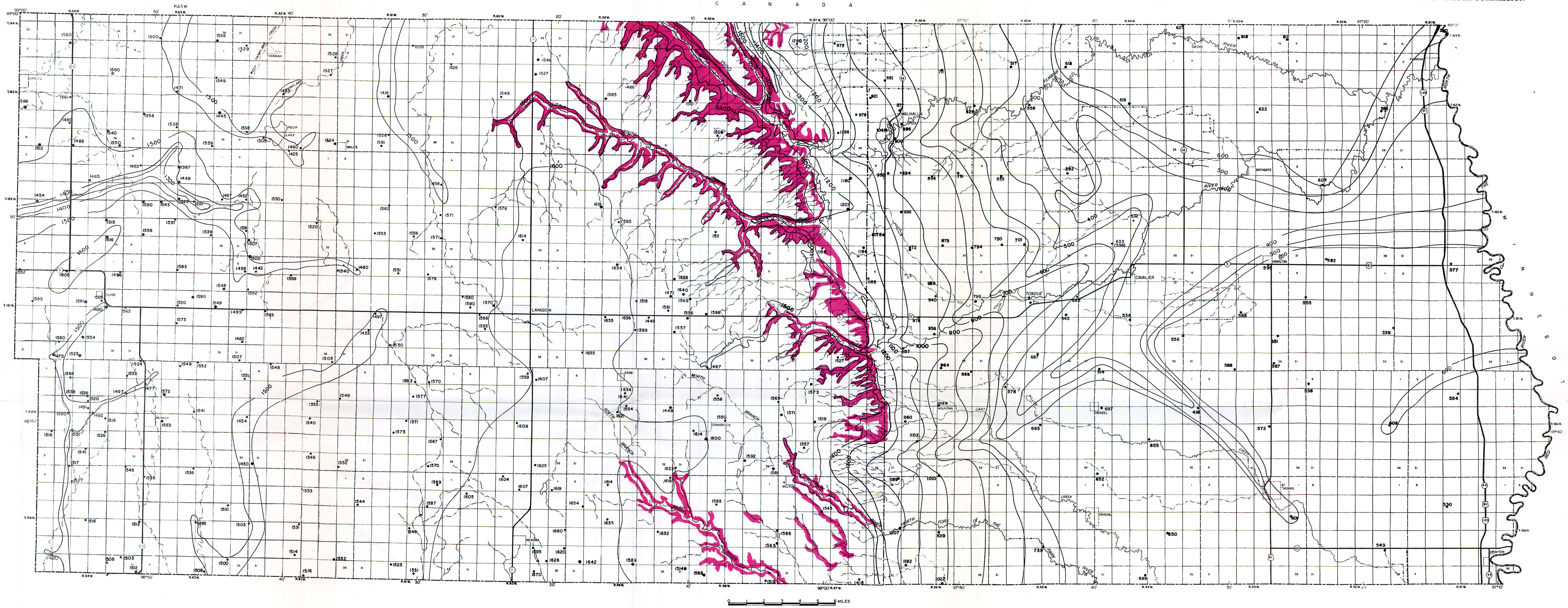
MISCELLANEOUS SYMBOLS

- Eskers
- Geologic Contacts
- Inferred Geologic Contacts
- Ponds and Lakes
- Beach Ridges
- Ice-drag Marks
- Washboard Moraines
- Drumlins
- Scarp
- Compaction Ridge
- Kp Cretaceous Pierre Formation Outcrop
- Kn Cretaceous Niobrara Formation Outcrop
- Kc Cretaceous Carlile Formation Outcrop
- 32 North Dakota State Road
- 81 United States Road

PART 1 PLATE 3
COUNTY GROUNDWATER STUDIES 20
BULLETIN 62

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION

PLATE 3—BEDROCK TOPOGRAPHY OF CAVALIER AND PEMBINA COUNTIES



Contour Interval=100 Feet

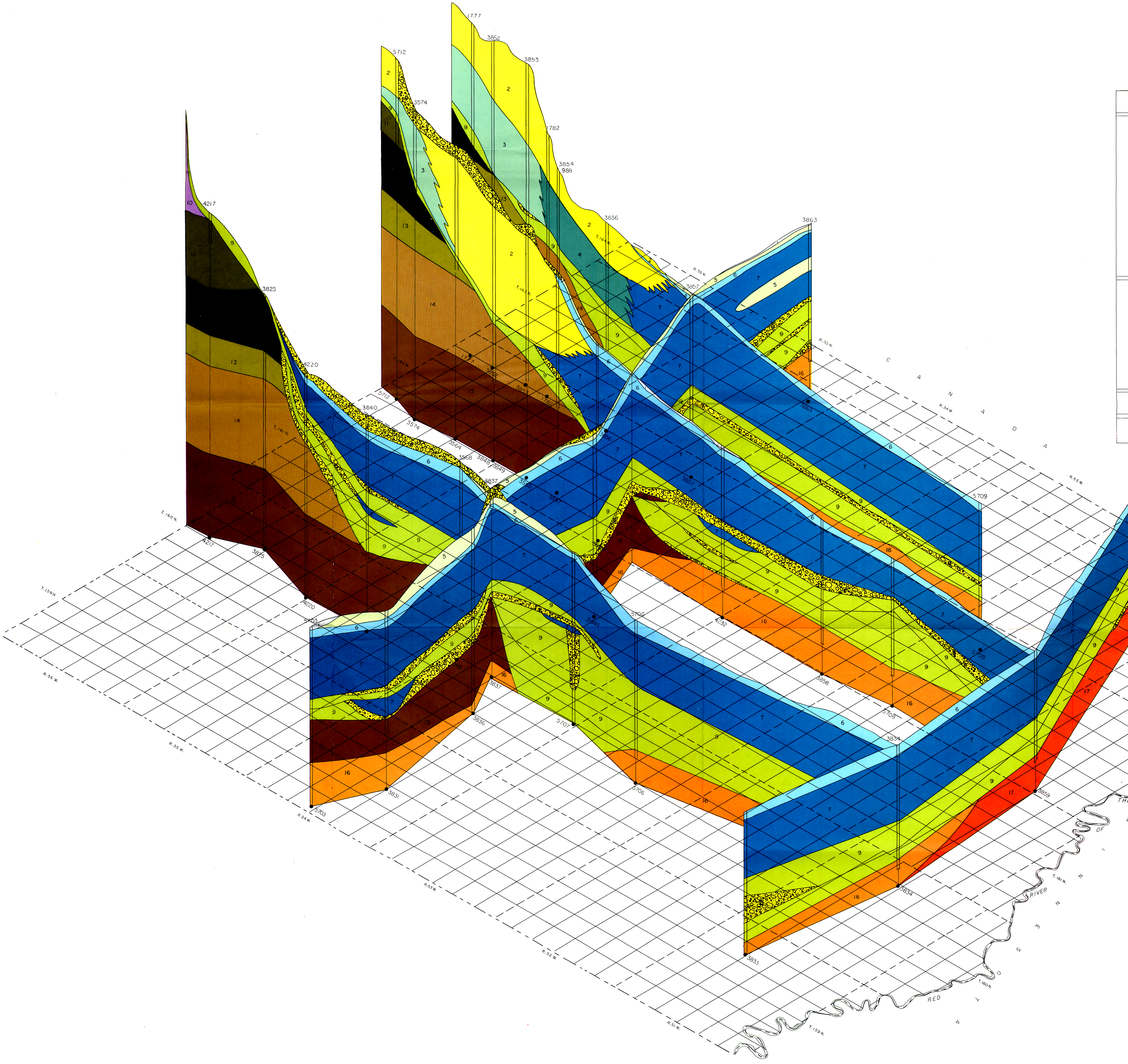
1500 Bedrock Elevation

Shaded areas indicate surface exposure of bedrock.

PART 1 PLATE 4
COUNTY GROUND - WATER STUDIES 20
BULLETIN 62

PLATE 4 - THREE - DIMENSIONAL CROSS SECTION OF PEMBINA COUNTY

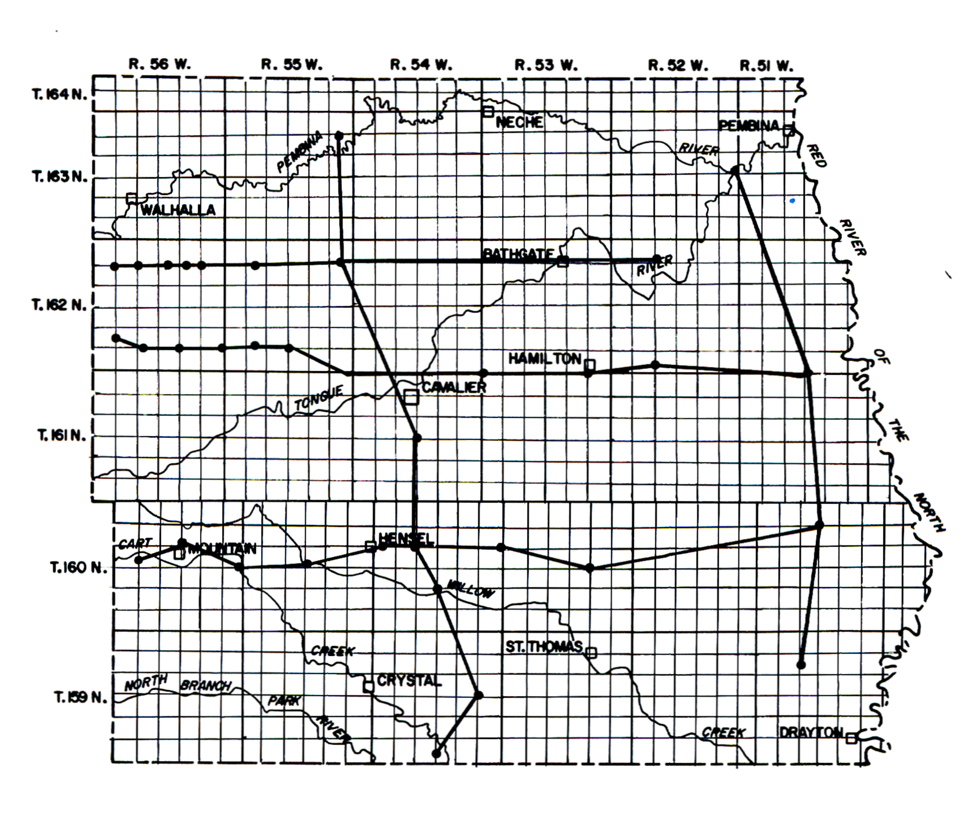
NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION



3-DIMENSIONAL GEOLOGIC DIAGRAM OF PEMBINA COUNTY

Unit	System	Group or Formation	Lithology
1	Tertiary	Walsh Formation	Clay and silt
2		Coleharbor Group	Sand
3			Shale and gravel
4			Sand grading to silt
5			Very fine sand and silt
6			Laminated silty clay
7			Clay
8			Sand and gravel
9			Till
10	Cretaceous	Pierre Formation	Shale
11		Niobrara Formation	Shale and marlstone
12		Carlile Formation	Shale
13		Greenhorn Formation	Shale, calcareous
14		Belle Fourche Formation	Shale
15		Dakota Group	Shale and sandstone
16	Jurassic	"undifferentiated"	Shale, sandstone, limestone, and anhydrite
17	Ordovician	"undifferentiated"	Dolomite and limestone

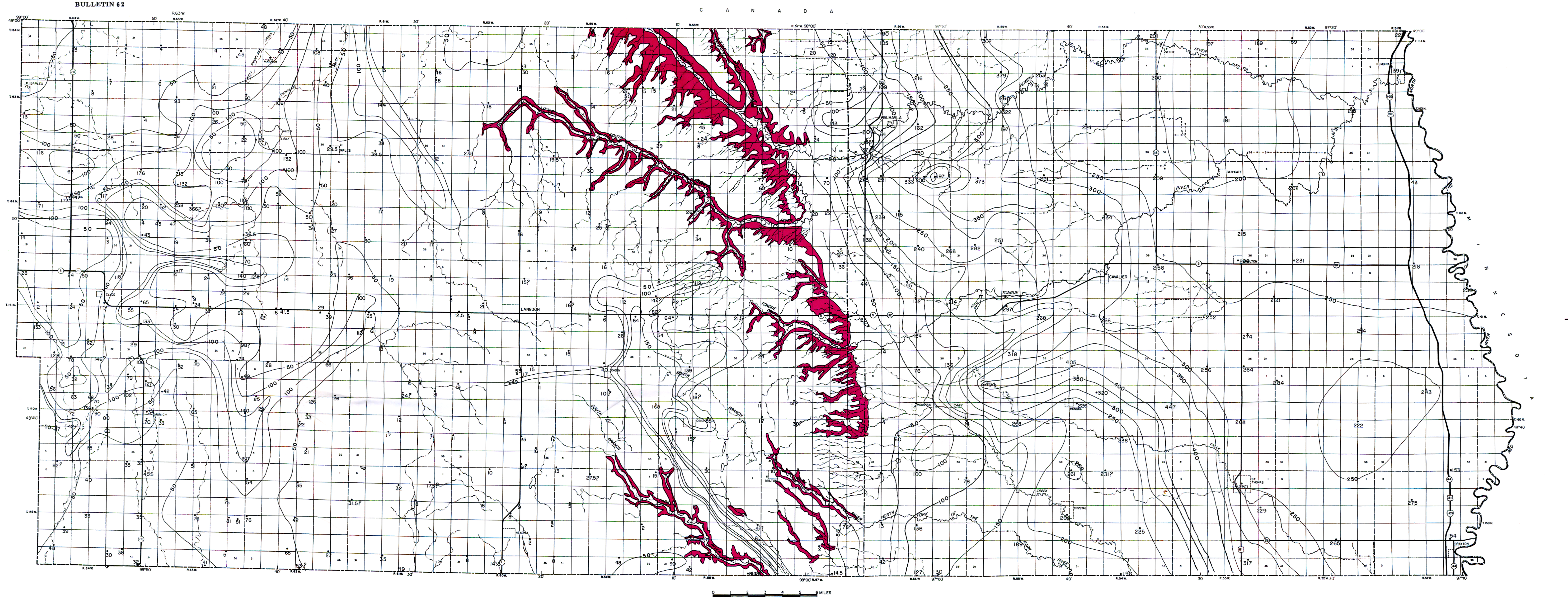
LOCATION OF CROSS SECTIONS



PART 1 PLATE 5
COUNTY GROUNDWATER STUDIES 20
BULLETIN 62

PLATE 5—THICKNESS OF DRIFT IN CAVALIER AND PEMBINA COUNTIES

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION

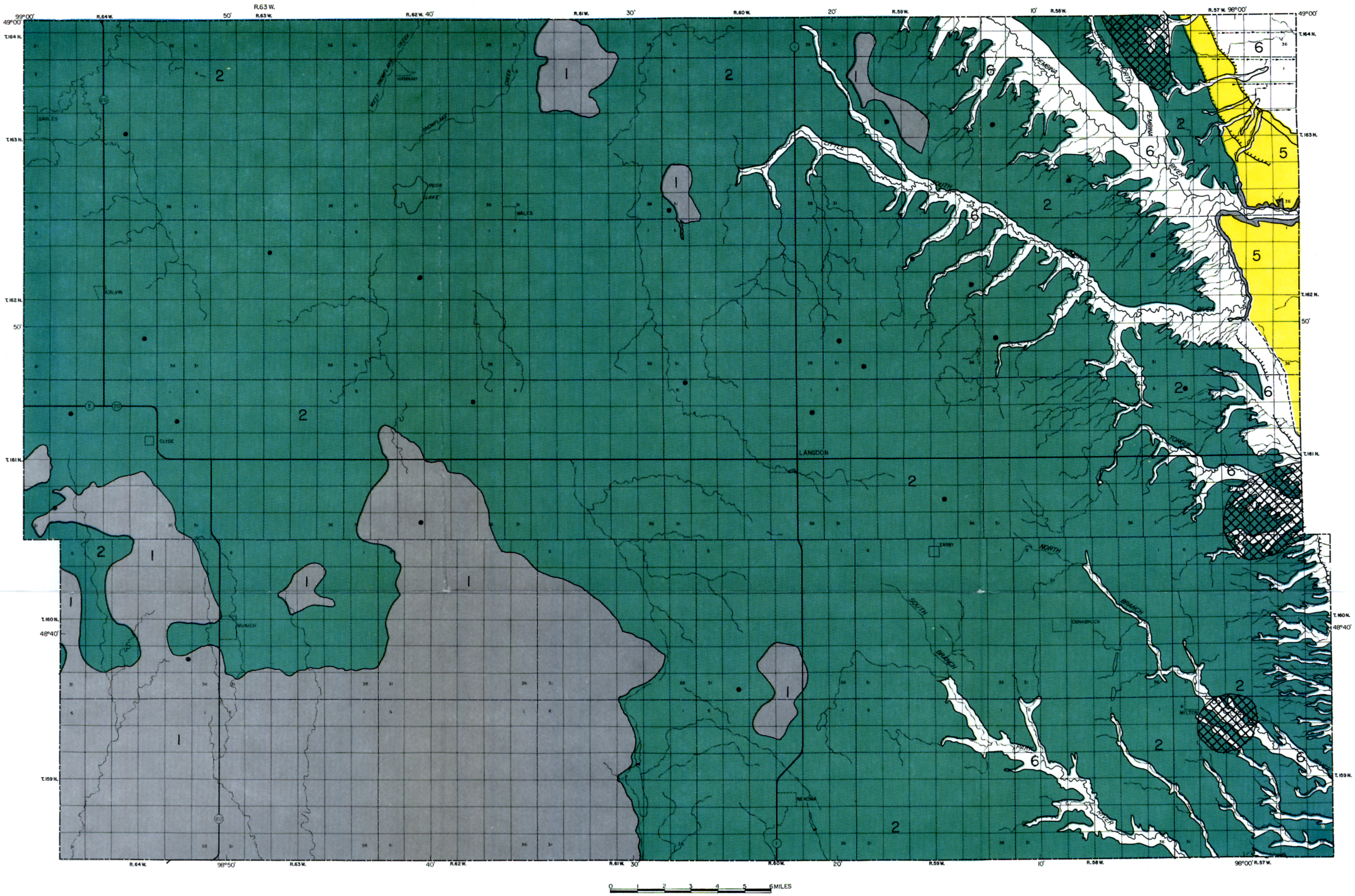


Contour Interval=50 Feet

235 Thickness of Glacial Drift

Shaded areas indicate surface exposure of bedrock.

PLATE 6.—POTENTIAL RESOURCES—CAVALIER COUNTY



Potential Resources Map

Surface Sand and Gravel Resources

1 — Small isolated deposits of variable quality for individual use. Usually found in sinuous ridges, rounded hills, and along streams.

2 — Occassional isolated deposits of variable quality for individual use.

3 — Small quantities of sand and gravel. Quality is variable but generally adequate for uses other than high quality aggregate.

4 — Extensive sand and gravel deposits. Generally of excellent quality, although shale-pebble content may exceed 30%. Large quantities of sand present.

5 — Extensive quantities of sand and little or no gravel. Sand generally well sorted and clean. May be of commercial quality.

6 — No surface sand or gravel supplies.

Map units 3 and 4 are not included in Cavalier County.

Areas that have been investigated for other resources

Resource	North Dakota Geological Survey Report of Investigations
Clays and shales	RI-17: Manz, O. E., 1954; Investigation of Lightweight Aggregate Possibilities of Some North Dakota Clays and Shales. RI-27: Manz, O. E., 1956; Investigation of Lake Agassiz Clay Deposits.

• Oil Exploration Tests

Miscellaneous Symbols

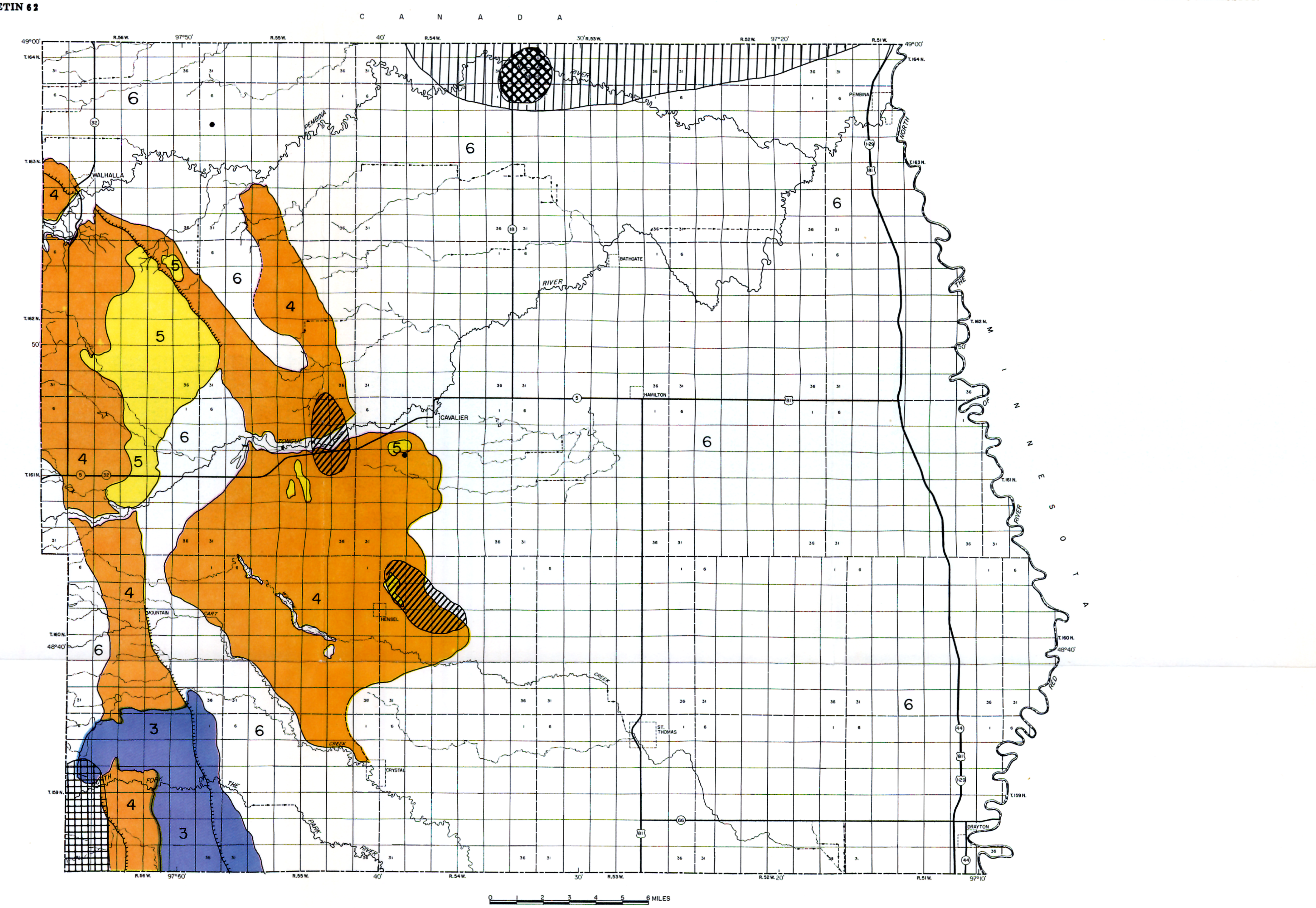
Prominent scarp

Contact, accuracy within .1 mile

Inferred contact accuracy between .2 and .3 mile

PLATE 7.—POTENTIAL RESOURCES—PEMBINA COUNTY

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION



Potential Resources Map

Surface Sand and Gravel Resources

1	Small isolated deposits of variable quality for individual use. Usually found in sinuous ridges, rounded hills, and along streams.
2	Occassional isolated deposits of variable quality for individual use.
3	Small quantities of sand and gravel. Quality is variable but generally adequate for uses other than high quality aggregate.
4	Extensive sand and gravel deposits. Generally of excellent quality, although shale pebble content may exceed 30%. Large quantities of sand present.
5	Extensive quantities of sand and little or no gravel. Sand generally well sorted and clean. May be of commercial quality.
6	No surface sand or gravel supplies.

Map units 1 and 2 are not included in Pembina County.

Areas that have been investigated for other resources

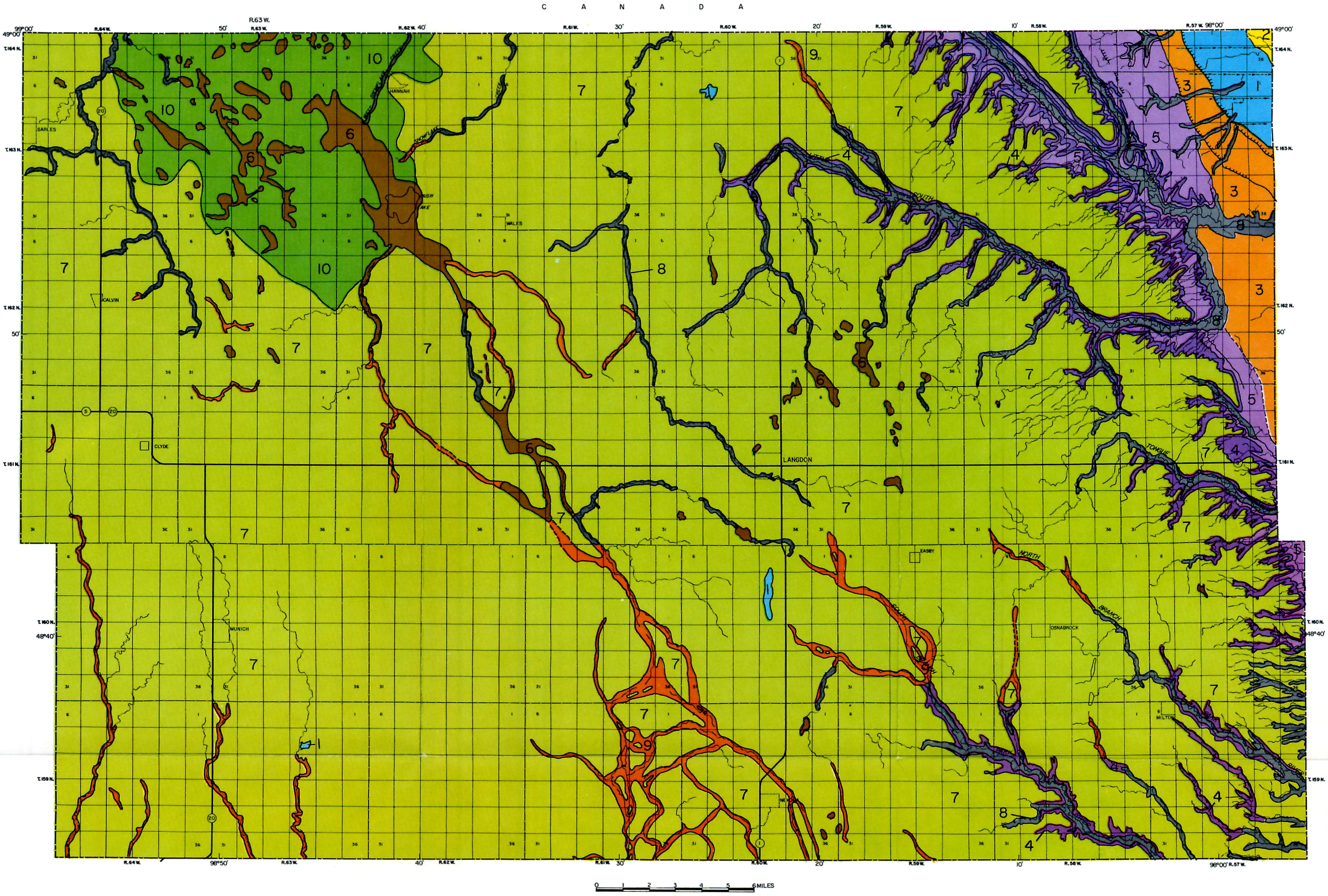
Resource	North Dakota Geological Survey Report of Investigations
Clays and shales	RI-17: Manz, O. E., 1954; Investigation of Lightweight Aggregate Possibilities of Some North Dakota Clays and Shales. RI-27: Manz, O. E., 1956; Investigation of Lake Agassiz Clay Deposits.
Cement rock	RI-41: Carlson, C. G., 1964; The Niobrara Formation of Eastern North Dakota: Its Possibilities for use as a Cement Rock. RI-48: Anderson, S. B. and Haraldson, H. C., 1969; Cement Rock Possibilities in Paleozoic Rocks of Eastern North Dakota.
Magnetic Anomalies	RI-49: Moore, W. L. and Karner, F. R., 1969; Magnetic Anomalies in Pembina County, North Dakota.
Gypsum—Dolomite	Open File Report: Results of Gypsum—Dolomite Exploratory Drilling Project, Pembina County, North Dakota.
• Oil Exploration Tests	

Miscellaneous Symbols

- Prominent scarp
- Contact, accuracy within .1 mile
- Inferred contact accuracy between .2 and .3 mile

PLATE 8.–GENERAL CONSTRUCTION CONDITIONS–CAVALIER COUNTY

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION



Miscellaneous Symbols

Prominent scarp

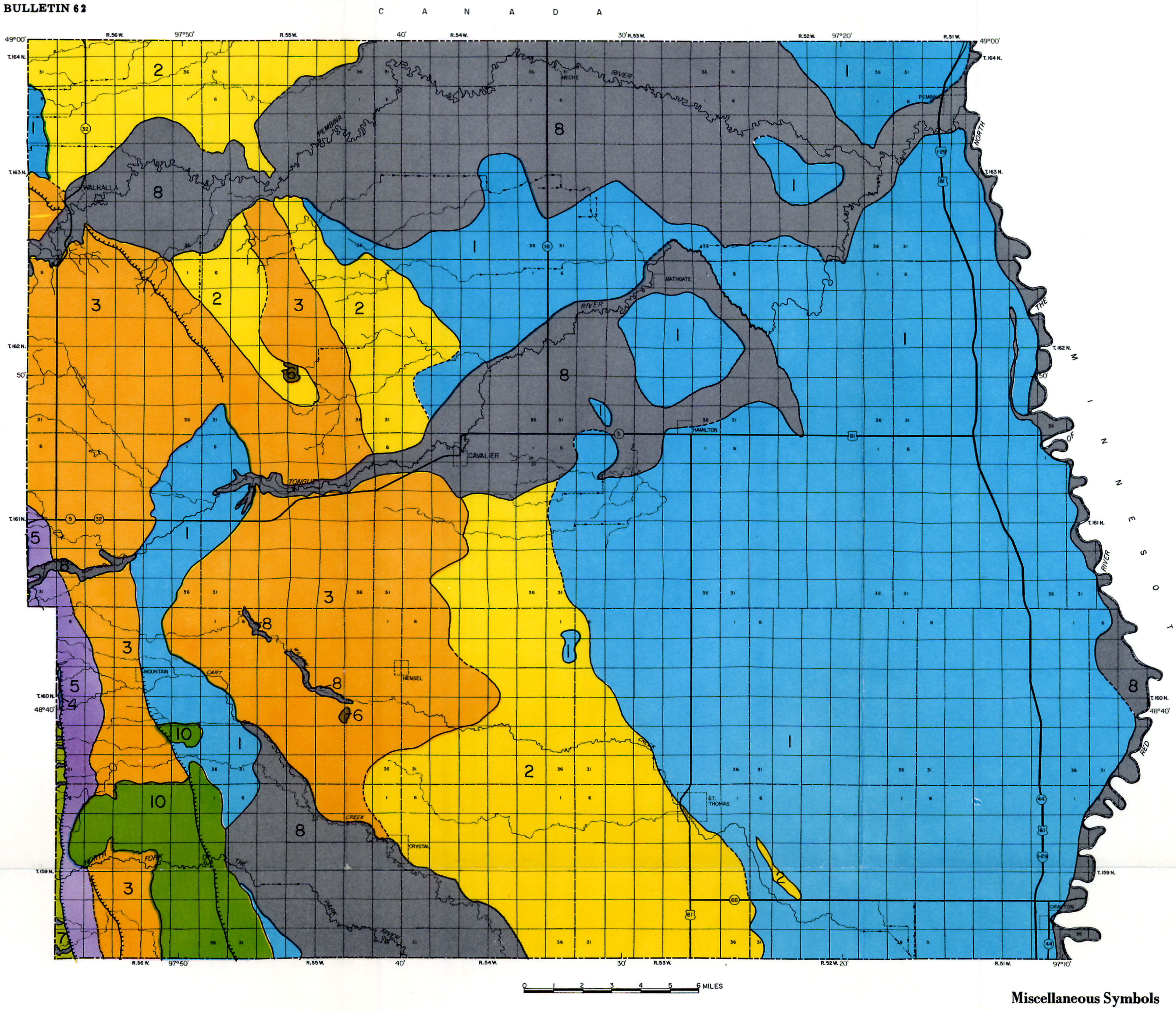
Contact, accuracy within .1 mile

Inferred contact accuracy between .2 and .3 mile

General Construction Conditions

Unit	Geology	Water Table	Permeability	Slope Stability in Open Cuts	Compressibility	Bearing Strength	Comments
1	Clay, minor amounts of silt; Lake sediment	High	Low	Low	High	Low	1. Material susceptible to frost heaving. 2. Highly plastic. 3. Poor internal drainage.
2	Silt and very fine sand; Lake sediment	Low	Moderate to high	Low	Moderate	Low to moderate	1. Silt and sand are gradational with clay and that may be encountered during excavation.
3	Sand and gravel; Beach and delta sediments	Low	High	Low to moderate	Low	High	1. Stable on natural slopes but is easily erodable in unprotected cuts.
4	Shale; includes siliceous upper Pierre shale, and calcareous Niobrara Formation	Low	Low to high	High	Low	High	1. Siliceous shale usually highly fractured resulting in high permeabilities. 2. Shale may be subject to slaking when wet. 3. Suitable foundation material for most types of construction.
5	Shale, clay, silt, sand, and gravel; Shale, colluvium and glacial sediments–Till	Low	Low to high	Low	Low to high	Low	1. Shale is very bentonitic, therefore plastic and may slump readily. 2. Sand, silt, and gravel is landslide material at the base of slopes and is subject to continued sliding. 3. Thin glacial sediments over plastic shales and clay, boulders abundant.
6	Clay, highly organic; Slough deposits	High	Low	Low	High	Low	1. Highly plastic and unstable. 2. High water table and internal drainage may cause problems.
7	Sandy clay silt, locally sand and gravel; Glacial Sediments–Till	Generally greater than 10 feet	Low to high	High to moderate	Low to moderate	High	1. Occassional sand and gravel lenses encountered in excavation. 2. Suitable for most types of construction.
8	Clay and silt, sand and gravel; Alluvium	High	Low to moderate	Low to moderate	Moderate to high	Moderate to low	1. Areas underlain by these deposits subject to flooding. 2. Clay and silt facies are moderately plastic and are susceptible to frost heaving. 3. Internal drainage may be a problem.
9	Sandy clay silt and sand and gravel; Glacial Sediments and Alluvium	Low to high	Low to high	Moderate to high	Moderate to low	Moderate to high	1. Occurs in channels that may be filled during spring runoff. 2. Sand and gravel may be encountered at shallow depths. 3. These channels are avenues for groundwater flow.
10	Sandy clay silt, overlain by thin discontinuous bodies of sand and gravel; Surface boulders abundant, Glacial sediments	Generally greater than 10 feet	Low to high	Moderate to high	Moderate to low	Moderate to high	1. Good internal drainage where overlain by sand and gravel. 2. Boulder at or near the surface may cause problems of workability. 3. Generally suitable for most types of construction, although extensive site investigation may be necessary because the variability of the sediment.

PLATE 9.—GENERAL CONSTRUCTION CONDITIONS—PEMBINA COUNTY



Miscellaneous Symbols

- Prominent scarp
- Contact, accuracy within .1 mile
- Inferred contact accuracy between .2 and .3 mile

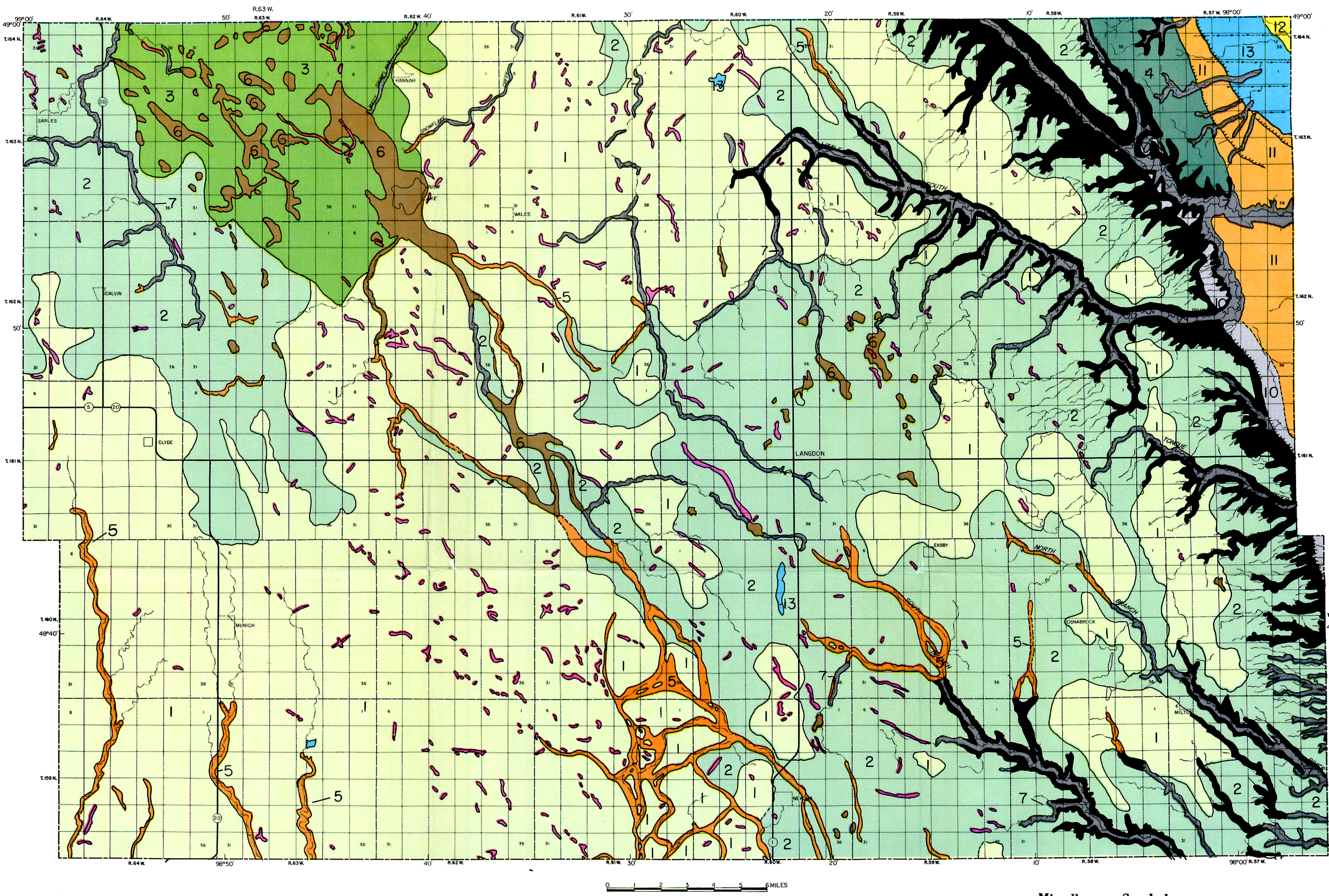
General Construction Conditions

Unit	Geology	Water Table	Permeability	Slope Stability in Open Cuts	Compressibility	Bearing Strength	Comments
1	Clay, minor amounts of silt; Lake sediment	High	Low	Low	High	Low	1. Material susceptible to frost heaving. 2. Highly plastic. 3. Poor internal drainage.
2	Silt and very fine sand; Lake sediment	Low	Moderate to high	Low	Moderate	Low to moderate	1. Silt and sand are gradational with clay and that may be encountered during excavation.
3	Sand and gravel; Beach and delta sediments	Low	High	Low to moderate	Low	High	1. Stable on natural slopes but is easily erodable in unprotected cuts.
4	Shale; includes siliceous upper Pierre shale, and calcareous Niobrara Formation	Low	Low to high	High	Low	High	1. Siliceous shale usually highly fractured resulting in high permeabilities. 2. Shale may be subject to slaking when wet. 3. Suitable foundation material for most types of construction.
5	Shale, clay, silt, sand, and gravel; Shale, colluvium and glacial sediments—Till	Low	Low to high	Low	Low to high	Low	1. Shale is very bentonitic, therefore plastic and may slump readily. 2. Sand, silt, and gravel is landslide material at the base of slopes and is subject to continued sliding. 3. Thin glacial sediments over plastic shales and clay, boulders abundant.
6	Clay, highly organic; Slough deposits	High	Low	Low	High	Low	1. Highly plastic and unstable. 2. High water table and internal drainage may cause problems.
7	Sandy clay silt, locally sand and gravel; Glacial Sediments—Till	Generally greater than 10 feet	Low to high	High to moderate	Low to moderate	High	1. Occassional sand and gravel lenses encountered in excavation. 2. Suitable for most types of construction.
8	Clay and silt, sand and gravel; Alluvium	High	Low to moderate	Low to moderate	Moderate to high	Moderate to low	1. Areas underlain by these deposits subject to flooding. 2. Clay and silt facies are moderately plastic and are susceptible to frost heaving. 3. Internal drainage may be a problem.
9	Sandy clay silt and sand and gravel; Glacial Sediments and Alluvium	Low to high	Low to high	Moderate to high	Moderate to low	Moderate to high	1. Occurs in channels that may be filled during spring runoff. 2. Sand and gravel may be encountered at shallow depths. 3. These channels are avenues for groundwater flow.
10	Sandy clay silt, overlain by thin discontinuous bodies of sand and gravel; Surface boulders abundant, Glacial sediments	Generally greater than 10 feet	Low to high	Moderate to high	Moderate to low	Moderate to high	1. Good internal drainage where overlain by sand and gravel. 2. Boulder at or near the surface may cause problems of workability. 3. Generally suitable for most types of construction, although extensive site investigation may be necessary because the variability of the sediment.

Map unit 9 is not included in Pembina County.

PLATE 10.–SANITARY LANDFILL SUITABILITY–CAVALIER COUNTY

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION



Miscellaneous Symbols

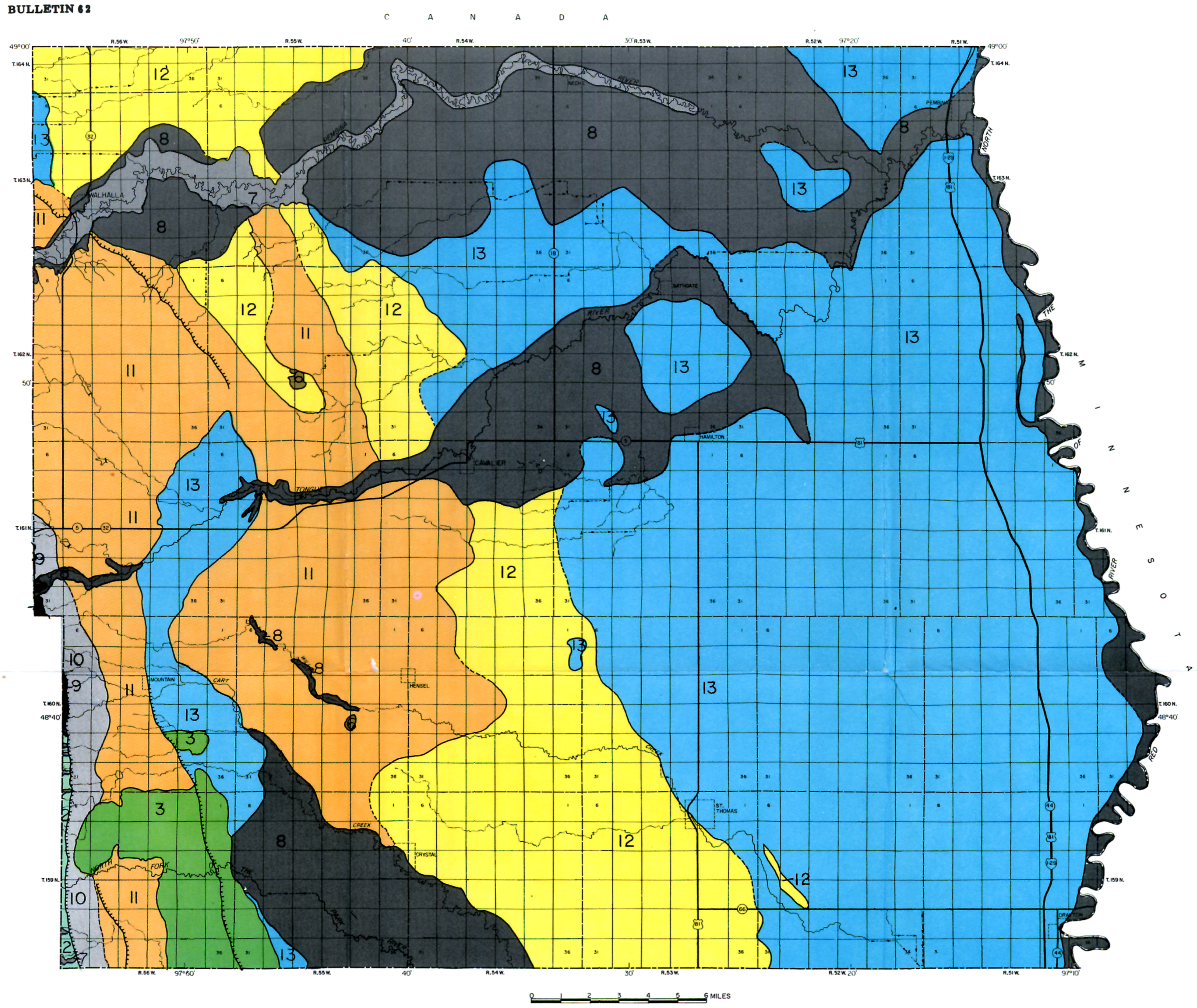
- Prominent scarp
- Contact, accuracy within .1 mile
- Inferred contact accuracy between .2 and .3 mile
- Eskers

Geologic Map Relating to Sanitary Landfill Suitability

Unit	Geology	Topography	Degree of Variability	Permeability	Water Table	Ease of Workability	Comments Relating to Use as a Landfill Site
1	Sandy-silty clay; numerous sand and gravel ridges (larger ones marked in red) present; Glacial Sediment–Till	Hummocky	Contains lenses of sand and gravel at various depths. Surface sand and gravel ridges (eskers) may be covered by thin veneers of glacial till.	Generally low, high where sand bodies encountered	Low to high	Moderate to low	1. Lateral variability requires extensive site investigation. 2. Extensive network of potholes and sloughs indicate possible drainage problems.
2	Sandy-clay silt, locally sand and gravel; Glacial Sediment–Till	Undulating	Local lenses of sand and gravel may be encountered with depth. Surface ridges as above not as common.	Generally low except where sand and gravel encountered	Generally greater than 10 feet	Low to moderate	1. Lateral variability requires extensive site investigation. 2. Bedrock generally close to the surface and is highly fractured which may provide avenues for rapid leachate removal.
3	Sandy-clay silt, overlain by thin discontinuous bodies of sand and gravel. Surface boulders very abundant locally; Glacial Sediment–Till	Nearly flat to undulating	Sand is discontinuous both laterally and vertically. Boulder concentrations.	Low except where sand and gravel encountered	Generally greater than 10 feet	Low to high	1. Surface sand and gravel may provide rapid lateral leachate movement. 2. Extensive near surface boulder concentrations may cause problems of workability.
4	Sandy-clay silt, locally sand and gravel. Underlain by Cretaceous Shales; Glacial Sediment–Till	Hummocky	Sand is discontinuous. Till thickness varies and extensive surface concentrations of boulders.	Low except where sand and gravel encountered	Low to high	Low to high	1. Lateral variability requires extensive site investigation. 2. Boulder concentrations may cause a problem of workability. 3. Underlying shales are very clayey and may be difficult to work. 4. Underlying shales may be unstable in steep slopes.
5	Sandy-clay silt and sand and gravel; Glacial Sediment, and river channel deposits	Occurs as shallow to moderately deep linear troughs	High degree of variability ranging from clay to coarse shale gravels.	Low to high	Low to high	Moderate	1. Channel troughs may be filled with surface water during certain times of the year. 2. Groundwater flow may be rapid in these channels. 3. Where water content is high, soil would be difficult to work when frozen. 4. Wet conditions may be common in the bottom of pit.
6	Clay, silty to sandy, rich in organics; slough deposits	Flat	May grade to coarser sediments with depth. Usually very uniform.	Low	High; may be above ground surface	Low	1. High water table will mean constant wet conditions in the bottom of a pit. 2. Soil difficult to work when wet or frozen. 3. Clay is plastic and stability of pit walls will be a problem.
7	Clay, silt, sand and gravel; River alluvium	Flat to gently sloping toward the river	Highly variable both laterally and vertically. Type of sediments are usually reflected by the type of sediments the river flows over.	Low to moderate	High	Low to moderate	1. Lateral permeable zones may move leaching into river system. 2. Working conditions difficult because of high watertable. 3. Flooding susceptibility is high.
8	Clay and silt; River overbank deposits	Flat to gently rolling	Generally uniform and may grade finer away from the river.	Low	High	Low to moderate	1. May be susceptible to flooding during periods of high spring runoff. 2. Working conditions may be difficult when soil is frozen. 3. Locally lateral movement along higher zones of permeability may occur. 4. High water table conditions will mean wet conditions in the bottom of the pit.
(black)	Clay and shale; Cretaceous bedrock (undifferentiated)	Moderate to steep slopes	Bedrock variable from hard, fractured Siliceous shale to bentonitic, soft clay.	Low to high	Low	Low to moderate	1. Highly fractured shale near the surface allows for rapid leachate removal. 2. Usually heavily vegetated. 3. Mostly exposed along the major river valleys where slopes are unstable and slumping and sliding may occur.
10	Clay, sand, silt, and gravel; Colluvium	Moderate to steep slopes	Highly variable.	Low to high	Low	Low to moderate	1. Lateral permeability may result in lateral leachate movement. 2. Material unstable and may slide.
11	Sand and gravel; Beach and Delta deposits	Rolling to hummocky	Sand and gravel generally well sorted and clean. Some areas almost exclusively medium coarse sand.	High	Low	High	1. High permeability. 2. Much of the area is a groundwater recharge area. 3. Suitable cover material not nearby.
12	Silt and very fine sand; Lake sediment	Flat to gently undulating	Uniform, laterally thins eastward.	Moderate to high	Generally greater than 10 feet	Moderate to high	1. Permeability may result in lateral leachate movement. 2. Where thin and underlain by clay, wet conditions may be a problem.
13	Clay and some silt; Lake sediment	Flat to gently undulating	Uniform, clay predominates.	Low	High	Low	1. Soil difficult to work when wet or frozen. 2. Difficult to keep pit dry because of high watertable.

Map unit 8 is not included in Cavalier County.

PLATE 11.—SANITARY LANDFILL SUITABILITY—PEMBINA COUNTY



Miscellaneous Symbols

- Prominent scarp
- Contact, accuracy within .1 mile
- Inferred contact accuracy between .2 and .3 mile

Geologic Map Relating to Sanitary Landfill Suitability

Unit	Geology	Topography	Degree of Variability	Permeability	Water Table	Ease of Workability	Comments Relating to Use as a Landfill Site
1	Sandy-silty clay; numerous sand and gravel ridges (larger ones marked in red) present; Glacial Sediment—Till	Hummocky	Contains lenses of sand and gravel at various depths. Surface sand and gravel ridges (eskers) may be covered by thin veneers of glacial till.	Generally low, high where sand bodies encountered	Low to high	Moderate to low	1. Lateral variability requires extensive site investigation. 2. Extensive network of potholes and sloughs indicate possible drainage problems.
2	Sandy-clay silt, locally sand and gravel; Glacial Sediment—Till	Undulating	Local lenses of sand and gravel may be encountered with depth. Surface ridges as above not as common.	Generally low except where sand and gravel encountered	Generally greater than 10 feet	Low to moderate	1. Lateral variability requires extensive site investigation. 2. Bedrock generally close to the surface and is highly fractured which may provide avenues for rapid leachate removal.
3	Sandy-clay silt, overlain by thin discontinuous bodies of sand and gravel. Surface boulders very abundant locally; Glacial Sediment—Till	Nearly flat to undulating	Sand is discontinuous both laterally and vertically. Boulder concentrations.	Low except where sand and gravel encountered	Generally greater than 10 feet	Low to high	1. Surface sand and gravel may provide rapid lateral leachate movement. 2. Extensive near surface boulder concentrations may cause problems of workability.
4	Sandy-clay silt, locally sand and gravel. Underlain by Cretaceous Shales; Glacial Sediment—Till	Hummocky	Sand is discontinuous. Till thickness varies and extensive surface concentrations of boulders.	Low except where sand and gravel encountered	Low to high	Low to high	1. Lateral variability requires extensive site investigation. 2. Boulder concentrations may cause a problem of workability. 3. Underlying shales are very clayey and may be difficult to work. 4. Underlying shales may be unstable in steep slopes.
5	Sandy-clay silt and sand and gravel; Glacial Sediment, and river channel deposits	Occurs as shallow to moderately deep linear troughs	High degree of variability ranging from clay to coarse shale gravels.	Low to high	Low to high	Moderate	1. Channel troughs may be filled with surface water during certain times of the year. 2. Groundwater flow may be rapid in these channels. 3. Where water content is high, soil would be difficult to work when frozen. 4. Wet conditions may be common in the bottom of pit.
6	Clay, silty to sandy, rich in organics; slough deposits	Flat	May grade to coarser sediments with depth. Usually very uniform.	Low	High; may be above ground surface	Low	1. High water table will mean constant wet conditions in the bottom of a pit. 2. Soil difficult to work when wet or frozen. 3. Clay is plastic and stability of pit walls will be a problem.
7	Clay, silt, sand and gravel; River alluvium	Flat to gently sloping toward the river	Highly variable both laterally and vertically. Type of sediments are usually reflected by the type of sediments the river flows over.	Low to moderate	High	Low to moderate	1. Lateral permeable zones may move leaching into river system. 2. Working conditions difficult because of high watertable. 3. Flooding susceptibility is high.
8	Clay and silt; River overbank deposits	Flat to gently rolling	Generally uniform and may grade finer away from the river.	Low	High	Low to moderate	1. May be susceptible to flooding during periods of high spring runoff. 2. Working conditions may be difficult when soil is frozen. 3. Locally lateral movement along higher zones of permeability may occur. 4. High water table conditions will mean wet conditions in the bottom of the pit.
9	Clay and shale; Cretaceous bedrock (undifferentiated)	Moderate to steep slopes	Bedrock variable from hard, fractured Siliceous shale to bentonitic, soft clay.	Low to high	Low	Low to moderate	1. Highly fractured shale near the surface allows for rapid leachate removal. 2. Usually heavily vegetated. 3. Mostly exposed along the major river valleys where slopes are unstable and slumping and sliding may occur.
10	Clay, sand, silt, and gravel; Colluvium	Moderate to steep slopes	Highly variable.	Low to high	Low	Low to moderate	1. Lateral permeability may result in lateral leachate movement. 2. Material unstable and may slide.
11	Sand and gravel; Beach and Delta deposits	Rolling to hummocky	Sand and gravel generally well sorted and clean. Some areas almost exclusively medium coarse sand.	High	Low	High	1. High permeability. 2. Much of the area is a groundwater recharge area. 3. Suitable cover material not nearby.
12	Silt and very fine sand; Lake sediment	Flat to gently undulating	Uniform, laterally thins eastward.	Moderate to high	Generally greater than 10 feet	Moderate to high	1. Permeability may result in lateral leachate movement. 2. Where thin and underlain by clay, wet conditions may be a problem.
13	Clay and some silt; Lake sediment	Flat to gently undulating	Uniform, clay predominates.	Low	High	Low	1. Soil difficult to work when wet or frozen. 2. Difficult to keep pit dry because of high watertable.

Map units 1, 4, and 5 are not included in Pembina County.