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COUNTY GROUND WATER STUDIES 7

GEOLOGY AND GROUND WATER RESOURCES

of

RICHLAND COUNTY

PART 1 — GEOLOGY

by

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Prepared by the United States Geological Survey
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and the Richland County Board of Commissioners.

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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents ground water basic data, and Part III describes the ground water resources. Part III will be published later and will be distributed as soon as possible.

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Geology and Ground Water Resources of Richland County, North Dakota

PART I - GEOLOGY

By Claud H. Baker, Jr.

ABSTRACT

Richland County comprises an area of approximately 1,450 square miles in the southeastern corner of North Dakota. About one-fifth of the county is in the Drift Prairie physiographic division; the remainder is in the Red River Valley (basin of glacial Lake Agassiz) physiographic division.

The stratigraphy of the sedimentary rocks underlying the Pleistocene deposits is relatively uncomplicated. Cretaceous Dakota Sandstone lies unconformably on the Precambrian crystalline basement. The Graneros Shale and the Greenhorn Formation, both of Late Cretaceous age, overlie the Dakota in most of the county, and no indurated rocks younger than the Greenhorn are present.

Pleistocene glacial drift mantles the entire county; the known thickness of the drift, including the deposits of glacial Lake Agassiz, ranges from 154 to 490 feet. Drift representing several ice sheets may be present but cannot be differentiated except in a few places. All of the surficial features of the county can be attributed to the last ice sheet (Mankato advance); local zones of oxidized till, extensive bodies of buried outwash, and buried lake silts are the only indications of the presence of older drift in the subsurface.

The major surficial features of the Drift Prairie in the county are stagnation moraine, a large body of overridden pitted outwash, and an ice-marginal drainage channel. Minor features include end moraine, ground moraine, and kames.

The flat expanse of the Red River Valley is interrupted by the Sheyenne delta and by the major shorelines of glacial Lake Agassiz. The Sheyenne delta is an extensive deposit in Richland County and an important aquifer. It covers 550 square miles and consists of sand and silt as much as 200 feet thick. The lake-floor deposits, where present, may include two distinct lithologies, but the upper unit is thin and irregularly distributed.

Few Pleistocene fossils have been found in Richland County, and most of the available material is of little value for age determinations.

INTRODUCTION

Scope and Purpose of the Study

This is the first of three reports detailing the results of a study of the geology and ground-water resources of Richland County, North Dakota (fig. 1). The study was made under the cooperative program of ground - water studies in North Dakota by the U. S. Geological Survey, North Dakota State Water Commission, and North Dakota Geological Survey; and was supported financially by the Richland County Board of Commissioners.

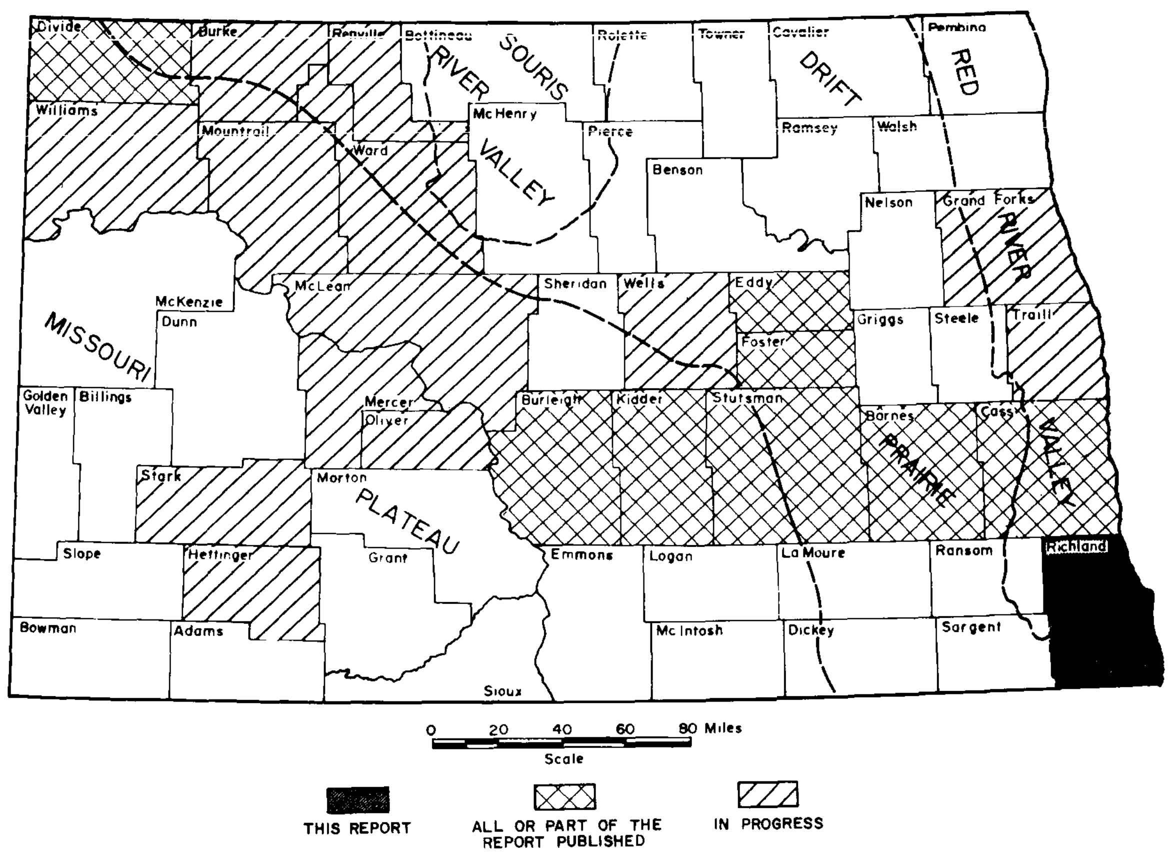
The primary purpose of the study was to determine the occurrence, availability, and quality of ground water in Richland County. This report describes the geology of the county to the extent necessary to provide a framework for the discussion of the ground-water resources. It places major emphasis on the lithology and water-bearing properties of the various rock units underlying the county. The second report, "Geology and Ground Water Resources of Richland County, North Dakota, Part II, Ground Water Basic Data," is a compilation of the basic data collected during the study, and has been published (Baker, 1966a). The third report, "Geology and Ground Water Resources of Richland County, North Dakota, Part III, Ground Water Resources," is an evaluation of the ground-water resources of the county, and will be published later.

Field Work and Acknowledgments

The surficial geology of the county was mapped by the author during the summers of 1963 and 1964. Field mapping was done on 7½-minute topographic quadrangle maps (scale 1:24,000), and on aerial photographs (scale 1:20,000) in areas not covered by topographic maps. Subsurface data were obtained from 67 test holes drilled during 1963 and 1964. Information collected from test holes drilled during four earlier studies in the county was used in the subsurface interpretation. The locations of the test holes are shown on plate 1 (in pocket).

Many people, both in and out of the U. S. Geological Survey, gave valuable assistance during this study. Special thanks are due to Q. F. Paulson, who worked closely with the author throughout the project. The test holes drilled during this study were logged by Roger Schmid, Larry Froelich, and Alain Kahil, all of the North Dakota State Water Commission. The personnel of the North Dakota Geological Survey provided helpful consultation on many points. Most of the grain-size analyses reported here were performed in the Hydrologic Laboratory,

Figure 1. Physiographic divisions and locations of county ground-water studies.



the vertebrate fossils were identified by the Paleontology and Stratigraphy Branch, and the carbon-14 age determinations are by the Isotope Geology Laboratory — all of the U. S. Geological Survey.

Previous Work

The Red River Valley was recognized as a former lake basin in 1823 by Keating, the geologist with the first scientific expedition to the area (Upham, 1895, p. 6). The first comprehensive study of the area was made by Warren Upham (1895), who mapped the basin of glacial Lake Agassiz and named most of the geomorphologic features associated with the former lake. Leverett (1912, 1932) mapped the southern end and outlet of the Lake Agassiz basin, and described the surficial geology of much of Richland County. Simpson (1929) included a brief discussion of the geology and hydrology of Richland County in his report on the ground-water resources of North Dakota. Dennis, Akin, and Jones (1949, 1950); Paulson (1953); and Powell (1956) described the geology of small areas of the county and dealt mainly with the aspects of geology that affect ground-water supply. Flint (1955) mapped the surficial geology adjacent to Richland County in northwestern South Dakota. Colton and others (1963) mapped the general glacial features of North Dakota.

Well-Numbering System

The test holes and wells are numbered according to their location within the United States land survey system (fig. 2). North Dakota is in the area surveyed from the fifth principal meridian and its base line; townships are all north of the base line and ranges all west of the meridian. The first numeral of the well number indicates the township, the second numeral the range, and the third numeral the section in which the well or test hole is located. The letters following the section number locate the well within the section; the first denotes the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section or 10-acre tract. In each case, the letters a, b, c, and d refer to the northeast, northwest, southwest, and southeast elements of the division. If more than one well or test hole is recorded within a single 10-acre tract, numbers 1, 2, 3, etc., are added after the letters. Thus, well number 132-50-15daa2 is the second well in the NE¼NE¼SE¼ sec. 15, T. 132 N., R. 50 W. The system is somewhat complicated by the presence of a portion of the Wahpeton and Sisseton Indian Reservation. Section lines within the reservation do not correspond with those outside it, and some sections (129-52-9, for example) occur both inside and outside the reservation. Locations within the reservation are indicated by the notation LTL (Lake Traverse Lands) following the range-township-section descriptions.

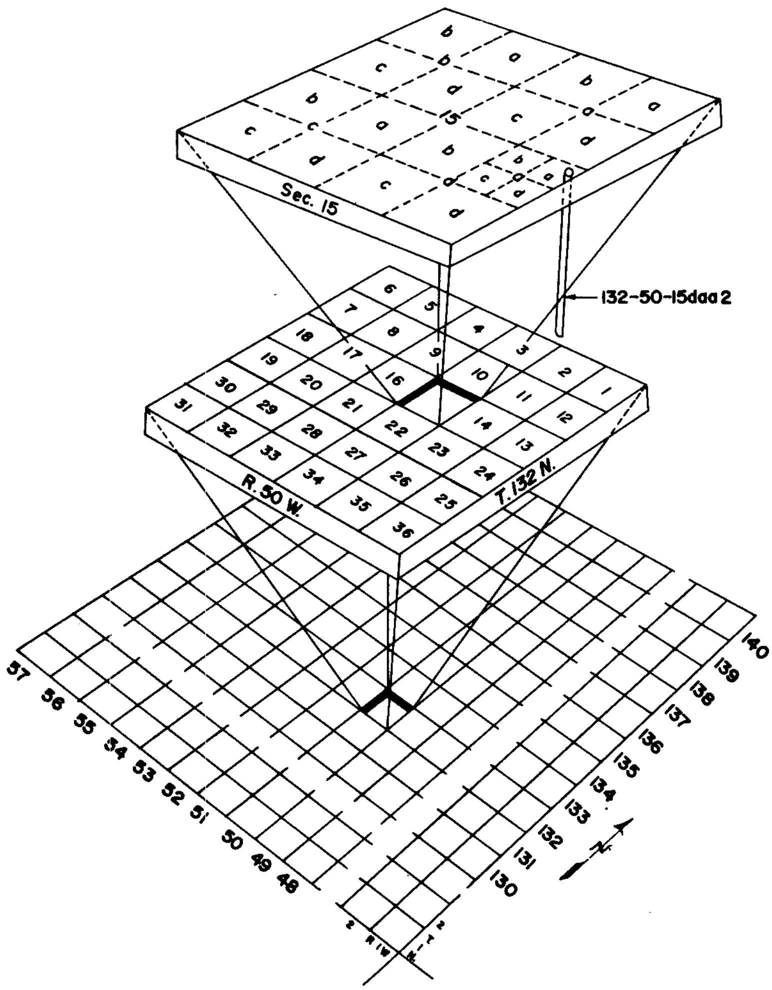


Figure 2. System of numbering test holes and wells.

GEOGRAPHY

Location and Size of County

Richland County is in the southeastern corner of North Dakota (fig. 1). It is bounded on the south by South Dakota and on the east by Minnesota, and it includes about 1,450 square miles. The population in 1960 was 18,824; approximately one-half of the population lived in the five principal communities of Wahpeton (5,876, the county seat), Hankinson (1,385), Lidgerwood (1,081), Wyndmere (644), and Fairmount (503). Three state highways (11, 46, and 13) cross the county in the east-west direction; State Highway 46 forms the northern boundary. State Highway 18 and U. S. Highway 81 are north-south routes through the county. About 40 square miles, near the southwestern corner of the county, are included in the Wahpeton and Sisseton Indian Reservation.

Physiography and Topography

Richland County is in the Central Lowland province of the Interior Plains (Simpson, 1929, p. 4). Most of the county is in the Red River Valley physiographic division, but about 300 square miles in the southwestern part is in the Drift Prairie physiographic division (fig. 1). The Red River Valley can be divided into the Sheyenne delta, which occupies approximately 550 square miles in the northwestern corner of the county, and the Lake Agassiz plain.

The north end of the Sheyenne delta stands about 100 feet above the lake plain; and the delta grades southward into the plain. The delta surface includes many areas of dunes where the local relief is as much as 50 feet within a square mile. Outside the dune areas the ground is gently rolling to nearly flat. The Sheyenne River crosses the delta in a steep-sided valley that is as much as 120 feet deep.

The Lake Agassiz plain is nearly flat; the only prominent relief features are the beaches. Locally, near Hankinson, sand dunes have been formed on the beaches, and the crests of the dunes are as much as 75 feet above the surrounding lake plain. Elsewhere the beaches rarely exceed 20 feet in height. The Red River of the North and its tributaries are entrenched 30 to 40 feet into the lake plain. Except for the beaches and stream valleys, local relief is commonly less than 5 feet.

Much of the Drift Prairie in Richland County is an area of high relief. Closed depressions are numerous. Local relief is commonly 50 to 75 feet within a square mile, but may exceed 150 feet. Near Lidgerwood the relief is not so great, and the topography can be described as strongly rolling. Nowhere does the Drift Prairie approach the levelness of the lake plain.

Drainage

Richland County is in the drainage basin of the Red River of the North. The Red River of the North and its south branch, the Bois de Sioux, form the eastern boundary of the county. There is little natural drainage in the lake plain, and a large part of the runoff from that area moves through manmade drains. The Wild Rice River crosses the county from west of east, but parallels the Red River through the northern half of the county. The Sheyenne River crosses the northeastern corner of the county.

The drainage pattern on the Sheyenne delta is poorly developed. Antelope Creek, Elk Creek, and several smaller unnamed streams drain into the Wild Rice River. A number of unnamed streams enter the Sheyenne River from the delta. Most of these minor streams are only a few miles long, and although spring fed, some are dry during a part of every year. Good subsurface drainage precludes the existence of permanent ponds on the delta, but marshy areas are numerous in wet seasons.

The drainage within the Drift Prairie part of the county is mostly interior. Closed depressions abound, and collect runoff during storms and periods of melting snow. There are numerous small ponds, many of which are reduced to marshes in drier seasons. A few permanent lakes exist, notably south and west of Hankinson. Streams are all intermittent, and commonly join marshes or ponds.

Soils and Land Use

Most of the soil of Richland County is of the chernozem type, characterized by black topsoil and limey subsoil. The soils of the lake plain are generally clay loams, which are heavy and often difficult to work, but very fertile; nearly all of the lake plain is cultivated. The soils of the Drift Prairie also are generally clay loams, but because of the greater erosion in the more rolling topography, soils are generally thinner than on the lake plain. The topography makes cultivation more difficult, and much of the Drift Prairie is used for grazing. The soils of the Sheyenne delta and the higher beaches are sandy loams, much lighter than the clay loams. The light soils are subject to wind erosion when plowed, and the dune topography makes cultivation difficult. Accordingly, much of this area is used for grazing. A portion of the Sheyenne delta is in the Sheyenne National Grassland, administered by the United States Forest Service, and use is restricted to grazing.

Climate

Richland County is in the northern Great Plains, and the climate is of the continental type, characterized by short summers and long cold winters. Summer temperatures above 90° F are common and winter temperatures are often as low as -20°. The average annual precipitation is about 20 inches, most of which falls as rain in the spring and summer.

GEOLOGIC HISTORY

Pre-Pleistocene History

Very little is known about the history of the Precambrian to Cretaceous interval in Richland County, for no rocks representing this long interval are present under the area (table 1). Certainly there was much erosion, for the Precambrian crystalline rocks were exposed at the beginning of Cretaceous deposition; and certainly the Precambrian rocks had been exposed for a very long time, for they are profoundly weathered. During this long interval, the Williston Basin to the northwest was slowly sinking and filling with sediments. Richland County is on the edge of the basin, and was probably a source area for the basin sediments. Perhaps Richland County too was submerged from time to time; if so, any sediments that were deposited were subsequently removed, for no trace of them remains.

When the Cretaceous seas invaded the area they covered an irregular and deeply weathered surface. The advance of the sea was slow, and very shallow water covered the area. The oldest sedimentary rocks in the area are littoral deposits of the Dakota Sandstone, and their irregular distribution and varying thickness suggests that many knobs and hills of the "granite" protruded as islands in the shallow sea. The sea probably retreated briefly after deposition of the Dakota sand, and erosion probably removed much of the deposit from the eastern part of the county.

Later in Cretaceous time deeper water completely covered the area. The sediments deposited during this time were chiefly black mud (Graneros Shale), formed in rather quiet, brackish water; a few thin beds and lenses of fine sand suggest that the shoreline was not far away. Younger deposits (Greenhorn Formation) contain much interbedded limestone, and were probably formed in somewhat deeper water with better circulation. The younger Cretaceous rocks that are present further west (Niobrara, Pierre, and other formations) are absent under Richland County. Probably at least some of these rocks were deposited in the area, but were subsequently eroded.

TABLE 1.—Stratigraphic sequence in Richland County (U. S. Geol. Survey nomenclature).

Age		Unit	Description	Thickness (feet)
Quaternary	Recent	Alluvium	Silt and clay on flood plains of modern streams.	0-40
	Pleistocene	Glacial Drift	Glacial till, glaciofluvial deposits, and glacial lake sediments.	154-490
Cretaceous		Greenhorn Formation	Black limey shale, generally contains minute white "specks" of calcium carbonate; interbedded with white to buff limestone.	0-212
		Graneros Shale	Black shale, locally with streaks and lenses of white sand; often marine fossils.	0-160
		Dakota Sandstone	White quartz sand with interbedded varicolored sandy shale, siltstone, and clayey sandstone.	0-238+
Cretaceous (?)		Undifferentiated rocks	Light gray to moderate yellowish-green "nodular" sand, interbedded with varicolored clay.	0-61
Precambrian		Undifferentiated crystalline rocks	"Granite." Generally deeply weathered in upper part.	?

After the retreat of the Cretaceous seas, the area again was subjected to erosion. Many of the Cretaceous rocks were stripped away, and the weathered basement rocks were exposed again in the deepest valleys (plate 2, in pocket). This last long period of erosion was terminated with the advance of the Pleistocene glaciers.

Pleistocene History

During Pleistocene time, Richland County was covered, probably several times by sheets of glacial ice. Flint (1955, pl. 3) shows the borders of at least five drift sheets (Mankato, Cary, Tazewell, Iowan, and Illinoian) in South Dakota, and presumably the ice that deposited each of the drift sheets advanced from areas north of Richland County. Colton and others (1963) show drift borders for at least four ice sheets of Wisconsin age that presumably crossed Richland County. One can suppose, then, that Richland County was covered by glacial ice several times during the Pleistocene.

Each of these ice sheets probably left deposits of drift, and each succeeding ice sheet probably removed and redistributed part of the deposits of its predecessor. The deposits of the various ice sheets are so similar in lithology, however, that there is no ready means of distinguishing between them. In Richland County there is clear evidence of more than one drift sheet in only a few places.

Great thicknesses of glacial drift were deposited in the county, and by the time of the last glacial retreat the original topography was completely buried. A portion of the last ice sheet broke off and melted in place, and the stagnant ice left characteristic topographic features in the southwestern corner of Richland County. The stagnant ice deposits were overridden by a minor readvance of the glacier, and then the final withdrawal of the ice began.

The regional slope in eastern North Dakota is to the northeast, as the last ice sheet retreated to the north, it blocked the drainage; accordingly, a large proglacial lake, called Lake Agassiz, was formed in eastern North Dakota and western Minnesota. Most of Richland County is within the Lake Agassiz basin.

At its maximum, Lake Agassiz extended from northeastern South Dakota to northern Manitoba, a distance of more than 550 miles, and had an average width of about 150 miles (Upham, 1895, p. 215). The greatest depth of Lake Agassiz in Richland County (the difference in elevation between the lowest point on the lake plain and the highest beach) was about 150 feet. The lake had an outlet to the south through a channel now occupied by the Bois de Sioux River and a chain of lakes and marshes (fig 3). Water flowing out of the lake eroded the

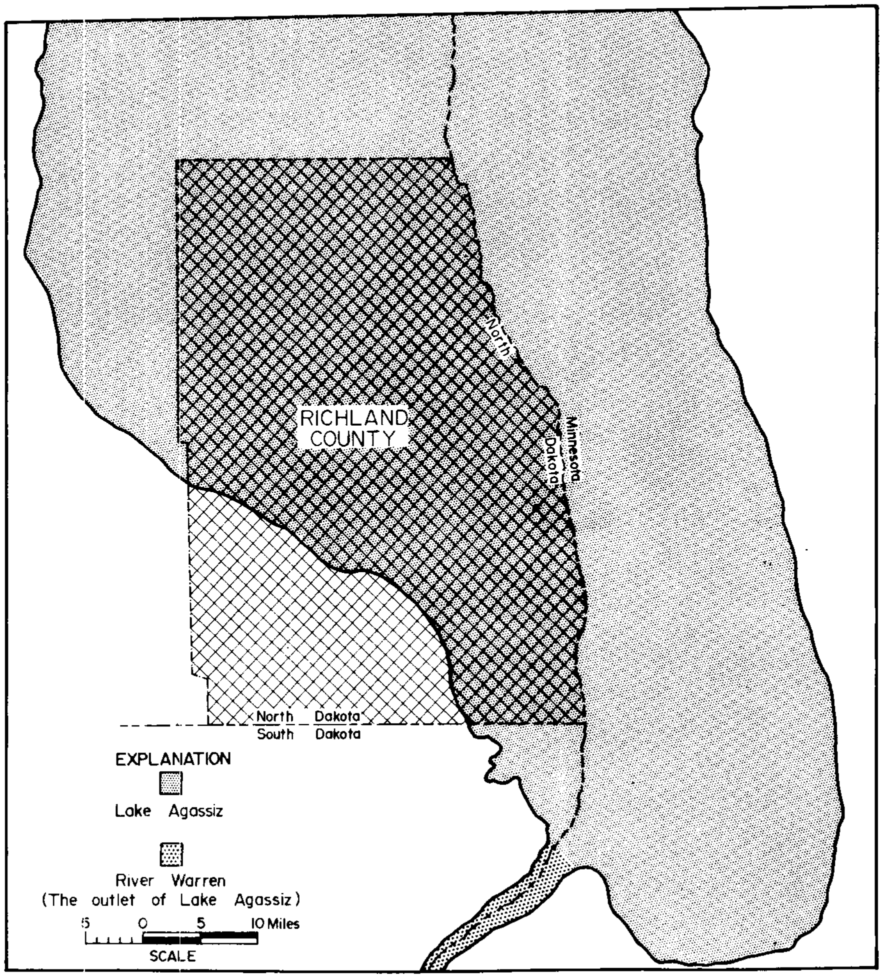


Figure 3. South end and outlet of Lake Agassiz during the highest stage of the lake.

bottom of the channel, and this deepening of the outlet caused a general lowering of the water level in the lake. The materials in the floor of the channel were not homogenous; consequently, the rate of erosion was not uniform. During periods of rapid erosion, the lake level fell rapidly; during periods of slow erosion, the lake level changed slowly and well - defined shorelines were formed. Finally, as the ice continued to retreat, lower outlets were uncovered to the northeast, and Lake Agassiz gradually receded from Richland County. Possibly a readvance of the glacial ice blocked the northern outlets and caused the lake to be refilled to the level of the southern outlet

(Johnston, 1916, p. 628). The effect of the draining and refilling was slight in Richland County; a few scattered deposits of silt on the lake plain may have been deposited during the second stage of the lake. The evolution of Lake Agassiz is shown in plate 3 (in pocket).

Many of the surficial features of Richland County were formed in Lake Agassiz. During the highest stage of the lake, a well-defined shoreline (Herman shoreline) was formed, and an extensive delta was formed at the mouth of the Sheyenne River. As the ice sheet dwindled and the lake was drained, other beaches were formed at lower levels, and parts of the courses of four of these lower beaches can be traced through Richland County. During the life of Lake Agassiz, wave action smoothed the lake floor, and a blanket of clay and silt was deposited in the deeper parts of the basin.

When the glacial ice far to the north finally melted and Lake Agassiz was drained, the lake plain had essentially the form that is seen today. Recent erosion has been very slight, and the only conspicuous topographic change in Richland County since the drainage of the lake has been the formation of sand dunes on the Sheyenne delta and in the vicinity of Hankinson. These dunes probably were formed very soon after the drainage of the lake, and have changed little in recent time.

PRE-PLEISTOCENE GEOLOGY

Stratigraphy of the Pre-Pleistocene Rocks

Richland County is covered with glacial drift and no outcrops of pre-Pleistocene rocks exist in the county. Information obtained from drill holes indicates that no Tertiary rocks are present. Cretaceous rocks, where present, lie directly on the Precambrian "granite." The stratigraphic relations of the bedrock units to each other and to the overlying drift are shown on the geologic sections, plate 4 (in pocket).

Precambrian Crystalline Rocks

The basement rock under Richland County consists of an undifferentiated complex of crystalline rocks that is referred to the Precambrian and generally termed "granite." Very little is known about the composition of these basement rocks, for drilling generally is stopped when the hard rock is reached. One oil-test hole near Wahpeton (Ruddy Bros. No. 1 Snowden, NW¼NW¼SW¼ sec. 11, T. 132 N., R. 48W.) was drilled approximately 245 feet into the crystalline rocks. Cuttings from this hole were examined by P. E. Dennis in 1948 and he described the samples as "gneissic granite, schist chips" (Dennis, Akin, and Jones, 1949, p. 42). Precambrian granite crops out in Minnesota, and probably the Precambrian basement rocks under Richland County are primarily of granitic composition, although there also may be some metamorphic rocks.

In most places, the hard Precambrian rocks are overlain by a layer of weathered clayey material (fig. 4) that is commonly referred to as

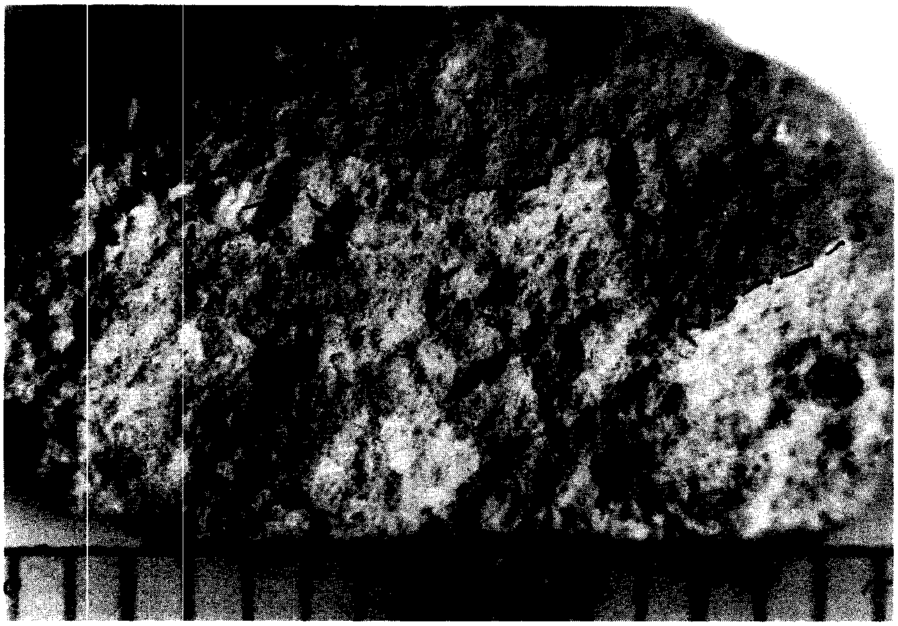


Figure 4. Drill cuttings of "weathered granite." a—faces of quartz crystals embedded in matrix of clay, b-b'—contact between reddish-brown clay, above, and pale-green clay, below. Sample from test hole 3170, 131-52-25ccc; depth about 700 feet. Scale in millimeters.

"weathered granite." Paulson (1953, p. 36) had core samples of this weathered material taken from a test hole near Fairmount and examined by electron microscopy. The material consisted of a matrix of kaolin-type clays containing numerous angular crystals of quartz, and it was believed to be an end product of intense weathering of granitic rocks (Paulson, oral communication). Test hole 3170 (131-52-25ccc) north of Lidgerwood penetrated more than 40 feet of weathered material, grading downward from kaolinitic clay to a mixture of clay, mica, feldspar, and quartz that resembled weathered granite. The hole was not drilled deep enough to reach unaltered granite.

The thickness of the zone of decomposition varies greatly. The oil-test hole near Wahpeton reportedly penetrated 175 feet of weathered material before reaching hard rock. Paulson (1953) reported that three holes drilled near Fairmont reached hard rock without penetrating a weathered zone. Only one hole drilled during the present study, test hole 3169 (131-51-13aab), reached the unaltered "granite." This hole penetrated 13 feet of weathered material. The "weathered granite" and its present material are assigned to the Precambrian, but the weathered zone may have been formed during all, or any part of, the long span of time from late Precambrian to Cretaceous.

Cretaceous Rocks

Rocks of Cretaceous age probably are present under most of Richland County (pl. 2). The Cretaceous rocks are extensively eroded in the eastern part of the county, and their distribution probably is not as uniform as plate 2 indicates. The rocks are subdivided into the Dakota Sandstone, the Graneros Shale, and the Greenhorn Formation. Pre-Pleistocene rocks younger than the Greenhorn have not been identified in the county.

North of Lidgerwood, test hole 3170 (131-52-25ccc) penetrated 61 feet of sedimentary material that cannot be definitely assigned to any of the known Cretaceous formations. At the base of the Dakota Sandstone, the drill entered a multicolored, noncalcareous sandy clay, very similar to the material generally called "weathered granite." Unlike the typical weathered granite, however, the clay contained many interbedded layers of sand.

Most of the sand consisted of light gray to moderate yellowish-green[1] "nodules" or "pellets" (fig. 5). The nodules are nearly spherical, and have an average diameter of about 1 mm; a few larger fragments (up to 4 mm) appear to be aggregates of the smaller spheres. Thin sections of several nodules were examined under the petrographic microscope, but no oolitic or spherulitic structure was discernible. Chemical tests indicate that the nodules are composed primarily of clay particles cemented with iron phosphate and carbonate (R. Gantnier, U. S. Geological Survey, written communication, 8/20/65).

The origin of this deposit of nodular sand and interbedded clay is highly conjectual. The nearly spherical shape of the nodules suggests formation in a shallow-water environment, where wave action was sufficient to keep the growing particles in motion. The clay layers, however, would require quiet water for their deposition because much wave action would tend to keep the clay in suspension. Probably, then, the deposit was formed in a marine environment of moderate depth—below the influence of normal wave action, but shallow enough to be agitated by storm waves.

[1] All color terms used in this report are from the "GSA Rock-Color Chart" (Goddard and others, 1948).

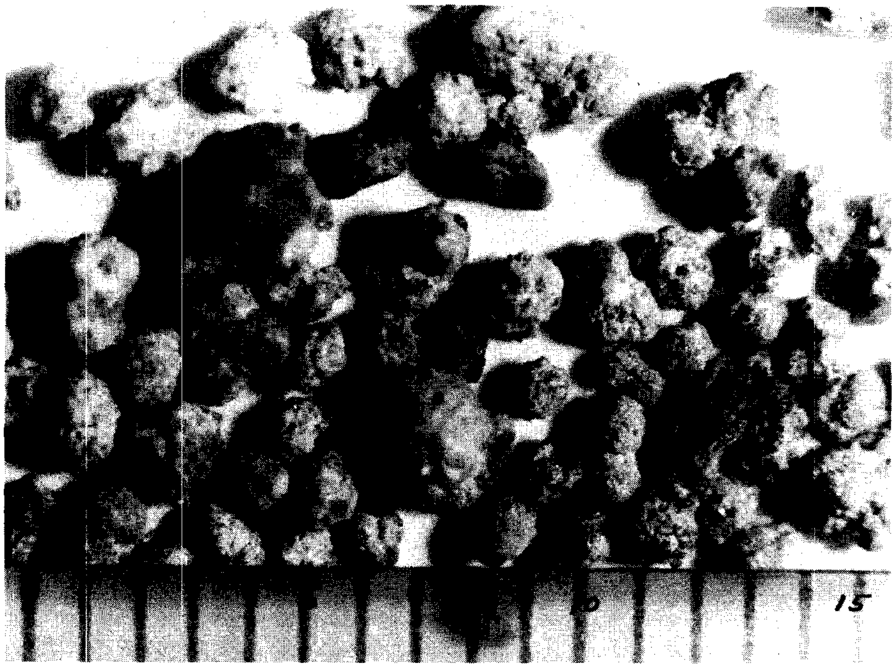


Figure 5. "Nodular" sand. Sample from test hole 3170, 131-52-25ccc; depth about 630 feet. Scale in millimeters.

The samples from the test hole furnish no clue about the age of the deposit, which could have been formed during any part of the long time between the Precambrian and the Cretaceous. No other rocks older than Cretaceous but younger than Precambrian are known to exist elsewhere in the county, and the granite underlying this deposit is deeply weathered. The nodular sand and interbedded clay is therefore tentatively assigned to undifferentiated rocks of Cretaceous(?) age.

DAKOTA SANDSTONE

The name Dakota Sandstone generally has been applied to the basal Cretaceous sandstones in eastern North Dakota, and is so used in this report. The Dakota Sandstone in Richland County is probably a littoral deposit, formed in a transgressing sea. The basal bed is generally fine to coarse sand; locally, gravelly or conglomeratic beds have been reported as the basal Dakota (Paulson, 1953, p. 30). The sand is generally clean, well-sorted, subrounded to rounded, and composed predominantly of quartz (fig. 6a). Some lignite or other carbonaceous material and pyrite have been reported from the basal

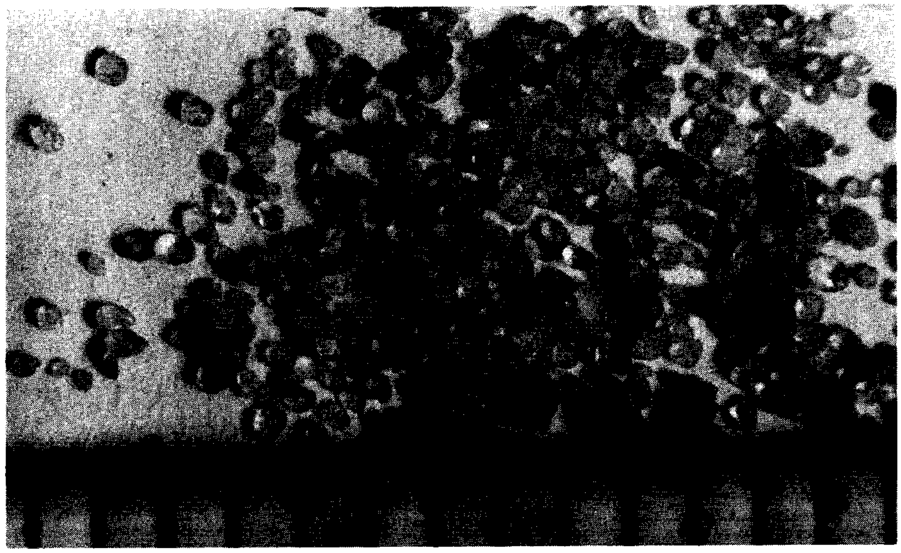


Fig. A

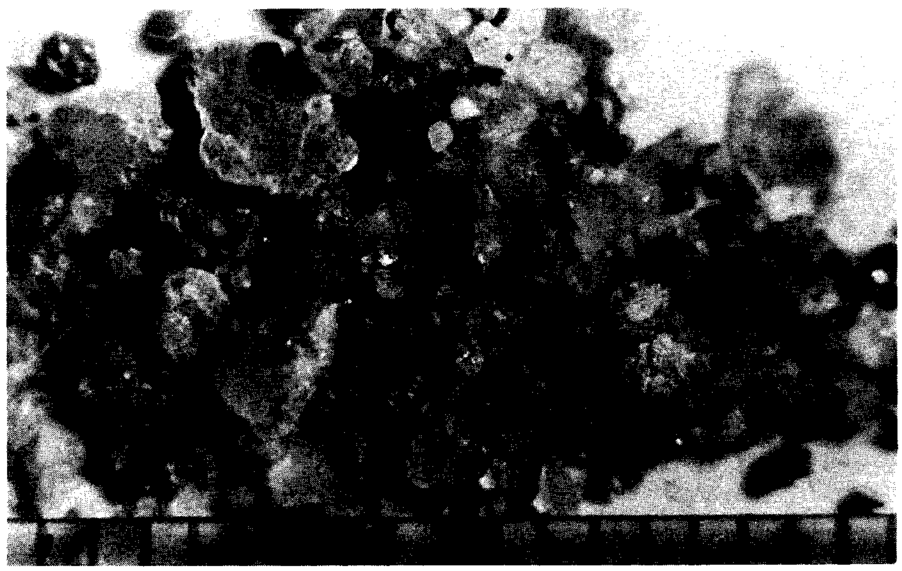


Fig. B

Figure 6. Two lithologies of the Dakota Sandstone. A) Typical fine-grained quartz sand from test hole 3169, 131-51-13aab; depth about 340 feet. B) Quartz-muscovite sand, showing wide range of grain sizes. Sample from test hole 3174, 130-52-20bbb; depth about 630 feet. Scales in millimeters.

Dakota (Paulson, 1953, p. 30), and locally muscovite is an abundant constituent (fig. 6b). The basal beds are generally poorly cemented or not cemented at all. Near the southwestern corner of the county (test hole 3174, 130-52-20bbb) the Dakota Sandstone includes vari-colored shale, siltstone, and clayey sandstone, as well as clean quartz-muscovite sand.

The materials comprising the Dakota Sandstone in Richland County must have been derived from two sources. The quartz-muscovite sand is probably the end product of intense weathering of granitic rocks. The size of the muscovite flakes and the angularity of the quartz grains both indicate that the material was not transported far. It was probably formed in place by wave action; the clay of the weathered granite was washed out, and the quartz-muscovite sand left as a lag deposit. The well-sorted rounded quartz sand must have been derived from more distant sources, and carried to its present location by stream and wave action.

The thickness of the Dakota Sandstone in Richland County varies greatly. In the eastern edge of the county, a maximum of 21 feet was penetrated in test hole F-477 (130-48-25cbb), but the formation was absent in many places, even where the younger Cretaceous shales were present (Paulson, 1953, p. 65). Powell (1956, p. 38) reported that test hole H-813 (130-49-17ccc) near Hankinson had been drilled through the Cretaceous shale and entered directly into the "weathered granite." The shale apparently lies directly on the "weathered granite." Dennis, Akin and Jones (1949, p. 42) reported a maximum of 46 feet of Dakota in test hole W-13 (132-50-7caa) in the vicinity of Barney. No Dakota was reported in the one test hole (K-1R, 136-51-5aba) that was drilled through the Cretaceous shale in the Kindred area (Dennis and others, 1950, p. 62).

The Dakota Sandstone was penetrated in six test holes drilled during the present study. Five other test holes reached the "granite" after passing through Cretaceous shale, but did not penetrate any Dakota Sandstone. The greatest thickness of Dakota penetrated was 238 feet in test hole 3174 (130-52-20bbb); this hole did not pass through the formation. Another test hole (3170, 131-52-25ccc) penetrated 96 feet of Dakota and an additional 61 feet of material assigned to undifferentiated rocks of Cretaceous (?) age before reaching the weathered granite. The known thickness of the Dakota Sandstone in Richland County thus ranges from 0 to 238 feet, with the greatest thickness near the southwestern corner of the county. The formation is very thin or entirely absent in most of the eastern half of the county.

GRANEROS SHALE

In earlier studies in Richland County, the Upper Cretaceous shales were grouped under the general term Benton (?) Shale. However, collection and analysis of additional sub-surface data have permitted the differentiation of the shales into the Greenhorn formation and the Graneros Shale.

The Graneros Shale is a shallow-water marine shale, probably formed in an environment of restricted circulation. The dominant lithology is black silty shale, noncalcareous to moderately calcareous. Thin stringers and lenses of fine-grained white sand are common, and crystals of pyrite are locally abundant. The only fossils recovered from the test drilling during the present study were unidentifiable shell fragments. However, Paulson (1953, p. 28-29) found fish bones and scales, shark teeth, and a number of dwarfed Foraminifera. Dennis, Akin, and Jones (1949, p. 26) reported fish scales and teeth, plant fragments, and Inoceramus prisms from cores of the "Benton (?) Shale"; but the cores were taken near the top of the "Benton (?)," and may be from the Greenhorn Formation rather than the Graneros.

The Graneros Shale is present under most of Richland County (pl. 2). It has been removed from the deeper parts of the bedrock valley in the north end of the county. The Graneros is absent locally in the southeastern quarter of the county, probably because of nondeposition. The known thickness of the Graneros Shale in the county ranges from 0 to 159 feet; the greatest thickness is in the southwestern corner of the county.

GREENHORN FORMATION

The Greenhorn Formation, the youngest consolidated rock in Richland County, is a marine shale, probably formed in water of moderate depth. It is composed principally of black shale, interbedded with thin layers of white- to buff-colored limestone. The shale is generally massive, cohesive, and highly calcareous, and it commonly contains abundant small (less than ½ mm) white specks of calcareous material (fig. 7). The interbedded limestone layers are generally thin and hard. No identifiable fossils were recorded from the Greenhorn Formation in Richland County.

The Greenhorn Formation underlies most of the western half of Richland County (pl. 2). The greatest thickness penetrated in the test drilling was 212 feet in test hole 3174 (130-52-20bbb). Very few holes were drilled through the Greenhorn, however, and greater thicknesses than this may be present.

Presumably the Greenhorn Formation and the Graneros Shale were coextensive when they were deposited, and probably covered all of Richland County. The difference in extent of the two formations at present is due to post-Cretaceous erosion.

Figure 7. Drill cuttings from the Greenhorn Formation showing "white specks." Sample from test hole 2183, 134-52-6ccd; depth about 260 feet. Scale in millimeters.

Topography of the Bedrock Surface

The topography of the bedrock surface under Richland County is shown on plate 2. This generalized map is based entirely on subsurface data, and is necessarily highly conjectural.

In general, the bedrock has an erosional surface of high relief. The general slope of the bedrock surface is to the north. The major feature is a deep, steep-sided channel, which trends northward from T. 131 N., Rs. 49 and 50 W. This channel probably represents the head of a major north-trending drainage channel. Test drilling in Cass County, which borders Richland County on the north, indicates a deeply incised bedrock channel that extends northward or northeastward along the eastern margin of Cass County (R. L. Klausing, oral communication). Thus, the channel in Richland County may be the head of the ancestral Red River drainage.

The major topographic features of the bedrock probably were formed during Tertiary time by subaerial erosion, but they were most likely altered by glacial erosion. The test drilling did not penetrate any material that could be recognized as a zone of weathering in the

Cretaceous shales. The apparent absence of a weathered zone in the shale suggests that some material was stripped off by the advancing glaciers.

PLEISTOCENE GEOLOGY

As discussed earlier in this report, Richland County is entirely covered with glacial drift. The known thickness of the glacial deposits (including deposits of glacial Lake Agassiz) ranges from 154 to 490 feet and averages more than 200 feet. The thickness and stratigraphic relations of the drift are shown on the cross sections in plate 4.

The surficial features of the county are all attributed to the waning of the last ice sheet in late Wisconsin (Mankato) time. Very little is known about the age of the buried drift; accordingly, all of the subsurface Pleistocene features will be discussed together under the heading of "subsurface features."

Subsurface Features

Only a few subsurface features are sufficiently well known to warrant a discussion here — the evidence of older tills, the larger bodies of buried outwash, and the evidence of buried lake deposits.

Older Till

Probably till of several different drift sheets, and therefore of several different ages, underlies Richland County. However, there are no outcrops in the county in which more than one till has been recognized, and the differentiation of tills in drill cuttings generally is very uncertain.

In many of the test holes drilled during this study, the till at depth was darker in color than the till nearer the surface. The difference in color is small; the shallower till is generally olive gray to dark olive gray and the deeper till is dark gray to olive black. The change in color might be accompanied by a minor change in lithology — the darker till containing more or fewer pebbles, or more or less clay — but as often there was no discernible lithologic change. Probably this darker-colored till is older than the till at the surface, and represents the deposits of one or more earlier drift sheets.

In the northeastern quarter of the county, unusually light-colored till (light gray to light olive gray) was encountered at a depth of 60 to 120 feet. The light-colored till was generally softer and sandier than the overlying till. This light-colored till may be a remnant of an earlier drift sheet.

Paulson (1953, p. 20-28) distinguished "older drift" in most test holes drilled in the Fairmount area, but his separation was primarily on the basis of color — the darker-colored till was assigned to the older drift. In a few holes, Paulson reported a recognizable weathered zone.

Four of the test holes drilled during this study, test holes 3181 (129-51-1bbb), 3182 (129-51-13bcb), 2311 (134-49-5cdd), and 2179 (136-50-19ccc), penetrated a thin zone of yellow to brown oxidized till at depths of 198 to 387 feet below the surface. These weathered zones, as well as those reported by Paulson and one reported by Powell (1956, p. 42), are good evidence of older till underlying the surficial drift. The weathered zones that have been recognized are at widely different elevations, and may represent two or more older drift sheets.

The scarcity of weathered zones within the till can be attributed to glacial erosion. As each ice sheet advanced, it probably removed a part of the drift left by the preceding ice sheet, including most of any weathered zone that had formed.

Buried Outwash

A few sizable bodies of buried outwash were discovered during test drilling, or were inferred from existing well data. The approximate boundaries of these larger outwash bodies are shown in figure 8.

Paulson (1953, p. 21-25) outlined and described a large body of buried outwash in the vicinity of Fairmount. This outwash deposit is rather thin (9 to 18 feet), but apparently extensive south and east of Fairmount.

In the vicinity of Colfax, a large number of wells obtain water from the drift at depths of 100 to 150 feet. Many of these wells flow, and in those that do not, the water rises nearly to the surface. The one test hole drilled in this area (test hole 2311, 134-49-5cdd) penetrated 52 feet of medium to coarse sand between 121 and 173 feet. Probably this sand is the source of the water in the nearby flowing wells, and represents a sizable body of buried outwash.

Four test holes in the northwestern part of the county penetrated several feet of gravel near the base of the glacial till. The gravels encountered in these holes are not known to be continuous, but the similarity of stratigraphic position suggests that they may represent a single large body of buried outwash.

Sand and gravel, capped by 8 to 15 feet of till, is exposed in a pit north of Wahpeton, in sec. 16, T. 133 N., R. 47 W. Nearby test holes

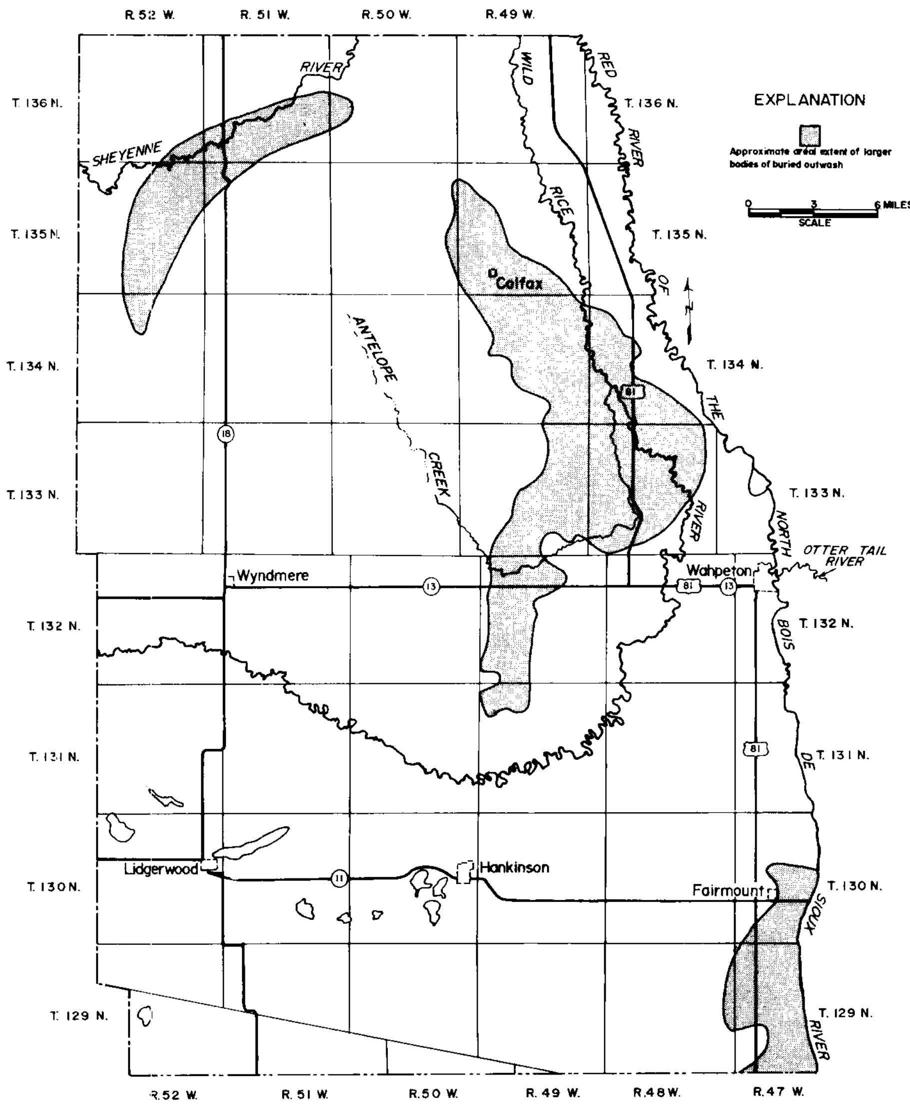


Figure 8. Approximate location of larger bodies of buried outwash.

show that the gravel body does not extend as much as a mile south or west, but it may extend north and east into Minnesota. The gravel is about 75 feet thick.

Small, probably discontinuous, sand and gravel bodies were encountered within the drift in many other test holes.

Buried Lake Deposits

Paulson (1953, p. 21) described older lake deposits within the till near Fairmount and discussed the probability that a lake existed in that area prior to the formation of Lake Agassiz. Few examples of older lake clay were found within the Lake Agassiz basin during the present study, but it is to be expected that much of such a deposit would be destroyed by glacial erosion.

Thick deposits of silt and clay, overlain and underlain by till, were penetrated in a number of test holes in the southern half of the county (fig. 9). The silt and clay are as much as 100 feet thick (section G-G′, pl. 4) and are believed to represent a former glacial lake. Little is known about the age or history of this lake.

Drift of Late Wisconsin Age

The surficial geologic features in Richland County are of late Wisconsin age, and have been altered only slightly by post-Pleistocene erosion. They can be separated into the till and associated stratified drift deposits of the Drift Prairie physiographic division, and the lacustrine deposits of the Red River Valley physiographic division. Surficial geologic features are shown on plate 1.

Till and Associated Stratified Drift

TILL

The composition of the surficial till varies, but the dominant size is in the silt-clay range. Boulders are common but not abundant; cobbles are locally abundant. The color of the till is dusky yellow to olive brown at the surface because of oxidation. The thickness of the zone of oxidation generally ranges from 15 to 30 feet. Exposures of unoxidized till are rare in Richland County, but samples from test holes are olive gray to dark olive gray.

Three till landforms are recognizable in Richland County: end moraine, ground moraine, and stagnation moraine.

End moraine.—An end moraine is a ridgelike accumulation of drift formed along the margin of a glacier (Flint, 1955, p. 112). Two low ridges of drift in southwestern Richland County that show distinct linear trends are here called end moraine.

The more prominent of these two end moraines is a northwest-southeast trending ridge in Tps. 129 and 130 N., R. 52 W. It has a length of about 10 miles and an average width of about 3/4 mile. The western edge is marked by a distinct slope, while the eastern edge

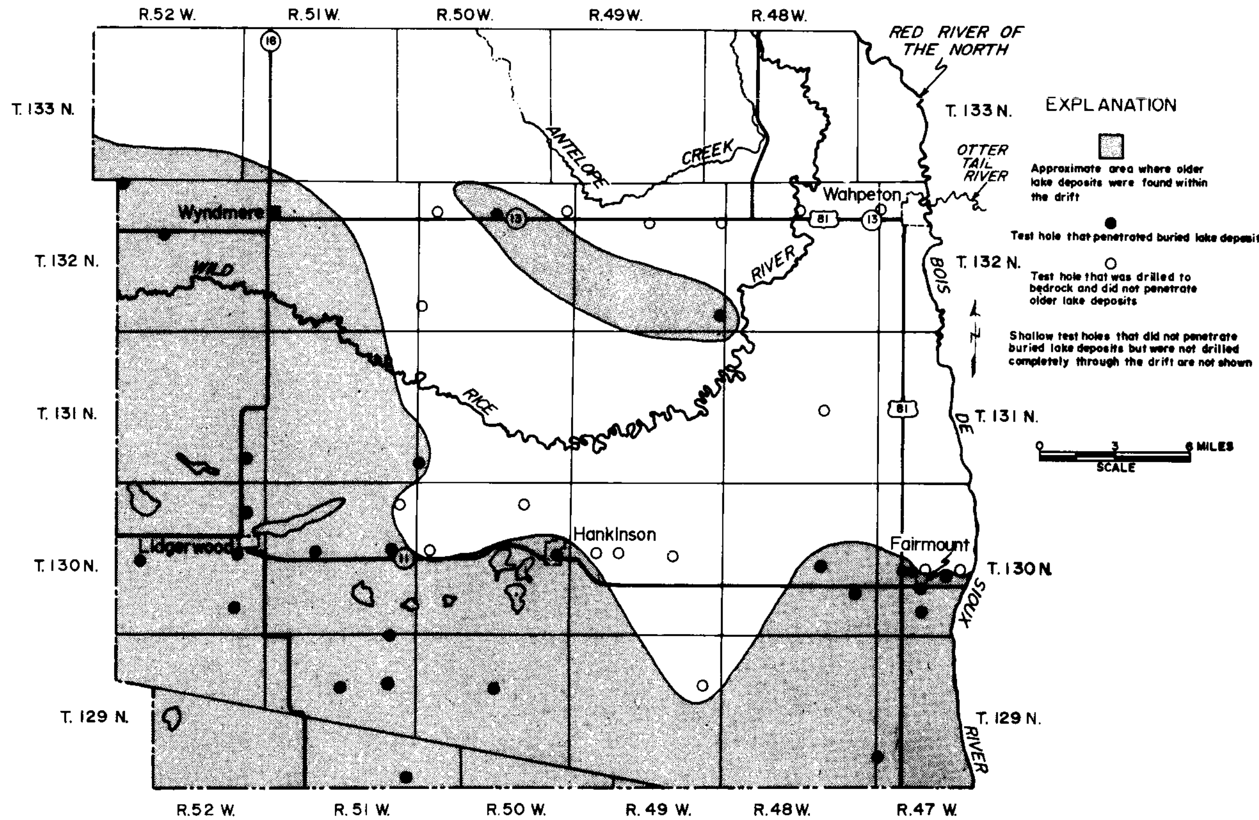


Figure 9. Location of buried lake deposits in southern Richland County.

is not easily distinguished. The ridge attains a height of 30 to 50 feet above the surrounding terrain. The ridge is composed principally of till, but a few small bodies of stratified drift are exposed in the slope on the western edge.

The smaller end moraine is in the southern half of T. 130 N., R. 51 W. It is V-shaped in ground plan, with the apex of the V pointing north. The total length is about 5 miles, and the average width is about 3/4 mile. This moraine is not a prominent feature; it rises only 20 to 30 feet above the surrounding terrain and its edges are not steep or abrupt. It is composed entirely of till.

Both end moraines lie within the area of the Dovre moraine of Upham (1895, pl. 27). They are the only parts of the Dovre moraine in Richland County that show linear trends; most of the area included in the Dovre moraine seems to be stagnation moraine (fig. 10). The segments of end moraine in Richland County do not appear to be related to any of the more prominent morainal systems mapped by Colton and others (1963).

Ground moraine.—Areas of till having low relief and lacking definite linear trends are called ground moraine (Flint, 1955, p. 111). Four areas in southwestern Richland County, totaling about 100 square miles, are shown on plate 1 as ground moraine.

The largest body of ground moraine (a, fig. 10) covers an area of about 60 square miles in Richland County and extends west into Sargent County. It is bounded on the south by an outwash channel and on the north and east by the highest beach of glacial Lake Agassiz. The topography is gently rolling, with local relief of 10 to 20 feet within a square mile.

A second body of ground moraine (b, fig. 10) lies west of the larger segment of end moraine described in the preceding section. The ground moraine covers about 20 square miles in Richland County and extends west into Sargent County. It contains numerous isolated kames. Between the kames, the surface of the till is gently rolling.

A third strip of ground moraine (c, fig. 10) extends west from the vicinity of Hankinson into Sargent County. This strip covers an area of about 15 square miles in Richland County.

Ground moraine occupies a small triangular area (about 5 square miles) between the highest beach of Lake Agassiz and an outwash channel (d, fig. 10), and extends into South Dakota.

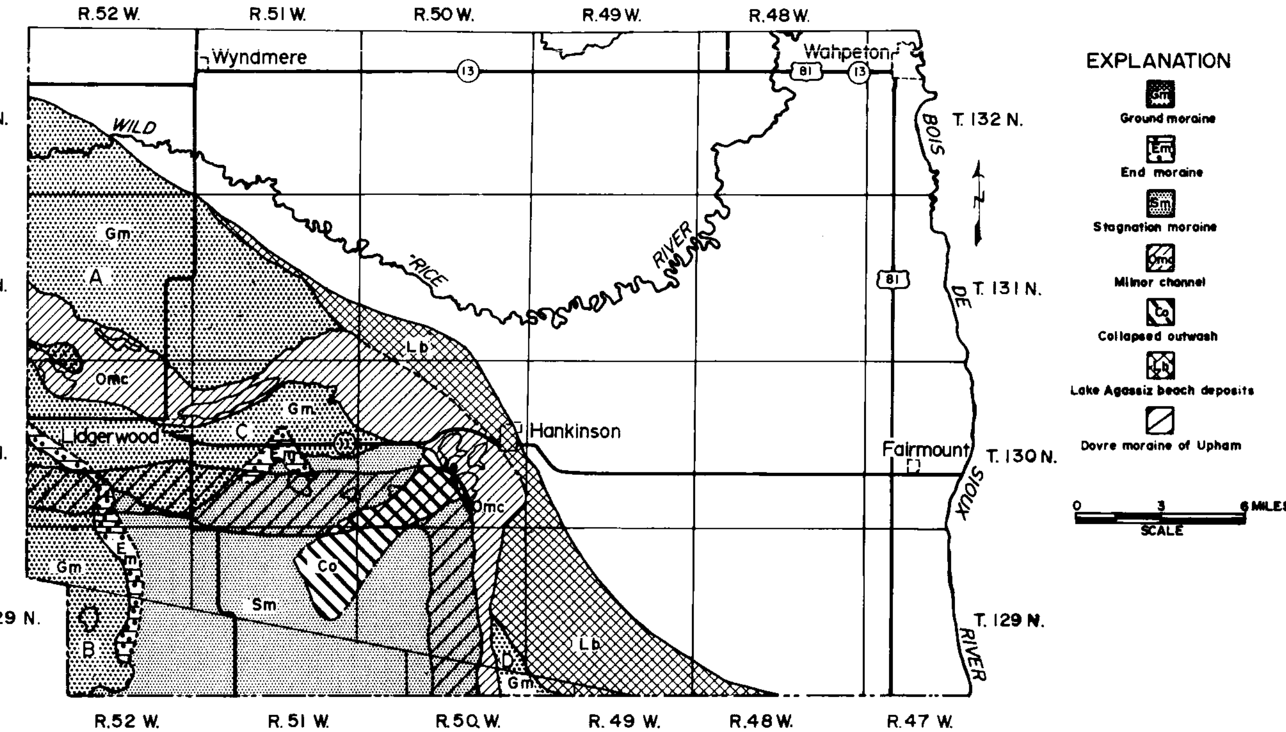


Figure 10. Relationship of ground moraine, end moraine, and stagnation moraine to Dovre Moraine of Upham in southern Richland County.

Stagnation moraine.—Stagnation moraine (Colton and others, 1963) or dead-ice moraine (Clayton, 1962, p. 35) is an accumulation of drift having high local relief but lacking the linearity or ridge development typical of end moraine (fig. 11). It is presumably formed when glacial ice stops moving and disintegrates in place.

Stagnation moraine covers an area of about 150 square miles in southwestern Richland County. It is bounded on the north and west by ground moraine and segments of end moraine and on the east by an outwash channel; it extends southward into South Dakota. The

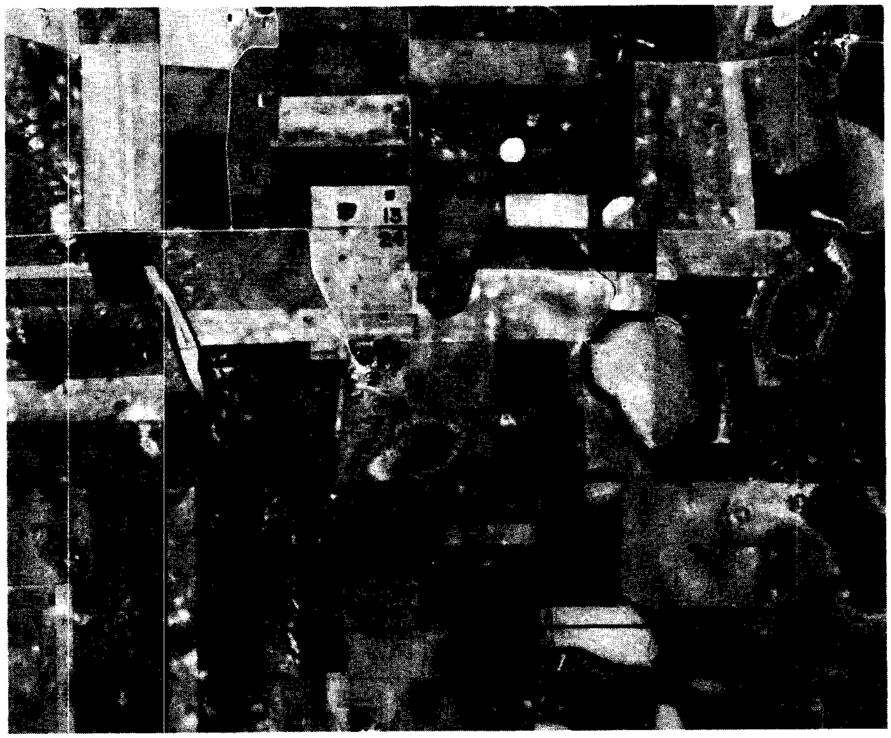


Figure 11. Typical stagnation moraine south of Hankinson. Vertical air-photo.

topography is strongly rolling, and the local relief averages 60 to 80 feet within a square mile, but may be as much as 200 feet.

A remarkable feature of the stagnation moraine in Richland County is the apparent accordance of the hilltops (fig. 12). The area appears to be one of negative relief; that is, a nearly plane surface broken by numerous kettle-like depressions. The author believes that the stagnation moraine was overridden and planed off by a minor

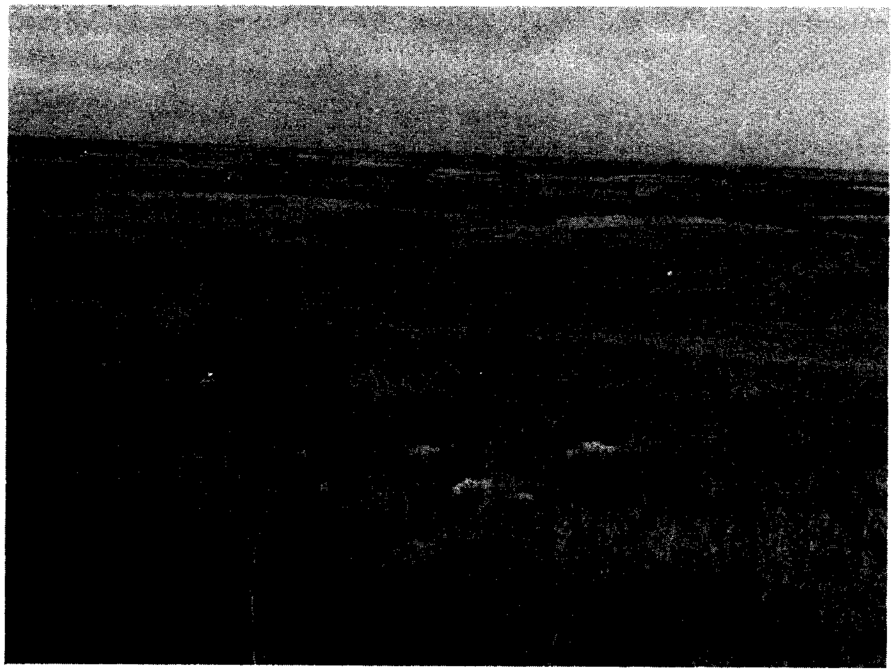


Figure 12. Stagnation moraine south of Hankinson showing accordance of the hilltops. View looking southwest from the NW corner sec. 1, T. 129 N., R. 51 W.

readvance of active ice while ice blocks were still present in the depressions. Further evidence to support this view is presented later in this report in the section on pitted outwash.

STRATIFIED DRIFT

Surficial deposts of stratified drift closely associated with the till in Richland County consist of pitted outwash, kames, and the Milnor channel deposits.

Pitted outwash.—Southwest of Hankinson, a thick, narrow body of outwash extends from Lake Elsie southwestward into stagnation moraine. The outwash deposit is tongue-shaped in plan, about 7 miles long, 2 miles wide, and from 70 to 130 feet thick. It is partly covered by a thin layer of till. The topography of the outwash is similar to that of the adjacent stagnation moraine.

Most of the outwash material ranges in size from medium sand to fine gravel. It is moderately well sorted, but scattered large pebbles (up to 50 mm) are common. Where the outwash is exposed in cuts, it is conspicuously cross stratified (fig. 13).

Figure 13. Cross stratification in pitted outwash exposed in large gravel pit in SE¼ sec. 32, T. 130 N., R. 50 W.

The eastern end of this outwash deposit is marked by a prominent steep slope that is probably an ice-contact face. Other evidence of ice-contact deposition, including large-scale slumping and great variations in grain size (silt to boulder gravel within a few feet), are exposed in a large excavation that intersects the ice-contact face (fig. 14).

The till that overlies this outwash body has a maximum thickness of about 20 feet. It is thickest in the areas between depressions, and very thin or absent on the slopes. Where the contact between till and outwash is well exposed, it is a plane that truncates the cross strata of the outwash (fig. 15).

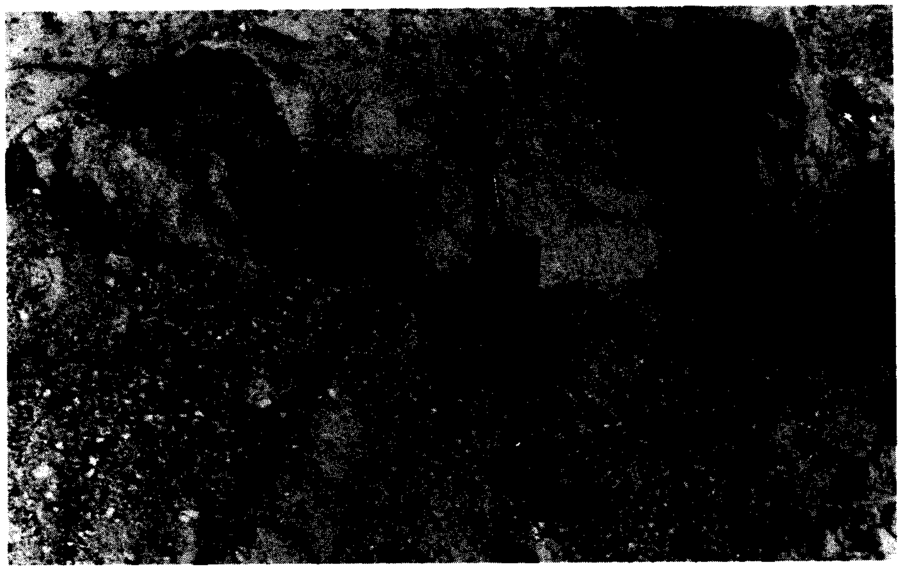


Fig. A

Fig. B

Figure 14. Ice-contact features exposed in gravel pit south of Hankinson (W½ sec. 27, T. 130 N., R. 50 W.) A) Very fine sand and silt adjacent to coarse gravel. B) Slump block in stratified drift.

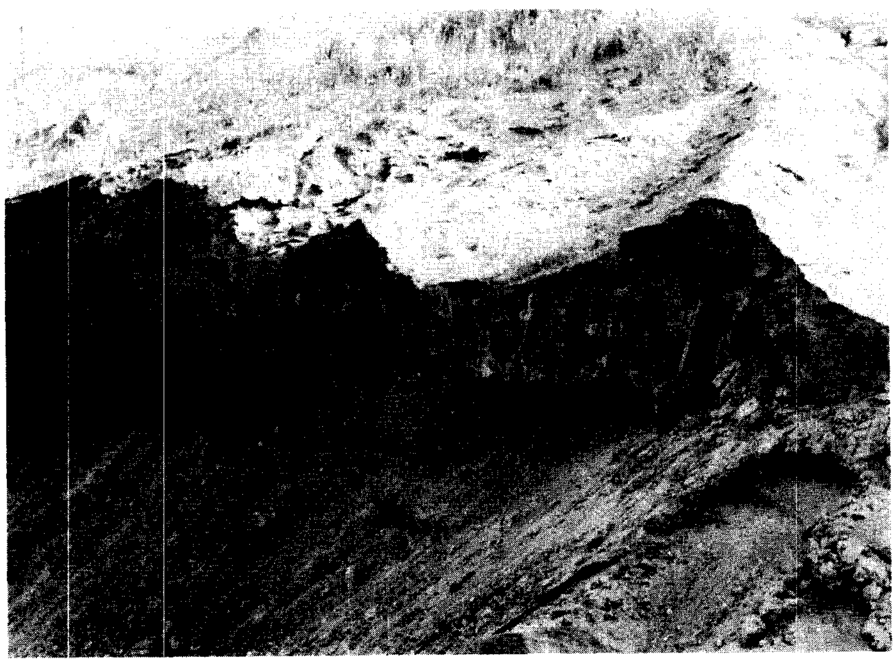


Figure 15. Cross stratification in pitted outwash truncated at contact with overlying till. Contact exposed in large gravel pit in SE¼ sec. 32, T. 130 N., R. 50 W.

That the outwash and the adjacent stagnation moraine were overridden by active ice is indicated by: (a) the outwash is overlain by till, (b) the till truncates the cross stratification of the outwash, and (c) the hilltops are accordant. Probably the active ice advanced before all of the stagnant ice was melted, because it is likely that the numerous kettle-like depressions would have been destroyed by the readvance if they had not contained blocks of ice.

Moreover, the thinning of the overlying till on the slopes of the depressions in the outwash is explained if stagnant ice was present in the depression when the till was deposited. When the ice melted out of the depressions, the surface area would be greatly increased, and the till would be left "draped over" the highs and thin or absent on the slopes.

Kames.—Scattered conical hills (fig. 16), each covering an area of a few acres, rise 30 to 50 feet above the ground moraine in the extreme southwestern part of the county. The hills are composed of poorly sorted stratified drift, and are classed as kames. The locations of the larger kames are shown on plate 1. The area in which they occur extends west into Sargent County.

Figure 16. Kames in southwestern Richland County. View looking northwest from the NW corner sec. 5, T. 129 N., R. 52 W.

Milnor channel.—A shallow valley (fig. 17), floored with deposits of sand and gravel, crosses the Drift Prairie in Richland County. Some of the sand and gravel deposits were originally thought to be beach ridges marking the shoreline of a very early stage of Lake Agassiz. The deposits were therefore called the Milnor beaches (Upham, 1895, p. 211) after a town in Sargent County. However, the deposits are actually channel features that mark an ice-marginal course of the Sheyenne River. The channel and its sand and gravel deposits have been renamed the Milnor channel and Milnor channel deposits (Baker, 1966b).

The Milnor channel, which ranges in width from 1 to 3 miles, extends through the southwestern quarter of Richland County, generally at the edge of the high-relief till. It turns abruptly south near Hankinson, and the bend of the channel abuts against the highest Lake Agassiz beach (Herman beach). The relationship between beach and channel deposits is obscure here; probably some of the thick sand deposits associated with the Herman beach in this area are reworked from the older channel deposit. Test drilling shows an average thickness of about 40 feet of sand and gravel in the center of the channel.

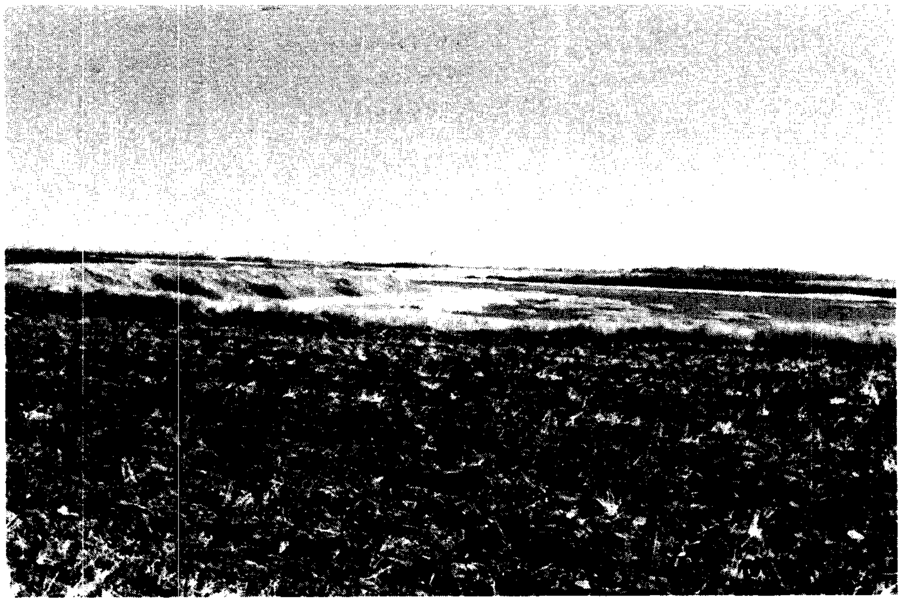


Figure 17. The Milnor channel west of Lidgerwood. View looking southwest from near the SW corner sec. 28, T. 131 N., R. 52 W.

Lake Agassiz Deposits

Most of Richland County, about 1,150 square miles, lies within the highest shoreline of glacial Lake Agassiz. The geologic features of the Lake Agassiz basin can be divided into the Sheyenne delta, beaches, and lake-floor deposits.

SHEYENNE DELTA

The Sheyenne delta was described and named by Upham (1895, p. 315-317). Later workers (Leverett, 1912, 1932; Elson, 1957) believed that this and other deltas named by Upham were not true deltas, but deposits of ice-contact stratified drift. Data collected from test holes and surface exposures during the present study lend support to Upham's interpretation. The present author believes that the Sheyenne delta is a true deltaic deposit.

The Sheyenne delta covers an area of about 750 square miles, of which about 550 square miles is in Richland County. It is crossed by the Sheyenne River, which is deeply entrenched into the delta. The northeastern edge of the delta is marked by a conspicuous, steep slope. The slope is prominent at the Cass-Richland County boundary, but it becomes less prominent southward and is barely visible south of Colfax. Near Wyndmere there is no surface expression of the delta edge, and the limits of the delta must be mapped on the basis of the changes in lithology.

Much of the surface of the delta in Richland County is covered with sand dunes, and the topography is strongly rolling (fig. 18). The highest dunes border the Sheyenne valley, where the local relief may exceed 50 feet. Most of the dunes are stabilized by vegetation, but there is considerable movement of sand wherever the vegetal cover is broken.

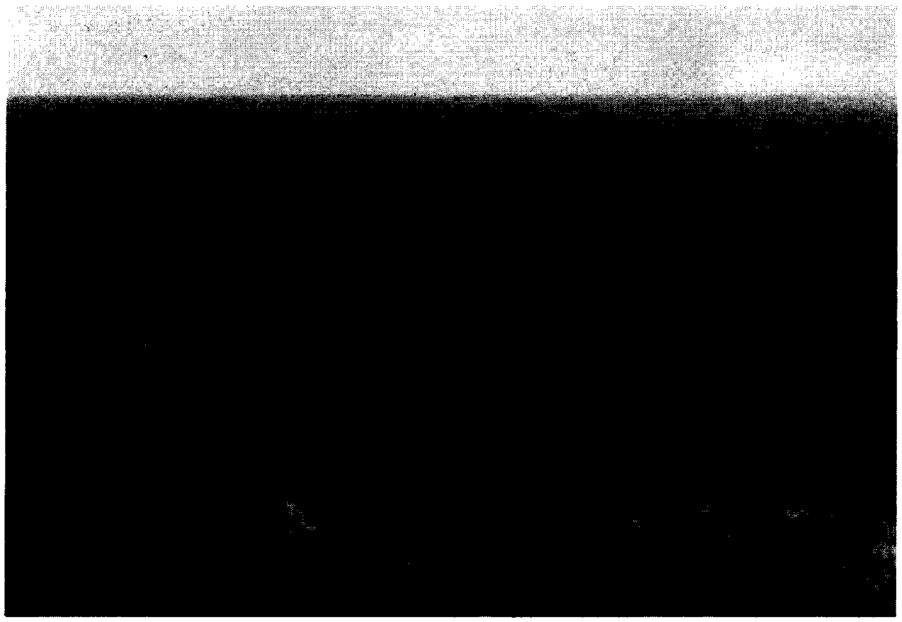


Figure 18. Dunes on the Sheyenne delta. View looking east toward the Lake Agassiz plain from near center of T. 136 N., R. 51 W. Oblique airphoto.

Near the Richland-Ransom County boundary, the delta sediments are primarily fine to medium sand, but the average grain size decreases eastward (fig. 19). Near the eastern edge, the predominant lithology is very fine sand and silt with some interbedded clay.

Stratification is well exposed in only one known locality, near the eastern edge of the delta (west edge of sec. 14, T. 136 N., R. 51 W.). Here fine sand, silt, and clay are interbedded, and the sand and silt are cross stratified. The most common type of stratification is ripple lamination (fig. 20a). Some silt and very fine sand beds are strongly contorted on a small scale (fig. 20b). The mode of formation of these contortions is not known, but such contortions, as well as the ripple lamination, are common features of deltaic and flood-plain deposits.

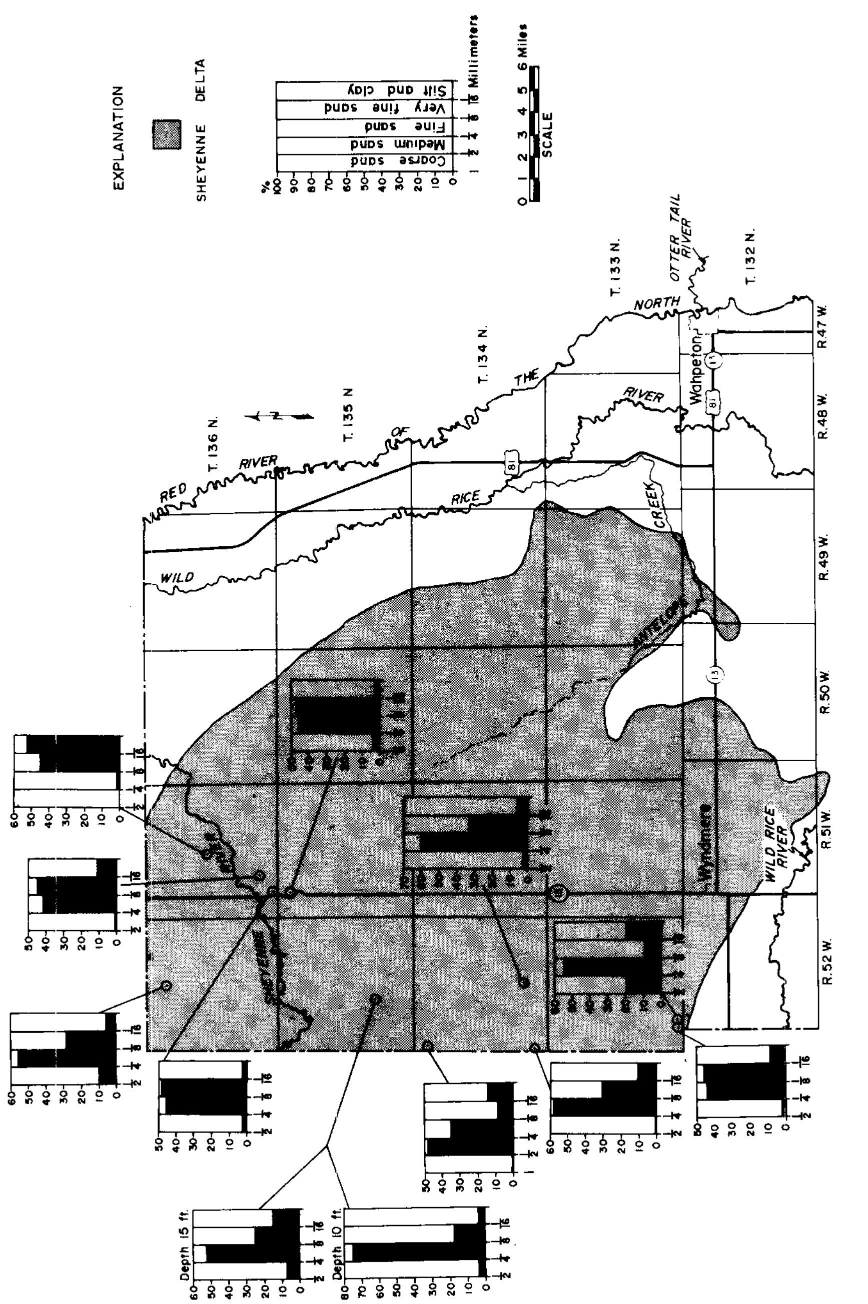


Figure 19. Grain-size analyses of sediments from the Sheyenne delta.

Fig. A

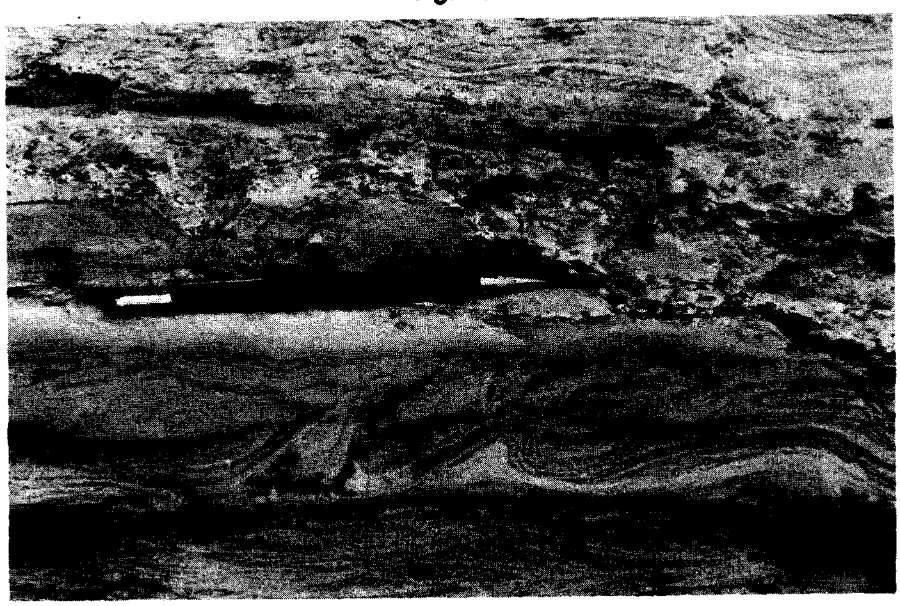


Fig. B

Figure 20. Stratification in the Sheyenne delta. A) Ripple lamination in beds of fine to very fine sand. B) Deformation in beds of very fine sand and silt. Section exposed in the bank of a gully in the west side of sec. 14, T. 136 N., R. 51 W.

An advancing delta is built out over its own bottomset beds as well as over existing lake-floor deposits, and it is impossible to distinguish in test holes between delta bottomsets and lake-floor deposits of essentially the same composition; therefore, a boundary cannot be established between delta and lake-floor deposits. The greatest thickness of sand penetrated during test drilling on the Sheyenne delta was 107 feet in test hole 2185 (135-52-21ccc), but it is questionable whether this figure should be taken as the thickness of the delta deposits at this point. The drill passed from sand into silty clay, and the hole was stopped after drilling only a few feet into the clay, before reaching the underlying till. The greatest known thickness of sand, silt, and clay; that is, the greatest known depth to glacial till, is 198 feet penetrated in test hole K-2R (136-51-7ddd). (See Dennis and others, 1950, p. 62). The average depth to till in the holes drilled during this study was about 150 feet. In test hole 2199 (132-52-6bbb), very near the southern edge of the delta, the delta sand is only 45 feet thick and has no clay or silt under it.

The steep northeastern slope of the delta was called an ice-contact face by Leverett (1932, p. 127). During the present study, however, no evidence of ice-contact deposition, other than steepness, was found. At the northern edge of the delta, in Cass County, the slope is continuous with the prominent ridge of the Campbell beach, one of the lower shorelines of Lake Agassiz (R. L. Klausing, oral communication). The steep slope of the delta is probably a wave-cut slope representing the Campbell shoreline.

If the steep northeastern slope of the Sheyenne delta marks the Campbell shoreline, the time of formation of the delta is fixed. The entire delta must have been formed before the lake declined to the Campbell level.

BEACH DEPOSITS

Except for the Sheyenne delta, the most prominent geologic features associated with the Lake Agassiz basin are the beach deposits. Upham (1895, p. 276-442) described five series of beaches that cross Richland County. These are named, from oldest to youngest: Herman, Norcross, Tintah, Campbell, and McCauleyville. The Herman beach is most readily traced in Richland County. The lower beaches are clustered together and are difficult to separate in the southeast corner of the county, and elsewhere only discontinuous short segments of them can be traced (pl. 1).

Herman beach.—The highest continuous shoreline of Lake Agassiz is called the Herman beach. The course of the Herman beach can be traced nearly all the way across Richland County from the South Dakota border near the southeastern border of the county to the Ransom County border west of Wyndmere.

The Herman beach generally is represented by a low ridge of sand or gravel (fig. 21), but locally it may be only a short steep slope. In a

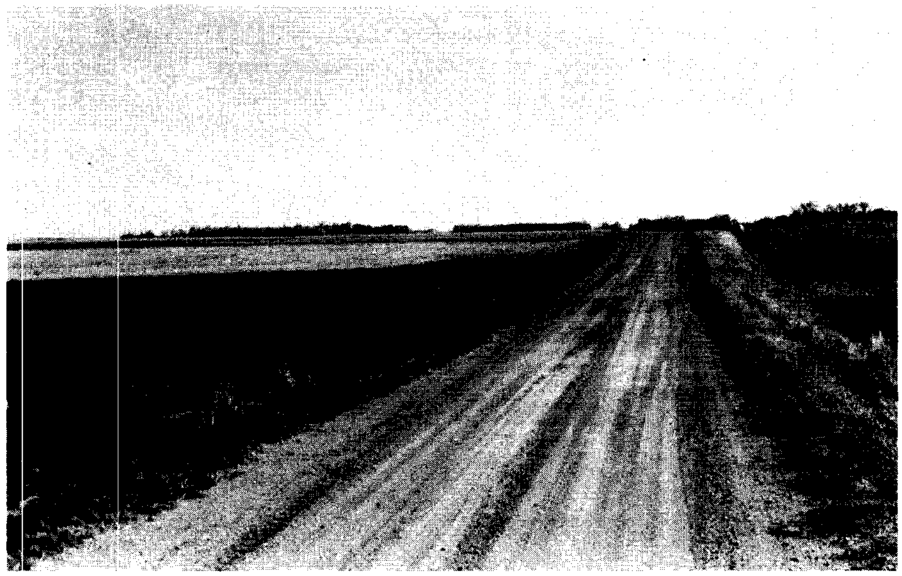


Figure 21. The Herman beach south of Wyndmere. Change in slope of the road marks the beach front. View looking south from the Lake Agassiz basin. Road marks line between secs. 4 and 5, T. 131 N., R. 51 W.

few places the beach is marked by sand dunes. Whether marked by ridge, slope, or dunes, the course of the beach can be recognized by the difference in topography on either side of it. Above the beach, on the landward side, the surface is gently to strongly rolling; below the beach, on the lakeward side, the surface is almost flat. Generally this change of topography is apparent on the ground; it is strikingly evident on topographic maps.

Near Hankinson there are two areas of prominent dunes associated with the Herman beach. The larger area, north of town, was regarded by Upham (1895, pl. 27) as a part of the Sheyenne delta. The area seems to be separate from the delta, however, and more closely associated with the Milnor channel. The second dune area, south of Hankinson, also may be partly related to the Milnor channel.

The source of the sand in these areas of dunes is not clear. Part of the sand may have been deposited as part of the Milnor channel deposits before Lake Agassiz came into existence; part may have been carried from the growing Sheyenne delta by longshore currents. Data from test holes in the Hankinson area indicate that a marked low exists there in the surface of the underlying till. The presence of this depression in the till may help account for the accumulation of the thick deposits of sand.

Lower beaches.—The beaches formed during the time that Lake Agassiz drained to the south are clustered together in the southeastern corner of the county, where a broad belt of sand and gravel extends from the Campbell beach to the Herman beach. The sand and gravel deposits are poorly sorted, and in most places they are only a few feet thick.

North of State Highway 11, the courses of the inner beaches become more obscure. Slight breaks in slope on the lake plain between the Wild Rice River and the Sheyenne delta may mark the courses of the Norcross and Tintah beaches. Upham (1895) found traces of these two beaches on the Sheyenne delta, but they cannot be detected now in the irregular dune topography.

A pronounced change in slope south of the Wild Rice River probably marks the course of the Campbell shoreline (fig. 22). The shore-

Figure 22. Campbell shoreline east of Hankinson. Change in slope of road marks the former shoreline. View looking west from the lake basin. Location near the SW corner sec. 24, T. 130 N., R. 49 W.

line cannot be traced between the Wild Rice River and the Sheyenne delta, but a break in slope is visible on the delta north of Antelope

Creek. From Colfax northward, the steep northeastern slope of the delta, which marks the course of the Campbell shoreline, is prominent.

The McCauleyville beach is represented by a short low ridge of gravel that crosses U. S. Highway 81 about 2 miles north of Fairmount. Short segments of a discontinuous ridge of sand, very apparent near Walcott (pl. 1), also probably represent the McCauleyville beach.

LAKE-PLAIN DEPOSITS

About one-fourth of the Lake Agassiz plain in Richland County contains no lake-floor deposits, but consists simply of smooth glacial till (pl. 1). The most probable reason for the absence of lake-floor deposits in this area is the proximity to the outlet of Lake Agassiz; currents strong enough to prevent the deposition of silt and clay may have prevailed near the outlet.

The till that is exposed in the lake plain has been reworked slightly by waves or currents, and is as smooth and flat as the adjoining lake clays and silts. Local concentrations of cobbles and pebbles (fig. 23) and adjacent patches of nearly pebble-free clay mark, respec-

Figure 23. Concentration of cobbles in a field in the Lake Agassiz plain north of Wahpeton. SE¼ sec. 18, T. 133 N., R. 47 W.

tively, the highs and lows that existed on the till surface before it was smoothed.

The remaining three-fourths of the lake plain is covered by lake-floor deposits ranging from a few feet to a few tens of feet in thickness. Dennis, Akin, and Worts (1949, p. 18-21) divided the lake-floor deposits into two units, an upper "silt" unit and a lower "clay" unit.

The two units of lake-floor deposits have not been recognized in test holes in Richland County. In outcrops along the banks of the Red River, however, two distinct units are visible in some places. In the river bank about 2 miles north of Abercrombie (NE corner of SW$\frac{1}{4}$ sec. 29, T. 135 N., R. 48 W.) the two units are well exposed (fig. 24). The

Figure 24. Exposure of two lithologic units of Lake Agassiz deposits in the bank of the Red River. SW¼ sec. 29, T. 135 N., R. 48 W.

upper, silty unit is about 6 feet thick. The upper unit is massive and weathers into large blocks, but the lower unit is laminated and weathers to small pebblelike fragments. Silt-clay analyses of samples from this and other localities are given in table 2. The presence of the two distinct units described by Dennis and others seems to be confirmed, but the upper unit is not everywhere present in Richland County.

TABLE 2.—Silt-clay analyses of lake-floor deposits from Lake Agassiz plain in Richland County.

Sample location	Depth (feet)	Percent silt[1]	Percent clay	Remarks
NE corner sec. 24, T. 136N., R. 50 W.	2	23.7	76.3	Sample taken from the wall of a drain.
SE corner sec. 26, T. 131 N., R. 49 W.	4	24.7	75.3	Clay overlain by 4 feet of sand at edge of Campbell beach.
NE corner of SW¼ sec. 29, T. 135 N., R. 48 W.	4	86.6	13.4	Both materials exposed in bank of Red River—see fig. 24.
Do.	8	18.0	82.0	Do.
NE corner of NW¼ sec. 29, T. 136 N., R. 48 W.	7	54.0	46.0	Bank of Red River — only one unit exposed.
SE¼SW¼SE¼ sec. 17, T. 135 N., R. 48 W.	4	87.8	12.2	Both materials exposed in bank of Red River.
Do.	10	20.2	79.8	Do.
SE corner sec. 23, T. 135 N., R. 49 W.	3	36.6	63.3	Taken from wall of a drain.
SE corner of NE¼ sec. 20, T. 133 N., R. 48 W.	3	10.4	89.6	Taken from exposure in road cut.

[1] Includes traces of sand.

Pleistocene Fossils

Very few fossils have been found in the Pleistocene deposits of Richland County. The remains that have been recovered consist of wood fragments, gastropod shells, and a few bones.

Wood fragments were reported from a number of test holes, but generally in very small quantity. However, a sample of wood fragments was collected from test hole 2309 (134-48-9baa) for radiocarbon age determination. The wood was at a depth of 57 to 59 feet, near the base of a gravel layer that is overlain and underlain by glacial till. The till underlying the gravel is darker colored and more compact than that overlying the gravel, and the gravel layer is believed to represent the interval between tills deposited by two different ice sheets. The radiocarbon date of the wood sample (No. W-1574) was more than 36,000 years before the present.

Shells of six species of gastropods that were collected from the bank of the Sheyenne River in the Sheyenne delta (sec. 8, T. 135 N., R. 52 W.) were identified by S. J. Tuthill of the North Dakota Geological Survey. All six species occur throughout Quaternary time, and are of no value as age indicators.

The vertebrate fossils were identified by Edward Lewis (written communication, 3/23/64), and included the following: (1) a fossil tooth, collected at the same locality as the gastropod shells tentatively identified as *?Cervalces* sp., a genus known to occur in deposits of Wisconsin age, but possibly as old as Yarmouth; and (2) bone fragments discovered in the McCauleyville beach ridge near Walcott, identified as belonging to the North American badger, *Taxidea taxus* (Schreber), of Pleistocene or Recent age.

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