GEOLOGY

of

NELSON AND WALSH COUNTIES, NORTH DAKOTA

by
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Prepared by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, the Nelson County Water Management District and the Walsh County Board of Commissioners.

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by

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ABSTRACT

Nelson and Walsh Counties are located in northeastern North Dakota on the eastern edge of the Williston basin. Precambrian rocks range in depth from 300 to 2,800 feet. They are overlain by Paleozoic and Mesozoic rocks that dip to the west at low angles. Glacial drift covers the entire area except along a few deeply eroded valleys where Cretaceous shale is exposed. The glacial drift reaches a maximum thickness of over 300 feet in the McVille trench of southern Nelson County.

Quaternary sediments, which belong to the Coleharbor Formation, consist of three main facies: 1) till, 2) sand and gravel, and 3) silt and clay. Landforms composed mainly of the first two of these lithologies cover most of Nelson County and western Walsh County; and landforms composed mainly of silt and clay, the Lake Agassiz deposits, cover eastern Walsh County. Holocene sediments, which belong to the Walsh Formation, consist of three main facies: 1) clay, 2) sand and silt, and 3) gravel. They overlie the glacial deposits in places throughout the two-county area.

Pre-Wisconsinan glacial deposits were tentatively identified, but the detailed stratigraphy of these deposits has not yet been worked out. Most of the landforms that can now be seen in the area were formed during Late Wisconsinan time.

Economic mineral deposits in Nelson and Walsh Counties include sand and gravel of the beach ridges and river terraces and ground and surface water. Although no commercial hydrocarbon production has yet been found, the many possibilities for stratigraphic and structural traps along with shallow drilling depths allowing easy and fast drilling should do much to promote exploration in the area.

INTRODUCTION

Purpose

This report is one of a series of county reports published by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the United States Geological Survey, the Nelson County Water Management District, and the Walsh County Board of Commissioners. Reports on the ground water basic data and the ground water resources of the area will be published separately.

Scope

The major objective of this report is to present a detailed description of the character and occurrence of the glacial deposits in the two counties because they form the major aquifers in the prospect area. Detailed geologic maps of the two-county area are included (Plates 1 and 2). The information in this report should be of value to anyone interested in the distribution of the geologic units that have potential as aquifers. Data are also supplied on the engineering properties of foundation materials at possible construction sites. Residents interested in knowing more about the area and geologists interested in the physical evidence supporting various geologic interpretations should find the report useful.

Those portions of the report dealing with the origin of the landforms and the geologic history are largely interpretations of the events that resulted in the present landforms. These interpretations are intended for those interested in the geologic processes and sequence of events during Pleistocene time.

Methods of Study

The geology of Nelson County was mapped during the 1967 and 1968 field seasons by Dennis N. Nielsen and Roger J. Reede. Ronald F. MacCarthy mapped a portion of Walsh County along the edge of the

Agassiz lake plain during the 1968 field season. I mapped Walsh County during the 1968 field season and checked Nielsen's and Reede's maps during the 1969 field season. Modifications necessary to adapt their maps to the map units used in this report were made at that time.

Data were plotted on 1:24,000 scale topographic maps where available. In other areas, county highway maps, scale 1:63,360, were used. Aerial photographs, scale 1:20,000, taken in 1959 in Nelson County and 1962 in Walsh County, were used to accurately place geologic contacts. The surficial mapping was done by driving along all section line roads and trails, recording lithologies at all roadcuts or exposures. Less accessible areas were covered on foot. A shovel and soil auger were used to obtain lithologic information in areas of poor exposures. In addition, about 25 auger holes were bored by the North Dakota Geological Survey truck-mounted auger. This auger is capable of sampling to a maximum depth of 150 feet. The North Dakota State Water Commission provided rotary drilling equipment that was used during the 1968 and 1969 field seasons for about 18,000 feet of test drilling.

Previous Work

A brief description of the geology and ground water resources of Nelson and Walsh Counties was presented by Simpson (1929). Other reports dealing with geology and ground water resources have been prepared for areas near Aneta (Dennis, 1947), Michigan (Aronow, 1953), and Lakota (Powell and Jones, 1962) in Nelson County, and Minto and Forest River (Brookhart and Powell, 1961), and Hoople (Jensen and Bradley, 1962) in Walsh County. Atlases describing the ground water resources of the two counties have been prepared by Joe Downey (Nelson County, 1970, and Walsh County, 1971a).

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

Lemke and Colton (1958) summarized North Dakota Pleistocene geology and later published their *Preliminary Glacial Map of North Dakota* (Colton, Lemke and Lindvall, 1963). A comprehensive study of the Paleozoic bedrock of eastern North Dakota (Ballard, 1963) includes the area covered in the present paper. Studies were made by Aronow (1957, 1963) on the glacial geology of the Devils Lake region and along the Sheyenne River. Geologic reports of the present county series already published for areas adjoining Nelson and Walsh Counties are those for Eddy and Foster Counties (Bluemle, 1965) and Grand Forks County (Hansen and Kume, 1970). In addition, several circulars describing samples from exploratory oil wells have been published and various studies of North Dakota bedrock have included all or parts of the two-county area.

Acknowledgments

I wish to acknowledge Mr. Joe Downey, U. S. Geological Survey, Grand Forks, North Dakota, for supplying valuable test hole data and other information. Mr. Downey also reviewed the manuscript.

Regional Geology

Nelson and Walsh Counties, which are located in northeastern North Dakota, have a combined area of approximately 2,284 square miles (Nelson, 997, and Walsh, 1,287) in Townships 149 to 158 North, Ranges 50 to 61 West) (Fig. 1).

The two counties lie in the Western Lake Section of the Central Lowland Province (Fenneman, 1946). The eastern two thirds of Walsh County is part of the Red River valley and has landforms that are related to glacial Lake Agassiz. The remainder of the area is part of the Drift Prairie and has landforms resulting from various glacial processes. Nelson and Walsh Counties are in the Red River of the North drainage basin. Perennial drainage is mainly eastward and northward via the Park, Forest, and Red Rivers in Walsh County and southeastward via the Goose and Sheyenne Rivers in Nelson County. All other streams in the two counties are intermittent.

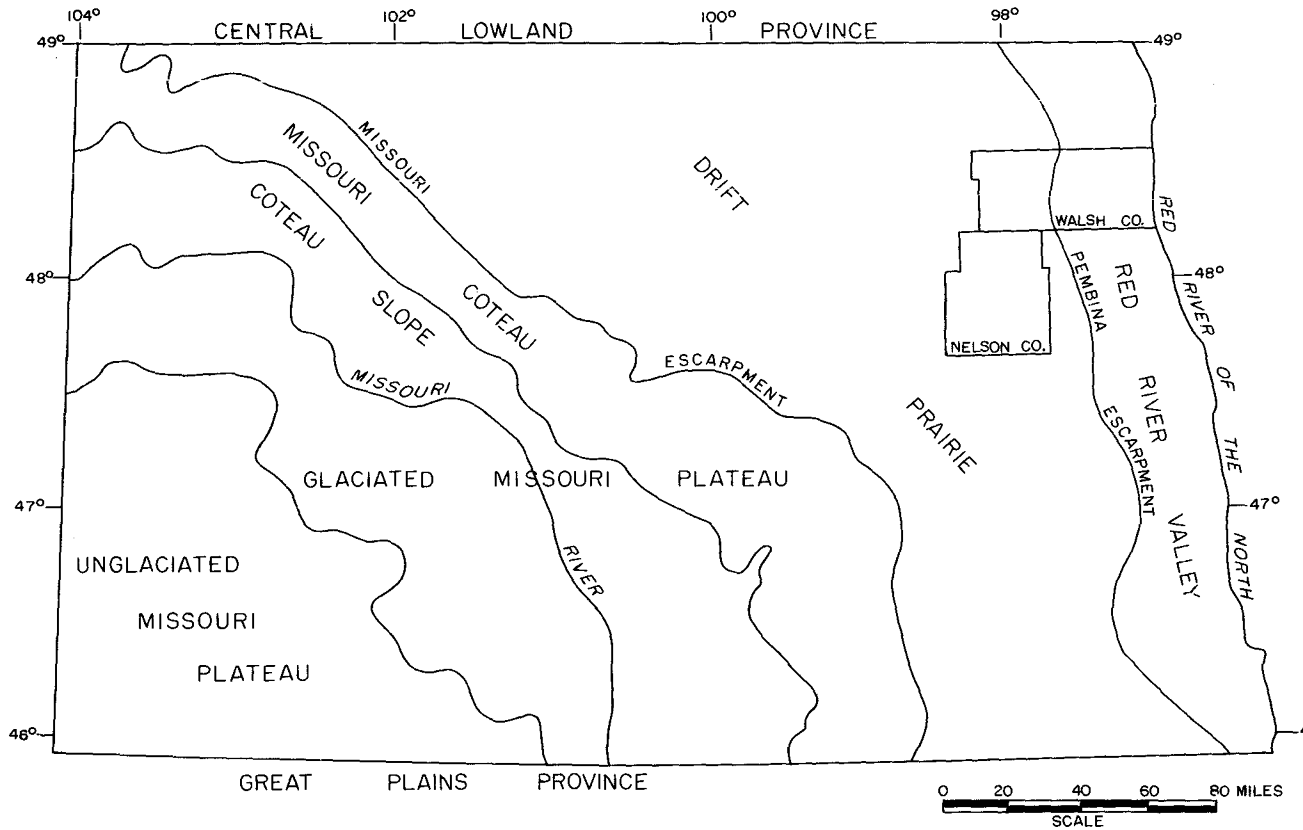


Figure 1. Map of North Dakota showing generalized physiography and the location of Nelson and Walsh Counties.

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

STRATIGRAPHY

General Statement

The discussion that follows is a description of the composition, equence, and correlation of the geologic units that occur in Nelson and Valsh Counties. The description proceeds from the oldest materials to he youngest. The younger, more easily accessible geologic units are lescribed in greater detail than are the older units. The landforms that occur in the two-county area are composed of the younger geologic naterials, which were deposited mainly by glacial action. Considerable attention will be given to these landforms.

Precambrian Rocks

Precambrian rocks range in depth from about 300 feet in southeastern Walsh County to about 2,800 feet in western Nelson County. Figure 2 shows the extent of the Precambrian basement rocks in the area. The basement rocks in the northwest half of Walsh County are part of the Ramsey gneiss terrane (Lidiak, in preparation). They are predominantly silicic to intermediate in composition with a gneissic fabric. Layered gneisses, granite or granodiorite gneisses, and foliated granites, or granodiorites, occur in this area. To the southeast, the Grand Forks plutonic terrane covers much of Walsh and central Nelson Counties. This terrane consists mainly of massive granodiorite and granite rocks with hypidiomorphic granular textures. The remainder of the area consists of belts of low-grade schists or gneisses, referred to here as the Amphibole schist terrane. Actinolite and hornblende schist are the predominant rock types in these areas with serpentinite subordinate. The rocks of the Amphibole schist terrane appear to be the oldest in the area; but, in general, all of the basement rocks of Nelson and Walsh Counties are of Early Precambrian age (older than 2.6 billion years).

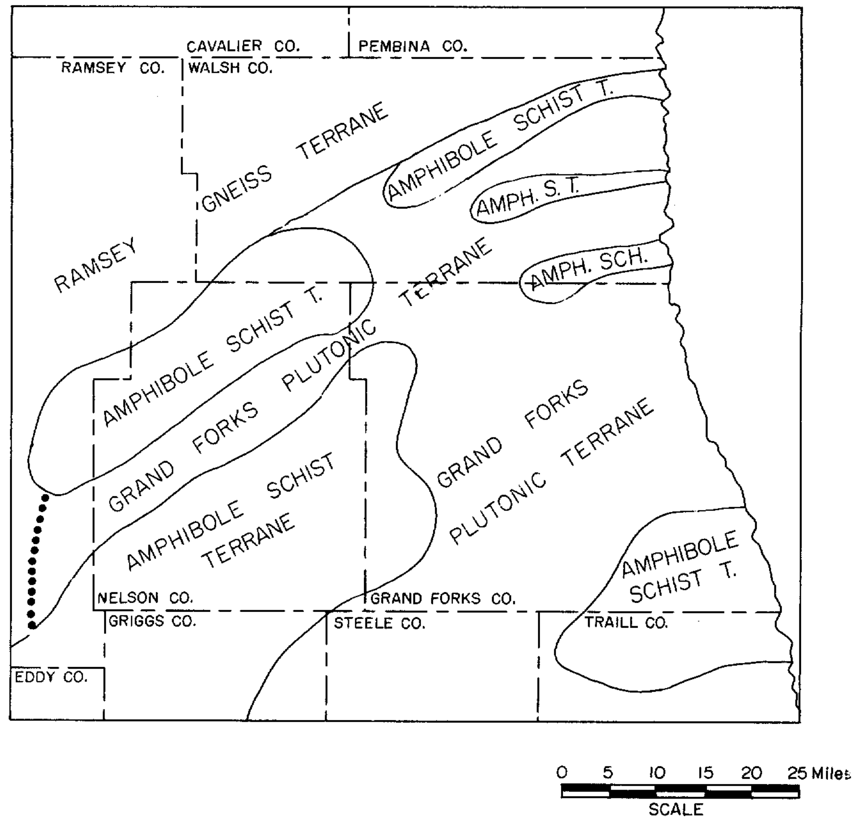


Figure 2. Geologic map of Precambrian rocks in the Nelson-Walsh County area (map from Lidiak, in preparation).

Paleozoic Rocks

Paleozoic rocks range in thickness from about 200 feet in southeastern Walsh County to about 1,300 feet in western Nelson County. For purposes of discussion, the Paleozoic rocks can be subdivided into 4 sequences, which are defined as preserved sedimentary rock records bounded by regional unconformities (Sloss, 1963). Two Paleozoic sequences are recognized in Nelson and Walsh Counties (Fig. 3). They are, in ascending order, the Tippecanoe and Kaskaskia Sequences. The Sauk and Absaroka Sequences, which are present further west, are not represented in the area.

TIPPECANOE SEQUENCE

The Tippecanoe Sequence is the result of a transgressive event during which seas invaded from the south and east. It is represented in the area by rocks of Middle Ordovician to Silurian age. The initial deposits of the sequence were the clastics and carbonate of the Winnipeg Group. These were followed by carbonate, with minor amounts of evaporite, of the Red River, Stony Mountain, Stonewall, and Interlake Formations. In Nelson and Walsh Counties the Tippecanoe Sequence ranges in thickness from 250 feet in southeastern Walsh County to about 1,000 feet in northwestern Walsh County.

KASKASKIA SEQUENCE

The initial deposits of the Kaskaskia Sequence represent a transgressive sea that spread over the area from the north and west during Devonian time. Only the extreme western edge of the two-county area has deposits of the Kaskaskia Sequence. The Prairie Formation, mainly limestone and anhydrite, is about 20 feet thick in extreme northwestern Walsh County. As much as 80 feet of alternating limestone and thin argillaceous beds of the Souris River Formation and about 150 feet of carbonate and shale of the Duperow Formation occur in western Nelson County.

ERA	SEQUENCE	SYSTEM	GROUP OR FORMATION		DOMINANT LITHOLOGY	THICKNESS IN FEET
Cenozoic	Tejas	Holocene	Walsh Formation		Sand and silt	0-25
		Quaternary	Coleharbor Formation		Till, gravel and silt	0-350
		Tertiary				Absent
Mesozoic	Zuni	Cretaceous	Pierre Fm.	Odanah Mbr.	Siliceous shale	0-350
				DeGray Mbr.	Shale	
				Gregory Mbr.	Bentonitic shale	
				Pembina Mbr.	Bentonitic shale	
			Niobrara Formation		Calcareous shale	0-160
			Carlile Formation		Shale	0-240
			Greenhorn Formation		Calcareous shale	0-80
			Belle Fourche Formation		Shale	0-250
			Mowry Formation		Shale	0-100
			Newcastle Formation		Sandstone and shale	0-80
			Skull Creek Formation		Sandy shale	0-90
			Fall River Formation		Sandstone, shale, and siltstone	0-250
			Lakota Formation			
		Jurassic	Redbeds		Red shale and sandstone	0-100
	Absaroka	Triassic				Absent
Paleozoic		Permian				
		Pennsylvanian				
	Kaskaskia	Mississippian				
		Devonian	Duperow Formation		Carbonates and shale	0-150
			Souris River Formation		Argillaceous limestone	0-80
			Prairie Formation		Limestone and anhydrite	0-20
	Tippecanoe	Silurian	Interlake Formation		Dolomite	0-120
			Stonewall Formation		Dolomite and limestone	0-70
		Ordovician	Stony Mountain Formation		Limestone and dolomite	0-130
			Red River Formation		Limestone and dolomite	150-570
			Winnipeg Group		Calcareous shale and sandstone	0-210
	Souk	Cambrian				Absent
Proterozoic		Precambrian			Granodiorite, granite, actinolite and hornblende schist and gneiss	Unknown

Figure 3. Stratigraphic column for Nelson and Walsh Counties, North Dakota. Shaded areas represent missing section.

Mesozoic Rocks

Mesozoic rocks range in thickness from zero feet in eastern Walsh County to about 1,500 feet in western Walsh and Nelson Counties. All of the Mesozoic rocks are part of the Zuni Sequence. Outcrops of the Cretaceous Pierre and Niobrara Formations occur along the Pembina Escarpment in Walsh County, and the Pierre Formation is exposed along the Sheyenne River valley in Nelson County.

ZUNI SEQUENCE

Rocks of the Zuni Sequence in North Dakota consist mainly of clastics that were deposited in widespread Jurassic and Cretaceous seas. Jurassic strata consist of reddish-brown siltstone, claystone, and fine-grained sandstone. They range in thickness from zero in the east to about 100 feet in the western part of the area. Cretaceous rocks include the Fall River and Lakota Formations, which consist of pale red and light gray claystone and siltstone interbedded with fine-grained quartzose sandstone. These are overlain by interbedded gray shale and siltstone and fine- to coarse-grained quartzose sandstone. The Fall River-Lakota Interval reaches a maximum thickness of about 250 feet in the area.

The Skull Creek Formation overlies the Fall River. It is a medium- to dark-gray, silty and sandy shale that thins eastward due to both erosion and nondeposition. The Skull Creek is overlain by the Newcastle Formation, a medium-grained sandstone interbedded with some shale. The Newcastle Formation reaches a maximum thickness of about 90 feet in southeastern Nelson County. It is overlain by shale of the Mowry Formation. The Mowry is overlain by the Belle Fourche Formation, a dark-gray, flaky to massive, spongy shale. The rest of the Cretaceous rock is gray shale, some of which is calcareous, along with isolated bentonitic layers; included, in ascending order, are the Greenhorn, Carlile, Niobrara, and Pierre Formations.

The Niobrara Formation is exposed along the South Branch of the Park River in Section 24, T. 157 N., R. 56 W. in Walsh County. About 20 feet of Niobrara shale is exposed at this location. It consists of a calcareous, highly jointed, tan to yellowish shale. The Niobrara Formation is also exposed in Section 6, T. 158 N., R. 57 W.

The contact between the Niobrara and Pierre Formations is exposed in Section 13, T. 157 N., R. 57 W. where about 20 feet of the

Pembina Member of the Pierre Formation can be seen. The Pembin Member exposed in this area consists of soft, black shale interbedde with yellowish beds of bentonite near the Niobrara contact. Higi concentrations of iron oxide occur near the contact. Overlying th Pembina Member in nearby river cuts is shale of the Gregory Member o the Pierre. It is a bentonitic shale with conspicuous ironstone banding Exposed surfaces tend to form a loose granular surface mulch as a resul of wetting, drying, freezing, and thawing. The Gregory Member is commonly slumped along the valley walls and is poorly exposed.

The DeGray and Odonah Members of the Pierre Formation were not differentiated in Nelson and Walsh Counties. Most Pierre Formation exposures above the Gregory Member probably belong to the Odonah Member, the uppermost member of the Pierre Formation in the area. Exposures of the DeGray-Odonah Members of the Pierre are abundant along the South Branch of the Park River in Tps. 157 to 158 N., R. 57 to 58 W. and along the Middle Branch of the Forest River in Walsh County. They are also common in many places in Nelson County, particularly along the Sheyenne River where continuous exposures occur in the McVille-Pekin area.

The Odonah Member of the Pierre Formation is generally a hard, siliceous, gray shale. It has reddish-brown and purple stains on joint faces and on concretions. Jointing is extensive in some exposures. The shale commonly weathers to thin plates or flakes, but cube-shaped blocks and chunks about 6 inches across occur in some exposures. The Odonah Member appears to be fractured along a north-south zone through western Walsh and central Nelson Counties. This may be the result of glacial movement or loading on the brittle shale.

Quaternary Sediment

COLEHARBOR FORMATION

General Statement

The Coleharbor Formation is the most extensive surface formation in Nelson and Walsh Counties. The Pierre and Niobrara Formations occur at the surface only in small exposures and along the Sheyenne River in Nelson County. The Coleharbor Formation, which consists mainly of glacial drift deposits, was named by Bluemle (1971) for the town of Coleharbor in McLean County, North Dakota, where it is well exposed in the bluffs along Lake Sakakawea. The thickness of the Coleharbor Formation in Nelson and Walsh Counties ranges from 0 to ore than 300 feet (Fig. 4). The total volume of the Coleharbor ɔrmation in Nelson County is about 15 cubic miles and in Walsh ɔunty about 38 cubic miles. The Coleharbor Formation consists ɩainly of beds and lenses of unsorted till; sorted gravel, sand, silt, and ay; and numerous boulders and cobbles. It has been divided into three ɩain facies: 1) till, 2) sand and gravel, 3) silt and clay.

ill Facies

Till is a mixture of sand, gravel, and boulders in a silt-clay matrix. ıbout 57 percent of the test hole footage drilled in Nelson and Walsh Counties during the present study was in till. It is likely, however, that he total percentage of till is somewhat higher because of the effort luring the drilling program to find and define aquifers composed of ;and and gravel. In Nelson and Walsh Counties, the till is commonly a stiff, silty clay containing angular, subangular, and rounded blocks of rock. The silt-clay fraction is olive-gray to light gray where unweathered, brownish to yellowish gray where weathered. The thickness of the oxidized zone averages about 20 feet in eastern Walsh County to about 25 feet in the western part of the two-county area.

Nineteen samples of till collected in northern Nelson County averaged about 6 percent gravel, 30 percent sand, 40 percent silt, and 24 percent clay. The gravel size fraction of the till averages 40 percent shale, 35 percent carbonate and 25 percent granite and basic igneous rocks. However, shale percentages are locally much higher in parts of western Walsh County where the Pierre Formation is near the surface.

The carbonate rocks found in the till appear to have been derived from the Paleozoic carbonate sequences of southern Canada, the granitic and basic rocks from the Canadian Shield, and much of the shale was probably locally derived. The till is generally non-bedded and uncemented. Crude local jointing is common and gypsum crystals are commonly oriented parallel to the joint faces.

All areas colored shades of green with the designation "Cb" on Plates 1 and 2 are characterized by landforms composed mainly of glacial sediment. Such areas are underlain by materials that were deposited directly from glacier ice (as opposed to areas underlain by materials that were deposited by fluvial processes, for example).

Ground moraine–Areas underlain by lodgement deposits that were directly influenced by the base of the moving glacier as well as ablational materials that were lowered from upon and within the melting ice are designated Cb1 on Plates 1 and 2. In most such areas, the ablational materials, which probably slid into place as mudflow deposits, probably account for most of the glacial sediment and little

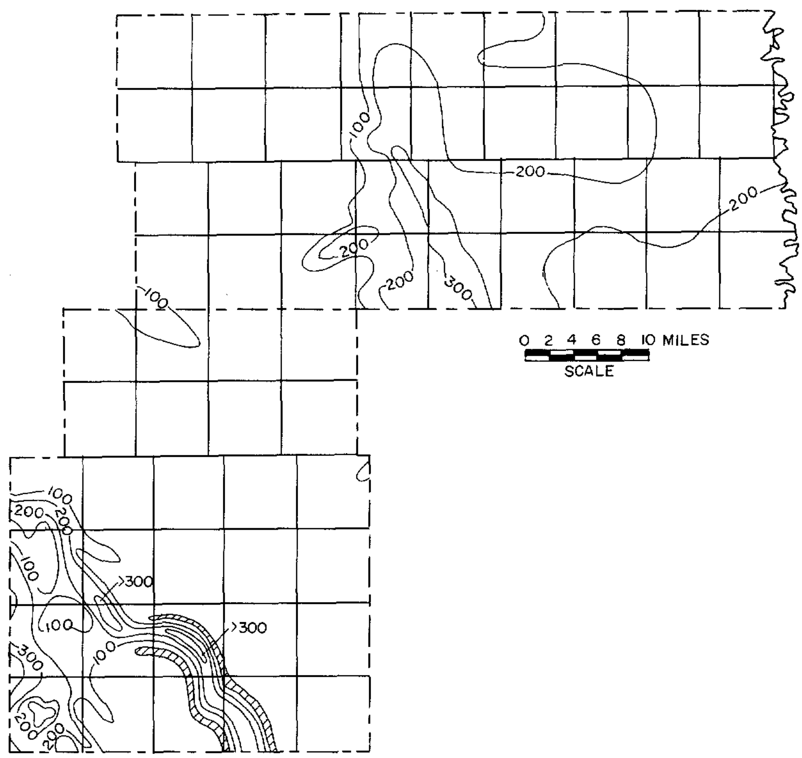


Figure 4. Isopach map of the Coleharbor Formation in Nelson and Walsh Counties, North Dakota.

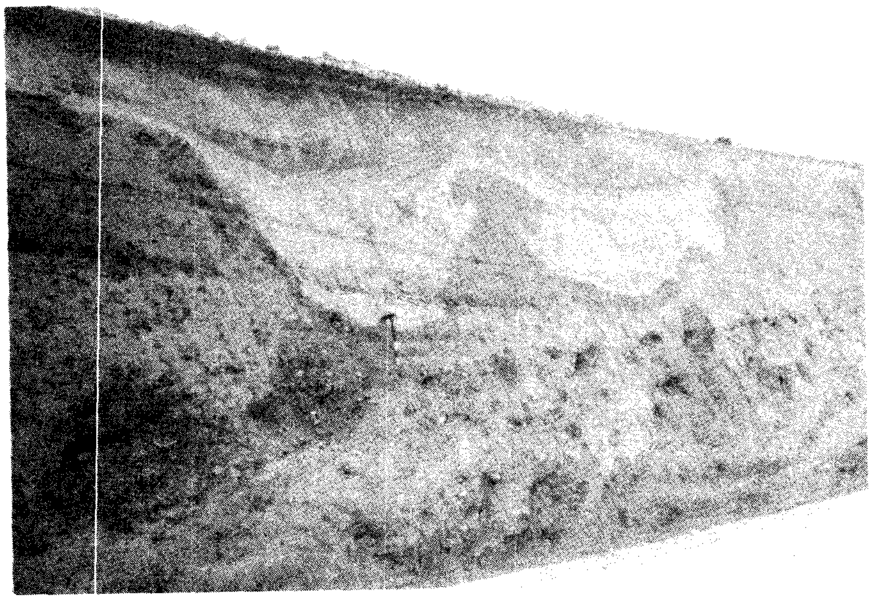


Figure 5. Channel in till filled with silt in Walsh County (SE ¼, SE ¼, Sec. 33, T. 156 N., R. 59 W.). The silt grades upward to medium-grained sand. Notice the boulder pavement just below the channel deposit. It separates a very hard, dense and sandy till (below) from a silty, rather soft till (above). Shovel is about two feet long.

lodgement material is present. For purposes of discussion, all of these materials will be designated ground moraine.

In most places in Nelson and Walsh Counties, the ground moraine is characterized by relatively smooth topography, gentle slopes, and relief averaging between 10 and 15 feet locally. Elevations on the ground moraine range between 1,450 and 1,550 feet. Drainage is generally poorly integrated. The surface is pitted by innumerable, nearly circular depressions averaging a few hundred feet across. Low, linear ridges, either straight or arcuate in plan, occur in some areas. They are particularly abundant in northern Nelson County (Fig. 6). The long axes of these washboard moraine ridges parallel the former ice margin. Nielsen (1969) studied the washboard moraines of northern Nelson County and concluded that they are remnant shear moraines that were deposited from a superglacial position. He stated that the shear moraines were formed by shearing of active ice over stagnant ice in marginal positions, forming debris-laden shear planes. Debris in the shear planes was released by ablation, forming ice-cored shear moraines. As evidence that the features are shear moraines, Nielsen cites the following facts: 1) some eskers and drumlinoid features are crossed by the washboard moraines; 2) the washboard moraines are discontinuous and have irregular shapes; 3) consistent proximal and distal slopes are absent; and 4) the preferentially oriented till fabrics are unrelated to regional ice flow. In view of the fact that the area in which the shear moraines occur was covered by stagnant ice, Nielsen's conclusions seem reasonable. The features cannot be annual ridges that mark the receding ice margin because, in this area, the glacier stagnated as a large mass and there was no orderly withdrawal of the margin.

Narrow, streamlined lineations occur in places on the ground moraine. These were formed by the moving glacier and their long axes parallel the presumed direction of ice flow. Relief on such lineations is low, and many are not apparent in the field, but they can be readily observed on air photos.

Ground moraine that has been washed by wave action along the shore of Lake Agassiz is designated Cb1a on Plate 2. Patches of gravel and sand occur sporadically, and beach ridges can be found in places. Boulders are generally more numerous than over unwashed areas because wave action has tended to remove the finer constituents of the till, leaving the heavier rocks behind. Several areas of wave-washed ground moraine occur in central Walsh County along the face of the Pembina Escarpment (Plate 2) at elevations ranging between 900 and 1,500 feet. Drainage is fairly well integrated over much of this area.

Areas of ground moraine that have been washed by running water are designated Cb1b on Plate 1. Patches of sand and gravel occur in

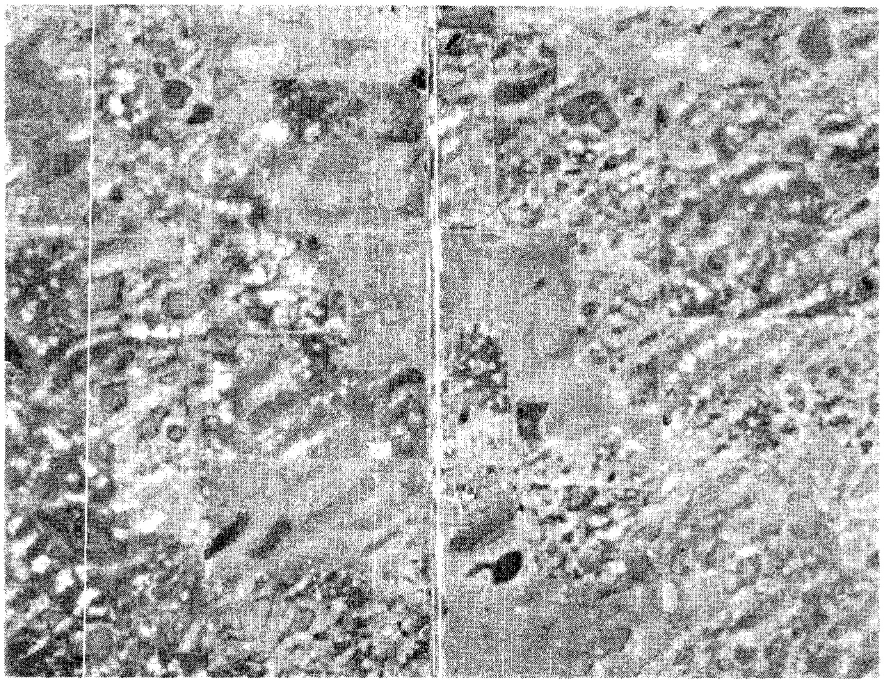


Figure 6. Vertical air photo showing washboard moraines in northern Nelson County. This area of about 3 square miles occurs northwest of Lakota (T. 153 N., R. 60 W.). North is to the top of the photo.

these areas but till is the main lithology. The only place in the two-county area where ground moraine that has been washed by running water occurs is in Nelson County, south of the Sheyenne River, but in Griggs County, to the south, such areas are extensive. These areas grade to sand and gravel surfaces toward the source of the water that washed the surface. Apparently, in Nelson County, the same water that deposited the sand and gravel in the Tolna-Pekin area washed the ground moraine surface to the southeast after dropping its bedload.

In the Pekin area of Nelson County (T. 150 N., R. 60 W.) is found an area that is essentially similar topographically to other areas of ground moraine but with much higher sand percentages. It is designated Cb1c on Plate 1. Apparently, this material was emplaced directly by the glacier as the ice moved over an area of gravel and sand (Figs. 7, 8, and 9).

Eroded ground moraine.–Steep slopes of till occur along the Tolna Coulee and near Stump Lake. These areas, designated Cb2 on Plate 1, consist of deeply incised topography that was eroded by the streams and their tributaries. Local relief is between 25 and 75 feet and drainage is integrated. In many places the slopes are partially covered by colluvial debris.

End moraine.–Materials that were deposited mainly at the ice margin are designated Cb3 on Plates 1 and 2. Till with local concentrations of gravel and sand characterize these areas. Boulders are locally abundant. End moraine deposits accumulated when the ice margin remained stationary for a period of time. The end moraines in Nelson and Walsh Counties were probably deposited as the ice carried debris to its margin and dropped it as the margin melted back at a rate in equilibrium with the forward motion of the ice. As the ice melted, the debris slid into position as mudflow deposits. Some of the material was probably emplaced by shearing of active ice over stagnant ice resulting in areas of drift-covered stagnant ice. Subsequent melting of the stagnant ice resulted in mudflow deposits. In a few places, previously deposited materials may have been pushed into position when the glacier readvanced short distances, but this was probably an uncommon occurrence.

Relief over areas of end moraine ranges up to 75 feet locally, and drainage is poorly integrated in most places. End moraines have overall or internal linearity, or both. In addition to relief, linearity is a primary requisite for recognition of end moraines. Such linearity may be on a small scale such as alignment of depressions, hills, or ridges, or it may

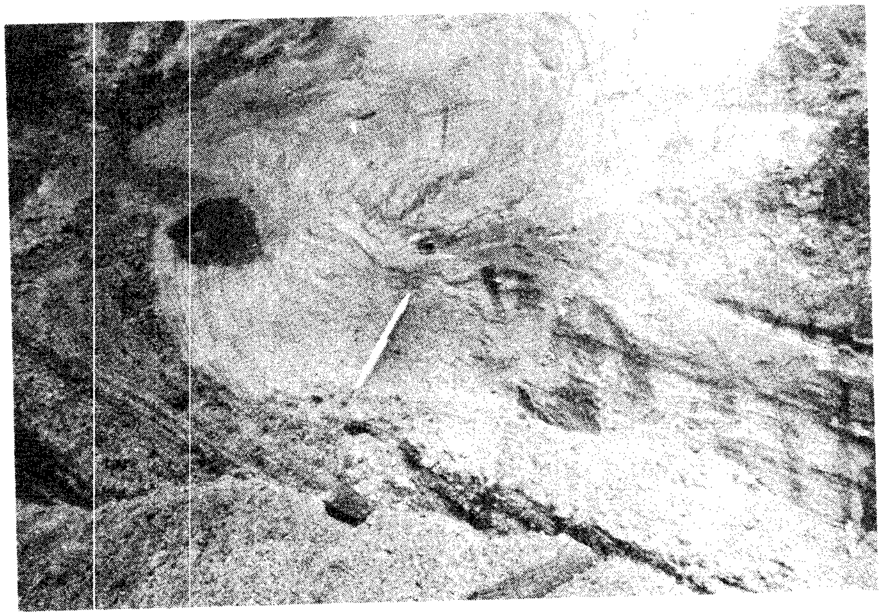


Figure 7. Folded sand overlying gravel in Nelson County. Till occurs above the area shown on the photo. Apparently, the sand was folded as the ice moved over the sand.

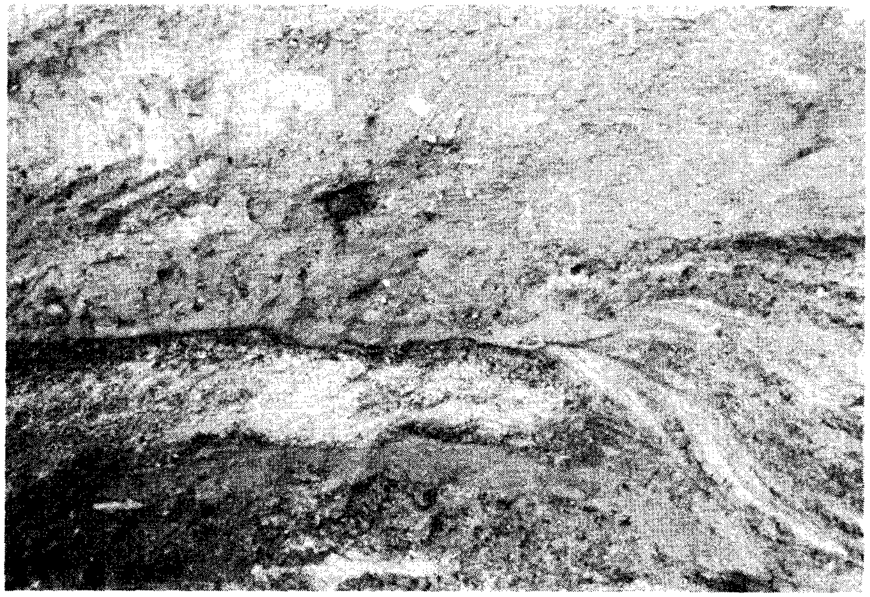


Figure 8. Till over sand and gravel in Nelson County (NE ¼, NE ¼, Sec. 2, T. 152 N., R. 59 W.). The sand unit, which appears to be glacial outwash, ranges in thickness from about a foot to over 10 feet in the cut. Apparently this is an overridden outwash deposit. The photo is about 4 feet across.

Figure 9. Contorted sand beds in till beneath the Agassiz lake plain in Walsh County (SE ¼, SE ¼, Sec. 1, T. 156 N., R. 55 W.). This appears to be overridden lake sediment.

be on an overall scale. In Walsh County between Edinburg and Fordville, internal linearity on the Edinburg End Moraine is negligible.

In southwestern Nelson County (T. 149 N., Rs. 60-61 W.), an ice-marginal deposit consisting mainly of silt and sand with little till has been designated Cb3a. This deposit, which occurs extensively in Griggs County to the south, apparently accumulated at the margin of a glacier that had shortly before advanced over an area of lake sediment. Except for its lithologic characteristics, this area of ice-marginal sediment is identical to nearby areas of end moraine.

Dead-ice moraine.–An area in south-central and southeastern Nelson County is underlain by material that was deposited during the melting of stagnant glacial ice. It is designated Cb4 on Plate 1. Till present on the surface and within the stagnant ice slumped and slid into its present position when the ice melted. Mudflow deposits probably constitute the largest portion of this area of dead-ice moraine. Considerable meltwater was present while the ice was melting, so gravel and sand are also common in the area.

The area of dead-ice moraine has relief comparable to nearby areas of ground moraine in Nelson County, but in other parts of the state, particularly on the Missouri Coteau, similar areas have much higher relief. In Nelson County, only small amounts of superglacial debris were involved in the formation of the areas of dead-ice moraine. Disintegration features are readily apparent on air photos of the Kloten area. If it were not for these, it would be difficult to distinguish areas of low-relief dead-ice moraine from areas of ground moraine.

Dead-ice moraine and ground moraine are not really entirely different types of landforms. In fact, they grade into one another. In general, the amount of superglacial and englacial material determines whether ground moraine or dead-ice moraine will form. Most of this material gets into the ice and to the glacier's surface, mainly near the glacier terminus, through the process of shearing. Shearing is an important process whenever the glacier experiences compressive flow, that is, whenever it moves uphill or over some sort of barrier. Irregular relief may result in compressive flow within the glacier.

If negligible amounts of material are incorporated into the ice as a result of shearing, the original streamlined features such as drumlins that are caused by the movement of the ice over the underlying surface, are preserved when the glacier melts. The small amounts of material on and in the ice do not obscure the features when they are let down on top of them and a striated ground moraine surface results. Slightly more shearing may result in the formation of washboard moraines; the nnant shear plane debris is dropped in place and not covered by ditional debris.

Additional shearing results in larger amounts of superglacial debris. umlins are usually not present in areas where shearing was fairly tensive because, although they may have formed, they were buried ıen the material contained in the glacier ablated. Washboard moraines e only vaguely recognizable if shearing was moderate and they are sent if shearing was extensive. Under conditions of extensive earing, large amounts of englacial and superglacial materials result ıd, depending on the volume of material involved, dead-ice moraine of ffering characteristics (concentration of disintegration features, equency and size of potholes, amount of surface relief, etc.) may sult. For example, if the material on top of the glacier is continuous, ut does not completely obliterate the conical sinkholes that always evelop over a stagnating glacier, medium-relief topography with gularly occurring circular ridges will result. The sinkholes that develop n a stagnant glacier are generally up to about 600 feet across. They ope toward their centers at about 40° and they are about 200 feet eep (Clayton, 1967, p. 31). These maximum sizes are governed by the act that the ice tends to be plastic and flow at thicknesses greater than bout 150 feet so the sinkholes can't be larger.

Wherever shearing was extensive and large amounts of superglacial nd englacial material resulted, a thick, continuous cover of drift ccumulated on the ice. When the ice melted under these conditions, ıigh-relief topography with irregular hills and depressions roughly 600 eet across resulted. Large areas of such high-relief dead-ice moraine are ound on the Missouri Coteau, Turtle Mountains, and Prairie Coteau of North Dakota. As the ice melted, the superglacial material continually noved to lower areas in the form of mudflows. As the higher areas lost heir cover of drift, which slid off, the ice was exposed to more rapid melting and the topography on the stagnant glacier was reversed. This reversal of topography continued until all the ice had melted.

In summary, the difference between ground moraine and dead-ice moraine is simply a matter of degree; increasing amounts of superglacial and englacial debris result in a continuous series of landforms ranging through ground moraine, low-relief dead-ice moraine, and high-relief dead-ice moraine.

Effect of pre-existing topography.–Preglacial topography covered by a veneer of till is designated Cb5 on Plates 1 and 2. Till was deposited on areas of Pierre Formation shale in the same way as occurred in other areas of ground moraine. However, the till in some areas was too thin to form constructional relief so the existing topography is due almost entirely to relief on the underlying shale. Two such areas occur in the Nelson-Walsh County area. One is located in T 149 N., R. 60 W. in southwestern Nelson County and consists of a northwest-southeast trending shale-cored ridge with relief of over 150 feet in less than a mile. Another such area is located in northwestern Walsh County in T. 158 N., R. 57 W. This area is relatively flat with local relief of less than 25 feet in a mile. Northwest-southeast trending lineations that were carved by the moving glacier can be seen on air photos of the area.

Large ice-transported hills.--Two hills that have been designated Cb6 occur in Nelson County. They are located in T. 151 N., R. 61 W. and in T. 150 N., R. 57 W. Although the evidence for mapping these particular hills as ice-transported features is tenuous, the hills are very similar to several hills in Sheridan and McLean Counties, North Dakota. In these areas, it can be demonstrated that large blocks of material were moved from nearby by the glacier (Bluemle, 1970). A depression, commonly filled with lake or slough, marks the location from which each hill came. In Nelson County, depressions are also located immediately up-ice from the two above-mentioned hills.

Deep test holes were not drilled in the two Nelson County hills, but in McLean County, North Dakota, a test hole was drilled in Dogden Butte (Sec. 15, T. 150 N., R. 79 W.). The sequence drilled in this hill, which is interpreted as having the same origin as the hills in Nelson County, included (from the surface downward): 68 feet of glacial drift, 212 feet of bedrock, 44 feet of glacial drift, and 146 feet of bedrock (Bluemle, 1971). This sequence shows that a block with a minimum thickness of 212 feet has been moved by the ice to the location of Dogden Butte. Dogden Butte rises about 250 feet above areas to the south and about 400 feet above areas to the north (because it is located on the northeast-facing Missouri Escarpment).

Sand and Gravel Facies

Gravel, gravelly sand, sand, silty sand, and sandy silt occur at the surface in many places in Nelson and Walsh Counties. About 31 percent of the test hole footage drilled in Nelson and Walsh Counties was in sand and gravel. This figure is probably higher than the actual percentage of sand and gravel that exists because of the effort during the drilling program to find aquifers composed of sand and gravel and to determine their characteristics. All areas colored shades of yellow or red with the designation "Cg" on Plates 1 and 2 are characterized by andforms composed mainly of sand and gravel. Such areas are ınderlain by materials that were deposited by fluvial and shoreline ›rocesses.

Glacial outwash.–Materials that were deposited by meltwater flowing from the glaciers along with alluvial materials deposited by water derived from local precipitation during and immediately following glaciation are designated Cg1. Included are materials on terraces along the major valleys, particularly the Sheyenne, and on the floors of meltwater trenches where they are not covered by modern alluvium. Outwash materials similar to those designated Cg1 that were deposited on top of stagnant ice are designated Cg2. Such materials collapsed when the stagnant ice melted (see Figs. 10 and 11), and the resultant mixing with till deposits contained in the stagnant ice produced siltier gravels.

Meltwater trenches.–Several modern river valleys in Nelson and Walsh Counties carried meltwater in glacial times. The Park and Forest Rivers in Walsh County and the Sheyenne River in Nelson County are all examples of small streams that flow in large meltwater trenches. The South Branch of the Park River in west-central Walsh County was apparently formed as an ice marginal feature with meltwater flowing south along the ice margin and into Lake Agassiz where it formed a portion of the Elk Valley Delta. A part of this trench is located in Tps. 156 to 157 N., Rs. 56 to 57 W. where it is a shallow, boulder-strewn sag that passes east of Lankin; very little gravel is associated with the valley. The South Branch of the Park River no longer flows through this trench but instead flows eastward from T. 157 N., R. 56 W.

The Middle Branch of the Forest River in western Walsh County also may have been formed as an ice marginal feature. It is smaller and has a thin layer of gravel on its floor.

The Sheyenne River meltwater trench is about ¾ mile wide and over 100 feet deep. It is deeper and narrower in areas where it passes through end moraine, shallower and wider in areas of outwash and ground moraine. The trench carried meltwater from Lake Souris to Lake Agassiz for a time at the end of the Wisconsinan Epoch.

Three terrace levels can be recognized in the Sheyenne River trench of Nelson County. The lowest, which is mainly a gravel fill feature, occurs at elevations of 20 to 25 feet above the present river floodplain. It is vague and discontinuous. The middle terrace is the best developed and widespread level. It is from 70 to 90 feet above the modern floodplain. It is characterized in many places by a covering of

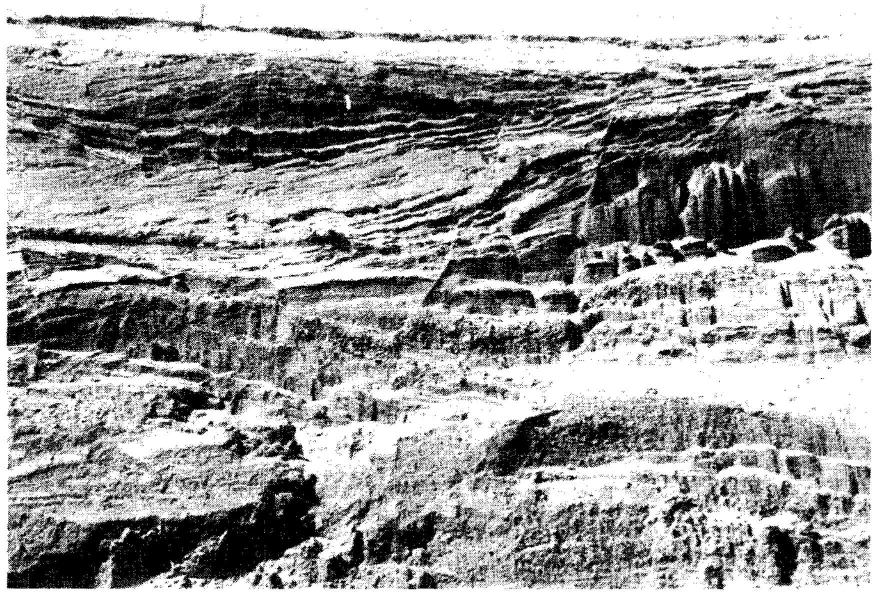


Figure 10. Cross-bedded and faulted exposure of sand and gravel in Nelson County (NW ¼, NE ¼, Sec. 6, T. 149 N., R. 58 W.). Large chunks of sand also occur within till a few feet away. Movement on the faults is down on the west side in nearly all cases; maximum movement is about 2 feet in places. Exposure was in an area of glacial outwash.

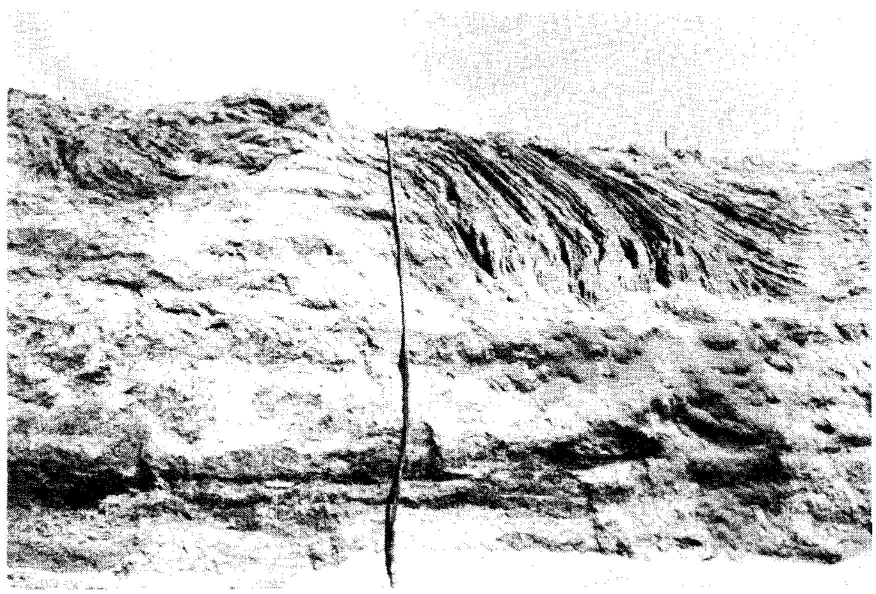


Figure 11. Slumped beds of sand within till in Nelson County (NW ¼, NW ¼, Sec. 11, T. 152 N., R. 57 W.). Exposure was in an area of ground moraine. The cut is about 25 feet high.

relatively high-quality gravel. The highest terrace is about 110 feet above the floodplain, and it was apparently formed when the route of the trench was first established. It lies only a few feet below the upland surface, which in most places is outwash sand and gravel.

Shore deposits.–Shore deposits, designated Cg3 on Plate 2, occur in central Walsh County (Fig.12). They consist mainly of gravelly sand and sandy gravel with some lenses of silt. Sorting in the gravels is good and graded bedding is common. This sand and gravel was deposited along the shore of glacial Lake Agassiz and consists mainly of beach ridges with intervening sheets of slightly reworked sand. Reworking of the deposit is suggested by the fact that nearly all such deposits are present on land that slopes eastward so that fluvial processes, creep, and, to some extent, wind have tended to modify the materials since they were deposited along the lake shore. A few beach ridges that occur in these areas contain exceptionally clean gravel, but such gravel is generally less than 10 feet thick. Figure 13 shows the locations of the beaches in Walsh County.

Eskers.–Ridges of sandy gravel occur throughout Nelson County and western Walsh County. These ridges, which are designated Cg4 and colored red on Plates 1 and 2, contain large amounts of shale. Bedding and sorting in the gravel is rather poor. The ridges are disintegration features that were deposited in channels in the stagnant glacial ice as it was melting from the area. Much of the gravel may have been deposited by streams flowing in tunnels at the base of the ice because commonly the gravel is covered by a cap of till that may have been laid down as ablational material when the ice melted. Commonly, the eskers end at valleys, which trend in the same direction as the ridges, suggesting that the streams flowed from the ice onto ice-free ground at these points.

The largest and most spectacular esker in the two-county area occurs in the Dahlen area of south-central Walsh and northeast Nelson Counties. The following is a quote from Kume (1966) who refers to the feature as the Dahlen esker:

> The Dahlen esker was deposited by a meltwater stream in an ice-walled channel, most likely a tunnel, near the base of a stagnant zone of the ice lobe. The stream flow probably was from east to west, toward the margin of the ice lobe. The flow direction, although suggested mostly by the position of the ice lobe, may be indicated by a kame near the terminus of the northeast branch. Kames differ from eskers by forming in a surface opening in the ice rather than in a tunnel or ice-walled channel. The possibility exists that the water entered an

Figure 12. Vertical air photo showing beaches and washed till plain. This area occurs in central Walsh County (T. 156 N., R. 55 W.) near Pisek, which can be seen on the northwest corner of the photo. The Campbell-McCauleyville beach can be seen along the western edge of the photo. Several Blanchard beaches can be seen over the eastern half of the photo. The intervening area is a wave-washed till surface covered by thin and discontinuous sand patches.

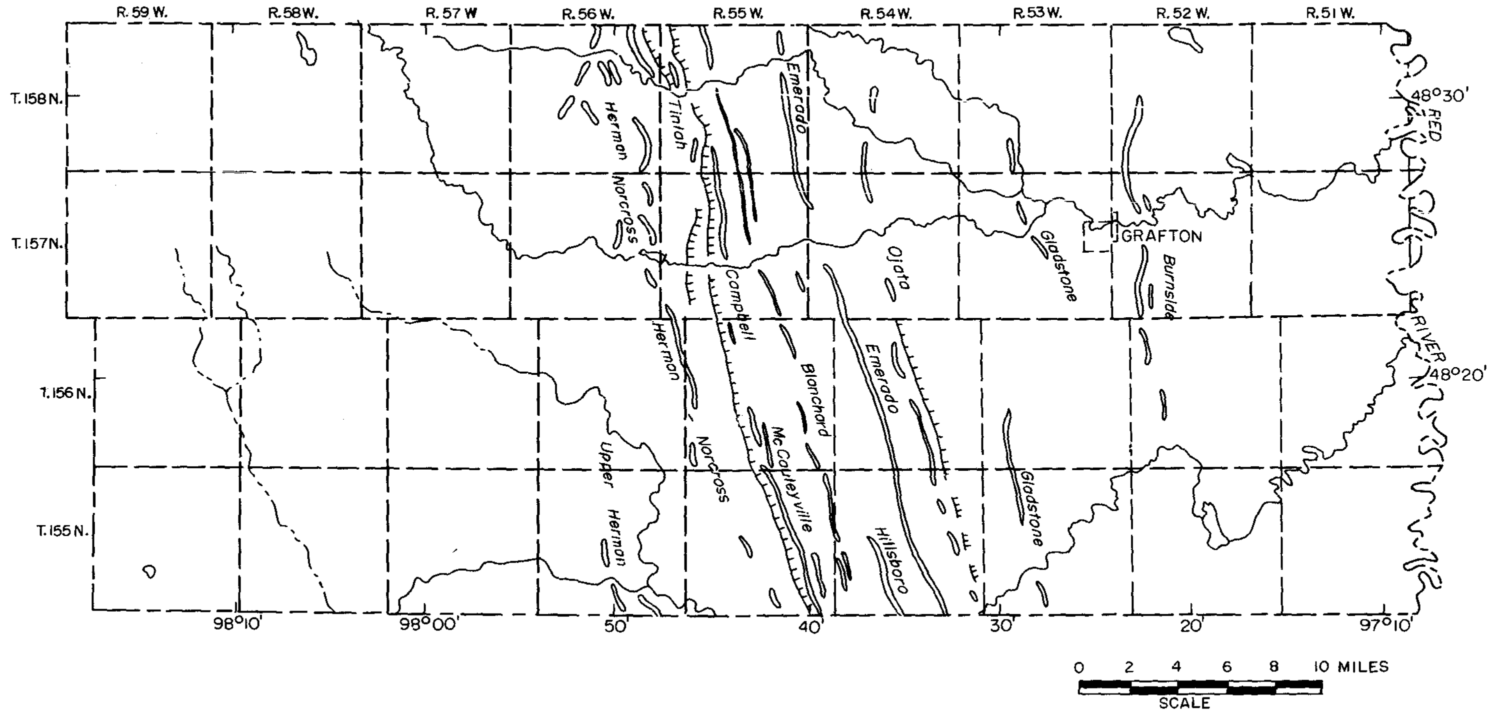


Figure 13. **Map of Walsh County showing strandlines (former shorelines) of Lake Agassiz. The black areas are beach deposits and the tic-marked lines are wave-cut scarps associated with the Campbell, Tintah, and Ojata strandlines.**

opening in the ice and then flowed through an ice-walled channel or tunnel. The meltwater stream deposited outwash in the surface opening and within its stream course now marked by the esker ridge.

Other prominent disintegration features are the Soo and Lanki eskers in Tps. 155 and 156 N., R. 56 W. according to Bluemle (1969)

These two eskers are prominent features with an overall branching aspect. They have very bouldery surfaces and a discontinuous cover of till over a gravel core. In some places, however, till occurs through the total thickness of the eskers. This is true also of the Dahlen esker. Several dozen smaller eskers located a few miles to the west belong to the same drainage system that formed in the stagnant glacier and deposited the Soo and Lankin eskers.

The two eskers, along with the Dahlen esker to the south, are located on an eastward-sloping area that was at the edge of a proglacial lake prior to the forming of glacial Lake Agassiz. Only patches of lake sediment occur in the area but heavy concentrations of boulders resulted from the extensive washing of the till surface by waves at the edge of the lake. The Lankin esker in particular has been modified by wave action at its southern end where the position of the Herman strandline coincides with it.

Buried sand deposits in eastern Walsh County.–Several large depressions that contain salt marsh occur in eastern Walsh County. These include Salt Lake and Lake Ardoch. Thick deposits of sand occur at depth beneath these salty areas under lake silt (see cross-section, Plate 2). During glaciation of the area, water flowing beneath the ice was apparently forced into the permeable Dakota Formation Sandstone due to the great hydrostatic and geostatic pressure of overlying water and ice. On deglaciation, large quantities of water were released from the contact between the Dakota Sandstone and the underlying Paleozoic rock. The rapid upward movement of this water resulted in the erosion of the overlying lake sediment and deposition of the sand. The discharging water was at a maximum after deglaciation and has since decreased to its present rate (Joe Downey, personal communication).

Differential compaction ridges.–Two small features that are considered to be differential compaction ridges occur in Walsh County in T. 157 N., R. 54 W., and in T. 155 N., Rs. 53 and 54 W. These areas are designated Cg5 on Plate 2. They consist mainly of sandy, shaly gravel that is silty near the top. Bedding is vague to good. It seems probable that these materials were deposited by streams flowing over the lake plain very soon after Lake Agassiz drained or perhaps during the interval of time between Lakes Agassiz I and II. At this time, the lake sediment must have contained a high percentage of water and, when this water was driven out as the lake silt settled, the more competent framework of the fluvial gravels kept them from settling, resulting in a ridge of silt-covered gravel. Similar differential compaction ridges were noted in Traill County (Bluemle, 1967, p. 26) and Cass County (Klausing, 1968, p. 33).

Silt and Clay Facies

Clay, silty clay, clayey silt, silt, and fine sand occur over the eastern half of Walsh County and in the Stump Lake area of western Nelson County. About 12 percent of the test hole footage in the area was in silt and clay deposits. All areas with the designation "Cs" and colored shades of blue on Plates 1 and 2 are covered by material that was deposited in glacial Lake Agassiz and in glacial Devils Lake and Stump Lake.

Lake plain.–The Stump Lake area is characterized by deposits of silty clay designated Cs1 on Plate 1. These silty clay deposits are little more than a veneer of lake sediment on a till surface. In eastern Walsh County, similar silty clay deposits are designated Cs2. The total thickness of lacustrine sediment covering areas designated Cs2 averages over 100 feet. Such areas are characterized by a flat, smooth, featureless surface. Areas of Cs2a have polygonal surface markings that are apparent on air photos. Low ridges are noticeable in the field. The polygonal markings may have formed when large blocks of floe ice settled into the materials on the lake floor when the lake drained, or they may be permafrost markings, although other permafrost features have not been identified in this part of North Dakota.

Areas of lake plain surfaced by clayey silt and underlain by lacustrine sediments that total 100 to 150 feet thick are designated Cs3. These areas, which are also very flat, are marked by numerous lineations (Fig. 14) that formed when wind-driven blocks of floe ice dragged on the lake bottom (Clayton and others, 1965). Areas designated Cs3a are similar to those designated Cs3, except surface lineations are lacking.

More sand characterizes the silt deposits that have been designated Cs4. Poorly-defined beach ridges occur in the area, and apparently areas of Cs4 represent a short-lived shoreline facies.

An area designated Cs5 on Plate 2 is lake plain surfaced by silt,

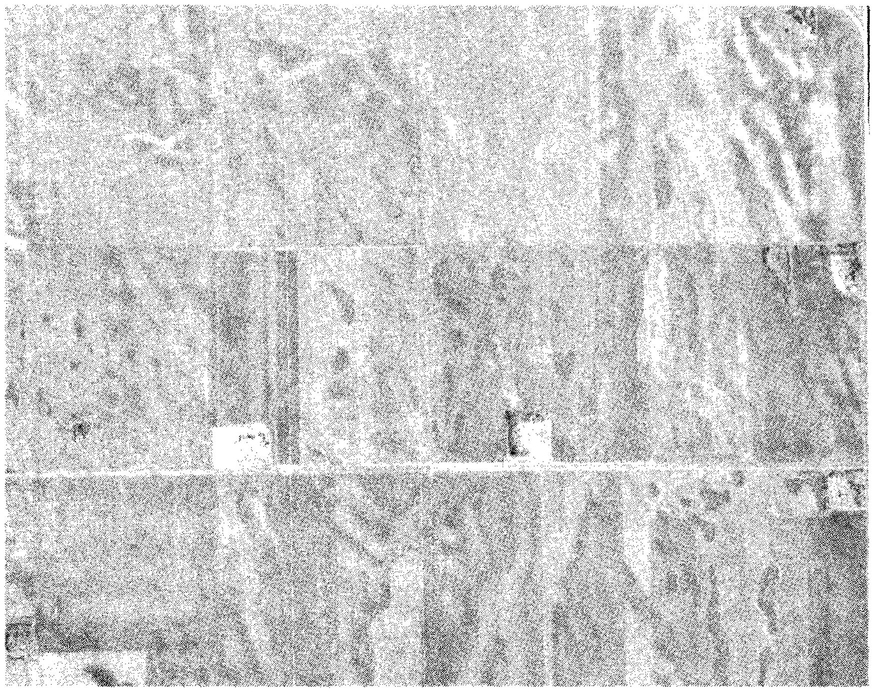


Figure 14. Vertical air photo of lineations on the Agassiz lake plain. This 3-square-mile area of clayey silt occurs in eastern Walsh County (Sec. 1, 2, 11, and 12, T. 156 N., R. 52 W.). The lineations formed when wind-blown blocks of floe ice dragged over the lake floor. North is to the top of the photo.

although some sand and gravel is found in places. This area, which occurs in central Walsh County (Tps. 155 to 158 N., R. 56 W.), apparently formed as an embayment between the ice margin and the Pembina Escarpment. Figure 15 shows an exposure of bedded sand in this area.

Holocene Sediment

WALSH FORMATION

Definition

The term "Walsh Formation" is proposed for the rock-stratigraphic unit that overlies the Coleharbor and all other formations and includes a variety of clay, sand, silt, and gravel deposits. It is named for Walsh County, North Dakota, where it is particularly widespread (see plate 2). The type area of the formation is in Tps. 157 to 158 N., Rs. 53 to 55 W., but no type section will be designated at this time. Sediments of the Walsh Formation have a "dirty" appearance due to the presence of small (or large) amounts of organic material that commonly give them a dark gray color. The Walsh Formation differs in this respect from the Coleharbor Formation, which lacks organic materials and has a clean appearance. Bison and other mammal bones are commonly found in exposures of the Walsh Formation along rivers.

The contact between the Walsh and Coleharbor Formations corresponds in most places to the Holocene-Pleistocene boundary. This boundary is dated at about 10,000 B. P. when grassland was replacing woodland in North Dakota and the rest of the Great Plains. As thick A1 soil horizons began to develop over the area, materials eroded from these horizons provided the dispersed organic content of the Walsh Formation.

Extent

Deposits fitting the description of the Walsh Formation occur widely throughout the Great Plains, but the geographic limits of the formation are not accurately known at this time. For practical purposes, it may be best to limit the Walsh Formation to areas where typical dark-colored prairie soils such as Chernozems and Chestnuts predominate. This single restriction of its extent seems logical as the formation is defined as containing significant amounts of organic materials that would tend to accumulate best in the prairie environment.

Figure 15. Plane and ripple-bedded sand at the west edge of Lake Agassiz. Typical of exposures in areas designated Cs5 west of the Edinburg End Moraine.

The Walsh Formation covers about 9 percent of Walsh and Nelson Counties, probably somewhat less than 5 percent of the remainder of North Dakota. It is less than 10 feet thick in most places in the two-county area, but more than 20 feet was measured in a few places near the Red River.

Recognition

The Walsh Formation is easily recognized; it always contains dispersed organic matter. Holocene deposits, such as clean dune sand or clean shoreline sediment, which are free of organic materials, belong to the Coleharbor Formation. Till is generally absent from the Walsh Formation, although it can be found in some landslide deposits. The Walsh Formation includes such things as the windblown topsoil that collected along fencerows during the 1930's; slough deposits, some of which may be Wisconsinan in age; river alluvium, which commonly overlies clean sand and gravel of the Coleharbor Formation; and colluvial deposits in front of steep slopes such as the Pembina Escarpment or the Missouri Coteau. The Walsh Formation has been divided into three main facies in Nelson and Walsh Counties: clay, sand and silt, and gravel.

Clay Facies

The clay facies of the Walsh Formation consists of very well sorted dark gray to black organic clay to fine sand that ranges from very tough to a rather soft consistency. The materials are mainly uncemented. The mineralogy of the clay is similar to the mineralogy of the Coleharbor Formation clays: montmorillonite and other clay minerals, carbonate, quartz, and feldspar. The clay is fine-bedded (1 to 4 mm) and is confined to sloughs where it averages 1 to 3 feet thick. Most of the deposits are unleached and calcareous.

The deposits of the clay facies were brought to the sloughs through slopewash processes, and, to some extent, eolian processes and redeposited by the pond water. Most of the clay deposits are characterized by flat topography with less than 1° slopes. They are represented on Plates 1 and 2 by light gray areas and many are designated by the symbol Wc. Many are too small for a letter designation and many more are too small to show. Areas of the clay facies are most common in poorly drained areas, although drainage in the immediate areas of sloughs is partially integrated.

Sand and Silt Facies

The sand and silt of the Walsh Formation is slightly to moderately organic. It consists mainly of river alluvium and windblown deposits.

River alluvium.–River alluvium is generally dark brown, gray or black sand, sandy silt, clayey silt, or silty clay. Vague horizontal bedding is common as are shells, wood fragments, and bones. Bison bones are abundant in the deposits. The alluvial materials are partially to well oxidized.

In Walsh and Nelson Counties, alluvial materials, which are designated by the letter symbol Ws1 on Plates 1 and 2, occur along all the perennial streams and many of the intermittent streams. The largest area of alluvial material is in north central Walsh County where an average of 1 to 5 feet of sandy to clayey silt overlies clayey silt (Cs3a) of the Coleharbor Formation. This area is characterized by numerous vague meander scars, which are best seen on air photos.

Windblown deposits.–Windblown materials, which are designated Ws2 on Plates 1 and 2, occur mainly in north central Walsh County. An average of less than 10 feet of windblown material occurs in this area, overlying Coleharbor Formation deposits consisting of shore facies sand and gravel (Cg3). Windblown deposits generally consist of nonstratified silt and very fine sand. Vague horizontal color banding is discernible in a few exposures. Considerable black silt is common, particularly in the most recent deposits. Well sorted fine sand with frosted grains occurs in places but it is not common. The windblown deposits are highly weathered. Dune topography with local relief of less than 5 feet characterizes the area. Other areas of windblown deposits were too small to map; however, they can be found throughout the area, particularly where the underlying material is sandy.

Gravel Facies

Sandy gravel and gravelly sand that occurs in the Walsh Formation is often poorly sorted with vague horizontal bedding or no bedding. In Walsh County, the underlying bedrock formation is the Pierre Formation shale. The Walsh Formation gravel consists of from 25 to 95 percent reworked shale that has been derived from the Pierre Formation. This facies of the formation consists of high percentages of the underlying materials that have been moved short distances by mass movement processes. Deposits of Walsh Formation gravel shown on Plate 2 are designated by the symbol Wg. The only mappable deposit of Wg is in T. 158 N., R. 56 W., in front of the Pembina Escarpment.

GEOLOGIC HISTORY DURING THE PLEISTOCENE

Topography on the Preglacial Surface

Prior to the earliest glaciation of the Nelson-Walsh County area, streams flowed generally eastward and northeastward, except in southwestern Nelson County, where they probably flowed westward and northwestward. Most of the area was drained by the ancestral Red River, the main channel of which was in Minnesota, a short distance east of Walsh County. Southwestern Nelson County was drained by a large river system that drained much of central North Dakota. The trunk stream of this river system entered Canada from Towner County, northwest of the present study area. Plates 3 and 4 show the bedrock topography of the two counties and the preglacial formations that lie beneath the Coleharbor Formation.

Prior to glaciation, elevations over the eastern half of Walsh County ranged from less than 500 feet near the state line to just over 700 feet at the base of the Pembina Escarpment. At the Pembina Escarpment they rose to about 1,500 feet, a rise of about 800 feet in a distance of about 15 miles. West of the escarpment, elevations were about 1,500 to 1,600 feet, except in southwestern Nelson County where they were under 1,400 feet. Generally, the landscape east of the Pembina Escarpment had rather low relief, but west of the escarpment relief was somewhat greater.

Shale of the Cretaceous Pierre Formation was at the surface over all of Nelson County and western Walsh County (Plates 3 and 4). A six-mile-wide strip of Cretaceous Niobrara shale extended from north to south through Rs. 56 and 57 of Walsh County and older Cretaceous shale and sand covered much of the remainder of Walsh County, except for the eastern edge. Jurassic redbeds covered the northeastern corner of Walsh County.

Pre-Wisconsinan Glacial History

Each time glaciers advanced over the area, they must have blocked the northward drainage in the Red River valley, resulting in proglacial lakes. Ideally, each glacial advance should be marked by: 1) a lower sequence of lake sediments deposited in proglacial lakes formed ahead of the advancing glacier; 2) a middle till sequence deposited by the overriding ice; and 3) an upper sequence of lake sediments deposited in proglacial lakes formed ahead of the receding glacier. In Walsh County, deeply buried lake deposits were found in only a few test holes; but in Grand Forks County to the south, Hansen and Kume (1970) found evidence for four buried horizons of lake sediment. Bluemle (1967a) reported two buried horizons of lake sediment in Traill County, North Dakota. Buried weathered horizons have been observed in several test holes in the Red River valley, but not enough evidence is yet available to work out a detailed stratigraphic sequence for the glacial deposits of the area.

West of the Pembina Escarpment, several multiple till exposures were studied in Nelson and Walsh Counties (Bluemle, 1967b). These tills were separated by gravel horizons, boulder pavements, erosion surfaces, and buried soil profiles (Figs. 16, 17, and 18). Some of the lower tills were exceptionally hard, compact and highly jointed with considerable iron and manganese oxide staining. The presence of well developed buried erosion surfaces, buried oxidized zones, and buried soil profiles on top of the lower tills at several places suggests that they may be relatively old, perhaps pre-Wisconsinan in age.

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

Much of central Nelson County, although it is mapped as ground moraine, is underlain at shallow depths by gravel and sand. The stratigraphic sequence, till over gravel over till (Figs. 19 through 22) was exposed in several places. The movement of the last glacier over the area of gravel in Late Wisconsinan time resulted in a very sandy till when outwash materials were incorporated in the till. The age of the outwash is not known. It may be Late Wisconsinan or, perhaps, older.

A trench with elevations below 1,200 feet crosses southwestern Nelson County from T. 152 N., R. 61 W., to the Griggs County line; and, from there southward, it apparently coincides with the modern Sheyenne River valley. This, the McVille trench, is deeply buried and has little or no surface expression throughout much of its length in Nelson County. It must have been cut as a diversion trench sometime prior to Late Wisconsinan time. The McVille trench is filled with over two hundred feet of sand and gravel and is an important aquifer. Similar gravel is found in the large preglacial valley a few miles to the southwest.

Figure 16. Boulder pavement separating two tills in Walsh County (arrow shows boulder zone). It separates hard, sandy till at the base from an equally hard clayey till. A second boulder pavement occurs about 10 feet above the one shown here; it is overlain by loose, highly weathered till.

Figure 17. The very hard and lithified till at the base of this excavation in Walsh County has an irregular erosion surface at the top. The till that lies on top of the erosion surface is wet and stratified. It is overlain by a silty surface till.

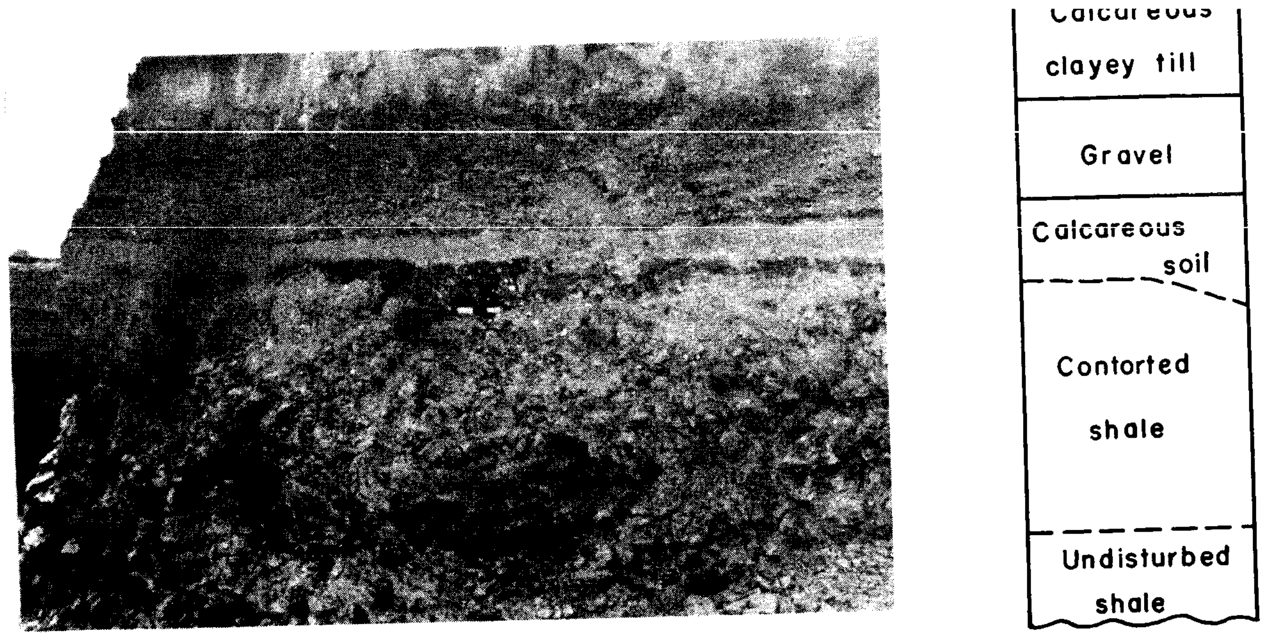


Figure 18. The highly contorted shale at this Walsh County site is overlain by a paleosol, outwash and till. The shale was contorted by ice before the soil formed on it because the soil itself is undisturbed.

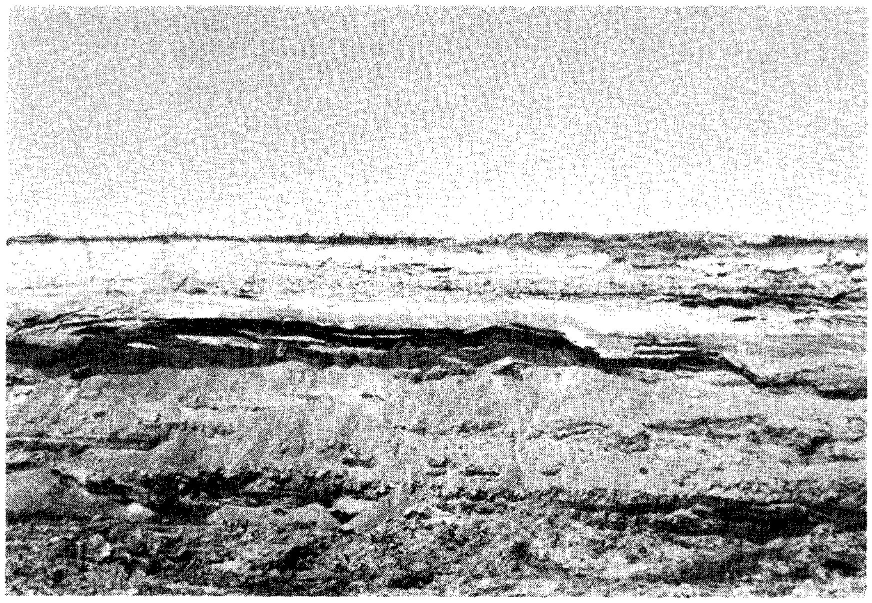


Figure 19. Exposure in southeastern Nelson County (SW ¼, SE ¼, Sec. 12, T. 149 N., R. 58 W.). Gravel at the base of this 25-foot-deep excavation is overlain by till, which is overlain by more gravel. The lower gravel is very shaly and contains considerable silt that looks like lake sediment. The upper gravel is strongly cross-bedded in places, plane-bedded in others, apparently a meltwater trench deposit.

Figure 20. Same location as Figure 19 (SW ¼, SE ¼, Sec. 12, T. 149 N., R. 58 W.). Here the till is shown overlain by the upper gravel. The ledge is on top of the till.

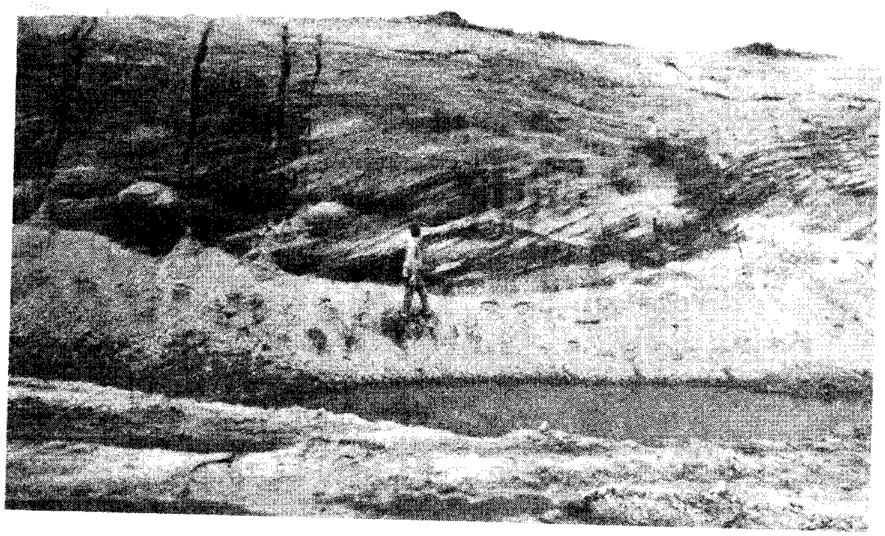


Figure 21. Exposure in south-central Nelson County (SW ¼, SW ¼, Sec. 1, T. 150 N., R. 59 W.) showing till, the upper 2 to 3 feet of material, overlying sand and gravel. This cut exposes the typical stratigraphic sequence in this part of Nelson County where glacial ice advanced over outwash.

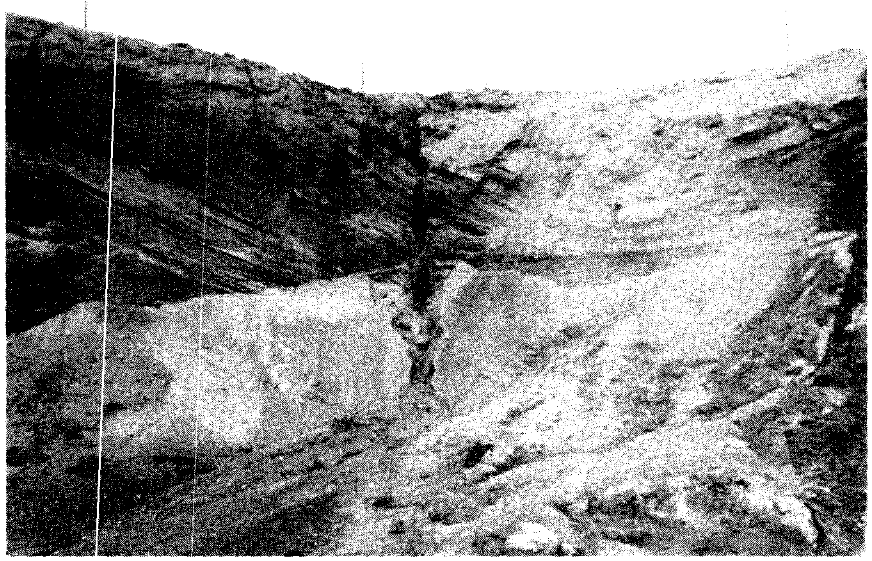


Figure 22. Same cut as shown in Figure 21 (SW ¼, SW ¼, Sec. 1, T. 150 N., R. 59 W.). Cross-bedded sand is shown here. The surficial geology in this area is ground moraine.

In summary, it can be said that evidence exists that pre-Wisconsinan glaciations did occur in the Nelson-Walsh County area. Detailed stratigraphic relationships are still unclear though, and, until further data are available, it will be useless to speculate about the ages of these glaciations. About all we can be sure of is that the uppermost drift horizon is Wisconsinan in age.

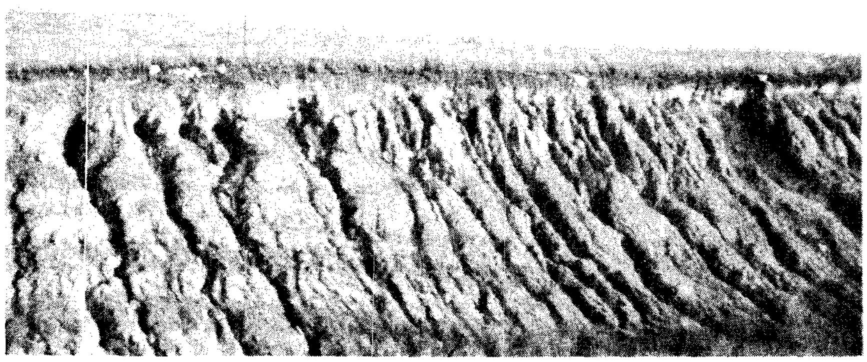
Wisconsinan Glacial History

Glacial drift of Early Wisconsinan age, the Napoleon drift, occurs over much of central North Dakota west of the limit of Late Wisconsinan drift. In eastern North Dakota, the Napoleon drift has not been definitely identified. Late Wisconsinan Lostwood drift covers Nelson and Walsh Counties, and little is known about the early part of the Wisconsinan Epoch. The discussion that follows deals mainly with the surficial geology of the area, the Late Wisconsinan Lostwood drift deposits.

The first part of the two-county area to become free of ice for the last time during the Late Wisconsinan Epoch was southern Nelson County. The ablating glacier split into two lobes as it flowed over a small bedrock high in T. 149 N., R. 60 W. An elongate hill of Pierre Formation shale that caused the lobation was extensively reworked by the ice, and nearly all the exposures observed on the hill consist of highly contorted shale. In-place shale was not seen on the hill, which is designated Cb5 on Plate 1. Immediately to the west of the hill, numerous exposures of reworked lake sediment were seen (Fig. 23). These lake sediments apparently were deposited in a proglacial lake that was overridden by the glacier. Similar overridden and reworked lake sediment is common in Griggs County and in Eddy County (Bluemle, 1965, p. 43).

The three diagrams that follow (Figs. 24 through 26) show the writer's concept of how the late Wisconsinan glacier receded from the area. No particular significance should be attached to the ice-marginal positions shown on each diagram, although an attempt was made to depict conditions that may have persisted for relatively prolonged periods of time.

As the glacier margin receded, southern Nelson County gradually became free of ice. The presence of ice marginal deposits of gravelly till in western and southern Nelson County suggests that the glacier stabilized for awhile in these areas (Fig. 24). These ice marginal deposits, which have been named the North Viking and Luverne End



'igure 23. Lake sediment overlain by till in southwestern Nelson County (Sec. 36, T. 149 N., R. 61 W.). These lake silts are widely exposed in this area and in nearby Griggs and Eddy Counties.

Moraines, are relatively hilly areas with local relief exceeding 40 feet in a mile.

While the glacier stood in the position shown in Figure 24, meltwater flowing from the ice deposited extensive areas of gravel in the Tolna, Pekin, and McVille areas. This gravel (Cg1 on Plate 1) ranges from less than 10 to over 100 feet thick, but the thicker gravel sequences overlie buried diversion trenches, and much of the total gravel thickness may have already been present before the surficial gravels were deposited.

As meltwater flowed southward away from the ice margin, it dropped its bedload and tended to scour the till surface so that parts of southern Nelson and northern Griggs Counties have a highly washed appearance with abundant stream meanders and lags of surface boulders.

Continued wasting of the glacial ice resulted in a large area of thin stagnant ice in the north half of Nelson County and in parts of western Walsh County (Fig. 25). Meltwater flowing from both the stagnant ice and from the active glacier along with runoff from local precipitation cut an intricate stream system in the stagnant ice mass. Some of the streams flowed on the ice, some cut valleys through the ice, and some did both. The stagnant ice was melting so the stream courses tended to shift often, resulting in a very large number of ice-contact gravel ridges and gravel-floored valleys when the ice completely melted. In many places, eskers end at the point where a valley begins, marking the spot where a stream flowed off the stagnant ice onto bare ground.

The second diagram depicts conditions at the time Stump Lake first formed. This proglacial lake, along with Devils Lake to the northwest, was fed by meltwater and local precipitation and has persisted to the present day, although it has shrunk considerably in size. At least two high strandlines were observed along the lake shore. These occur at elevations of 1,453 and 1,441 feet. The 1,453-foot strandline also exists around Devils Lake. The present elevation of the Stump Lake water level is about 1,385 feet.

The presence of ice-marginal till deposits, the Edinburg End Moraine, in central Walsh County (Tps. 155 to 158 N., Rs. 55 and 56 W.) indicates that the glacier stabilized for awhile in this position (Figs. 26 and 27). The till of the Edinburg End Moraine is interbedded with lake deposits in places and can be traced southward from Walsh County, through Grand Forks County, and into Traill County a short distance. In Walsh County, a gravel deposit that underlies the end moraine is exposed on both its distal and proximal sides. The gravel may be outwash that was deposited just before the Edinburg End

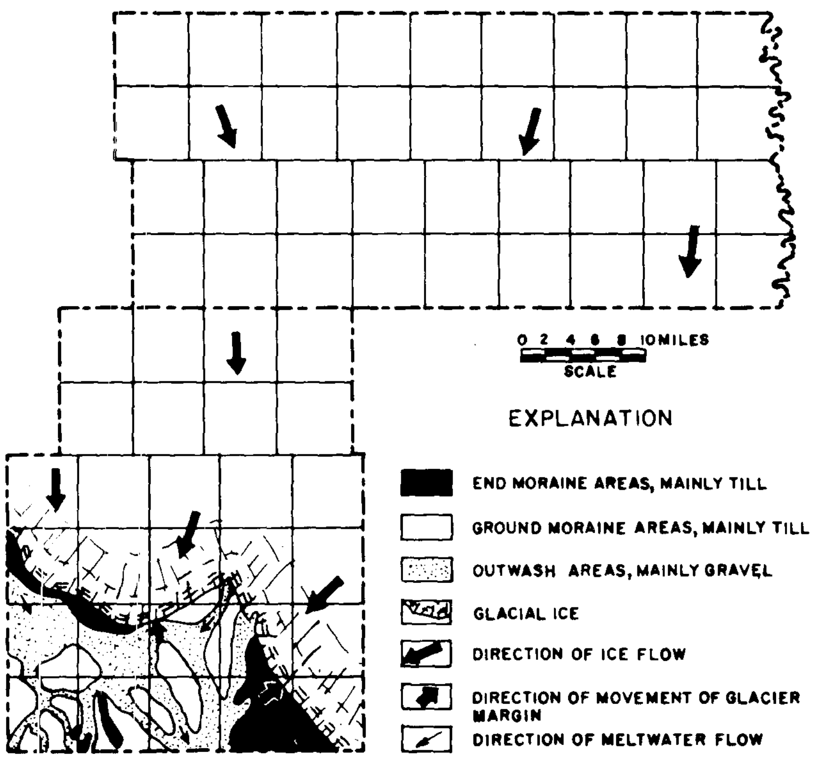


Figure 24. Map of Nelson and Walsh Counties showing the receding ice margin in Late Wisconsinan time. Here, the ice margin is in the approximate position of the North Viking and Luverne End Moraines. Meltwater from the ice deposited outwash in southern Nelson County at about this time.

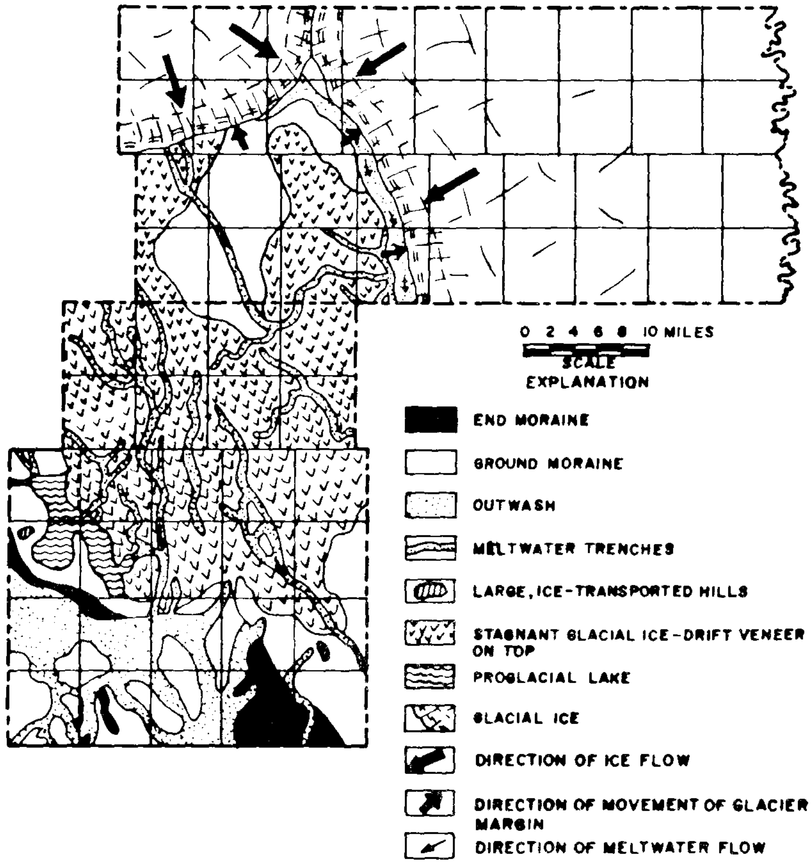


Figure 25. The active ice margin is shown in Walsh County on this illustration. It appears that a portion of the glacier stagnated shortly prior to this time, leaving stagnant ice in much of Nelson County. Several small meltwater trenches were cut at about this time; many were on the stagnant ice so numerous eskers were deposited. The Dahlen esker in southern Walsh County was one of these.

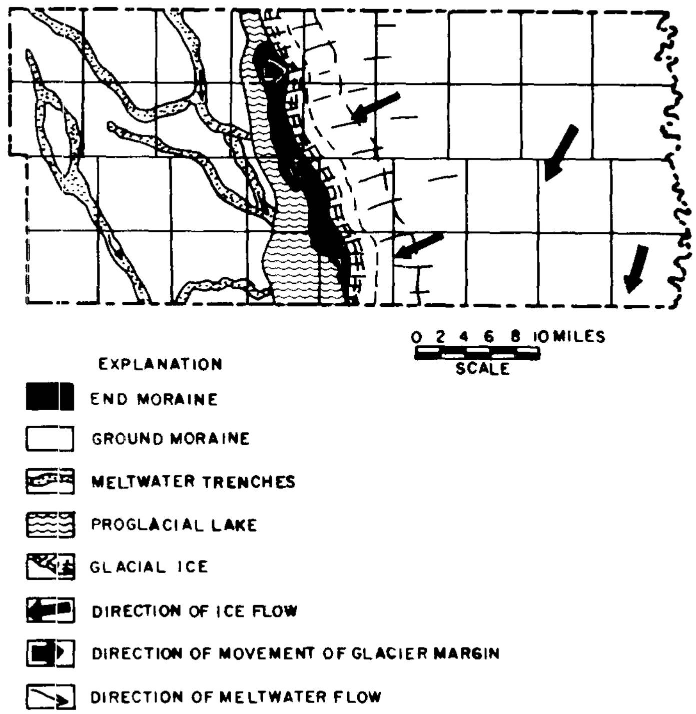


Figure 26. Map of Walsh County showing the ice margin in the position of the Edinburg End Moraine. Lake Agassiz already existed west of the ice margin, and the streams deposited considerable sediment in the lake at about this time.

Figure 27. Vertical air photo of an area of about 4 square miles in central Walsh County (T. 157 N., R. 56 W.) showing the location where the Park River cuts through the Edinburg End Moraine (west half of photo). Shore sands cover the surface above the Park River valley in the eastern half of the photo. A few dunes can be seen in the northeast corner.

Moraine formed, in which case it would have been necessary for the ice margin to have receded to a position slightly east of the position of the end moraine while the gravel was deposited and then to have readvanced slightly. Or, the gravel may be older and unrelated to the receding Late Wisconsinan glacier.

About 50 miles to the south of Walsh County, lake sediments have been found at elevations as much as 300 feet above the Herman Beach, which has long been considered to mark the highest level of Lake Agassiz. Such high-level lake deposits were not observed in Walsh or Nelson Counties, and it appears that the earliest Lake Agassiz sediment in this area was deposited while the ice margin stood at the Edinburg position. At this time, a narrow strip of lake sediment was deposited in Tps. 155 to 158 N., R. 56 W. (Plate 2).

As the glacier receded from the area, the high-level proglacial lakes of southeastern North Dakota may simply have expanded as the water level dropped and the ice margin receded from the valley, or the water level may have dropped rapidly from the high levels as the ice receded and then slowly rose again to the Herman level. Evidence from southeastern North Dakota suggests that the first of these possibilities is the more likely and that the water level slowly dropped through the upper beach levels, the Herman, Norcross, and Tintah, as the glacier receded from the Red River valley. Large rivers emptied into the lake during this period of time and the Pembina, Elk Valley, and Sheyenne Deltas formed. The ancestral Park River flowed into the lake near Lankin, contributing to the Elk Valley Delta. The valley of the Sheyenne River through Nelson County was probably established at about this time, too.

The lake drained and a drying interval occurred between about 11,500 and 10,000 years ago. During this interval, forests became established on the lake plain. Lake Agassiz again flooded the area about 10,000 years ago as a result of an ice advance (Valders?), and rose to the Campbell level. The Campbell strandline is generally one of the best developed shore features of Lake Agassiz. This has been thought by most workers to reflect a prolonged period of stability in the lake at the Campbell level. However, MacCarthy (1970) has suggested that the prominence of the feature may be mainly the result of a rise in the lake to the Campbell level rather than a prolonged stand at that level. He believes that the size of the scarp is the result of a rise in lake level of about 40 feet. The McCauleyville "beach," which is closely related to the Campbell scarp, is probably really an offshore bar formed as the scarp was cut.

About 9,000 years ago, the lake level slowly began to drop and, as it did so, the lower series of beaches, including the Blanchard, Hillsboro, Emerado, Ojata, Gladstone, and Burnside Beaches formed. The Gladstone and Burnside Beaches, which occur in the Grafton area, consist mainly of reworked lake silt with little sand. They are subdued features.

Eventually, Lake Agassiz drained for the last time and the main drainage, the Red, Park, and Forest Rivers became established on the lake plain. These rivers were probably rather large streams for some time after the lake drained. The rivers, and their tributaries, before they finally became confined to their present valleys, meandered over the surface of the lake plain, depositing a veneer of alluvium over a wide area. Meander scars are apparent on air photos.

ECONOMIC GEOLOGY

Cement Rock and Limestone

Carlson (1964) investigated the Niobrara Formation in eastern North Dakota as a potential raw material for the manufacture of cement. The high lime zones of the Niobrara Formation in the area average about 61 percent calcium carbonate. The calcium carbonate content is not high enough to make Portland grade cement and the material is too fine to upgrade by sieving. The expense of shipping in limestone to raise the calcium carbonate content is too great to be economical at this time.

Three areas of Walsh County were included in the study. Five test holes were drilled in the Edinburg area (T. 158 N., R. 56 W.), three in the Park River area (T. 157 N., Rs. 56 and 57 W.), and one in the Lankin-Fordville area (T. 155 N., R. 56 W.). The zones of highest calcium carbonate in the Niobrara Formation in the Edinburg and Park River prospect areas are present beneath most of the area west of the Agassiz lake plain, but they are too deep to be of economic interest. To the east, where it had been hoped that the high lime zones might be at shallower depths, the zones have been removed by erosion. The overburden of glacial drift in the Lankin-Fordville prospect area is too great to allow mining of the high lime zones at this time.

Paleozoic carbonates, particularly the Ordovician Red River Formation, were studied by the North Dakota Geological Survey in 1967 (Anderson and Haraldson, 1968) to determine the possibilities of using them as cement source rocks. The Red River Formation ranges in thickness from 100 to 500 feet in eastern Walsh County. The most promising samples obtained during this study were from near Manvel in Grand Forks County. In one test hole, a 40-foot cored interval (from 220 to 260 feet) averaged 85.6 percent calcium carbonate, although the magnesium carbonate content of 7.5 percent was somewhat higher than is desirable for the manufacture of Portland grade cement.

To obtain a product containing an acceptable magnesium content, Anderson and Haraldson recommend that the Red River Formation limestone be blended with the shaly limestone of the Niobrara Formation. Although the Niobrara has a calcium carbonate content averaging only 61 percent in a 10- to 12-foot bed, it has a low magnesium carbonate content averaging 1.4 percent over the same interval. A blend of the two limestones (Red River and Niobrara) should possess a permissible magnesium carbonate content, while keeping the calcium carbonate content well above the lower limits necessary for the manufacture of Portland cement.

Clay Deposits

Although no brick plants are currently in operation in the Red River valley, the city of Grand Forks had four plants early in the century and several other plants have operated at various times in the valley. The materials used in the production of this common brick were limited and of variable quality so the production of good quality brick for an extended length of time was unsuccessful.

Manz (1956) investigated some Lake Agassiz clays to ascertain their value as brick material. He concluded that good common brick, building or drain tile can be readily made from the silt and clay units of the Lake Agassiz deposits such as are available in the Grafton area. He stated that several of his trial pieces had desirable face brick properties, but that the firing range is so limited that careful control would be required.

In west-central Walsh County along the Pembina Escarpment, bentonitic clays occur in the Pembina Member of the Pierre Formation. This bentonitic clay (Fuller's Earth) is a calcium and magnesium type and is a natural bleaching powder. The thickness of individual bentonite beds ranges from less than an inch to about a foot. The bentonitic clays in Walsh County are not being used at the present time. The nearest bentonite mining operation is just north of the International line along the Pembina Escarpment at Morden, Manitoba where clay is taken from

the Pembina Member of the Pierre Formation. The clay is used f
bleaching of mineral, vegetable, and animal oil and as a binder f
taconite pelletizing. Tests show that the 8 to 14 feet of overburden c
the bentonitic clay in the Morden area can be used as a raw material f
light weight aggregate.

Concrete Aggregate

Most of the aggregate material available in the Nelson-Wals
County area contains from 1 to 5 percent physically unsound particle
and a trace to 2 percent of material that can be reactive with high-alka
cement. Shale and iron oxide are probably the most commo
deleterious materials. Some sources also contain rock particles that hav
a harmful carbonate covering. Even so, satisfactory, although no
always the highest quality, concrete can usually be produced using th
glacially derived sand and gravel found in the area.

The only commercial source of concrete aggregate in th
two-county area is located in the SW¼, Sec. 10, T. 155 N., R. 56 W.
near Fordville in southern Walsh County. This gravel contains
considerable amount of shale and some iron oxide. Reserves have been
calculated at about 5 million cubic yards. The gravel produced from
this pit has the following composition (data dated 1960 from a private
lab):

Crushed Gravel	Percent
Granite and related rock	35.4
Diorite and related rock	5.1
Limestone and dolomite	35.4
Quartzose rock	3.4
Trap rock	4.7
Felsite	2.2
Claystone	1.1
Loose material	0.6

According to the North Dakota Highway Department in a report dated January 10, 1961, the gravel has the following physical characteristics:

Specific gravity (bssd)				2.70
Soundness				Satisfactory
Dry rodded weight (lbs./cu. ft.)	109	114	113	
Deleterious Materials (percent)				
Soft particles	0.2	0.2	0.2	
Shale	0.0	0.1	trace	
Iron oxide	0.7	1.1	0.9	
Decantation			0.1	
Gradation: Sieve Size	Percent Passing			
1½"	100		100	
1"	54	100	82	
¾"	10	98	65	
½"	0.5	31	21	
No. 4	0.3	0.1	0.2	

Sources for Road Material

About 30 commercial sources of borrow material are located in Walsh County, about 12 in Nelson County (information from North Dakota Highway Department data). Most of these are rather small operations that operate only part time. Equipment is not currently located at many of the sites. In addition to the known commercial sites (locations are listed below), a few hundred more possibilities for borrow material exist. They include all deposits of Cg4, many of which are identified only by a red symbol (Plate 1). Also included are the yellow areas, particularly those in central Walsh County designated by the symbol Cg3. The total value of sand and gravel production for Nelson and Walsh Counties for 1967, the last year for which figures are available, was $252,000.00.

Most of the gravels contain shale in amounts that range from a trace to 10 percent. A few aggregates contain shale in amounts up to 20 percent. The North Dakota Highway Department rejects any road material containing over 12 percent shale.

Known Commercial Gravel Sources

Location	Owner	Estimated Reserves in cubic yards
SE 1/4, Sec. 4, T. 148 N., R. 64 W.	Cliff Rader, Starkweather	25,000
SE 1/4, Sec. 10, T. 158 N., R. 64 W.	C. H. Berg, Starkweather	Unknown
Sec. 4, T. 158 N., R. 64 W.	George Evans, Bartlett	20,000

Sec. 27, T. 158 N., R. 60 W.	Clarence Myrik	Unknown
SE 1/4, Sec. 28, T. 158 N., R. 56 W.	Ellingson Gravel Co.	Unknown
NW 1/4, Sec. 33, T. 158 N., R. 56 W.	Oppenboen Gravel Co.	Unknown
NE 1/4, Sec. 35, T. 158 N., R. 56 W.	Kerry Pit	425,000
T. 158 N., R. 56 W.	Burlington Northern RR	1,000,000+
SE 1/4, Sec. 29, T. 157 N., R. 57 W.	Ellingson Gravel Co.	2,000,000+
NW 1/4, Sec. 21, T. 156 N., R. 56 W.	Sina Anderson, Park River	280,000
NW 1/4, Sec. 11, T. 156 N., R. 59 W.	Gustave Sjorberg, Adams	100,000
SW 1/4, Sec. 22, T. 156 N., R. 56 W.	Mary Little Pit	100,000
NE 1/4, Sec. 33, T. 156 N., R. 56 W.	Maurice Borgenson, Park River	250,000
Sec. 27, T. 156 N., R. 56 W.	Walsh County Pit	1,000,000+
SW 1/4, Sec. 9, T. 156 N., R. 55 W.	L. J. Kadlec, Pisek	40,000
Sec. 15, T. 155 N., R. 56 W.	Bradshaw Gravel Co., Fordville	5,000,000
NW 1/4, Sec. 27, T. 155 N., R. 56 W.	W. Ratcliff Pit	75,000
SE 1/4, Sec. 23, T. 155 N., R. 55 W.	L. Cawley, Conway	100,000
E 1/2, Sec. 5, T. 153 N., R. 58 W.	State owned pit	22,000
SE 1/4, Sec. 25, T. 153 N., R. 57 W.	Walter Krueger, Niagara	10,000
NE 1/4, Sec. 36, T. 153 N., R. 57 W.	State owned pit	100,000
SW 1/4, Sec. 25, T. 151 N., R. 61 W.	Lee Farms Estate, Tolna	75,000
SW 1/4, Sec. 22, T. 150 N., R. 61 W.	Earl Burns Estate Pit	115,000
NW 1/4, Sec. 29, T. 150 N., R. 60 W.	Ingvold Hoiberg Pit	Unknown
SW 1/4, Sec. 20, T. 150 N., R. 59 W.	Orlando Martinson, McVille	Unknown
SW 1/4, Sec. 6, T. 150 N., R. 57 W.	Henry Solberg, Aneta	55,000
NE 1/4, Sec. 12, T. 149 N., R. 58 W.	Andrew Sigurdson, Aneta	15,000
NW 1/4, Sec. 5, T. 149 N., R. 57 W.	Melvin Solberg, Aneta	45,000

Hydrocarbons

As of January 1, 1971, 22 exploratory petroleum tests had been drilled in Nelson and Walsh Counties but no production has yet been found. Summaries providing lithologic descriptions of four of these wells have been published (Hansen, 1956; Garske, 1958; Anderson, 1961; and Bluemle, 1963). Interest continues in the area because of the presence of the Newcastle and other Cretaceous sands which underlie the area. The Paleozoic formations that produce oil further west in North Dakota have good porosity in Nelson and Walsh Counties. The many possibilities for stratigraphic and structural traps along with shallow depths allowing easy and fast drilling should do much to promote exploration in the area.

ENGINEERING PROPERTIES OF NEAR-SURFACE MATERIALS

The following discussion is not intended to be a detailed description of the engineering properties of the surface and near-surface materials. Transported soils, such as glacial drift or alluvial soils, show great variations over relatively short distances, but it is hoped the values included here will be useful as a basis for more detailed study. Maps of Nelson and Walsh Counties (Figs. 28 and 29) show graphically the distribution of various data available for the two counties. In the discussion that follows, the term "soil" is used in the engineering sense and includes any earthen material, excluding bedrock. References used in compiling this part of the report include Rominger and Rutledge (1952), The Asphalt Institute (1961), and Portland Cement Association (1962).

Consistency Tests

The consistency tests, or the Atterberg Limits, include the liquid limit, the plastic limit, and the shrinkage limit although the shrinkage limit is seldom used. A value frequently used in conjunction with these limits is the plasticity index. Plasticity refers to the ability of a material to be deformed rapidly without cracking or crumbling and then maintain that deformed shape after the deforming force has been released. This non-reversible, or plastic, deformation is probably the sum of a large number of small slippages at grain-to-grain contact points along with minute local structural collapses throughout the soil mass. Plastic deformation can become large and is an important factor in highway and foundation engineering work.

In general, the engineering properties of a soil depend on the amount of water present. The three consistency tests, expressed as moisture contents, are arbitrarily used to differentiate between the various states of the material. If water is slowly added to a perfectly dry sample of soil and uniformly mixed with it, the soil will gradually assume some cohesion and change from a semisolid to a plastic state. When the soil contains just enough water (expressed as a percentage of dry weight) to be rolled into a 1/8-inch-diameter thread on a solid surface without breaking, it is said to have reached its plastic limit. The plastic limit is governed by clay content. As more water is added and the mixing continues, the soil gradually becomes a viscous liquid. The water content at which two halves of a soil cake will flow together is

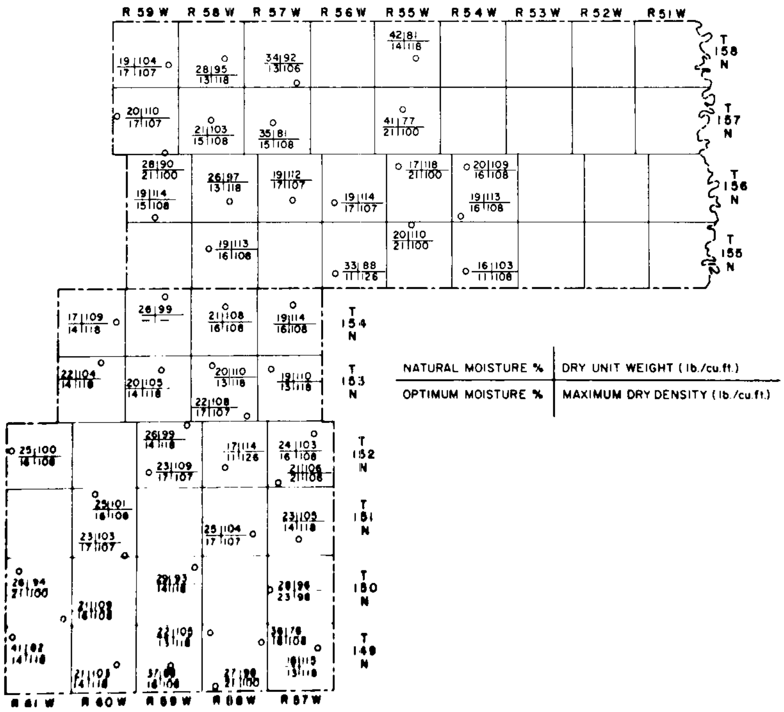


Figure 28. Map of Nelson and Walsh Counties showing values for four types of engineering data and the locations where such data was available.

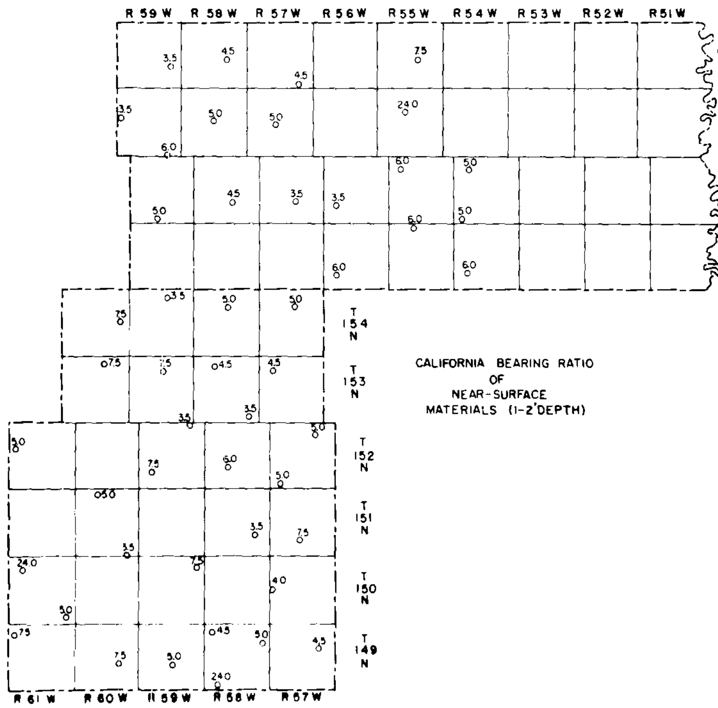


Figure 29. Map of Nelson and Walsh Counties showing California Bearing Ratio values for several locations.

Figure 30. Photo of landslide that occurred several years ago on State Highway 17 at the Red River (NE ¼, Sec. 24, T. 157 N., R. 51 W.). This newly completed stretch of highway slid when the weight of the roadbed was too great for the weak, underlying clay unit to support. Photo by Robert L. Hetzler. (Bliss and Laird, 1963).

called the liquid limit. The difference between the liquid and plastic limits is the range of moisture content over which a material is in the plastic state and is known as the plastic index. Generally, high liquid limits indicate soils of high clay content and low load-carrying capacity. Sandy soils have low liquid limits of the order of 20. In these soils the test is of little significance in judging load-carrying capacity. A low plasticity index, such as 5, shows that a small change in moisture content will change the soil from a semisolid to a liquid condition. A high plasticity index, such as 20, shows that considerable water can be added before the soil becomes liquid.

Based on over 100 analyses of near-surface (1-foot to 2-foot depth) materials in Nelson and Walsh Counties, liquid limits range up to about 70 in areas surfaced by tills, up to about 35 in areas of sand and gravel, and up to nearly 100 in certain clay deposits in eastern Walsh County. The clay unit in which the highest values occur is buried beneath Lake Agassiz sediment. It is a soft, black, structureless clay that commonly contains small, buff-colored concretions or carbonate pebbles. The clay has a high moisture content, high liquid limit and plasticity index, and a low density. Its weakness has caused many construction problems over the years. It slumps easily and large structures placed on the clay tend to be unstable. In 1955, a large grain elevator constructed on the clay near Fargo, North Dakota, collapsed. Other large structures have also had stability problems. The plastic indexes of the near-surface till deposits average about 18 with slightly lower values in the silt and clay deposits.

Moisture-Density Tests

Moisture-density tests are designed to aid in the field compaction of soils so as to develop the best engineering properties of the material. Generally, the strength or shearing resistance of the soil increases with higher densities. The presence of a certain amount of water is needed to get optimum densities. Too much water, however, tends to force the particles apart and the higher densities cannot be obtained. The greatest density obtained in compaction tests is termed "maximum density" and the corresponding moisture content is termed "optimum moisture." Moisture-density relations, such as optimum moisture and maximum density, are comparative factors. A high maximum density will range from 125 to 145 pounds per cubic foot, oven-dried weight, and a low maximum density will range downward from about 100 to 85 pounds per cubic foot. A low optimum moisture coincides with a high maximum density and will be of the order of 8 percent; a high optimum moisture coincides with a low maximum density and may be of the order of 20 percent. In general, clays have maximum densities on the order of 90 to 105 pounds per cubic foot and optimum moisture contents of 20 to 30 percent. Silty clays have maximum densities of 100 to 115 pounds per cubic foot and optimum moisture contents of 15 to 25 percent. Sandy clays have maximum densities of 110 to 135 pounds per cubic foot and optimum moisture contents of 8 to 15 percent. For sandy or gravelly soils with no fines, there is no significant change in density with the use of water.

In Nelson and Walsh Counties, the natural moisture content of the near-surface till deposits generally ranges between 15 and 30 percent, whereas optimum moisture percentages in these materials generally are from 10 to 20 percent. Natural moisture percentages in the lake clays of eastern Walsh County are commonly over 50 percent, considerably in excess of optimum percentages.

The tills have average maximum dry densities of about 105 pounds per cubic foot. Although little information was available for the clays of eastern Walsh County, average dry densities are rather low, commonly less that 100 pounds per cubic foot and as low as 60 or 70 pounds per cubic foot in places. This results in low compressive strengths in the clays.

Shear Strength and Compressibility

The shear strength of a soil is the result of friction between soil particles plus cohesion. Cohesion is the shear strength not due to friction. Shearing strength is not constant but depends on water content, rate and time of loading, confining pressure, and numerous other factors. The clay-gravel road made up largely of gravel and sand, with a small amount of silt to fill voids and a small amount of clay to give cohesion, illustrates a soil of high bearing value produced by high internal friction, due to sand and gravel, and high cohesion, due to clay. Wet clay illustrates a soil of low bearing value because internal friction is negligible since no coarse grains are present, and cohesion is low since it has been destroyed by moisture. The same clay, air-dry, will have high bearing value due to high cohesion brought about by the removal of moisture.

Compressibility is influenced greatly by soil structure and past stress history of a deposit. Deposits that formed as a result of a sedimentation process are usually more compressible than their residual or windblown counterparts. Commonly, till shows marked differences in consolidation characteristics with depth. These differences, which may be due to long-term load effects caused by the weight of the overriding glacier, must be recognized in determining the probable amounts the materials will settle after a structure is placed on it. Such "preconsolidation load" characteristics commonly result in relatively high, and therefore favorable, relative densities for many tills.

Compressive strengths of near-surface materials in Nelson and Walsh Counties range from less than 10 pounds per square inch (psi) for some of the clays of eastern Walsh County (even less than 4 psi in a few extreme cases) to over 100 psi for some of the harder tills and shales, although the tills have average compressive strengths between 40 and 60 psi. Gravels also have relatively high compressive strengths. Failure strain percentages, the result of triaxial compression tests, generally range from 10 to 15 percent (the amount a sample can be deformed before failure takes place) but a few samples were as low as 2 percent.

California Bearing Ratio

Bearing capacity failures most often result from uneven loading or overloading of structures located on weak materials, such as the previously mentioned clay unit of eastern Walsh County. The bearing value of a sample is most often expressed as the California Bearing Ratio (CBR), which is a comparative measure of the shearing resistance of a soil. The CBR is the load, in pounds per square inch, required to force a piston of 3 inch end area into the soil a certain depth, expressed as a percentage of the load, in pounds per square inch, required to force the piston the same depth into a standard sample of well graded crushed stone. The standard of comparison for computing a material's bearing value is shown in the following table:

Penetration in.	Standard load psi
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

For example, if a specimen requires a load of 450 psi to obtain 0.1-in. penetration, its bearing value will be (450/1000) X 100=45 percent. The percent symbol is omitted when reporting the CBR. CBR figures for near-surface materials are plotted on Figure 29. Generally they are highest in gravels, lowest in clays.

Summary

Except for local problems that may arise where ground water conditions are unfavorable, the areas of Nelson and Walsh Counties surfaced by till (Cb on Plates 1 and 2) can be expected to present few major construction problems. It should be standard procedure to conduct certain tests before major construction is undertaken. Test borings should be carried out to determine the nature of the materials at the site, to determine whether permeable materials occur in the near subsurface, and to determine whether potential ground water problems exist.

In eastern Walsh County, the buried clay unit mentioned earlier may cause construction problems (Fig. 30). If it occurs at or near the surface near rivers or ditches, it may tend to slide unless proper construction techniques are followed. Particularly heavy structures placed in such locations can slide easily. If heavy structures must be placed in such locations, potential problems may be prevented by changes in foundation or structure design. Engineers should always be consulted before construction is undertaken.

REFERENCES

Anderson, S. B., 1961, Summary of the Pembina Mountain Oil Exploration Co. - Isaac Akre No. 1: North Dakota Geol. Survey Circ. 240, 3 p.

Anderson, S. B., and Haraldson, H. C., 1968, Cement-rock possibilities in Paleozoic rocks of eastern North Dakota: North Dakota Geol. Survey Rept. Inv. 48, 62 p.

Aronow, Saul, 1957, On the post glacial history of the Devils Lake region, North Dakota: Jour. Geol., v. 65, no. 4, p. 410-427.

Aronow, Saul, 1963, Late Pleistocene glacial drainage in the Devils Lake region, North Dakota: Geol. Soc. Amer. Bull., v. 74, p. 859-873.

Aronow, Saul, Dennis, P. E., and Akin, P. D., 1953, Geology and ground-water resources of the Michigan City area, Nelson County, North Dakota: North Dakota Ground-Water Studies no. 21, 108 p., North Dakota State Water Commission.

Asphalt Institute, 1961, Soils manual for design of asphalt pavement structures: Manual Series no. 10, The Asphalt Institute, College Park, Maryland, 176 p.

Ballard, F. V., 1963, Structural and stratigraphic relationships in the Paleozoic rocks of eastern North Dakota: North Dakota Geol. Survey Bull. 40, 42 p.

Bliss, H. N., and Laird, W. M., 1963, A teacher's guide to geologic features as illustrated by a geologic field trip in Walsh County, North Dakota: Dept. of Public Instruction, Bismarck, No. Dak., 48 p.

Bluemle, J. P., 1963, Summary of the Traugott Drilling Co. - Hattie Bakke No. 1, Walsh County, North Dakota: North Dakota Geol. Survey Circ. 262, 6 p.

Bluemle, J. P., 1965, Geology and ground water resources of Eddy and Foster Counties, North Dakota, Part 1, Geology: North Dakota Geol. Survey Bull. 44 and North Dakota State Water Commission County Ground Water Studies 5, 66 p.

Bluemle, J. P., 1967a, Geology and ground water resources of Traill County, Part 1, Geology: North Dakota Geol. Survey Bull. 49 and North Dakota State Water Commission County Ground Water Studies 10, 34 p.

Bluemle, J. P., 1967b, Multiple drifts in northeast North Dakota: North Dakota Geol. Survey Misc. Series 30, p. 133-136.

Bluemle, J. P., 1970, Anomalous hills and associated depressions in central North Dakota: Geol. Soc. America (abstract), Program, 23rd. annual meeting, Rocky Mountain Section, p.325.

Bluemle, J. P., 1971, Geology and ground water resources of McLean County, North Dakota, Part 1, Geology: North Dakota Geol. Survey Bull. 60 and North Dakota State Water Commission County Ground Water Studies 19, 65 p.

Bluemle, M. E., 1969, Geologic field trip from Grand Forks, North Dakota to Kenora, Ontario: North Dakota Geol. Survey Misc. Series 40, 5 p.

Brookhart, J. W., and Powell, J. E., 1961, Reconnaissance of geology and ground water of selected areas of North Dakota: North Dakota Ground-Water Studies no. 28, 91 p.

Carlson, C. G., 1964, The Niobrara Formation of eastern North Dakota; its possibilities for use as a cement rock: North Dakota Geol. Survey Rept. Inv. 41, 56 p.

Clayton, Lee, 1962, Glacial geology of Logan and McIntosh Counties, North Dakota: North Dakota Geol. Survey Bull. 37, 84 p.

Clayton, Lee, 1967, Stagnant-glacier features on the Missouri Coteau in North Dakota: North Dakota Geol. Survey Misc. Series 30, p. 25-46.

Clayton, Lee, Laird, W. M., Klassen, R. W., and Kupsch, W. O., 1965, Intersecting minor ridges on Lake Agassiz plain: Jour. Geology, v. 73, no.4, p. 652-656.

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U. S. Geol. Survey, Misc. Geol. Inv. Map I-331.

Dennis, P. E., 1947, Ground water in the Aneta area, Nelson County, North Dakota: North Dakota Ground Water Studies no. 7, 25 p., North Dakota State Water Commission.

Downey, Joe, 1970, Ground-water resources of Nelson County, northeastern North Dakota: U. S. Geol. Survey Hydrologic Atlas 428.

Downey, Joe, 1971a, Ground-water resources of Walsh County, northeastern North Dakota: U. S. Geol. Survey Hydrologic Atlas 431.

Downey, Joe, 1971b, Ground-water basic data Nelson and Walsh Counties, North Dakota: North Dakota Geol. Survey Bull. 57, Part 2 and North Dakota State Water Commission County Ground-water Studies 17, Part 2, 459 p.

Fenneman, N. M., 1946, Physical divisions of the United States: U. S. Geol. Survey Map.

Garske, Jay, 1958, Summary of the Reelfoot Development Co., Inc. - Louis and Alvina Bryl No. 1: North Dakota Geol. Survey Circ. 207, 5 p.

Hansen, D. E., 1956, Summary of the Oil Exploration Co. - Joe W. Lamb No. 1: North Dakota Geol. Survey Circ. 143, 2 p.

Hansen, D. E., and Kume, Jack, 1970, Geology and ground water resources of Grand Forks County, Part 1, Geology: North Dakota Geol. Survey Bull. 53 and North Dakota State Water Commission County Ground Water Studies 13, 76 p.

Jensen, H. M., and Bradley, Edward, 1962, Ground water near Hoople, Walsh and Pembina Counties, North Dakota: North Dakota Ground-water Studies no. 49, 19 p.

Johnston, W. A., 1916, The genesis of Lake Agassiz: a confirmation: Jour. Geol., v. 24, p. 625-638.

Johnston, W. A., 1921, Winnipegosis and Upper Whitemouth River area, Manitoba, Pleistocene and Recent deposits: Can. Dept. Mines Mem. 128, 42 p.

Klausing, R. L., 1968, Geology and ground water resources of Cass County, North Dakota, Part 1, Geology: North Dakota Geol. Survey Bull. 47 and North Dakota State Water Commission Ground Water Studies 8, 39 p.

Kume, Jack, 1967, The Dahlen esker of Grand Forks and Walsh Counties, North Dakota: North Dakota Acad. Science Proceedings, v. 20, p. 119-124.

Laird, W. M., 1944, The geology and ground-water resources of the Emerado quadrangle: North Dakota Geol. Survey Bull. 17, 35 p.

Laird, W. M., 1956, Guide for a geologic field trip in northeastern North Dakota: North Dakota Geol. Survey Bull. 30, 20 p.

Laird, W. M., 1964, The problem of Lake Agassiz: North Dakota Acad. Science Proceedings, v. 11, p. 114-134.

Lemke, R. W., and Colton, R. B., 1958, Summary of Pleistocene geology of North Dakota, *in* Mid-Western Friends of the Pleistocene Guidebook 9th Ann. Field Conf.: North Dakota Geol. Survey Misc. Series 10, p 41-57.

Lidiak, E. G., in preparation, Buried Precambrian rocks in North Dakota.

Manz, O. E., 1956, Investigation of Lake Agassiz clay deposits: North Dakota Geol. Survey Rept. Inv. 27, 34 p.

MacCarthy, R. F., 1970, The Campbell strandline of glacial Lake Agassiz in Walsh County, North Dakota: The Compass, v. 47, no. 3, p. 147-153.

Mayer-Oakes, W. J., (ed.), 1967, Life, Land and Water: University of Manitoba Press, Winnipeg, Manitoba, 416 p.

Nielsen, D. N., 1969, Washboard moraines in northeastern North Dakota: Univ. of North Dakota, Grand Forks, North Dakota (unpublished master's thesis) 51 p.

Nikiforoff, C. C., 1947, The life history of Lake Agassiz: an alternative interpretation: Amer. Jour. Sci., v. 245, p. 205-239.

Portland Cement Association, 1962, PCA soil primer: Portland Cement Association, 33 West Grand Ave., Chicago, Illinois, 52 p.

Powell, J. E., and Jones, S. L., 1962, Ground water resources in the Lakota area, Nelson County, North Dakota: North Dakota Ground-Water Studies no. 48, 68 p., North Dakota State Water Commission.

Rominger, J. F., and Rutledge, P. C., 1952, Use of soil mechanics data in correlation and interpretation of Lake Agassiz sediments: Jour. Geol., v. 60, p. 160-180.

Simpson, T. G., 1929, Geology and ground-water resources of North Dakota, with a discussion of the chemical character of the water by H. B. Riffenburg: U. S. Geol. Survey Water-Supply Paper 598.

Sloss, L. L., 1963, Sequences in the cratonic interior of North America: Geol. Soc. America Bull., v. 74, p. 93-114.

Tyrrell, J. B., 1896, The genesis of Lake Agassiz: Jour. Geol., v. 4, p. 811-815.

Tyrrell, J. B., 1914, The Patrician glacier south of Hudson Bay: Geologique International, Canada, 1913, Compt. Rendu, p. 523-524, Ottawa.

Upham, Warren, 1895, The Glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, 658 p.