GEOLOGY

of

BENSON AND PIERCE COUNTIES, NORTH DAKOTA

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Prepared by the North Dakota Geological Survey
in cooperation with the United States Geological Survey,
the North Dakota State Water Commission, the Benson County
Water Management District, and the Pierce County
Water Management District.

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ABSTRACT

The surficial deposits of Benson and Pierce Counties consist mostly of glacial drift of Late Wisconsinan age which is mapped as the Coleharbor Formation. In areas where the glacial deposits have been eroded and redeposited, they are mapped as the Walsh Formation. Testhole data show that the surficial deposits lie on older drift deposits, some of which may be of Early or pre-Wisconsinan age, but all of the drift deposits are referred to the Coleharbor Formation. The Coleharbor Formation is generally less than 100 feet thick in Pierce and western Benson Counties, except in preglacial buried valleys where it is commonly more than 200 feet thick and as much as 350 feet thick. In eastern Benson County the Coleharbor Formation is generally 100 to 200 feet thick, except in preglacial buried valleys where greater thicknesses occur.

The surficial deposits of Benson and Pierce Counties are divided into map units on the basis of lithologic and interpretive genetic criteria. The lithologic units of the Coleharbor Formation are an unsorted, silty, sandy, pebbly, boulder-clay or till facies, a sand and gravel facies, a silt and clay facies, and a mixed (ice-contact) facies. The boulder-clay or till facies is subdivided into low to high relief stagnation deposits, low relief stagnation deposits, eroded slope deposits, and drift covered, ice-shove deposits. The sand and gravel facies was subdivided into ice marginal deposits, outwash apron or channel deposits, outwash deposits, collapsed outwash deposits, and lacustrine deposits. Mappable units of the Walsh Formation are a silt and clay facies, a sand facies, and a mixed (alluvial-colluvial) facies.

Scattered bedrock exposures are present along some outlet channels of glacial Lake Souris, some present drainages, and in some of the ice-shove hills. The formations exposed at these localities are the Pierre, Fox Hills, and Hell Creek, all of Late Cretaceous age.

Groundwater supplies are generally available from the Coleharbor Formation or the Fox Hills Formation where it is present. Widespread gravel deposits are present in the Coleharbor Formation except for lake plain areas. Gravel quality is variable, often being very shaly or poorly sorted. The highest quality deposits are generally found along meltwater or present drainages. No oil has yet been found, but reservoir rocks of Paleozoic and Mesozoic age are present in these counties.

INTRODUCTION

Purpose of Study

This report is one of a series of reports prepared by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, and the local water management boards. The area of study included all of Benson and Pierce Counties, an area of about 2,512 square miles (Benson 1,432; Pierce 1,080), located in north-central North Dakota (fig. 1).

The primary purposes of this study were: (1) to provide a geologic map of the area, (2) to interpret the geologic history of the area, (3) to locate and define aquifers, and (4) to consider the natural resources of the area.

Methods of Study

Field mapping began in the summer of 1967 by T. F. Freers and continued through the 1968 field season. Field work was completed during the 1969 field season by C. G. Carlson. The map was compiled by Carlson with areas of primary responsibility shown on plate 1. The report was written by Carlson who is responsible for all subjective interpretations of the data collected in this study.

Stereoscopic pair photo coverage, scale 1:20,000, and aerial photo mosaics, scale 1:63,360, were available for the entire area. Most of the area was covered by topographic sheets of the 7.5-minute series (see pl. 1), and in those areas field data was plotted directly on the sheets, which remain as open file data. Contacts were determined with the aid of aerial photos and plotted on county road maps, scale 1:63,360, obtained from the North Dakota Highway Department.

Lithologic information was obtained mainly from roadcut or road ditch exposures or through the use of a 5-foot hand auger. Supplementary information was obtained through use of the North Dakota Geological Survey truck-mounted auger (about 6,400 feet of auger hole were drilled) and through testhole drilling (about 40,000 feet were drilled) by the North Dakota State Water Commission. Information from files of the North Dakota Geological Survey for the oil exploration tests provided further information for the subsurface stratigraphy.

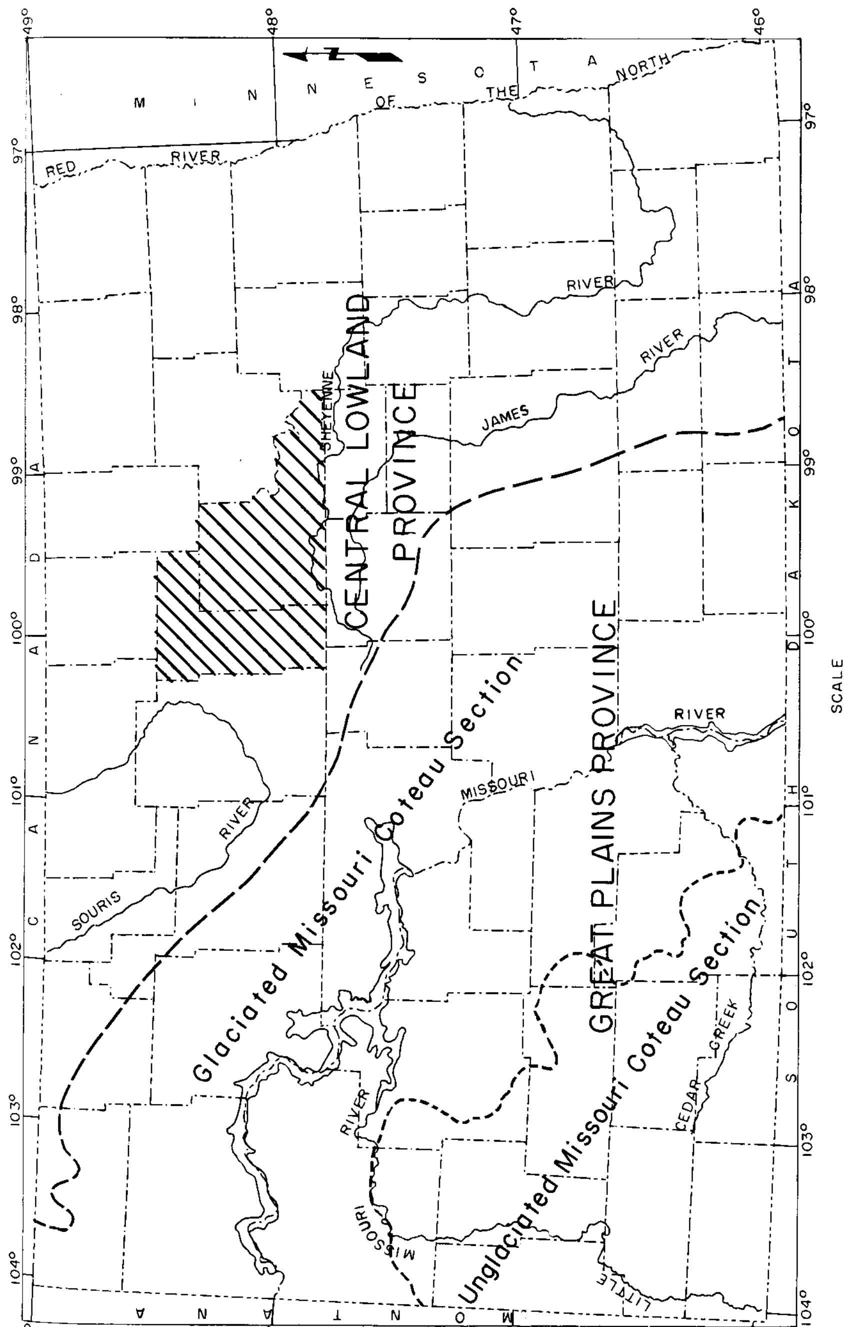

FIGURE 1. Location map showing area of study and physiographic subdivisions.

Previous Work

Regional studies by Upham (1896), Simpson (1912, 1929), and Leverett (1932) made some mention of the area of study. More recent regional studies relating more specifically to this area were made by Lemke and Colton (1958), Lemke (1958), Lemke, and others (1965), and Clayton (1966). Detailed studies of the geology of local areas within the two counties include those of the Flora quadrangle (Branch, 1947), the Oberon quadrangle (Tetrick, 1949), and the Tokio quadrangle (Easker, 1949). Groundwater studies were conducted in the Minnewaukan area (Aronow, Dennis, and Akin, 1953) and the Leeds area (Randich and Bradley, 1962). The glacial and post-glacial history of the Devils Lake areas has been discussed by Aronow (1957) and Hansen (1958). A guidebook for the Devils Lake area (Laird, 1957) includes the southeastern part of Benson County. A generalized map of this area on a scale of 1:500,000 is provided by Colton, Lemke, and Lindvall's (1963) Preliminary Glacial Map of North Dakota.

Geologic studies for the current groundwater series for adjacent counties have been published for Eddy County (Bluemle, 1965), Wells County (Bluemle and others, 1967), Rolette County (Deal, 1972), and Nelson County (Bluemle, 1973). Field studies have been conducted and geologic maps were available for Sheridan and McHenry Counties.

Acknowledgments

The help of various individuals and agencies in the collection of data for this study and their review of the manuscript is appreciated. Philip G. Randich, U.S. Geological Survey, author of parts II and III of this study, assisted by Charles E. Naplin, North Dakota State Water Commission, provided testhole data which aided the geologic interpretations of this report. Visitations in the field with geologists of the cooperating agencies also aided in the interpretations.

Regional Setting

Physiographically, the Benson and Pierce County area is in the Western Young Drift Section of the Central Lowland Province (fig. 1), an area characterized by numerous undrained depressions, poorly integrated drainage, and a variable thickness of glacial drift. Most of the area is in the Drift Plains District. Exceptions are parts of western Pierce County, which is in the Souris Lake Plain District, and the eastern part of Benson County, which is in the Devils Lake Plain District.

The surficial deposits consist of Pleistocene sediments of Late Wisconsinan age laid down on deposits of earlier glaciations or rock of Cretaceous age. The slope of the bedrock topography is toward the north and east. The dip of the sedimentary rocks is toward the west, reflecting the position of this area on the eastern flank of the Williston basin, an intracratonic basin, the center of which is in western North Dakota.

PRE-QUATERNARY STRATIGRAPHY

Precambrian Rocks

Only four wells have penetrated Precambrian rocks in Benson and Pierce Counties, but wells in adjacent counties provide additional information and a means of projecting the probable composition and depth to the Precambrian rocks of these counties. Based on this information Lidiak and Karner (in preparation) have recognized three separate terranes in this area, the Towner Granite Terrane, the Ramsey Granite Terrane, and an Amphibolite Schist Terrane. Depth to the Precambrian rocks ranges from about 3,000 feet in southeastern Benson County to about 6,000 feet in western Pierce County.

Paleozoic Rocks

Paleozoic rocks range in thickness from about 3,200 feet in western Pierce County to about 2,300 feet in northeastern Pierce County and about 1,200 feet in southeastern Benson County. Much of the variation in thickness is due to episodes of erosion marked by unconformities on the cross section (fig. 2). For purposes of discussion, it is convenient to divide the stratigraphic section into sequences, a sequence being the preserved sedimentary record bounded by major regional unconformities. Paleozoic sequences recognized in this area are, in ascending order, the Sauk, Tippecanoe, and Kaskaskia.

Sauk Sequence

All the rocks of the Sauk Sequence are included in the Deadwood Formation which consists of interbedded clastics and carbonates. Based on testholes in adjacent areas about 200 feet of Deadwood is probably present in southwestern Pierce County. It thins northeastward to an erosional edge in the adjacent counties.

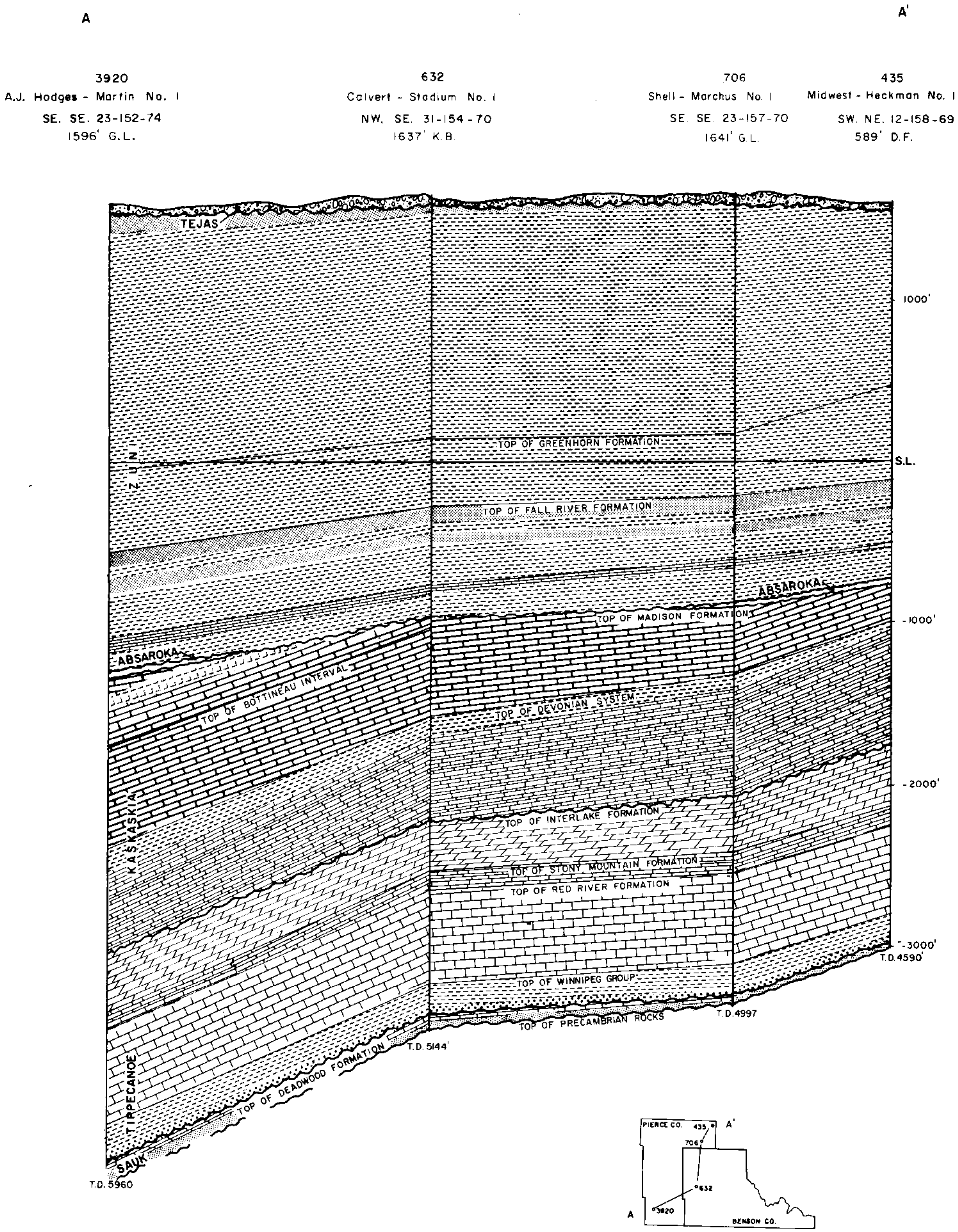

FIGURE 2. Geologic section of subsurface stratigraphy of Benson and Pierce Counties.

Tippecanoe Sequence

Rocks of the Tippecanoe Sequence range in thickness from about 1,100 feet to 1,250 feet. The relatively uniform thickness reflects stable conditions during deposition of these rocks and a location where the depositional thicknesses of all the formations, with the exception of the Interlake Formation, have been preserved. The Tippecanoe Sequence began with clastics of the Winnipeg Group followed by carbonates and minor evaporites of the Red River, Stony Mountain, Stonewall, and Interlake Formations. The Interlake Formation thins from about 250 feet in western Pierce County to an erosional edge in southeastern Benson County.

Kaskaskia Sequence

Rocks of the Kaskaskia Sequence range in thickness from about 100 feet in southeastern Benson County to about 1,800 feet in western Pierce County. The Devonian rocks are mostly carbonates with minor amounts of evaporites and shales. They thin southeastward, primarily because of depositional thinning, but also as a result of minor unconformities between Mississippian and Devonian rocks as well as within the Devonian rocks. The Mississippian rocks are primarily carbonates with some anhydrite. They thin eastward from a thickness of about 1,000 feet in southwestern Pierce County to an erosional edge in southeastern Benson County. The thinning is mainly a result of erosion associated with the regional unconformity.

Mesozoic Rocks

Mesozoic rocks are mostly fine-grained clastics that range in thickness from about 1,500 feet in southeastern Benson County to about 2,900 feet in western Pierce County. These rocks are divided into two sequences in this area, the Absaroka and Zuni (figs. 2, 3).

Absaroka Sequence

The Spearfish Formation of Triassic age is the only remnant of the Absaroka Sequence in the two counties. It consists of redbeds that range in thickness from about 60 feet in northwestern Pierce County to an erosional edge, which nearly coincides with the Pierce-Benson boundary.

Zuni Sequence

The Zuni Sequence includes the rocks of Jurassic and Cretaceous age. The Jurassic rocks, which consist mainly of shale with some fine

ERA	SEQUENCE	SYSTEM	FORMATION OR GROUP		THICKNESS	DOMINANT LITHOLOGY
MESOZOIC	ZUNI	CRETACEOUS		HELL CREEK	0- 150	Clay, Sandstone, Shale
			MONTANA GROUP	FOX HILLS	0- 350	Sandstone and Shale
				PIERRE	150- 860	Shale
			COLORADO GROUP	NIOBRARA	220- 260	Shale, Calcareous
				CARLILE	330- 325	Shale
				GREENHORN	120- 200	Shale, Calcareous
				BELLE FOURCHE	140- 180	Shale
			DAKOTA GROUP	MOWRY	80- 100	Shale
				NEWCASTLE	0- 50	Sandstone
				SKULL CREEK	70- 100	Shale
				FALL RIVER	200- 325	Sandstone and Shale
				LAKOTA		Sandstone and Shale
		JURASSIC		MORRISON	0- 60	Mudstone
				SUNDANCE	75- 430	Shale and Sandstone
				PIPER	120- 225	Limestone, Shale and Anhydrite
	ABSAROKA	TRIASSIC		SPEARFISH	0- 100	Siltstone
PALEOZOIC		PERMIAN				
		PENNSYLVANIAN				
	KASKASKIA	MISSISSIPPIAN		MADISON	0-1,100	Limestone, Anhydrite
		DEVONIAN		THREE FORKS	0- 50	Shale, Siltstone and Dolomite
				BIRDBEAR	0- 80	Dolomite
				DUPEROW	100- 325	Interbedded Dolomite and Limestone
				SOURIS RIVER	75- 225	Interbedded Dolomite and Limestone
				DAWSON BAY	0- 125	Dolomite and Limestone
				PRAIRIE	0- 50	Limestone and Anhydrite
				WINNIPEGOSIS	0- 150	Limestone and Dolomite
	TIPPECANOE	SILURIAN		INTERLAKE	0- 250	Dolomite
				STONEWALL	50- 65	Dolomite
		ORDOVICIAN		STONY MOUNTAIN FM.	130- 160	Argillaceous Limestone
				RED RIVER	540- 575	Limestone and Dolomite
			WINNIPEG GROUP	ROUGHLOCK	25- 65	Calcareous shale and Siltstone
				ICEBOX	125- 135	Shale
				BLACK ISLAND	10- 60	Sandstone
	SAUK	CAMBRIAN		DEADWOOD	0- 200	Limestone, Shale and Sandstone
PRECAMBRIAN ROCKS						

FIGURE 3. Bedrock stratigraphic column for Benson and Pierce Counties.

grained sandstone, thin from about 600 feet in northwestern Pierce County to about 100 feet in southeastern Benson County. The thinning reflects a minor unconformity between the Jurassic and Cretaceous Systems. The unconformity is overlain by sand and minor shale of the Lower Cretaceous Lakota-Fall River Interval. These sediments are overlain by marine shale of the Skull Creek through Pierre Formations. The Fall River-Lakota Interval, an aquifer that contains saline water, is generally 200 to 300 feet thick and is penetrated at depths of about 1,400 to 2,200 feet from east to west.

Cretaceous rocks range in thickness from about 1,200 feet in eastern Benson County to about 2,250 feet in western Pierce County. Most of the thinning is due to preglacial erosion of the Cretaceous formations, which subcrop beneath the drift.

The Pierre Formation crops out along the Sheyenne valley and subcrops beneath the drift in eastern Benson County. The Fox Hills Formation consists of thin-bedded shale and sand probably deposited near shorelines during the regressive phase of the Cretaceous seas. The Fox Hills Formation crops out along the Sheyenne drainage in western Benson County and along the glacial Lake Souris outlet channels in southern Pierce County. It subcrops beneath the drift in western Benson County and most of Pierce County. Remnants of the non-marine Hell Creek Formation are the youngest bedrock present in the area. Exposures are limited to the ice-shove areas of southwestern Pierce County.

QUATERNARY STRATIGRAPHY

Coleharbor Formation

The Coleharbor Formation was defined by Bluemle (1971, p. 16) to include all of the glacial sediments in North Dakota. The type section is located about 6 miles west of Coleharbor in McLean County. In that area evidence of multiple episodes of glaciation exists. The same is true of the Benson-Pierce County area where testholes penetrated till-sand-till successions with as many as 3 to 6 separate till sections present at many localities. Although some recognizable differences can be seen between some of the till sections they are not lithologically distinguishable as continuous units on the basis of sample descriptions. It is therefore convenient to include all the drift deposits in this area within the Coleharbor Formation.

The Coleharbor Formation is subdivided into map units on the basis of objective observations of near-surface lithologies that were divided into lithofacies and then a subjective interpretation based on genetic considerations. Four lithofacies were recognized: a boulder-clay or till facies, a sand and gravel facies, a silt and clay facies, and a mixed facies. Topographic expression, differences recognizable on aerial photos, and relationships to adjacent facies (pl. 1) were used as the basis of subjective interpretations of origin.

In the Souris Lake Plain District, the composition of the Coleharbor Formation in testhole footage was 23 percent till, 31 percent sand and gravel, and 46 percent silt and clay. In the rest of the two counties testholes penetrated 73 percent till, 20 percent sand and gravel, and only 7 percent silt and clay, except in areas where testhole drilling was directed at delineating buried valleys. In those areas the sand and gravel facies accounted for 40 to 60 percent of the footage.

The thickness of the Coleharbor Formation is greatest in the buried valleys of the preglacial or ice marginal drainages (pls. 2 and 3). In these areas, thicknesses of 250 to 350 feet are common; whereas in most of Pierce County and southwestern Benson County the drift is less than 100 feet thick. An area about 2 to 3 townships wide (Twps. 153 to 157 N., Rs. 67 to 69 W.) that extends through eastern Benson County is characterized by drift in the 100- to 200-foot-thick range. This area of thicker drift is characterized by testholes that penetrated multiple till successions.

Boulder Clay or Till Facies

The boulder-clay or till facies represents the unsorted glacial drift which is generally composed of silty clay with variable amounts of angular, subangular or rounded sand grains, pebbles, cobbles, and boulders. In some areas, however, the unsorted drift is silty and sandy so the general term for unsorted drift, till facies, will be used in this report. This facies is generally yellowish brown to moderate yellowish brown in the oxidized zone, which ranges in depth from 10 to 25 feet; it is generally an olive gray below the oxidized zone. Till samples from the subsurface are commonly olive gray, but some medium gray and medium dark gray till has been reported. Some testholes also reported brownish gray till indicating preservation of buried oxidized zones. Where testholes penetrated multiple till successions the buried tills are similar in composition to the near surface till. The buried till is commonly described as pebbly, silty clay, but in some localities sandy or gravelly till was also reported. The most noticeable difference between the near-surface and buried tills in areas of multiple tills is that the buried tills are more compact, often as tough or tougher to auger than the bedrock.

The till facies is divided into 6 map units. Five of these units ($Cb_{1,2,4,5,6}$) are based primarily on surface expression with its implied depositional or erosional history. The other unit (Cb_3) was separated on the basis of higher sand content in the till in parts of its area. Local areas of water-sorted sediment (too small to show on a map of the scale of plate 1) are present within these map units.

Ice Marginal and/or Low to High Relief Stagnation Deposits.—Areas mapped as Cb_1 are areas of the till facies which were either deposited at the margin of an active ice sheet or were topographically high areas during the melting of the ice and its accompanying deposition of debris. Most of these areas are characterized by low to medium or medium to high local relief. Generally low relief refers to areas with less than 30 feet of local relief per section, medium relief refers to areas with 30 to 60 feet of relief per section, and high relief refers to areas with greater than 60 feet of relief per section. High relief areas (Cb_1) grade into low relief areas (Cb_2) so boundaries are somewhat arbitrary (fig. 4). Areas mapped as Cb_1 generally lack the linear trends typical of end moraines, whereas circular disintegration ridges typical of stagnant ice deposits are common. The outer margin of the till facies mapped as Cb_1 has outwash channels and aprons leading away from these margins. The channel and apron deposits coincide with the present drainage. Some undrained depressions of one to three square miles and many smaller ones are present north and east of the area mapped as Cb_{1NV}. This suggests that the margin of the active glacier which deposited the surface drift of this area may have been some distance beyond the map area during the final stages of active ice movement and that, during the melting stages, most of the areas mapped as Cb_1 were merely topographically high areas of stagnant ice.

The area designated Cb_{1H} is a continuation of the area mapped as the Heimdal End Moraine in Wells and Eddy Counties. In Benson County this area is characterized by low to medium relief stagnation features. Local relief that is less than 30 feet in secs. 13 and 14, T. 152 N., increases slightly southward but remains less than 60 feet in most areas. Two testholes were drilled to bedrock in this area; one (152-71-36ccc) penetrated 55 feet of drift, the other (151-70-18ccc) 40 feet of drift.

The area designated Cb_{1MR} is a continuation of the area mapped as the Martin End Moraine in Wells and Sheridan Counties. The

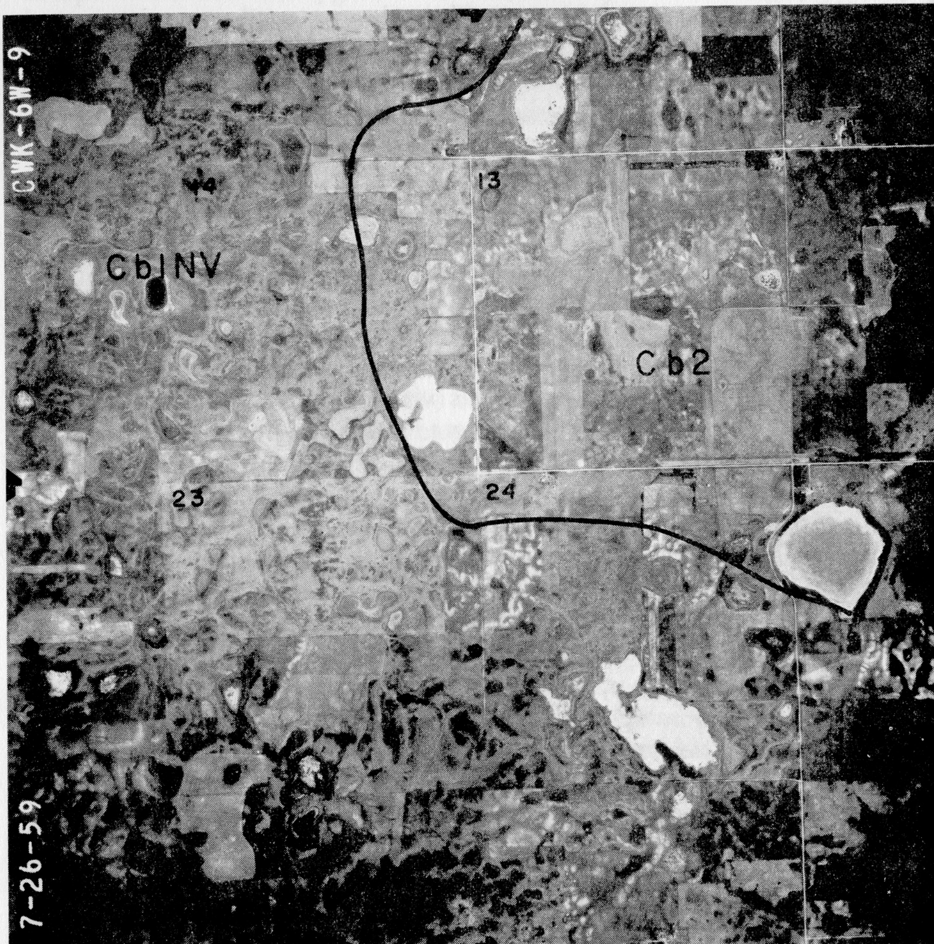

FIGURE 4. Air photo of the boundary between medium to high relief stagnation deposits (Cb_{1NV}) and low relief stagnation deposits (Cb_2) in T. 155 N., R. 71 W., Benson County. (U.S.D.A., CWK-6W-9)

segments in Twps. 152 and 153 N. are similar in appearance on aerial photos to the areas designated Cb_{1H}; the low to medium relief stagnation features are present and six testholes were drilled to bedrock with drift thicknesses ranging from 9 to 54 feet. In Twp. 151 N. the drift is much thicker. Two testholes (151-73-16ddd, 151-73-32ccc) penetrated over 200 feet of drift, and one testhole (151-73-28ccc) penetrated 185 feet of drift; however, these testholes are in an area of a bedrock valley. The near-surface till was less than 40 feet thick in each of these testholes.

The area designated Cb_{1MC} is a continuation of the area mapped as the McHenry End Moraine in Eddy County. In Benson County this area (fig. 5) is characterized by medium to high local relief with variable lithology from silty boulder-clay to gravel. Two testholes (151-64-4ccc, 151-64-23ddc) that were drilled in the area designated Cb_{1MC} penetrated drift to depths of 120 and 165 feet with the dominant lithology sand and gravel. Part of the area in Eddy County was mapped as collapsed end moraine. Areas of collapsed outwash lie adjacent to Cb_{1MC} in Benson County suggesting that this area is mainly a continuation of the collapsed end moraine of Eddy County.

The area designated Cb_{1NV} is a continuation of areas previously mapped as the North Viking End Moraine in Benson County and adjacent areas. It is characterized by medium to high relief with some areas of low to medium relief. Circular disintegration ridges are common. Measured thicknesses of drift range from 72 to 326 feet, but most of these holes penetrated multiple drift sheets and the first till commonly extends less than 50 feet from the surface.

Low Relief Stagnation Deposits.—The area north and east of the ice marginal area Cb_{1NV} is characterized by low to medium relief, many circular disintegration ridges, some areas of "washboard moraines," numerous ice contact deposits, and some undrained depressions, which have received some post-glacial sediment. The till facies in this area has been mapped as Cb_2. It was usually noted as a clayey till. Testholes commonly penetrated multiple till sections with the till facies extending less than 70 feet from the surface. The "washboard moraines," which are low (10 feet or less), inconspicuous, parallel ridges are most prominent in Twps. 153 to 156 N., Rs. 67 and 68 W. (fig. 6), where they have a northwest-southeast trend. Washboard moraines are less numerous in Twps. 156 to 158 N., Rs. 69 and 70 W. Here they have both northeast-southwest trends and northwest-southeast trends.

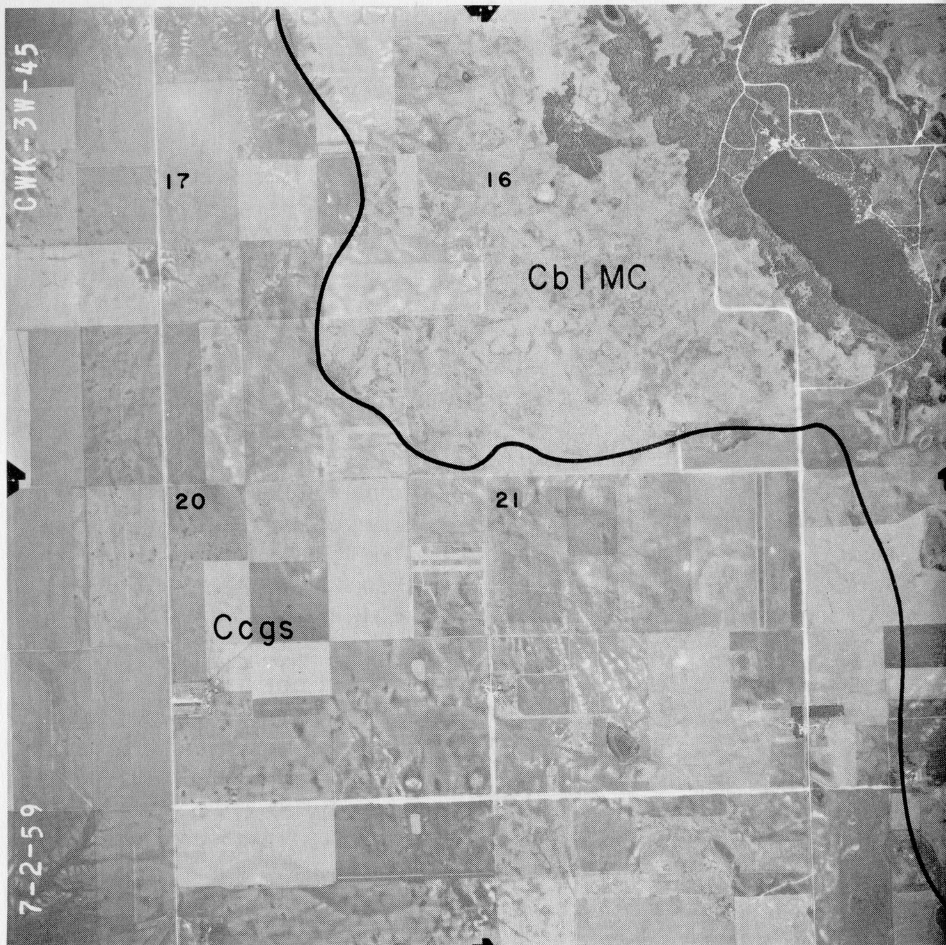

FIGURE 5. Air photo of collapsed outwash (Ccgs) area adjacent to medium to high relief stagnation deposits (Cb_{1MC}) in T. 151 N., R. 64 W., Benson County. (U.S.D.A., CWK-3W-45)

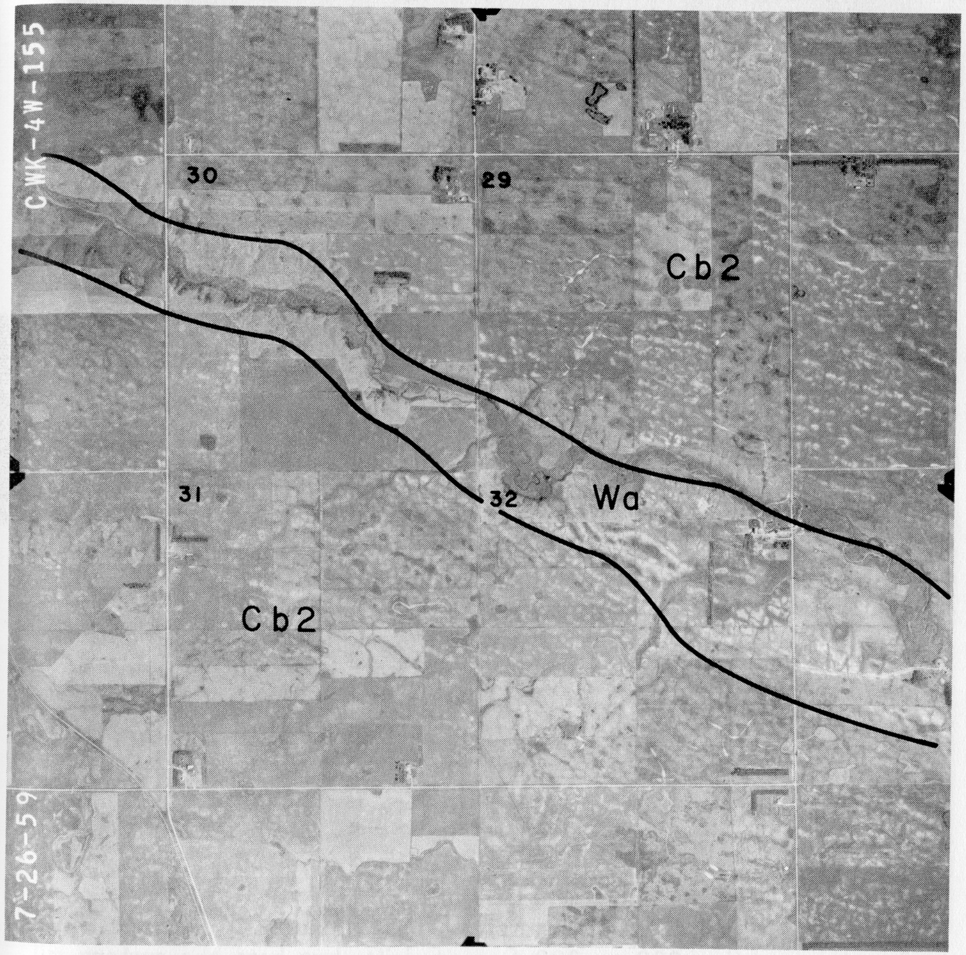

FIGURE 6. Air photo of "washboard moraines" in low relief stagnation deposits (Cb_2) in T. 155 N., R. 67 W., Benson County. (U.S.D.A., CWK-4W-155)

The area mapped as Cb_3 has surface characteristics somewhat similar to area Cb_2 and the deposits there were probably deposited in the same manner; but the composition, particularly near the western margins of this unit are noticeably sandier than the typical till facies mapped as Cb_2. This sandier till seems to grade south and eastward into the more typical boulder-clay facies so that in T. 154 N., Rs. 71 and 72 W., the till is indistinguishable from till in areas mapped as Cb_1 or Cb_2. The position of the washboard moraines and the relationship of this unit to area Cb_{1MR} suggests that it was deposited by an ice lobe advancing over the area from the northwest. The sandier composition to the northwest reflects the influence of ice movement over lake sediments from lakes related to earlier glaciations. In the area north of Rugby this ice lobe advanced over the pre-existing gravel hills leaving a thin mantle of sandy till in most areas. As it continued southeastward advancing over till-covered areas it resulted in a till that is the "normal" boulder-clay facies. Distribution of map unit Cb_3 reflects the distribution of lake sediments during melting of the ice. Lake sediments are generally present below elevations of 1,550 feet and in the area northeast of Rugby are present up to elevations of 1,590 feet. Areas above these lake sediments are capped by till which was mapped as Cb_3.

The area mapped as Cb_4 is an area of the boulder-clay facies that is an extension of areas mapped as Heimdal and Grace City ground moraine in Wells County. This area is characterized by low relief. Washboard moraines are scarce and there is a general absence of ice-contact deposits, but circular disintegration ridges are common (fig. 7). The absence of ice-contact features probably results from development of an integrated drainage system during early stages of melting of the stagnant ice. Thickness of drift is highly variable. The area that is a continuation of the Heimdal ground moraine of Wells County is an area of thin drift. Testholes in T. 151 N., Rs. 67 to 69 W., commonly penetrated less than 50 feet of drift. Toward the north, drift was 50 to 70 feet thick in most of the testholes in Twps. 153 to 154 N., Rs. 70 and 71 W. The area near Selz in Twps. 151 and 152 N., Rs. 71 to 73 W. (Grace City ground moraine), has thicker drift with testholes there penetrating 200 to 300 feet of drift, but here the surface till, which is thin, masks a bedrock valley that was mostly filled before the last ice advance (pl. 5).

Eroded Slope Deposits.—An area paralleling the valley of the Sheyenne River has topography that has been altered since the melting of the glacier. It was mapped as Cb_5 and is characterized by till-covered slopes extending from the uplands to the floodplain with numerous

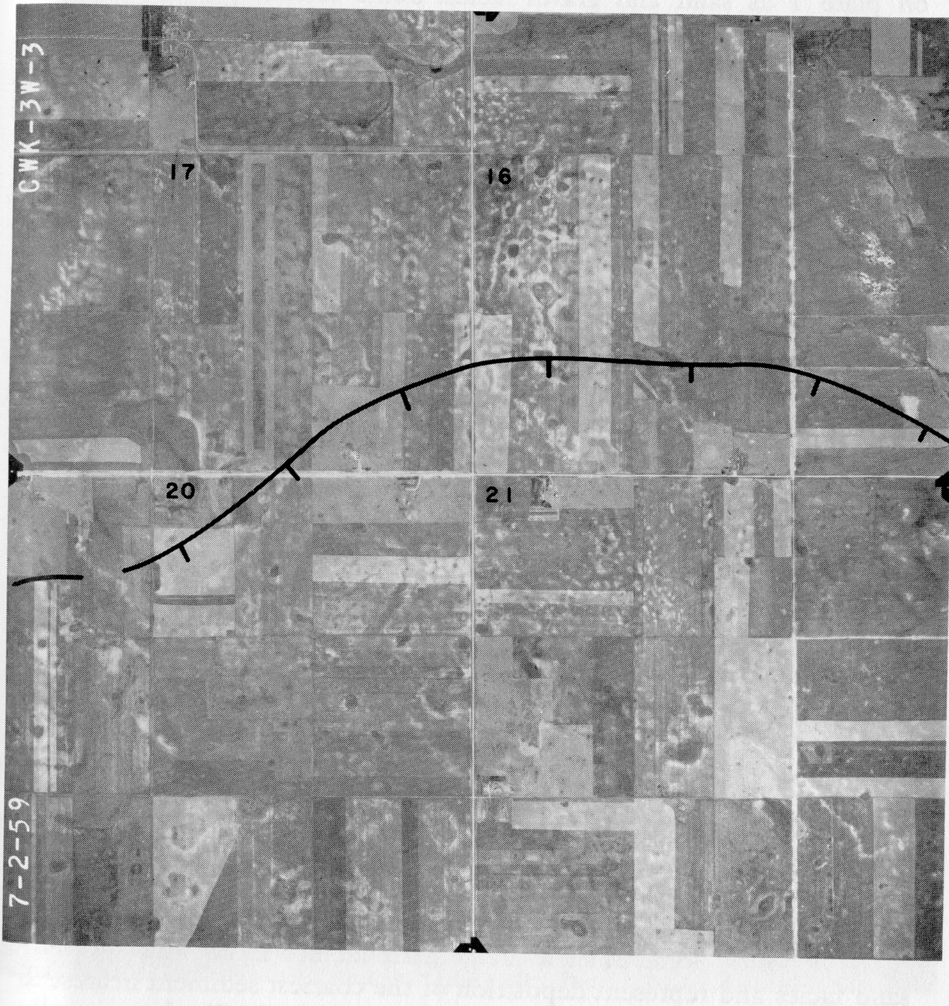

FIGURE 7. Air photo of low relief stagnation deposits overlying buried preglacial channel deposits T. 151 N., R. 71 W., Pierce County. (U.S.D.A., CWK-3W-3)

bedrock exposures, particularly in roadcuts. Scattered patches of water-sorted deposits (kame terrace, Cgs) occur at various elevations along the valley walls, the larger of which were separated and are shown on plate 1 as sand and gravel facies. Some smaller patches are also present.

Drift Covered Ice-Shove Features.—Several of the drift-covered (Cb_6) hills in southwestern Pierce County have exposures of disturbed bedrock on their western flanks. The pattern of the ridges on aerial photos (fig. 8) indicate that these hills were probably formed by ice shove and shearing by an ice lobe advancing southeastward (Bluemle, 1970, p. 325), which then overrode the hills.

A hill in Twps. 154 and 155 N., R. 69 W., in Benson County has a similar appearance except that no bedrock exposures are present. It is in an area of relatively thick drift near the Pierre-Fox Hills contact and a bedrock escarpment (pl. 2) that may have caused shearing similar to that of southwestern Pierce County. This may have happened as the last ice advanced over this area or it may be an ice-shove feature of an earlier glaciation that was not appreciably changed by the last ice sheet.

Sand and Gravel Facies

The water-sorted deposits of the Coleharbor Formation were divided on the basis of grain size into two facies with the coarser fraction mapped as the sand and gravel facies. This facies, which is the second most extensive of the surface units, was divided into five map units on the basis of grain size, sorting, and mode of deposition. Map units recognized were gravel and gravelly sand, outwash apron or channel deposits, collapsed outwash, outwash, and lacustrine sand.

Gravel and Gravelly Sand.—Areas mapped as Cgs are areas in which the coarser fraction of the sand and gravel facies is well sorted. These deposits are of several types. One type is located along the valley walls of present drainages that also carried away much of the meltwater as the last ice sheet melted. They are probably kame terrace deposits. Another type of deposit is closely associated with the ice-marginal (Cb_1) deposits. Some of these are gradational into an adjoining gravelly sand facies and represent deposition of the coarsest sediment nearest to the source of supply. In Twps. 157 and 158 N., R. 71 W., these gravelly deposits may have been deposited by meltwater flowing into the early, high level stages of glacial Lake Souris.

Most of the high hills north of Rugby in Rs. 72 and 73 W. seem to be cored mostly by gravel and gravelly sand. Where these hills have a cap of till, they were mapped as Cb_4; where the cap of till was missing, they were mapped as Cgs. Good exposures generally reveal a great

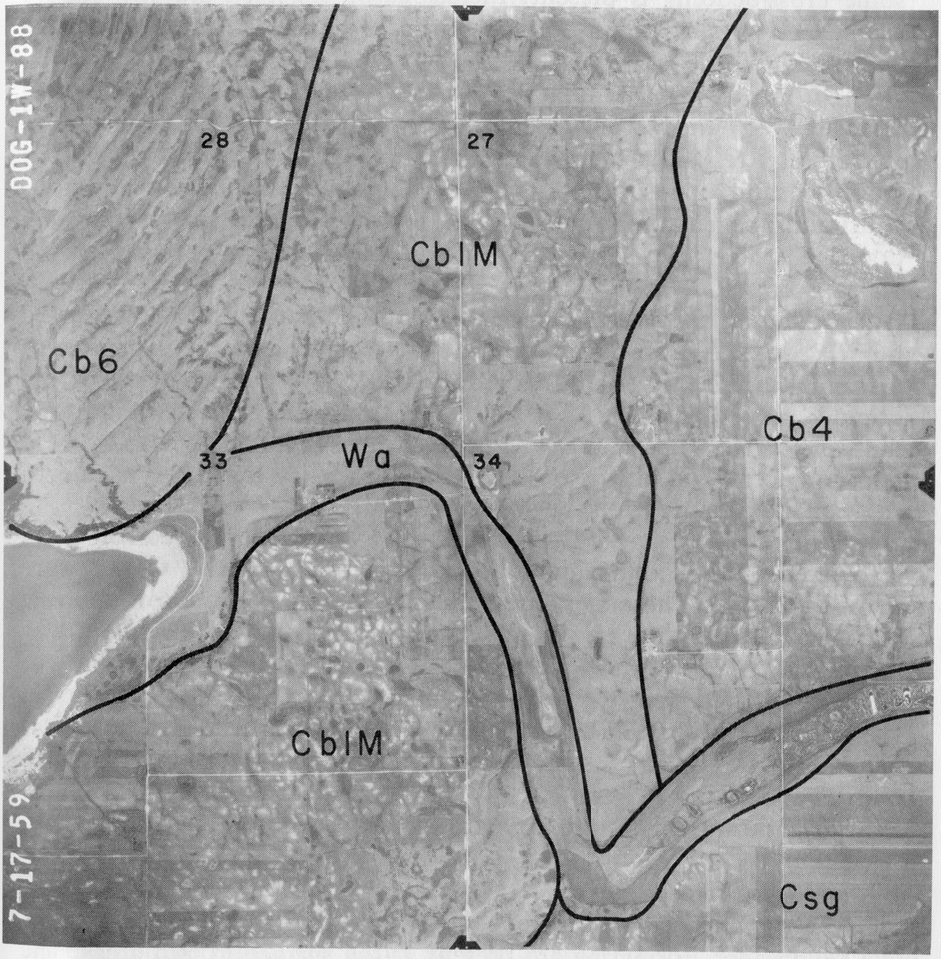

FIGURE 8. Air photo of drift covered ice-shove hills (Cb_6) and adjacent deposits in T. 152 N., R. 73 W., Pierce County. Medium to high relief stagnation deposits (Cb_{1MR}) cut by channel overlain by mixed facies (Wa) of the Walsh Formation. Outwash deposits (Csg) and low relief stagnation (Cb_1) deposits also shown. (U.S.D.A., DOG-1W-88)

variety of grain size and bedding characteristics, but nearly always the sediment is poorly sorted, almost as if the sediment were dumped so rapidly that the sorting one might expect in waterlain deposits is not present. The layers of gravelly sand are mainly horizontally bedded, but some cross-bedding is present. Inclusions of unsorted gravelly till are sometimes present. These hills are probably kame deposits that were overridden by the last glacial advance.

Outwash Apron or Channel Deposits.—Outwash apron or channel deposits (Csg) are present near the ice marginal (Cb_1) till deposits and are closely related genetically. These low relief deposits of gravel, gravelly sand, and sandy gravel are present as outwash aprons continuing as channel deposits leading to valleys of the present-day drainage where they may be present below younger deposits of the Walsh Formation.

Collapsed Outwash.—An area in Twps. 151 and 152 N., Rs. 62 to 66 W., consists of predominantly sand and gravel deposits in an area of medium to high (50 to 100 feet) local relief with local patches of the boulder clay facies (fig. 5). Testholes in this area generally penetrated multiple tills. The surface relief indicates that these water-sorted deposits were laid down on buried ice and that the relief is due to subsequent collapse as the buried ice melted.

Outwash.—Areas of low relief topography developed on sand associated with ice marginal deposits of Cb_{1MR} and Cb_{1H} were mapped as C_{os}. These areas are similar to the outwash apron deposits (Cgs) except that they are generally finer grained and better sorted.

Lacustrine Sand.—Widespread areas of nearly flat, fine- to very-fine-grained sand (Cls) occur in Twps. 151 to 158 N., R. 75 W., in the Souris Lake Plain District, at elevations below 1550 feet. Similar lacustrine sand occurs at higher elevations (1550 to 1580) in Twps. 156 and 157 N., Rs. 71 and 72 W. These high-level sand deposits were deposited during early stages of glacial Lake Souris.

Silt and Clay Facies

Fine-grained lacustrine deposits of the silt and clay facies (Csc) of the Coleharbor Formation are present at the surface in two areas. The most extensive are the yellow-gray to light-yellow-brown, thin-bedded deposits in the Souris Lake Plain. Less extensive deposits are present in the Minnewaukan area and extending eastward in Twps. 152 and 153 N. in the Devils Lake basin.

Mixed Facies

There are numerous areas within the general area of low relief stagnation deposits (Cb_2 and Cb_4) where there are low hills or ridges which are composed of variable lithologies deposited as ice contact deposits (Cic). The twisting, linear ridges are eskers which generally are composed of gravel and gravelly sand. The smaller, knob-like forms are kames which may contain well sorted sand and gravel deposits, but which often also contain silt and clay deposits or unsorted drift. A few of the mixed-facies ice-contact deposits are also present in areas of ice-marginal (Cb_1) and collapsed outwash deposits (Cgs).

HOLOCENE STRATIGRAPHY

Walsh Formation

The Walsh Formation was proposed by Bluemle (1973, p. 33) for the rock-stratigraphic unit that overlies the Coleharbor and all other formations in North Dakota. In Benson and Pierce Counties three types of deposits that resulted from erosion and redeposition of glacial drift are mapped as Walsh Formation. These are a silt and clay facies (slough deposits), a sand facies (sand dunes), and a mixed sand, silt, and clay facies (alluvium-colluvium).

Silt and Clay Facies

Mappable deposits of this facies (Wc) are confined to sloughs that are present in the low relief stagnation areas. Most of the undrained depressions (sloughs) associated with the circular disintegration ridge stagnation features of the ice marginal and/or low to high relief stagnation areas probably contain thin deposits of this facies, but they are of local extent and they were not separated as map units.

Sand Facies

Lacustrine sand (Ws) deposits of the Coleharbor Formation have been modified into low dunes in several areas of the Souris Lake Plain District (Twps. 73 and 74 W.). Another area of dunes is present in T. 151 N., Rs. 62 and 63 W., where the Warwick outwash apron has been wind-modified into dune topography.

Mixed Sand-Silt-Clay Facies

Alluvium-colluvium (Wa) consisting of variable amounts of silt, sand, and clay is present on the floodplain of the Sheyenne River and some of its tributaries. This facies is also recognizable along intermittent drainages in eastern and southeastern Benson County, as well as along the outlet channels of glacial Lake Souris.

GEOLOGIC HISTORY

Pre-Pleistocene

The pre-Pleistocene history of this area is based on the preserved sedimentary section discussed previously under pre-Quaternary stratigraphy. The history is one of alternating episodes of submergence with marine deposition followed by episodes of emergence with removal of part of the sedimentary record. Comparisons of the preserved section in the Benson-Pierce County area with areas to the west show that this area, being nearer the margin of the Williston basin, has been subject to longer intervals of erosion resulting in less of the sedimentary record being preserved. This erosional thinning is particularly significant through the Paleozoic Era. In the Mesozoic Erathem the erosional thinning is minimal until the end of the Cretaceous, and then the thinning of the Hell Creek, Fox Hills, and Pierre Formations is due primarily to erosion during the Tertiary period.

The pre-Pleistocene topography was dominated by a drainage divide in western Benson County with an escarpment held up by the Fox Hills Formation paralleling the Pierre-Fox Hills Contact (pl. 2). The drainage and general slopes trended toward the northeast. Early glaciations diverted drainage southeastward. New channels were cut by both the diverted drainage and meltwater from the glaciers. The bedrock topography (pl. 2) is therefore a composite of the pre-glacial topography and modifications resulting from glaciation.

No major valleys of the pre-Pleistocene drainage were present in most areas of these two counties, but a short segment of a major valley with a north-northwest trend in Towner and Ramsey Counties was present in the southeastern corner of Benson County. That stream may have been the northeastward course of the preglacial Knife-Cannonball drainage. A shallow, northeast trending valley in northwestern Pierce County was a tributary of that stream. Some tributaries of that stream are also present in eastern Benson County.

A deep northwest-southeast trending valley in southwestern Pierce County may have been the course of the preglacial Knife River or have been a tributary of the Knife River drainage. On the basis of its course and the composition of the valley fill which includes thick sand and gravel deposits it was probably also a diversion channel for meltwater from an early glaciation.

Pleistocene

Pre-Wisconsinan and early Wisconsinan ice sheets passed over this area to reach areas in western North Dakota where deposits of these early ice sheets are exposed. Many testholes penetrated multiple sections of till (pl. 4), and it seems likely that pre-Wisconsinan and early Wisconsinan glaciers left deposits of drift in Benson and Pierce Counties and that some of these drift deposits have been preserved. The lack of recognizable physical differences to correlate sections of till between testholes, and the lack of ways of dating these deposits, make attempts to construct an accurate history of deposition of the buried drift deposits difficult at the present time. Detailed till analysis may provide the answers; but perhaps the best approach for the present is to look at the most recent Pleistocene deposits, interpret their depositional history, and then infer some general interpretations for the buried drift.

Surface features suggest that the unsorted drift of the last ice sheet was deposited when stagnant ice melted. Topographically high areas on the present land surface are generally highs on the bedrock surface (pl. 4) that were already topographic highs when the first ice advanced over the area. In some areas, such as southwestern Pierce County, highs on the bedrock surface are the result of the glaciers' shoving of blocks of bedrock. In most areas the present topography is the result of successive glaciers moving over the pre-existing topography with little modification of the pre-existing surface. Sully's Hill is an exception, which may be explained as an ice-shoved drift feature. When the last ice sheet began to melt, the thinnest ice, and hence the first ice-free areas, were probably the areas that were topographically high before the advance of the last ice sheet. These areas were therefore again established as drainage divides.

Glacial Lake Souris formed to the north and west of a divide (areas Cb_{1MR} and Cb_{1NV} on pl. 1) during an early stage of melting at elevations up to about 1,590 to 1,600 feet. The lake probably didn't remain at this level very long as at these levels numerous outlets to the southeast were available. From south to north, these outlets were Pagel Lake, Antelope Lake, Lesmeister Lake, Girard Lake-Buffalo Coulee, Long Lake, and possibly the Cranberry Lake-North Fillmore outlets. These outlets have surface elevations of 1,530 to 1,550 feet except for the Girard Lake spillway, which has surface elevations as low as 1,470 feet. With the exception of the Girard Lake spillway, these outlets were not used for more than short periods of time, though, or they would have been cut wider and deeper than they are.

A combination of the evidence of surface elevations of the outlets of glacial Lake Souris and elevations of the surface deposits within the lake plain suggests that the lake dropped to the 1,550-foot level relatively quickly. In Twps. 156 to 158 N., Rs. 71 to 72 W., there are numerous hills and depressions. Most of the hills are cored by sand and gravel and capped by sandy till with the till present at elevations above 1,550 feet. The hills are deposits of earlier glaciations which were present as islands during early stages of glacial Lake Souris. The depressions result from melting of blocks of stagnant ice that were insulated during early stages of lake sedimentation. Fine- to very-fine-grained sand is present in low relief areas at elevations of 1,550 to 1,590 feet except along the eastern margin where sand and gravel deposits flank the area mapped as Cb_{1NV}.

In Twps. 151 to 154 N., Rs. 73 to 74 W., a similar pattern is present. At elevations of less than 1,550 feet, lacustrine sediments are present; above 1,550 feet sandy till is the surface sediment on most of the hills. Some of the hills are definitely sand and gravel-cored while others may be. The hills are deposits of early ice sheets which were islands during early stages of lake sedimentation. In areas of low relief, fine-grained sand covers the surface up to elevations of 1,590 to 1,600 feet. Numerous sloughs that occur at elevations ranging from about 1,510 to 1,560 feet indicate stagnant ice during early stages of lake sedimentation in this area also. The lack of gravel deposits near the area mapped as Cb_{1MR} is probably due to the number of channels cutting through this topographically high area. They resulted in the coarse material being deposited as outwash or kame terraces by meltwater flowing through or along the margins of the outlet channels.

Shorelines at elevations below 1,550 feet are indistinct, due partially to lowering lake levels before the buildup of beach deposits and partially to post-glacial changes. The Girard Lake spillway, with surface elevations as low as 1,470 feet, provided a southeast outlet to at least that level. No testholes were located in the channel southeast of Girard Lake so its depth is unknown. Testholes to the northwest suggest a northwestward sloping bedrock valley.

The area mapped as Cb_{1NV} marks the south and west drainage divide of the Devils Lake basin. The high area north from T. 155 N. marks the divide between the Souris River drainage and the Devils Lake drainage. During the melting of the stagnant ice in this area meltwater flowing westward from the divide was ponded in glacial Lake Souris. Meltwater flowing eastward was ponded in glacial Lake Cando and glacial Devils Lake. Washboard moraines indicate that ice moved over the divide from the northwest to meet the ice advancing from the northeast in T. 156 to 158 N., R. 69 W. The junction of these directions of flow is not marked by a large accumulation of drift but many ice-contact deposits are found in this area and some meltwater channel deposits are found in the Ibsen Lake area. The abundance of ice-contact deposits probably resulted from the poorly integrated drainage that existed while the ice was melting.

The area south from T. 155 N. marks the divide between the Sheyenne River and the Devils Lake basin. A narrow band of outwash deposits occurs along the southern margin of the topographically high area with channels leading to the Sheyenne River. The general lack of ice-contact deposits in this dead-ice moraine area probably reflects the early development of this integrated drainage system. That the channels (e.g., Trappers Coulee, Big Coulee) were cut by meltwater is clearly shown on cross sections (pl. 4, C-C'). Breaks in the topographically high area (Cb_{1NV}) provided routes of flow for meltwater from east of the divide in the Sheep Lake and Fish Lake areas (T. 154 N., R. 69 W.) at elevations of 1,570 to 1,600 feet. However, most of the meltwater probably flowed eastward into the Devils Lake basin.

The level of Devils Lake has fluctuated through recorded history and probably ever since the ice melted. Lake deposits of silt, clay, and very-fine-grained sand are present up to elevations of 1,450 feet in Benson County indicating that this was the highest stage of the lake. When it was at this level further inflow could escape through the Stony Lake-Long Lake channel and the Twin Lake channel to the Sheyenne drainage. Some water may also have drained through the Stump Lake area to the Sheyenne River in Nelson County.

East and south of the Twin Lake outlet the surface till and outwash were deposited on buried stagnant ice. The surficial and buried outwash are typically poorly sorted sand and gravel characterized by a high percentage of shale pebbles. Distribution of this outwash indicates that it must have been deposited prior to or during the early stages of cutting of the Sheyenne valley.

The Sheyenne valley served as an outlet for much of the meltwater of the last glaciation. The till-covered valley walls indicate that it had also served as a meltwater outlet for previous glaciations. The North Fork of the Sheyenne River flows in a narrow valley from its headwaters to the junction with the Girard Lake spillway just southeast of Buffalo Lake. The valley then widens to about ¼ to ½ mile in width and is cut about 80 to 100 feet below the upland level. A short segment of the South Fork flows northward in a narrow valley to its junction with the North Fork in T. 151 N., R. 71 W. At this junction the Sheyenne cuts through the Heimdal "End Moraine" and continues eastward between the North Viking and Heimdal "End Moraines." Channels from those topographically high areas indicate that meltwater from those areas was added to the Lake Souris overflow to cut the valley of the Sheyenne. The course through the Heimdal "End Moraine" in T. 151 N., R. 71 W., may follow a topographic sag resulting from a valley cut into bedrock by a tributary of the deep channel in the Selz area. This segment was probably established during the melting of an earlier glaciation and reoccupied by meltwater from the latest glaciation.

The history of earlier advances of ice sheets over this area is best preserved in three areas. These are the Souris Lake Plain, the channel in the Selz area, and the area north and east of the "North Viking End Moraine." Generally the topographically high areas have relatively thin drift and may record an incomplete sedimentary record of the ice advances.

Testholes in the Souris Lake Plain commonly penetrated 2 or 3 layers of till that were separated by lacustrine and/or outwash deposits. This indicates that during the melting of earlier ice sheets ponding of meltwaters occurred in the same general area as during the latest glaciation. Outlet channels probably drained to the southeast during early stages of melting of earlier glaciers, too. The channel in the Selz area was probably used by some of this meltwater. The Girard Lake Spillway may also have been used during early glaciations, but it probably then joined the channel in the Selz area to continue in the New Rockford channel in Wells County. It seems likely that if the Girard Lake Spillway were used in early glaciations it was only during early stages and the New Rockford or other channels were the main southeast outlets of most of the earlier glaciations.

The surface deposits in the Selz area are till deposited by a Late Wisconsinan ice sheet. The topography of the buried valley (pls. 2,5) is not reflected at the surface, indicating that most of the fill (drift) in this valley was already present when the last ice advanced over the area. Examination of the fill indicates a complicated history of cut and fill. A possible sequence of events that would account for the sequence of deposits in the testholes is shown on the cross section (pl. 5, B-B'). At least four intervals of valley cutting, shown as a., b., c., and d. are indicated. The actual sequence of events may be more complicated.

Valley a. represents the preglacial profile; valleys b., c., and d. represent cutting by diverted drainage, interglacial drainage, or outlet channels of glacial lakes. Four or more different ice sheets advanced over the area depositing till units 1, 3, 5, and 7. Units 2, 4, and 6 are primarily water-sorted material deposited by glacial meltwaters and diverted or ponded drainage. Unit 2 is predominantly sand and gravel with some interbedded silt and clay. The sand and gravel contains conspicuous amounts of lignite, scoria, and rocks of siliceous composition suggesting a western source. These deposits are generally poorly sorted suggesting an upper flow regime transport.

Testholes in eastern Benson County suggest that the bedrock topography had a significant effect on drift thickness. The Pierre-Fox Hills contact was apparently nearly coincident with an escarpment. East of this escarpment the drift is thicker than it is on or to the west of the escarpment. Most testholes penetrate multiple sections of till separated by water-sorted sediments (pl. 4, sections C-C', D-D') that probably reflect a record of multiple glaciations. Some of the testholes which penetrated only unsorted drift have suggestions of multiple glaciation based either on electric log characteristics or in some cases sample descriptions. Examination of the cross sections suggests that in most areas the drift deposits of the last ice advance do not exceed 50 feet in thickness. A comparison of the drift thickness (pl. 3) with the bedrock topography (pl. 2) shows that the thickest drift is present in areas which were originally topographic lows; the thinnest drift is in areas which were originally topographic highs, so the net effect of successive glaciations has been to reduce local relief, but the original divides are mostly reflected as divides of the present drainage.

Holocene

The glacial deposits have been slightly modified in some areas by the forces of wind and water. Where these modifications resulted in recognizable deposits they were mapped as the Walsh Formation.

The effect of wind has been of two types. One effect has been to remove some of the fine-grained sediment from the area. This effect is quite noticeable in recent time because of cultivation practices, but it may not have been significant under native vegetation conditions. Another effect has been to transport sand for short distances in areas of surface sand and redeposit it as low dunes.

In areas of interior drainage, slopewash from topographically high areas washes sediment into the low slough areas. Some thin silt and clay deposits are probably present in all of the undrained depressions, but only the larger areas were separated as map units.

Most of the present-day drainages were cut or deepened by meltwater of the last glaciation. Alluvial deposits are now gradually accumulating in these valleys as a result of the decreased capacity of the present drainage.

A lake or a chain of lakes commonly occurs in outlet channels of glacial Lake Souris and glacial Devils Lake. These lakes are shallow and probably result from slopewash of the channel walls exceeding the capacity of the intermittent drainage that now occupies the channels.

ECONOMIC GEOLOGY

Groundwater

Adequate supplies of water for domestic use are generally available within the glacial drift in most areas of Benson and Pierce Counties. In a few areas the drift is composed entirely of unsorted materials, and in these areas it may be necessary to seek supplies from the bedrock formations. The buried valleys are areas of high yield aquifers. For information on specific areas one should consult part two of this bulletin, which provides information from previous testholes, and part three, which describes the aquifers in terms of areal extent, chemical quality, and water-bearing characteristics. General availability of groundwater is provided by Hydrologic Atlas 476 (Randich, 1972) and part three of this bulletin.

Sand and Gravel

Gravel deposits of some kind are generally present within six miles of any site in these counties with the exception of some areas within the Souris Lake Plain. However, the quality of the gravel deposits varies so widely that each deposit must be investigated to determine its usefulness for a specific purpose. Troublesome points are related mainly to poor sorting and high shale content.

In general, the better sorted deposits are those located along the valleys of the present-day drainages. These are also less shaly. The ice-contact deposits are more variable, ranging from clean, well sorted sand and gravel to poorly sorted or fine-grained material. The linear ice-contact features (eskers) commonly provide the best prospects. Sand and gravel deposits in southeastern Benson County, particularly in the collapsed outwash area, are generally very shaly.

Petroleum

As of January 1, 1973, 44 oil exploration tests have been drilled in the two-county area; 18 in Benson County, and 26 in Pierce County. No commercial finds have yet resulted, but only six of the tests have penetrated Silurian rocks, and only 19 of the tests have penetrated Devonian rocks. Considering the thickness of the preserved sedimentary rocks and the position on the eastern flank of the Williston basin, further testing may yet find oil in Benson and Pierce Counties.

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PLATE I - SURFICIAL GEOLOGY OF BENSON AND PIERCE COUNTIES

By C. G. Carlson and T. F. Freers

NORTH DAKOTA GEOLOGICAL SURVEY
NORTH DAKOTA STATE WATER COMMISSION

EXPLANATION

		Lithology	Map Symbol	Landform; Characteristics
WALSH FORMATION	SILT AND CLAY FACIES	Medium gray to dark gray silt, silty clay and clayey silt.	W_s	Sloughs or undrained depressions.
	SAND FACIES	Yellowish brown to medium brown, fine to very fine grained sand.	W_{sd}	Low dunes.
	MIXED SAND–SILT–CLAY FACIES	Grayish brown to medium and dark gray silty, clayey sand, clayey silt, and silty clay.	W_c	Stream floodplains; valley floor deposits.
COLEHARBOR FORMATION	BOULDER CLAY FACIES	The boulder clay facies typically consists of a nonsorted, nonstratified mixture of boulders, cobbles, pebbles, and sand grains in a matrix of silt and clay. Usually yellowish brown to olive gray in the near surface oxidized zone.		Cb1 Subunits.
			C_{b1NV}	Cb1NV - North Viking End Moraine(?). Ice marginal and/or low to high relief stagnation deposits. Circular disintegration ridges common.
			C_{b1M}	Cb1M - Martin End Moraine(?).
			C_{b1H}	Cb1H - Heimdal End Moraine(?).
			C_{b1MC}	Cb1MC - McHenry End Moraine(?).
			C_{b2}	Cb2 - Low relief stagnation deposits; washboard moraines are common in parts of area; ice-contact deposits also common, circular disintegration ridges present in some areas.
			C_{b3}	Cb3 - Low relief stagnation deposits; caps over-ridden hills in some areas; washboard moraines and circular disintegration ridges present in some areas; generally absent in siltier, sandier areas.
			C_{b4}	Cb4 - Low relief stagnation deposits; circular disintegration ridges and washboard moraines generally faint, poorly developed, or absent.
			C_{b5}	Cb5 - Eroded slope deposits—veneer of drift on pre-existing nonglacial topography.
			C_{b6}	Cb6 - Drift covered ice-shove features—till surface with a core of disturbed bedrock or glacial drift.
	SAND AND GRAVEL FACIES	Gravel, gravelly sand and sand.	C_{gs}	Cgs - Gravel and gravelly sand; occurs as kame deposits along present drainages; as ice-marginal deposits adjacent to areas of Cb1.
			C_{sg}	Csg - Gravel, gravelly sand and sandy gravel. Occurs as channel deposits or outwash aprons in areas between present drainages and areas mapped as Cb1.
			C_{cgs}	Ccgs - Gravel, gravelly sand and sandy gravel. Occurs in areas near areas mapped as Cb1; characterized by medium to high relief; probably deposited on stagnant ice.
			C_{os}	Cos - Sand and gravelly sand. Areas of low relief near areas of Cb1.
			C_{ls}	Cls - Sand and silty sand. Low relief, well sorted, thin bedded, lacustrine deposits.
	SILT AND CLAY FACIES	Silt, clayey silt, silty clay and clay.	C_{sc}	Csc - Silt, clayey silt and silty clay. Low relief, thin laminated lacustrine deposits.
	MIXED FACIES	Variable lithology. In some areas mostly sand and gravel; some unsorted drift; some silt and clay.	(red symbol)	Cic - Kames, eskers.
HELL CREEK FORMATION		Sandstone, very light gray and light brownish gray, very fine grained, silty; silty clays, carbonaceous lenses.	△	Exposed in ice-shove hills.
FOX HILLS FORMATION		Sandstone, yellowish brown, fine to very fine grained; silt and shale, generally thin bedded.	○	Exposed along valley walls and ice-shove hills.
PIERRE FORMATION		Gray to black shale; a few bentonitic layers.	×	Exposed along valley walls.
			////	Washboard moraines, low linear ridges, prominent on aerial photos.
			⚒	Gravel pit.

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PLATE 2- BEDROCK TOPOGRAPHY OF BENSON AND PIERCE COUNTIES

EXPLANATION

- Line of Cross Section
- NDSWC Test Hole
- BEDROCK EXPOSURE

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PLATE 3 - DRIFT THICKNESS IN BENSON AND PIERCE COUNTIES

PLATE 4 - GEOLOGIC SECTIONS OF GLACIAL DRIFT STRATIGRAPHY

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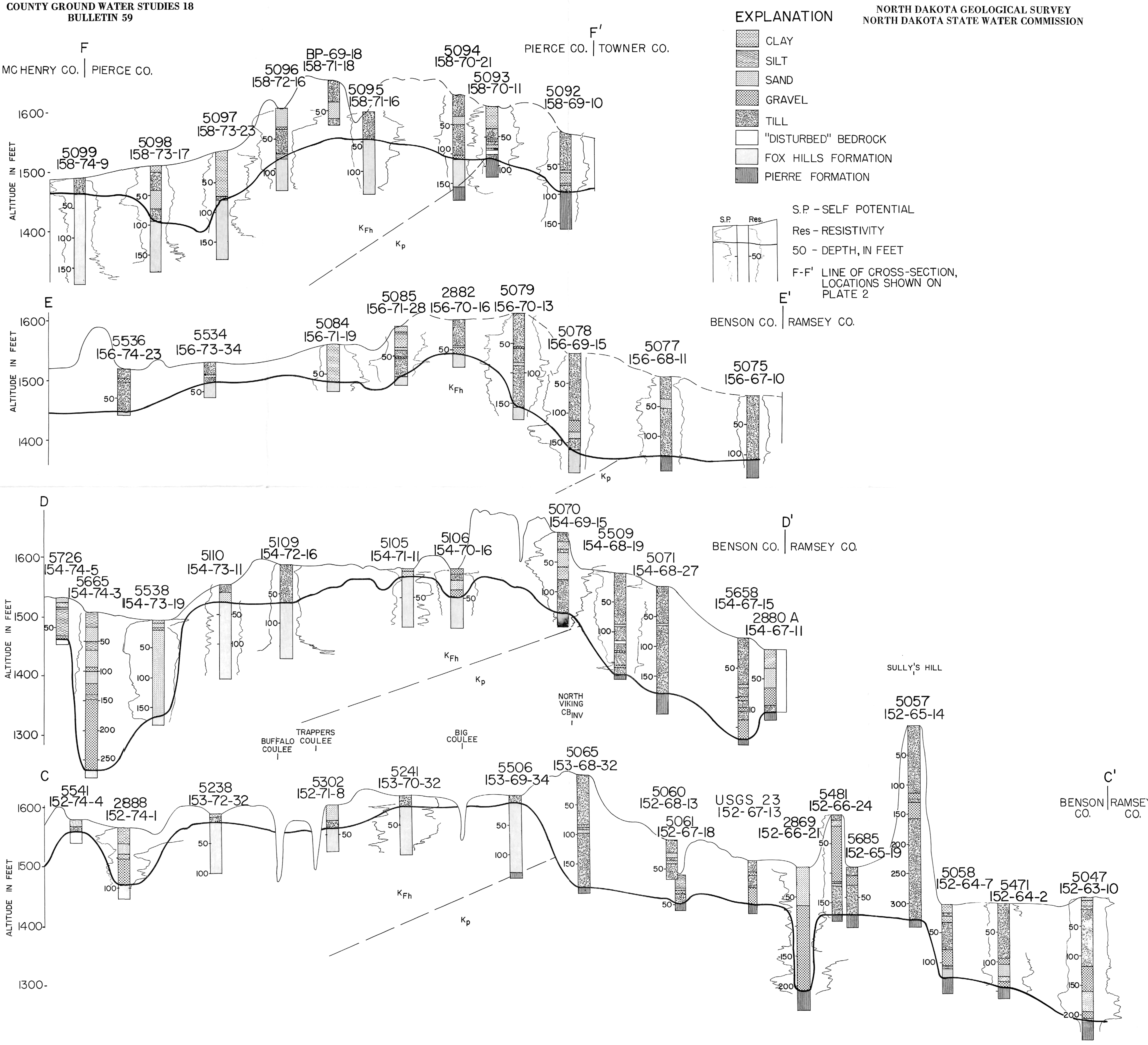

PLATE 5 - GEOLOGIC SECTIONS OF A BURIED PREGLACIAL VALLEY IN SOUTHERN PIERCE COUNTY

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