NORTH DAKOTA GEOLOGICAL SURVEY
Wilson M. Laird, State Geologist

BULLETIN 49

NORTH DAKOTA STATE WATER COMMISSION
Milo W. Hoisveen, State Engineer

COUNTY GROUND WATER STUDIES 10

GEOLOGY AND GROUND WATER RESOURCES

of

TRAILL COUNTY

Part 1—GEOLOGY

by
John P. Bluemle

Prepared by the North Dakota Geological Survey
In cooperation with the North Dakota State
Water Commission, the United State Geological Survey,
and the Traill County Water Management District.

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ABSTRACT

Traill County, in eastern North Dakota on the Minnesota state line, is underlain by 150 to 500 feet of glacial sediments. As much as 500 feet of Cretaceous and Ordovician sands and shales underlie the glacial sediments except in the eastern part of the county where Precambrian igneous rocks lie directly beneath the glacial deposits. The varying thickness of the glacial deposits results primarily from the erosion surface that had developed on the preglacial rocks; the upper surface of the glacial deposits is essentially flat.

All but the extreme southwest corner of Trail County was covered by the glacial Lake Agassiz. The dominant landform is lake plain that is quite level but modified by numerous beach ridges. Areas in the north-central and southwest parts of the county are ground moraine that was washed in the waters of the lake and is consequently also quite level.

Surficial deposits are chiefly silty clay, sandy silt, boulder-clay, sand and gravel. All of these, with the exception of the boulder-clay, were deposited by the proglacial Lake Agassiz; the boulder-clay was deposited directly by the ice. Subsurface data from Traill County indicate there are three horizons of glacial drift separated by weathered zones. The lowermost of these horizons is a lake sediment that is present only in lows on the bedrock surface. The middle horizon is a gravelly till and the uppermost one consists of gravel, till, delta and lake sediments depending on the location.

As the late Wisconsinan glacier in eastern North Dakota receded from the Red River valley, a large proglacial lake (Lake Agassiz) formed to the south of it. Rivers flowing into the lake from the west deposited thick sequences of sandy silt at their mouths where the Elk Valley and Galesburg deltas are now. Successively lower beaches developed along the shore of the lake as the water level fell. When the ice front retreated far enough to open a Lake Agassiz outlet into the Superior basin, the lake drained completely but it was reflooded when the ice readvanced a short distance. During the final stages of the existence of the lake, large amounts of silt were deposited in the eastern part of Traill County.

Geology of Traill County, North Dakota

By

JOHN P. BLUEMLE

INTRODUCTION

Purpose

This report is a descriptive and interpretive analysis of the geology of Traill County. The study was conducted by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission, the Traill County Water Management District, and the United States Geological Survey. Reports dealing with ground water basic data and hydrology will be published separately.

Primary objectives were: 1) to provide an accurate map of the geology of Traill County; 2) to arrive at an understanding of the processes that shaped that geology; 3) to examine the relationship of the glacial geology to ground water conditions; and 4) to determine the location, extent and economic potential of the mineral resources of the area.

Methods of Study

Traill County was mapped by the North Dakota Geological Survey during the 1965 and 1966 field seasons. Field information was plotted directly on United States Geological Survey topographic maps of the 7½ minute series, available for parts of eastern and southern Traill County. Elsewhere, blank base maps of the same scale were used. Aerial photograph steropairs, scale 1:63,360, were available for the entire area. Lithologic information was obtained from road cuts and shallow holes dug with shovel and soil auger and from test holes bored by a truck-mounted auger capable of sampling to depths as great as 150 feet. Additional information was obtained from test holes contracted for by the Water Resources Division of the United States Geographical Survey.

Acknowledgments

I thank the individuals and agencies who have contributed to this study. Hans M. Jensen of the United States Geological Survey supplied test hole data and other valuable information. Roger W. Schmidt of the North Dakota State Water Commission supplied logs on certain test holes. Alan M. Cvancara of the University of North Dakota Geology Department identified the fossil shells and Robert W. Seabloom of the University of North Dakota Biology Department identified the fossil bone fragments.

Regional Geology

Traill County, an area of 861 square miles in eastern North Dakota, is located in Townships 144 to 148 North and Ranges 49 to 53 West. Except for the southwest corner, the county lies on the glacial Lake Agassiz plain (fig. 1), a nearly level area underlain by glacial-lake sediments. The southwest corner of the county is on the Drift Prairie, a gently undulating area underlain mainly by glacial till. The drainage of the area is directed generally eastward toward the north-flowing Red River which marks the eastern booundary of Traill County.

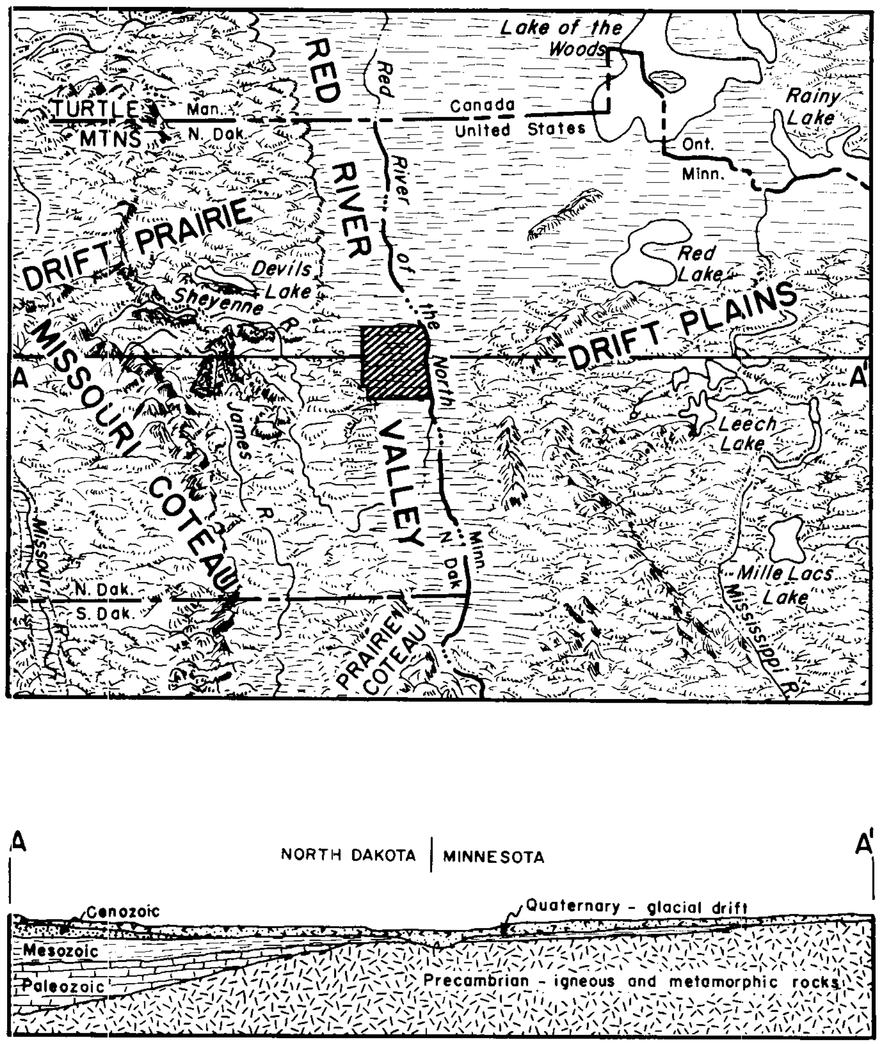


Figure 1. Physiographic map showing the location of Traill County. The cross-section A-A′ shows the regional geologic relationships.

Traill County lies on the extreme eastern edge of the Williston Basin and the northwest flank of the Transcontinental arch. All the bedrock formations have a westerly regional dip and become thicker westward. In parts of eastern Traill County, the sedimentary rocks are absent and Precambrian igneous and metamorphic rocks of the Canadian Shield lie directly beneath the glacial drift.

Previous Studies

One of the earleist writers to discuss the geology of Glacial Lake Agassiz in detail was Upham (1896) 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. Leverett (1932) described the geology of Minnesota and included a short discussion on Lake Agassiz. Laird (1964) summarized the literature on Lake Agassiz. In addition to these regional studies, ground water papers have been published by the State Water Commission for the Traill County communities of Buxton, Hatton, Hillsboro, Portland, and Reynolds.

STRATIGRAPHY

The landscape and surface geology of Traill County today bear virtually no resemblance to their preglacial counterparts. In general, the preglacial landscape had developed throughout Tertiary time with no really major interruptions until the pleistocene glaciers advanced over the area. Drainage was northward through a broad valley that is now buried beneath lake sediments. A generalized map of the preglacial surface is shown on figure 2.

Precambrian Rocks

Precambrian schists and granites were penetrated during drilling of several test holes in eastern Traill County. They occur at depths of 295 to 466 feet in eastern Traill County; in the western part of the county the depths are generally greater than 500 feet. In some of the holes, several tens of feet of multicolored, sandy and clayey material, interpreted as weathered igneous rock, were penetrated. This soft material is greenish to bluish-gray and white. It contains grains of mica and chlorite. Samples of the weathered Precambrian rocks obtained from wells in eastern Traill County and analyzed by X-ray diffraction methods contained abundant montmorillonite and chlorite clays along with considerable quartz. The samples obtained from the harder, unweathered material beneath this weathered zone were a greenish chlorite schist from one hole, a hornblende schist from another, and chips of greenish gray granite or metamorphic rocks from the remaining wells.

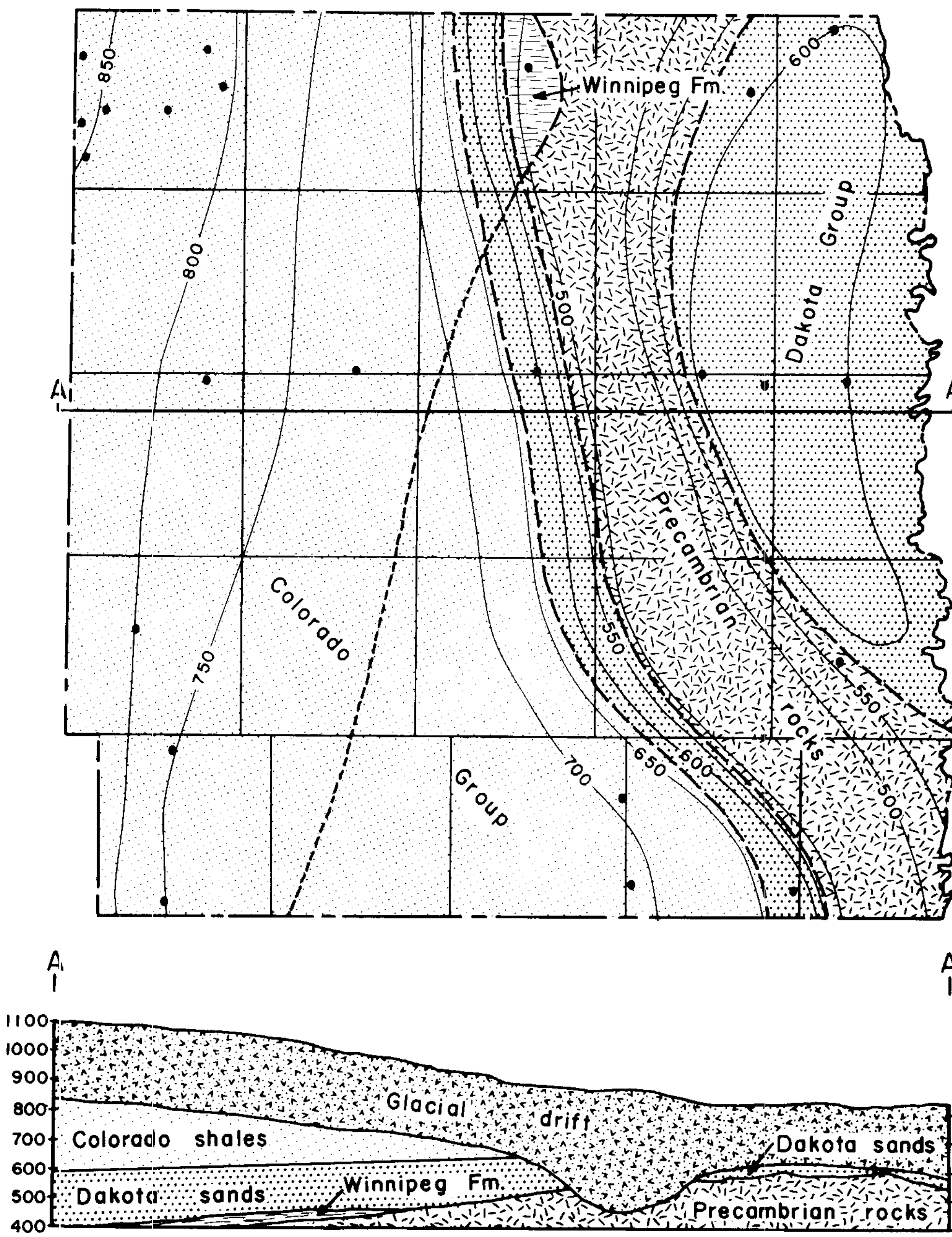


Figure 2. Topographic map of the bedrock surface beneath the glacial drift. Precambrian rocks subcrop beneath the drift in the valley, along with some Paleozoic Winnipeg shales in the northern part of the county. Colorado Group shales subcrop over the western half of the county; Dakota Group sands in the east. The approximate eastern limit of the Winnipeg shale beneath the Cretaceous sediments is shown as a dashed line.

Paleozoic Rocks

The Winnipeg Formation of Ordovician age occurs beneath the western half of Traill County (fig. 2) where it is as much as 110 feet thick. It is overlain by Cretaceous sands and shales over most of this area but in north-central Traill County, it is directly overlain by glacial drift. The Winnipeg Formation lies nonconformably on Precambrian rocks in Traill County. In eastern North Dakota, the Winnipeg Formation is composed mainly of greenish-gray, fossiliferous shale underlain by a thin calcareous sandstone. In one well, number 1193 in northern Traill County, the sandstone is underlain by a reddish limestone that has not been found elsewhere in North Dakota.

Mesozoic Rocks

Mesozoic rocks, all of early Cretaceous age, are as much as 300 feet thick in Traill County. The Dakota Group is represented by sands and shales throughout much of the county. Rocks of the Dakota Group unconformably overlie the Pre cambrian rocks in places. Except where their surface is eroded and they are overlain by glacial drift, the Dakota Group rocks are conformably overlain by the Colorado Group shales.

In general, the lower 100 feet of the Dakota Group is sand that is medium to coarse grained, frosted and kaolin cemented with granules of siderite and light gray to white bentonitic, sandy siltstones. This part of the Dakota Group is known as the Lakota-Fall River interval. Overlying the Lakota-Fall River interval is shale that is medium to dark gray, soft, calcareous and sandy. The Lakota-Fall River interval of the Dakota Group has long served as an aquifer in North Dakota; in Traill County, wells tap the aquifer at depths of about 400 feet and many of them flow at the land surface, but this water is generally too highly mineralized for most domestic purposes.

In western Traill County, shales of the Colorado Group conformably overlie the Dakota Group sediments and are in turn overlain by glacial drift. Generally they are medium to dark gray, soft and calcareous with pyrite, calcite prisms, limestone nodules and traces of bentonite and shaley limestone. Their total thickness ranges up to about 250 feet.

Pleistocene Deposits

The location and extent of the various glacial deposits are shown on plate 1, the geologic map of Traill County. In the pages that follow, the distribution, both at the surface and at depth, the lithology, the topographic expression and origin of these glacial deposits will be discussed. Later in the report the glacial history of the county will be discussed.

BOULDER-CLAY DEPOSITS

General lithology.—Boulder-clay is a mixture of sand, gravel and boulders in a silt-clay matrix. In Traill County it is a stiff clay containing angular, subangular and rounded blocks of rocks. The clay fraction is olive gray to light olive gray where unoxidized, brownish to yellowish gray where oxidized. The larger particles in the boulder-clay consist primarily of granite, metamorphic rocks, dolomite, limestone, lignite and shale. In general, the lower boulder-clays tend to be more stony and less silty than those that occur nearer the surface.

Occurrence.—At least three horizons of boulder-clay can be identified in Traill County. The lower two of these are not exposed at the surface but the uppermost one is exposed over the north-central and southwest parts of the county (pl. 1). The lowermost boulder-clay is hard, sandy to gravelly, and quite stony; it occurs at elevations from 575 to 650 feet (pl. 2). It lies directly on the bedrock surface in places, on a lake deposit in other areas. In several test holes the upper few feet of this lowermost boulder-clay are oxidized and boulders are particularly abundant there. In most of the test holes in which it was penetrated, the lowermost boulder-clay has an easily identified unconformity at its surface.

A second boulder-clay directly overlies the lowermost one in places, but in some of the test holes either a gravel horizon or lake sediments lie between the two boulder-clays. The second boulder-clay horizon is sandy, very stony, and unoxidized throughout. It is from 20 to 50 feet thick and occurs sporadically throughout the county at varied elevations.

The uppermost boulder-clay is silty to sandy with only a few pebbles and boulders, except for the upper 10 to 60 feet which are more stony. In the area where the uppermost boulder-clay is exposed, boulders are concentrated on the surface. This boulder-clay deposit is as much as 150 feet thick. It is overlain in the eastern part of the county by as much as 70 feet of silty clays and in the west by as much as 150 feet of sandy silts. Near Caledonia, the surficial boulder-clay is bedded and has a stratified appearance.

Surface expression of the boulder-clay deposits.—Figure 3 shows the location of the exposed surface of the uppermost boulder-clay. In north-central Traill County it is gently undulating, with relief commonly less than 10 feet in a square mile. It has a flat aspect to the observer in the field. Innumerable tiny depressions, visible on air photos, contribute to poorly developed drainage that results in many sloughs. On the boulder-clay surface in southwest Traill County, local relief is also slight, but that area slopes eastward at about 25 feet in a mile. Some ponds occur, but drainage is generally better than in north-central Traill County because of the steeper regional slope.

Sand ridges that lie on the surface modify the overall aspect of

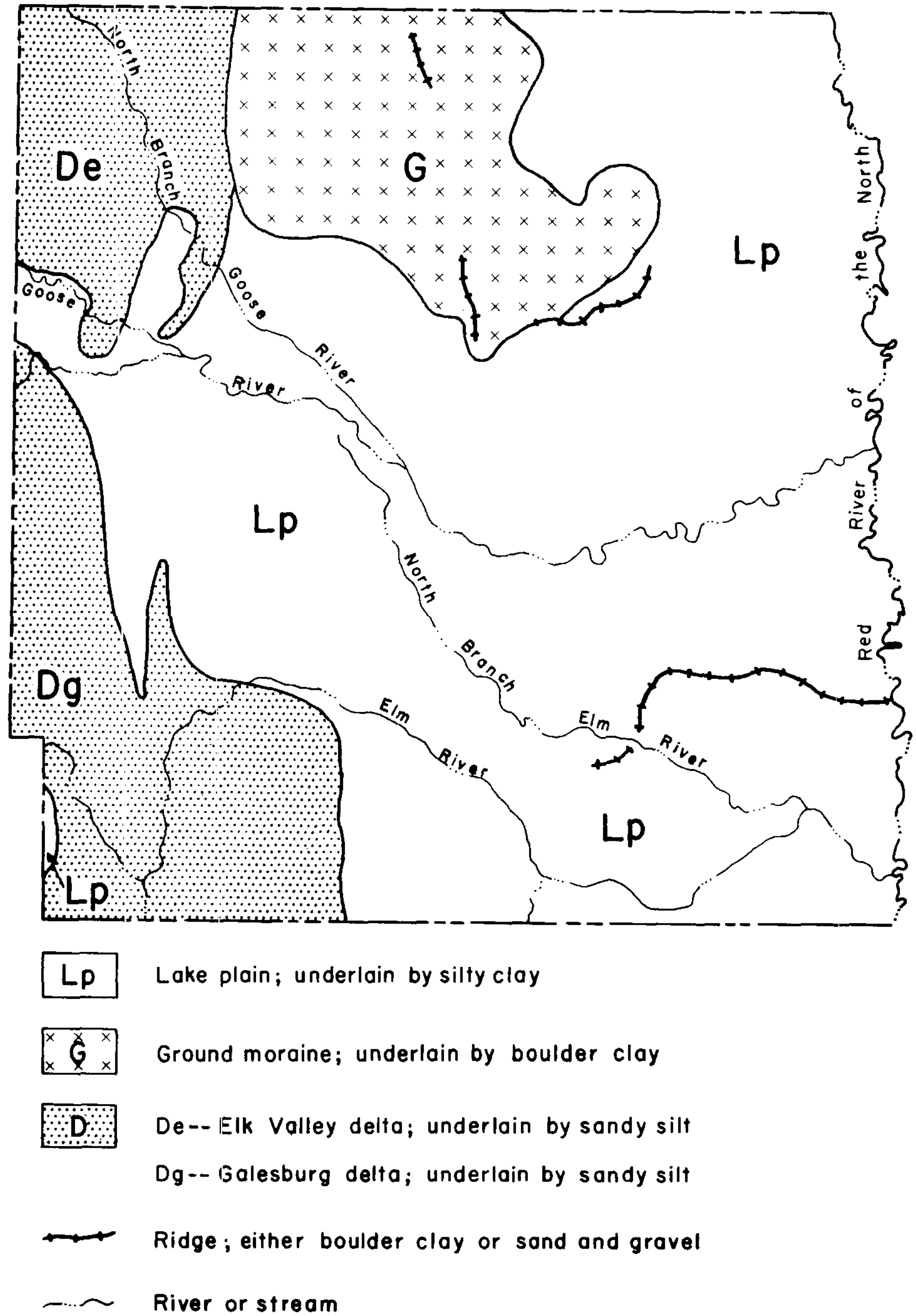


Figure 3. Map showing the landforms of Traill County, except for the beaches.

the area and scattered, low scarps have been cut in the surface in many places. All of these scarps face eastward and most of them are less than 10 feet high; some of the longer ones are shown on plate 1. In two locations, secs. 8 and 17, T. 148 N., R. 51 W., and secs. 22, 27 and 35, T. 147 N., R. 51 W., very bouldery, 15 foot high ridges occur.

Origin of the boulder-clay deposits.—Most boulder-clay is till, that is, nonsorted, nonstratified sediment carried by and deposited in contact with a glacier. Till was deposited by the ice during the several advances of the glacier over the area; hence the presence of more than one till horizon. In Traill County, much of the boulder-clay was deposited in the waters of proglacial lakes so it has a stratified aspect not normally associated with till; such material occurs at the surface in the Caledonia area. It is a variety of lake sediment rather than till, if till is defined as a nonstratified deposit. This particular situation illustrates the value of using lithologic map units such as boulder-clay rather than using generic units such as till or lake sediments when mapping.

SILTY CLAY DEPOSITS

General lithology.—The silty clay deposits consist of admixtures of silt and clay and are essentially gravel free. The material is commonly laminated, varved, or rhythmically banded, and cohesive with very few pebbles and little sand. The pebbles that do occur are mostly less than ¼ inch in diameter.

Occurrence.—Silty clay occurs at the surface in the blue areas on plate 1 and at least two horizons of silty clay exist at depth (pl. 2). The lowermost of these is a hard, relatively sandy, dark gray clay as much as 100 feet thick, that lies directly on bedrock in places, particularly in the eastern part of the county. It is common in topographic lows on the bedrock surface. A second horizon of silty clay that was found in at least 10 test holes in north central Traill County, is as much as 80 feet thick. It is very silty, cohesive and laminated. The uppermost layer of silty clay is also as much as 80 feet thick. In the subsurface, this deposit consists of sandy to silty, soft but cohesive clay, light olive gray (5Y 5/2) to olive gray (5Y 4/1) except, where oxidized it is various shades of buff. Near the Red River, the upper 20 feet of the deposits tend to be sandy. In extreme southwest Traill County a small amount of silty clay occurs in secs. 18, 19, 30 and 31, T. 144 N., R. 53 W. These deposits are oxidized to depths of at least 35 feet and they are underlain by a sand that is uniform textured and medium grained. These deposits occur at elevations of 40 to 50 feet higher than the highest silty clays to the east and they are apparently unrelated to them.

Description of the exposed silty clay deposits.—The lithology of the surficial silty clays is quite uniform throughout the county but variations do exist. In the area around Blanchard, the surficial deposits consist almost entirely of very cohesive, brownish-gray clay with virtually no sand or pebbles. The banding of the sediments, where it can be seen, is very fine and close. Gypsum crystals up to 1 inch in diameter are abundant from about two to six feet below the surface.

In the Mayville area the upper deposits tend to be more silty, and in a 40-foot-deep cut about ½ mile south of town, silt overlies clay (SE ¼, sec. 6, T. 146 N., R. 52 W.), Here, 4 to 15 feet of rhythmically banded silts lie unconformably on at least 20 feet of clay. The variation in thickness of the silt is due to relief on the surface of the clay; the upper surface of the silt is fairly flat. The silt at this location contains little clay or sand. Black bands are present near the base of the silt unit. At one place in the excavation there are 9 to 11 six-inch thick layers of light-colored silt, each separated by about 1 inch of black material, apparently a series of varves. The clay underlying the silt is darker in color than the silt and cohesive and blocky.

In the eastern third of the county, surficial sediments are much like those in the Blanchard area but slightly more silty. Banding is also more common in the sediments of eastern Traill County. The silt and sand content increases northward so that the siltest sediments exposed in the county occur in the northeast corner where the silt-sand fraction is commonly greater than the clay fraction.

The lithologic distribution described in the foregoing paragraphs deviates locally in the vicinity of sand ridges and near the streams where the sand content tends to be relatively higher. Considerable sandy wash occurs east of many of the sand ridges and, in the area south of Portland, scattered windblown sand deposits are present.

Surface expression of the silty clay deposits.—The area where the silty clay is exposed at the surface of the Glacial Lake Agassiz plain is shown on plate 1. It is characteristically very flat with local relief of less than 2 feet in a square mile (except for man-made modifications such as road embankments, etc.). It has an average northeasterly slope of about 8 feet in a mile across the county except in the western half of the county where the regional slope is as much as 20 feet in a mile and near the Red River where the slope is commonly less than 4 feet in a mile. Elevations on the lake plain range from about 1,000 feet in western Traill County to about 850 feet in the northeast corner of the county.

The lake plain is generally quite featureless except near the sand ridges, scarps, and valleys. Although the area has poorly developed drainage, there are very few sloughs such as those typical of the boulder-clay surface. This is a result of the many drainage ditches that have been dug throughout the area. Shallow depressions that occur on the surface of the silty clay in the western half of the county probably formed as a result of sapping by salt-water springs from the subcrop of sandstones of the Lower Cretaceous Dakota Group. The small patch of silty clay in extreme southwest Traill County has as much as 50 feet of local relief due to deep gullies that have been eroded into the area from all directions. The total extent of the area is not known because the larger portion of it is located in Steele County to the west which has not yet been mapped.

Origin of the silty clay deposits.—The silty clays of Traill County accumulated in proglacial lakes. Although the ages and extent of the proglacial lakes in which the lower two horizons of silty clays were deposited are not known, the history of the Glacial Lake Agassiz, in which the uppermost layer of silty clay was deposited, has been worked out in considerable detail (see the section of this report dealing with historical geology). The local surficial variations from more clayey to more silty deposits, both laterally and vertically, are very important to the interpretation of the history of Lake Agassiz.

The rhythmically banded silts in the Mayville area discussed earlier may represent seasonal accumulations of sediments (varves). Ideally, darker sediments are deposited slowly during the cold winter months when the amount of water flowing into the lake is negligible and the lighter colored sediments are deposited more rapidly during the summer months. If this generalization is valid in this case, the deposition of the banded parts of the silt may have been rapid with 8 feet or more of sediment being deposited in from 9 to 11 years. The source of the relatively more silty sediments near the surface of the lake plain throughout eastern Traill County was probably from silt-laden streams flowing into the lake during its waning phases. The silts were probably deposited in early post-glacial time during the pluvial period when greatly increased precipitation resulted in extensive runoff and erosion of areas adjacent to Lake Agassiz and correspondingly rapid deposition of the silts.

Fossils in the surficial silty clays.—Due to a lack of good exposures, fossils were found in only one location in the silty clay area. This was in a highway cut at the edge of a valley about 5 miles east of Mayville (SE ¼, SE¼, SW¼, sec. 31, T. 147 N., R. 51 W.) The site is located about 1½ miles west of the McCauleyville beach; the Campbell beach is not developed in the area, but its strandline is about 6 miles to the west, based on elevations taken from Army Map Service topographic sheets. The cut exposes a 9-inch to 1-foot-thick layer of marly, fossiliferous material. Included in the fossils were two fragments of a bone and several pelecypod shell fragments. According to Dr. A. M. Cvancara of the University of North Dakota Geology Department:

> Fragments of shells at this locality suggest the presence of the following mussel species: *Anodonta grandis?, Anodontoides ferussacianus, Lampsilis siliquoidea,* and *Lampsilis ventricosa?* The first three species are common in lakes, rivers varying size, although *Anodontides ferussacinus* is more characteristic of presently the smaller river in the Red River Valley. *Lampsilis ventricosa* is generally characteristic of medium to larger rivers presently in the valley. Its occurrence in lacustrine sediments suggests a lake environment with river influence. (written communication, April 13, 1967)

Of the bones, Dr. R. W. Seabloom of the Department of Biology at the University of North Dakota says:

> These were fragments of a metatarsal of a member of the order Artiodactyla, and probably in the family Cervidae. The fauna at the time of approximately 10,000 BP was essentially modern, indicating that the bone was probably from a moose, caribou or elk. It is not massive enough for *Bison*, or slender enough for deer (*Odocoileus*). (written communication, April 6, 1967)

It should be noted that the 10,000 year date Dr. Seabloom refers to is based on the writer's interpretation of the history of Lake Agassiz presented later in this report. It may be slightly in error but, even if it is, there is still no doubt that the bones occur within Lake Agassiz sediments and probably belong to the interval of time when the lake was drained (see later discussion on the geologic history).

SANDY SILT DEPOSITS

General lithology.—The sandy silt deposits consist essentially of cross-bedded, loose sandy silts or silty sands with only small amounts of clay and little or no gravel. The included sands are typically fine to very fine and well rounded. Near the surface the sandy silts are generally loose with some small pebbles. Where bedding could be seen, it was usually associated with the more sandy areas; stream cuts in the deposits almost invariably expose bedded sand. Boulders are absent on the surface.

Occurrence.—The sandy silt deposits occur at the surface and at depth in western Traill County (pls. 1 and 2). In the Hatton area, they consist of from 100 to 150 feet of fine sands that grade to silt in places; they grade imperceptibly into silty clays on the south. In general, the upper 10 to 20 feet of the sediments are particularly sandy and, where exposed, they are bedded. The sandy silt deposits in the Clifford-Galesburg area contain more coarse sand than those in the Hatton area. The sandy silt deposits in southwest Traill County are generally from 50 to 120 feet thick (pl. 2, cross-section D-D').

Surface expression of the sandy silt deposits.—The areas where sandy silts are exposed are shown on plate 1. The area of sandy silts in northwest Traill County is relatively flat with local relief of less than 5 feet in a square mile and a regional southeasterly slope of about 12 feet in a mile. The eastern boundary of the sandy silts is marked by a 5-foot to 20-foot-high, east-facing scarp that lies from ½ to 2 miles west of a sand ridge (the Campbell beach, to be discussed later). The surface is smooth except near sand ridges, scarps, and near the valleys of the Goose River and the North Branch of the Goose River. Restricted areas have numerous tiny depressions, possibly blowouts, and small mounds of sand (dunes) are common. A 2-mile to 4-mile-wide zone near the east edge of the sandy silts has an eroded appearance on aerial photographs and small east-trending valleys occur there. Some modern sapping has occured at the edges of the valleys. The area of sandy silts in southwest Traill County slopes eastward at from 20 to 30 feet in a mile and has local relief of about 15 feet in a square mile due to recent stream erosion, blowouts and sand dunes. Southwest of Galesburg the deposits merge with gravel and sand in a valley that is cut us much as 60 feet into the surrounding lake silts. The east edge of the sandy silts is hidden beneath sand deposits (pl. 1); east of there stony clay is exposed at the surface.

Origin of the sandy silt deposits.—The sandy silts of western Traill County (pl. 1) were deposited in part by running water that issued into shallow lakes. It is possible some of the more deeply buried sandy silt deposits are bottom-set beds, deposited when the water was relatively deeper, but those that are now exposed at the surface are top-set beds; that is, they consist of material that was laid down in horizontal layers on top of the deltas after considerable thicknesses of sediments had built up.

The sediments of the deltas were transported from an extensive area west of Lake Agassiz by a network of streams that were fed by tremendous amounts of pluvial runoff. The present interpretation is that the sandy silts in the Galesburg area, the Galesburg delta (fig. 3), were deposited slightly earlier than the sandy silts in the Hatton area, the Elk Valley delta. It seems probable too, that the eastern boundaries of the two deltas were ice marginal, at least during part of the time they were being formed. The fact that ice-contact faces are difficult to find does not rule out that they may have once existed; subsequent submergence beneath the waters of Lake Agassiz and wave action along the shore probably effectively obliterated ice-contact faces.

SAND AND GRAVEL DEPOSITS

General characteristics.—Sand and gravel occur at several horizons in the Traill County glacial deposits (pl. 2) as well as at the surface (pl. 1). Such characteristics as sorting, size and shape of the sand and gravel particles depend on the feature with which the deposit is associated. Sorting is best in the many sand ridges (beaches) where the sands are also commonly quite fine and well-rounded. Coarser gravels are found in some other ridges (ice-contact features) and in some of the buried sand and gravel deposits that are valuable aquifers. Most of the various sands and gravels are composed of a mixture of granitics, limestone and dolomite although some deposits contain considerable shale.

Occurrence.—Probably the most important buried deposit of sand and gravel is the Hillsboro aquifer. It trends southward in east-central Traill County beneath a narrow zone that corresponds, in a general sort of way, with an overlying ridge of sand (The Hillsboro beach) Cross-section E-E', plate 2, drawn from north to south through the aquifer, cuts through the winding aquifer several times. The sands of the upper parts of the aquifer vary from coarse in the north to very fine in the south where they grade into silts and sandy clays. The basal parts of the aquifer consist mainly of coarse sand and gravel throughout the entire length of the cross-section.

In addition to the Hillsboro aquifer, other less extensive deposits of buried sand and gravel were found throughout Traill County. A 10-foot to 15-foot thick gravel horizon occurs at a depth of about 10 feet in part of T. 150 N., R. 48 W., but its lateral extent is not known. It is a shaly gravel that is about 50 percent sand. In general, small restricted sand and gravel deposits such as this one are more numerous in the eastern than in the western parts of Traill County.

In southeast Traill County a 5-mile-long, low, sinuous ridge extends from near Kelso eastward into Minnesota. This ridge will be referred to as the Kelso ridge. It is from 5 to 15 feet high and about 0.2 miles wide. Several test holes were augered in the ridge; the deepest was 73 feet. The holes penetrated as much as 31 feet of fine-grained to medium-grained sand along with lenses of gravel that occur at various depths beneath the surface of the ridge. Test holes on either side of the ridge revealed no sand. Except where undisturbed lake clays and silts similar to those beneath the surrounding area occur near the surface of the ridge, the upper few feet of sediments on the ridge consist of fragments of banded clay that appear to have rounded edges indicating they were transported by running water.

Most of the sand and gravel that occurs at the surface in Traill County is associated with beaches or bars, but at least one feature interpreted to be an ice-contact ridge contains considerable gravel. This ridge will be referred to as the Cummings ridge. It occurs in northeast Traill County about 2 miles north of the town of Cummings between sec. 24, T. 147 N., R. 51 W., and sec. 10, T. 147 N., R. 50 W. (pl. 1). The Cummings ridge is a sinuous, 4½-mile-long ridge that is as much as 15 feet high on the west but lower eastward, so that near its eastern end it is almost imperceptible. The feature is from ¼ to ½ mile wide. Several test holes were augered in the ridge to depths as great as 44 feet. They show that only the upper 3 to 6 feet of the ridge is composed of coarse sand and gravel; the deeper strata beneath the ridge consist chiefly of fine sand. Twelve gravel pits, most of them small and abandoned, are situated on the ridge. Some of the larger pits, such as those in the SE ¼, sec. 18, T. 147 N., R. 50 W., are in medium to coarse, well-sorted gravel that is suitable for road surfacing material.

The several beach ridges throughout Traill County contain the largest share of commercially important sand and gravel supplies. The strandlines in which the beaches occur are defined by the elevations at which the edge of Lake Agassiz stood while the respective beaches were being formed. These strandlines are shown on figure 4 along with the beach ridges that occur within them. No gravel is present in those parts of the strandlines where beaches are absent, and not all parts of the beaches contain gravel. The best gravel occurs in short segments of the Campbell, McCauleyville and Blanchard beaches and short segments of the other beaches contain at least some useful deposits. The general characteristics of the beaches are summarized in Table 1.

BOULDERS

Boulders occur throughout the buried boulder-clay deposits but, with one exception, it is difficult to generalize as to their relative abundance in the various horizons. The exception is the lowermost

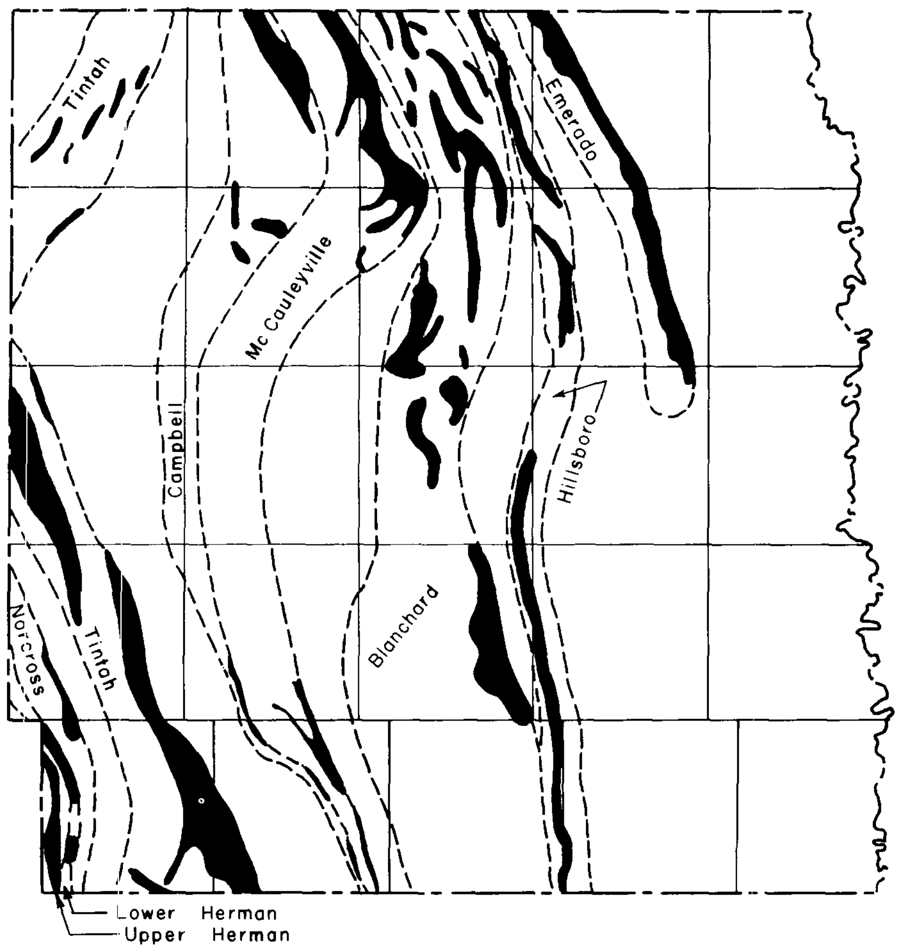


Figure 4. Map of Traill County showing strandlines (former shorelines) of Lake Agassiz (dashed lines). The black areas are actual beaches.

boulder-clay reached in the deeper test holes. This deposit contains abundant boulders, particularly near its upper surface where it is weathered and oxidized. Apparently, the finer fractions of the boulder-clay at this depth were removed by erosion, leaving the boulders behind.

On the surface, boulders are abundant on the area of washed boulder-clay in northern Traill County. The washing action of Lake Agassiz over this area removed most of the fine materials, leaving great numbers of boulders behind. Boulders are also abundant on the area of boulder-clay west of Blanchard. Except for the area around Caledonia in extreme eastern Traill County, boulders are very scarce over the remainder of Traill County. A few boulders and cobbles can be seen in the Caledonia area near the Red River, and a few miles to the east, on the Minnesota side of the river, boulders are abundant. Where the Goose and Red Rivers join, the boulders have resulted in a rapids in the stream.

Granitic lithologies represent between 85 and 90 percent of the boulders and cobbles on the surface throughout Traill County. Metamorphic rocks are generally from 5 to 10 percent of the total and the remaining fraction consists mainly of carbonates. Smaller rock particles such as pebbles and granules in the surficial gravels and boulder-clay deposits average only about 15 to 30 percent igneous varieties. Carbonates represent between 50 and 75 percent of the rocks in this size range and shale as much as 20 percent of the total.

GEOLOGIC HISTORY

The geology of the surface of Traill County represents only a very small fraction of the total geologic history of the area. All the surficial landforms in the country were formed during a period of time that dates back little more than 12,000 years. However, beneath the surface at depths of from 200 to 500 feet is bedrock that is as much as 600 million years old. A short summary of the preglacial portion of the geologic history follows first. The discussion of the glacial history that comes later is in more detail, because it was during the glacial epoch that the landforms we observe today were formed; and we know much more about the glacial history of the area than we do of the the preglacial history.

Summary of the Preglacial History

The history of Traill County before the advance of the glacier over the area was characterized by alternating periods of submergence beneath warm, shallow seas and emergence above those seas. During the times the area was submerged beneath the seas, deposition of sands, silts, and limestones occurred and during the times the

TABLE 1

Strandline	Elevation	Characteristics in Traill County
Upper Herman	1145-1166	A low, narrow inconspicuous band of coarse sand and gravel, as much as 16 feet thick in sec. 19, T. 144 N., R. 53 W. Sand is fair quality but limited in quantity. A low scarp marks the east edge of the beach.
Lower Herman	1120-1135	A very low, narrow inconspicuous band of sand of highly variable content. Commonly less than 3 feet thick.
Norcross	1100-1120	A broad, low mound of sand and gravel, commonly 1 to 3 feet thick but at least 5 feet thick between sec. 6, T. 144 N., R. 53 W., and sec. 19, T. 145 N., R. 53 W. In this area, the beach is well-defined, 1/8 to 1/2 mile wide and consists of clean, fine to medium-grained sand.
Tintah	1030-1075	In southwest Trail County, a zone about 1 to 3 miles wide consisting of sporadically occurring ridges of coarse sand and gravel. It is an inconspicuous mound except in the Clifford area and near the Steele County line where more than 5 feet of fine to medium-grained sand occurs. Several small pits are located in the beach in this area. In northwest Traill County, it is a zone about 5 miles wide in which several small beach ridges, consisting of as much as 15 feet of very uniform fine sand occur.
Campbell	990-1005	A prominent ridge of fair gravel and much clean sand in northern Traill County, at least 20 feet thick in places. The beach is aboue 1 mile wide with numerous superimposed ridges and a prominent frontal scarp. Several pits are located in the beach. In southern Traill County, where there is little sand or gravel, a prominent scarp occurs.
McCauleyville	970-990	In northern Traill County, a promnent ridge of high-quality gravel, at least 15 feet thick in places and 1 mile wide. The gravel is coarse in places and may be pre-beach ice-contact deposits. In southern Traill County, little said or gravel is associated with the scarp that marks the McCauleyville.
Blanchard	940-955	A 3-mile to 6-mile-wide zone extending from north to south through central Traill County consisting of several low ridges of sand and gravel. Gravel occurs in secs. 21, 28, and 33, T. 147 N., R. 51 W., as well as in sec. 36, T. 145 N., R. 51 W.
Hillsboro	925-940	A prominent, 1/4-mile to 1/2-mile-wide ridge of silt and sand. The ridge lies on sand of the Hillsboro aquifer, and its base is vague; but it is apparently as much as 20 feet thick. The sand is generally too fine for commercial use.
Emerado	895-905	A low, 1/2 to 1-mile-wide mound of fine, silty sand. It is less than 10 feet thick in most places. The sand is generally too fine and limited in extent for commercial production.

area rose above the seas, these sediments were eroded. Table 2 is an outline of the geologic history of Traill County showing when the various times of submergence and emergence took place and what happened at those times. In Traill County, the total thickness of sedimentary rocks under the glacial drift is relatively small when compared to the amounts in other areas such as western North Dakota. This is because Traill County did not sink and receive thick accumulations of sediments as did the center of the Williston Basin in western North Dakota.

It is not known just when the igneous and metamorphic rocks of the Pre-cambrian basement in Traill County were formed. However,

GEOLOGIC PERIOD OF TIME (approximate age in parentheses)	EVENTS THAT OCCURRED IN TRAILL COUNTY		RESULTING ROCKS STILL PRESENT IN TRAILL COUNTY
Pleistocene (began about one million years ago)	Area above water	Ice sheets deposited glacial drift on top of the bedrock.	Glacial drift (see table 3 for a summary history)
Tertiary (70,000,000 years)		Erosion throughout Tertiary time with possible deposition of some sandstones that were subsequently removed by the continuing erosion	
Cretaceous (125,000,000 years)	Area submerged	Continuing deposition of shales in slightly deeper seas Deposition of sands and silts by streams flowing from the east into shallow seas.	Colorado Group (shales) Dakota Group (sandstones)
Jurassic (150,000,000 years)		Deposition of thin limestones and redbeds in and near shallow seas that may not have reached into Traill County	
Triassic (180,000,000 years)	Area above water	Erosion of the Mississippian limestones and the exposed areas of the Precambrian surface.	
Permian (210,000,000 years)			
Pennsylvanian (250,000,000 years)			
Mississippian (300,000,000 years)	Area submerged	Some limestones may have been deposited	
Devonian (350,000,000 years)	Area above water	Erosion of Ordovician sandstones, shales, and limestones and the exposed areas of the Pre-cambrian surface.	
Silurian (400,000,000 years)	Area submerged in shallow seas	Deposition of sands and silts from nearby areas; some limestone may have been deposited as the water became deeper.	Winnipeg Formation (sandstones and shales)
Ordovician (450,000,000 years)			
Cambrian (500,000,000 years)		Erosion of the igneous and metamorphic basement rocks.	
Precambrian (more than 600,000,000 years ago)	Area above water	Formation of the igneous basement rocks in Traill County as well as in the remainder of North America.	Igneous and metmorphic rocks

Table 2. Chart showing generalized geologic history of Traill County.

they were in place by the end of Precambrian time about 600 million years ago. Erosion of these rocks probably took place for a very long time before the shallow, Ordovician sea flooded the area. In this sea the sands and shales of the Winnipeg Formation were deposited. It seems likely that rocks of the Winnipeg Formation covered all of Traill County but later erosion has removed them from the eastern half of the county.

When the sea left the area in late Ordovician or early Silurian time erosion occurred. In Mississipian time, seas probably again covered Traill County, but any sediments that were deposited have since been eroded away. Throughout Pennsylvanian, Permian, and Triassic time the area was subjected to erosion. In Jurassic time seas may have covered the area (thin limestones and redbeds were disposited a few miles to the west), but no rocks of Jurassic age remain in Traill County.

During much of Cretaceous time Traill County was submerged. It was during this time that the sandstones and shales of the Dakota and Colorado Groups were deposited. Perhaps the seas remained through late Cretaceous time but no bedrock that young is present today. If late Cretaceous rocks were deposited in Traill County, they were removed during the period of erosion that began in late Cretaceous time and continued throughout Tertiary time to the present day.

Bedrock Topography

The erosion that immediately precided the advance of the Pleistocene glaciers over the area resulted in a surface on the bedrock much like that shown on figure 2. The most important feature of this preglacial landscape was a broad, north-trending valley about 200 feet deep that crossed the eastern part of the area. Relatively flat, well-drained uplands sloped toward the valley from both the east and west.

On the uplands to the west of the valley, Cretaceous shales of the Colorado Group were exposed at the surface. Nearer the valley and to the east, Cretaceous Dakota Group sandstones and siltstones were exposed. The center of the valley was cut into Precambrian granites and schists and, in the northern part of the county, a small area of Ordovician Winnipeg shales was exposed.

Glacial History

Four major glacial drift sheets have been recognized in the Upper Midwest. They are, from oldest to youngest, the Nebraskan, Kansan, Illinoian and Wisconsinan glacial stages. The three interglacial periods that have been recognized by some geologists are the Aftonian, which occurred between the Nebraskan and Kansan glacial stages; the Yarmouth, which occurred between the Kansan and Illinoian glacial stages; and the Sangamon, which occurred between the Illinoian and Wisconsinan glacial stages.

It is possible to identify three horizons of glacial drift separated by weathered zones in Traill County. The uppermost horizon consists of four units: the silts and clays that were deposited in the Glacial Lake Agassiz, an underlying sandy till, a buried sequence of lake sediments and a buried layer of sand and gravel. This sequence of glacial sediments lies on a gravelly till, the upper surface of which is oxidized to a depth of about 35 feet.

The gravelly till that comprises the middle of the three drift horizons is as much as 200 feet thick. It lies on lake sediments of the lowermost horizon in places, on bedrock wherever the lake sediments are absent. Minor lithologic breaks do occur in the till but, on the whole, it is fairly uniform and, except for its uppermost 35 feet, it is unoxidized throughout. The gravelly till was probably deposited during a single glacial advance.

The lake clay that comprises the lowermost drift horizon must be the oldest glacial deposit in Traill County. It occurs only in the lower parts of the bedrock valley of eastern Traill and Grand Forks Counties (D. E. Hansen, personal communication). Ice advancing southward dammed water in the north-trending valley shown on figure 2, resulting in a proglacial lake. Because the lake sediments are oxidized to a depth of 17 feet (test hole number 1959, letter from Roger Schmidt of the North Dakota State Water Commission) and overlain by the gravelly till of the middle horizon, it seems likely that they are significantly older than the gravelly till. The absence of oxidized till immediately above the lake sediments suggests the possibility that the ice that dammed the valley forming the lake in which the lake sediments were deposited may never have advanced over the area.

Because of the almost total absence of information on pre-Wisconsinan glacial deposits in North Dakota, it is very difficult to determine the ages of the lower two drift horizons. Even the regional configuration of the topography prior to Sangamon time is unknown, so it cannot be determined in which direction the pre-Wisconsinan glaciers might be expected to have moved. Certainly, one, or perhaps two, of the glacial stages that preceded the Wisconsinan are represented by the lower drift horizons (table 3) but until further data are available, speculation will not be made about their ages. All that can be said with certainty now is that the uppermost horizon is Wisconsinan in age.

ADVANCING PHASE OF THE WISCONSINAN ICE SHEET

In early Wisconsinan time, perhaps 50,000 years ago, ice advanced southward through the broad lowland that is now the Red River Valley. The ice moved over the Sangamon erosion surface which consisted chiefly of deeply weathered drift of earlier glacial stages

Wisconsinan Stage	Deposition of lake sediments on the sandy till (Lake Agassiz deposits).
	Deposition of sandy till on both lake sediments and outwash. This was apparently a continuous sequence of events.
	Deposition of 10-20 feet of outwash on the oxidized till surface with about 80 feet of lake sediments deposited in places.
Pre-Wisconsinan (Sangamon?) Interstage	Time of weathering. Oxidation of the gravelly till to depths as great as 35 feet.
Pre-Wisconsinan glacial advances	Deposition of 200 feet of gravelly till.
	Time of weathering. Oxidation of lake sediments to depths of at least 17 feet.
	Deposition of as much as 150 feet of lake sediments. Present only in the deep bedrock valley below an elevation of 580 feet.

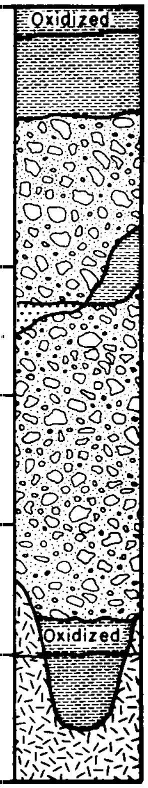


Table 3. Glacial stratigraphy of Traill County, North Dakota.

along with some areas of exposed Cretaceous bedrock. Because the regional slope on this surface was northward, proglacial lakes formed ahead of the advancing ice. Test holes in northeast Traill County indicate the presence of 10 to 20 feet of sand and gravel. Much of the outwash that was deposited became incorporated into till as the ice overrode it resulting in the sandy till unit shown on plate 2 (cross-section B-B').

RECEDING PHASES OF THE WISCONSINAN ICE SHEET

High lake phase.—After the ice front had advanced over Traill County, the area was continually covered by ice until late Wisconsinan time about 12,500 years ago when the ice finally began to recede from eastern North Dakota. As it rapidly shrank, it became increasingly confined by the bedrock margins of the Red River Valley. Ahead of the receding ice margin, a proglacial lake, Glacial Lake Agassiz, formed in the valley resulting in thick deposits of lake sediments.

The ice margin shown on figure 5 has not yet receded far enough to allow Lake Agassiz to extend into Traill County. However, ponding occurred at the ice margin on the ground moraine in Steele County resulting in a lake or lakes in which several tens of feet of silty sediments were deposited. Meltwater flowed from the ice and ice-margi-

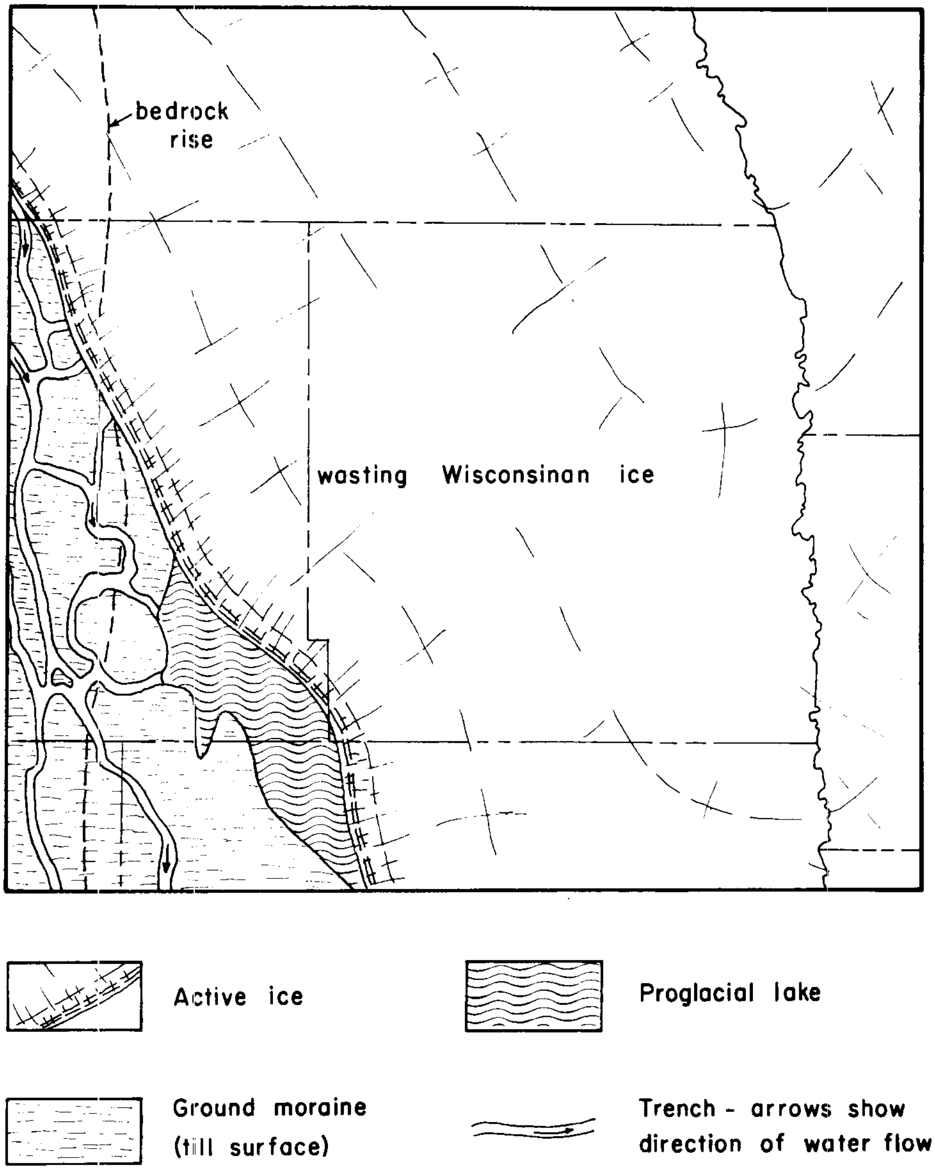


Figure 5. High lake phase. This and the following series of illustrations show the progressive development of landforms in and near Traill County. On this illustration, Traill County is still covered by ice. To the west where the ice is no longer present, ground moraine is exposed and a lake has been dammed against the ice margin.

nal lakes southward into parts of Lake Agassiz that had already formed in Ransom and Richland Counties and helped to develop the Sheyenne Delta. The extent of the area of Steele, Cass, and Traill Counties covered by these lakes is not accurately known and the lake shown on figure 5 is simply a guess based on the discovery of high-elevation lake silts during a reconnaisance of the area. During this phase until the lake fell to the Campbell level, runoff of Lake Agassiz drained southward through the Browns Valley outlet into the Minnesota River.

Galesburg delta phase.—As the ice margin continued to recede, it exposed increasingly lower outlets for the meltwater. The ponded area in Steele, Cass and Traill Counties drained about 12,000 years ago leaving silt deposits which were immediately dissected by streams from the west. Water from these streams deposited thick layers of very sandy silt in the narrow, ice-marginal lake that formed just east of and below the drained area (fig. 6). This lower lake probably was connected with already existing parts of Lake Agassiz to the south. Very likely, no beaches had an opportunity to form yet due to the scouring action of the south-flowing water and the rapidity with which the events were occurring. The sandy silts deposited in the lake shown on figure 6 comprise the Galesburg delta.

Edinburg moraine-Elk Valley delta phase.—The ice margin paused for a short time during its withdrawal from the area slightly less than 12,000 years ago. At this time, the many streams flowing into the proglacial lake were depositing thick sequences of sandy silt in the area shown on figure 7, northwest of the dashed line in the lake. These sediments comprise what is known as the Elk Valley delta. At the same time, the low Edinburg end moraine formed at the edge of the ice, probably mostly below the surface of the water. A continued slightly slower rate of recession for the next hundred years or so resulted in the deposition of the till in north central Traill County. In southern Traill County, clays were deposited in deep, still waters.

Herman-Tintah phase.—As the ice rapidly receded from the area about 11,500 years ago, the level of the lake dropped slowly, pausing long enough to develop the upper and lower Herman, Norcross, and Tintah strandlines, each of which has associated beaches (fig. 8). During the time the level was dropping from the upper Herman to the Campbell level, the lake drained southward through the Browns Valley outlet.

When the ice margin melted back far enough in Ontario to open a Lake Agassiz outlet into the Superior basin slightly less than 11,500 years ago, the lake level dropped rapidly so that its shore was probably well to the north of Traill County until about 10,000 years ago when it refilled again to the Campbell strandline. Beaches formed east of the Campbell strandline in Traill County at this time (about 11,000 years ago) but they were covered again when the lake refilled.

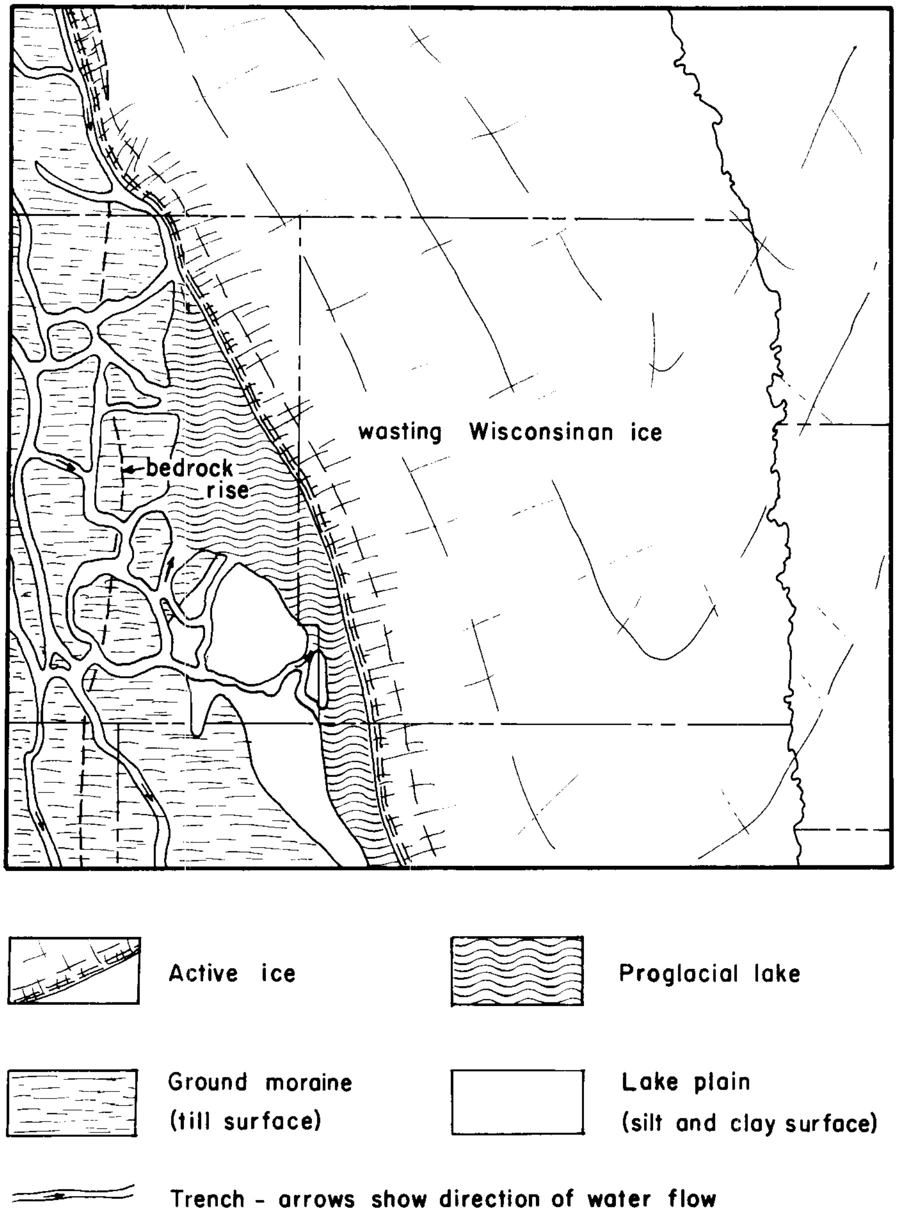


Figure 6. Galesburg delta phase. The ice margin here crosses southwest Traill County and a lake exists along its west margin. The lake of figure 5 has been drained and is being dissected by streams that are carrying runoff from the west and depositing sands and silts in the new lake. These sands and silts comprise the Galesburg delta today.

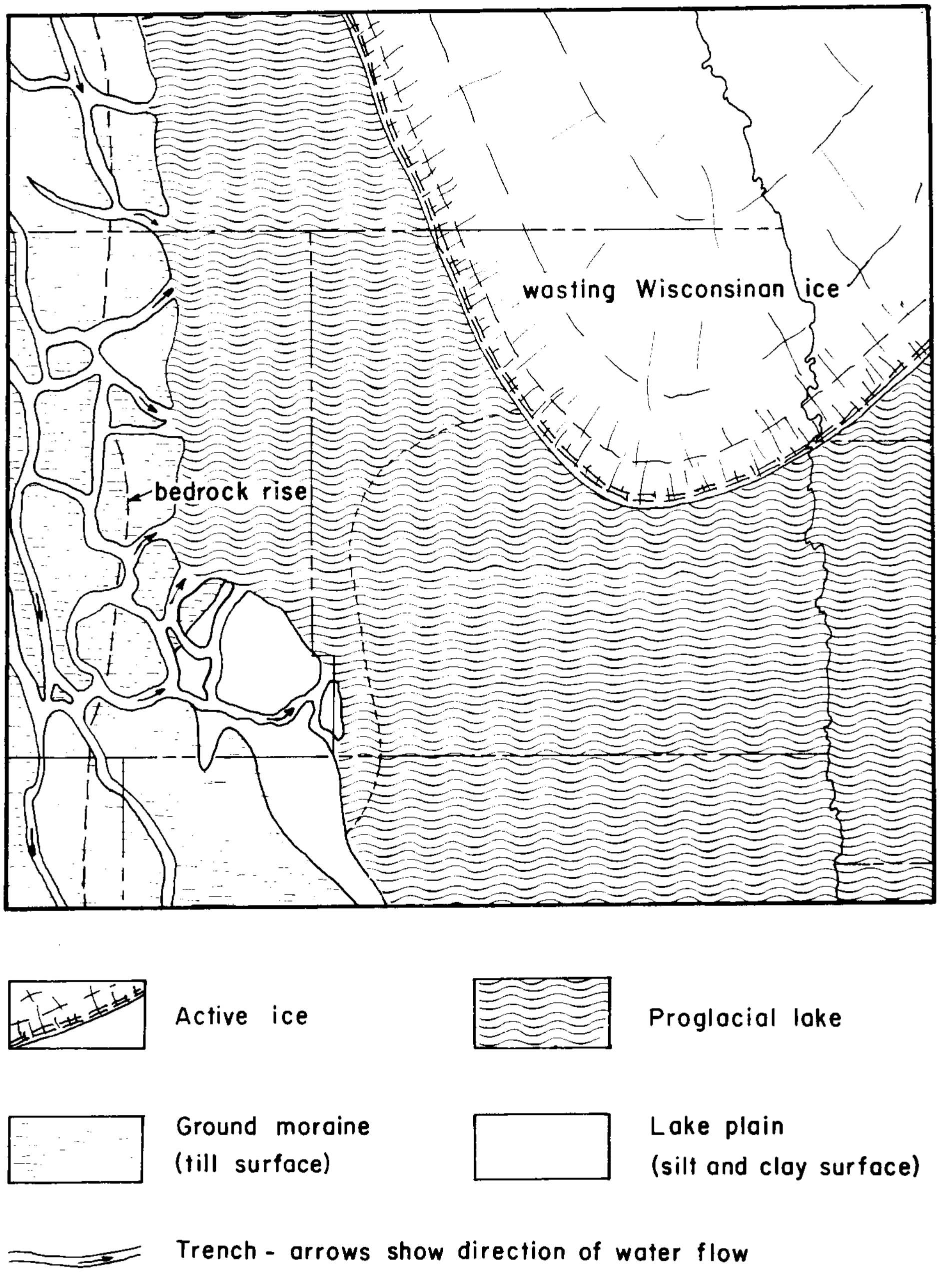


Figure 7. Edinburg moraine—Elk Valley delta phase. Here, the ice covers northeast Traill County and the proglacial Lake Agassiz covers the remainder. Streams entering the lake at this time deposited the sands and silts of the Elk Valley delta in the lake. At the edge of the ice, till accumulated in the water; much of it is buried by lake sediments today.

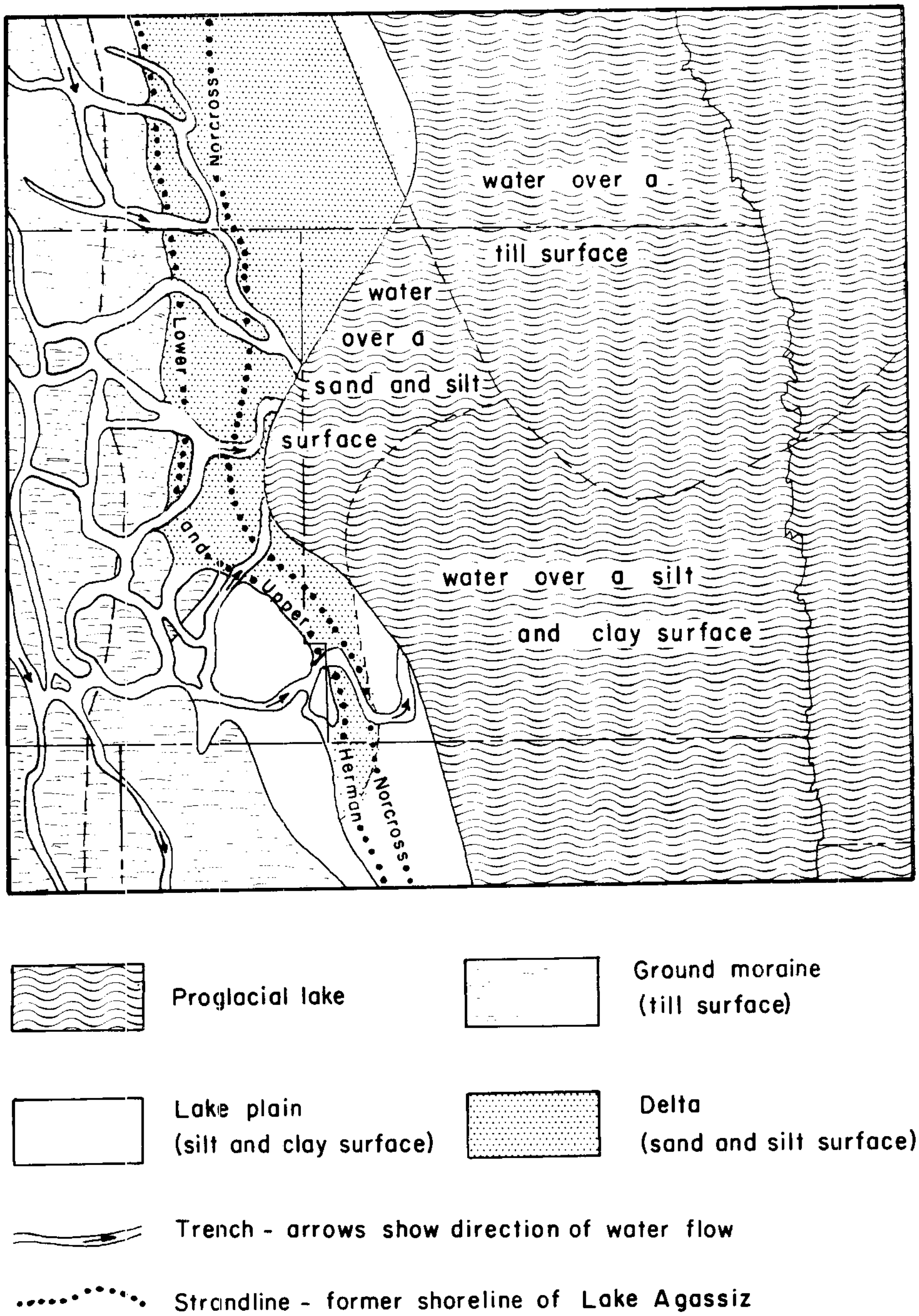


Figure 8. Herman-Tintah phase. As the water level dropped, it exposed the delta sediments and lake plain. During this interval of time, the Upper and Lower Herman, Norcross, and Tintah beaches formed at the edge of the lake.

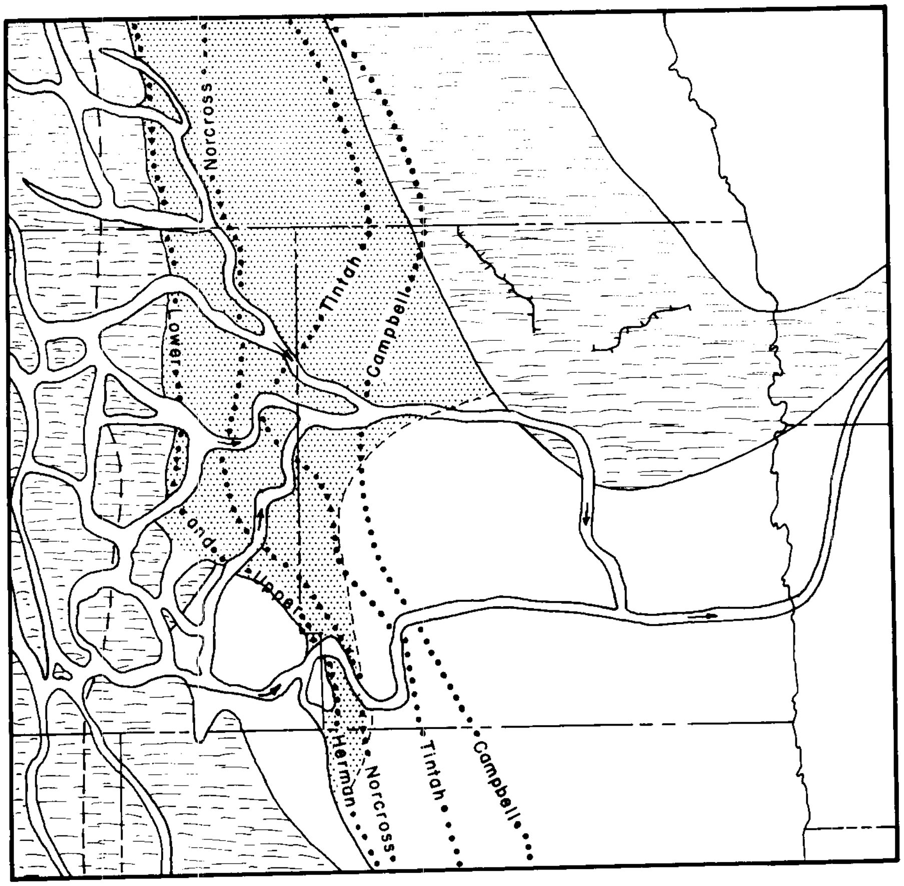
First draining of Lake Agassiz.—During the drying interval that occurred while the lake was temporarily partially drained (11,500 to 10,000 years ago), the large volumes of pluvial runoff from the Drift Prairie to the west established the stream routes shown on figure 9. The ancestral Goose River flowed eastward, then south, into the ancestral Elm River which flowed eastward into Minnesota a few miles and turned northward. Lake sediments covered most of the southeastern part of the area, till covered the northeastern and western parts, and delta sediments covered a strip in western Traill, eastern Steele, and central Grand Forks Counties.

Lake Agassiz again flooded the area about 10,000 years ago as a result of advancing Valders ice (Zoltai, 1965, p. 268). Zoltai also suggests that an earlier advance of the Valders ice also occurred resulting in flooding but in Traill County evidence for only one temporary draining of the lake was found.

Lake Agassiz II phase.—Lake Agassiz rose again to the Campbell level and stayed there until about 9,000 years ago when it slowly began to drop. Several pauses in the dropping of the water level are marked by the McCauleyville, Blanchard, Hillsboro, and Emerado strandlines. Additional strandlines, still lower, are present in counties to the north.

When the lake flooded the area, the sands and gravels deposited in the ancestral Goose and Elm Rivers in central and eastern Traill County were covered by lake sediments. The paths of these early rivers were quite different in the central parts of the Red River Valley than they are now as a comparison of figure 9 and plate 1 will show. Later, when the lake drained for the last time and the area dried, the sedimentary framework of the buried sands and gravels kept them from becoming as compacted as the adjacent lake sediments, silts and clays, which drained more thoroughly. Ridges resulted above these deposits (fig. 10). The Kelso ridge overlies deposits of the ancestral Elm River in southeast Traill County and it is easily traced in the field. The deposits of the ancestral Goose River correspond to the Hillsboro aquifer (pl. 2, cross-section E-E') but, because they are at the Hillsboro strandline, compaction ridges comparable to the Kelso ridge have been modified by shore erosion and beach deposition.

Campbell-Hillsboro phase.—As already stated, the level of Lake Agassiz II began to drop from the Campbell level about 9,000 years ago. The McCauleyville "beach" lies directly east of the Campbell beach and is presumably the next younger beach. However, it consists of coarse gravel and sand, not at all like the deposits of the other beaches, which are mainly medium-grained to fine-grained sand. Its overall surface expression on airphotos is very much like that of an offshore bar with associated spits (fig. 4). In northern Traill County the McCauleyville lies on till and it seems likely that it first



Ground moraine (till surface)

Lake plain (silt and clay surface)

Delta (sand and silt surface)

Ice-contact ridge of sand and gravel

Trench - arrows show direction of water flow

Strandline - former shoreline of Lake Agassiz

Figure 9. First draining of Lake Agassiz. When the ice receded far enough, an outlet was opened into the Superior basin and the lake drained exposing the surface shown above. The Goose and Elm Rivers crossed Traill County (the Elm is the one on the south that enters Minnesota) cutting trenches in the lake sediments and depositing sand and gravel in those trenches.

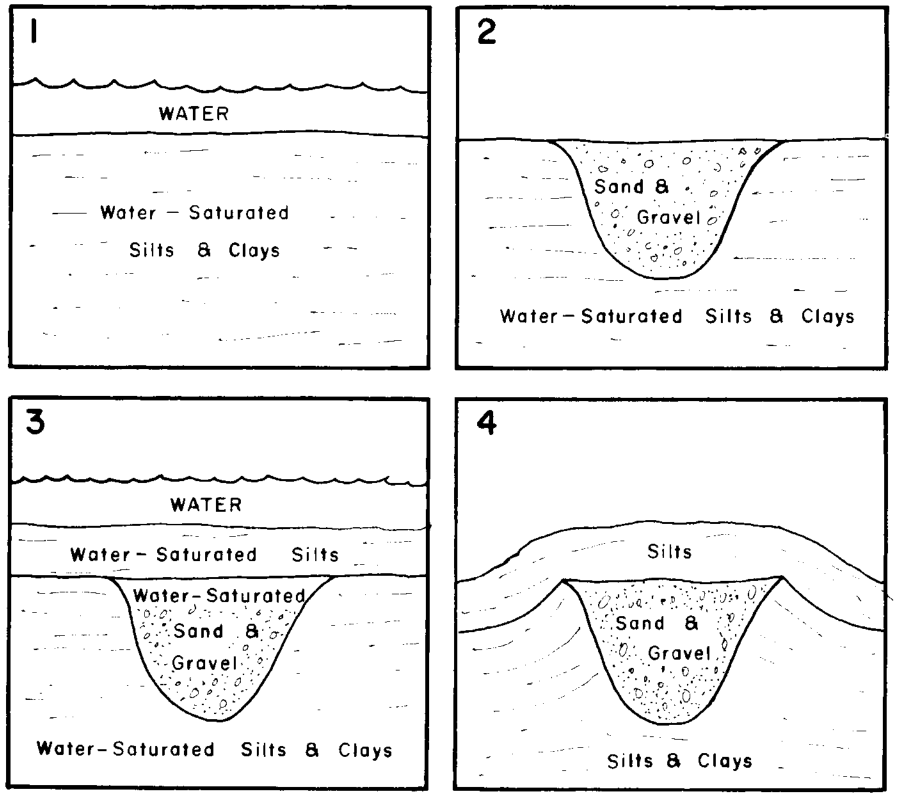


Figure 10. Steps in the formation of a compaction ridge such as the Kelso Ridge.
1. Silts and clays were deposited in the lake.
2. A valley was cut during the time the lake was drained. Sand and gravel were deposited in the valley.
3. Silts were deposited when the lake again flooded the area.
4. The area was drained for the last time. The sand and gravel in the valley did not settle as much as the surrounding silts and clays when they dried.

formed as an ice-contact ridge and was later modified by wave action into the beach/bar configuration while the edge of the lake stood at at the Campbell strandline.

The several small beaches of the Blanchard strandline occur over a broad zone in Traill County. They probably formed while the lake level fluctuated slightly resulting in several changes in the position of the shoreline.

The Hillsboro strandline appears to represent a slightly longer period of stability in the level of the lake (fig. 11). Except for minor beaches such as the Emerado beach, east of the Hillsboro strandline the lake plain is particularly level and underlain by siltier sediments than those to the west. As much as 80 feet of silt and sandy silt underlie parts of northeast Traill County; the amounts of silt decrease southward. The uppermost several feet are particularly silty in places.

The sediments are siltier east of the Hillsboro strandline than to the west and can be explained in the following manner. During the earlier phases of Lake Agassiz when the lake drained southward, the water was deep and much of it was derived from melting ice. In this cold-water environment, there was negligible circulation and the water at the bottom of the lake was quite still. Silt was deposited, of course, but along with it, considerable thicknesses of clay. Later, when the lake stood at the Hillsboro strandline and drained northward, the water was shallow and most of it came from inflowing streams carrying pluvial runoff. In such a warm-water environment, circulation was better and the slowly north-moving water dropped its load of silt while retaining the clay fraction.

Another indication that the Hillsboro strandline marks a relatively long period of stability in the lake level is the fact that the Goose and Elm River valleys are considerably narrower and shallower east of the strandline than west of it. This suggests that while the lake stood at the Hillsboro strandline, water flowing into it had an opportunity to develop relatively large valleys. Certainly, while the lake stood at this level, large amounts of water, probably containing much of the silt indicated above, flowed into the lake. That the dropping of the lake level from the Hillsboro strandline apparently also marks a significant decrease in precipitation is indicated by the much smaller valleys east of there.

Air photos reveal patterned ground over much of the area east of the Hillsboro strandline; patterned ground does not occur west of there (see plate 1 for the limits of the patterned ground). Not ordinarily noticeable from the ground, the pattern results from very low-relief, intersecting ridges and grooves on the lake plain surface. Patterned ground is particularly conspicuous in the area southeast of Hillsboro (fig. 12). Several theories have been proposed to explain the origin of patterned ground. They include: 1) Horberg's (1951) theory that the lineations represent an unusual type of tundra or permafrost patterned ground or the ridges are fractures fillings formed in lake ice; 2) Colton's (1958) theory that the ridges formed by squeezing of soft lake sediment up into cracks in thick lake ice when the lake level fell: 3) Nikiforoff's (1952) theory that the ridges formed by the normal processes of wave action and running water; 4) Mollard's (1957) and later Elson's (1961 theories that the pattern may reflect a fracture system in the underlying bedrock; and 5) Clayton's (1965) theory that the lineations resulted when wind-driven ice blocks moved over the lake and dragged on the nearly flat lake floor. The present writer believes that the last of these theories best explains the patterned ground of eastern Traill County.

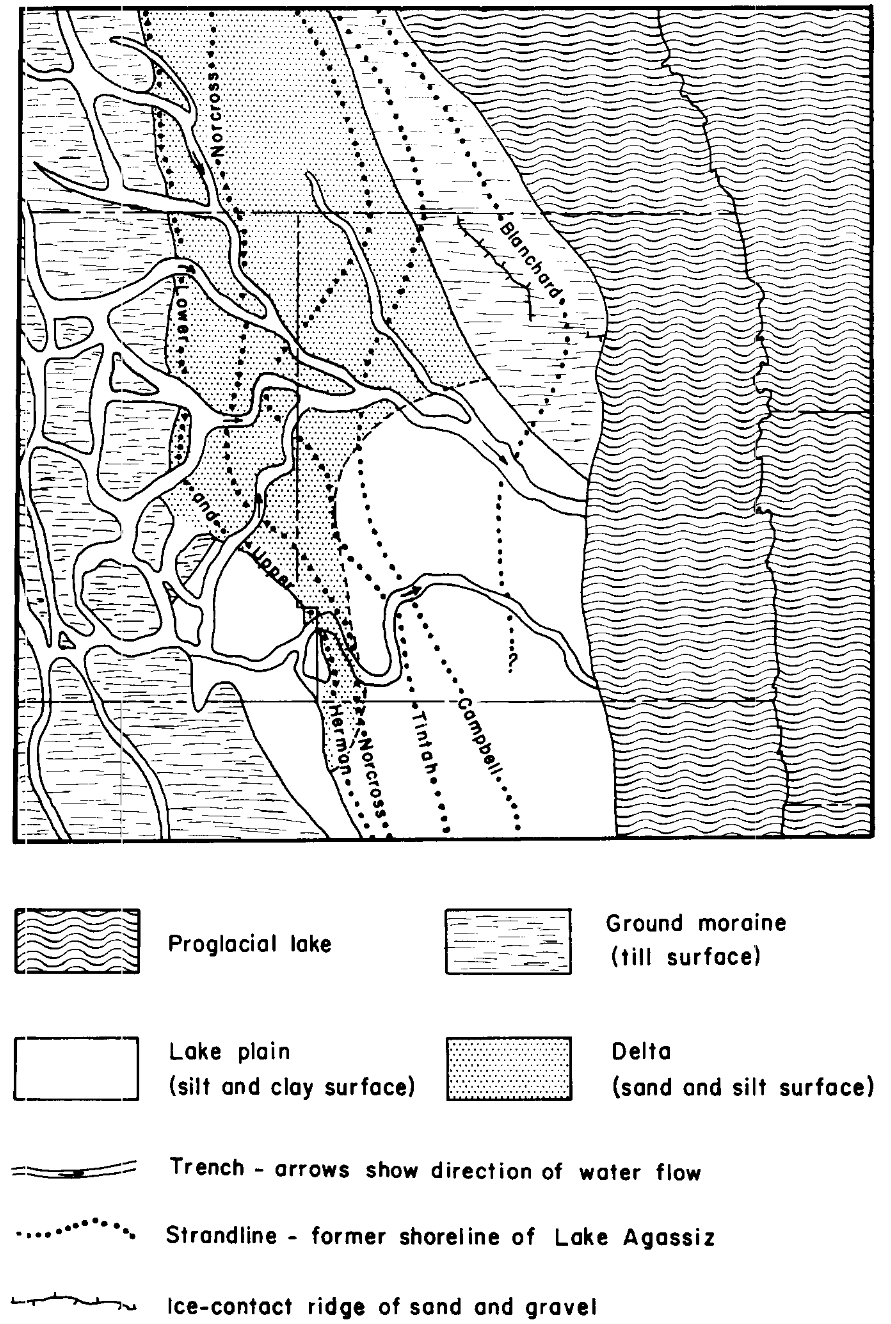


Figure 11. Campbell-Hillsboro phase. The lake refilled at least to the Campbell level when ice again blocked the outlet to the Superior basin. Here, the water is shown at the Hillsboro level. Silts were deposited by streams entering the lake at this time.

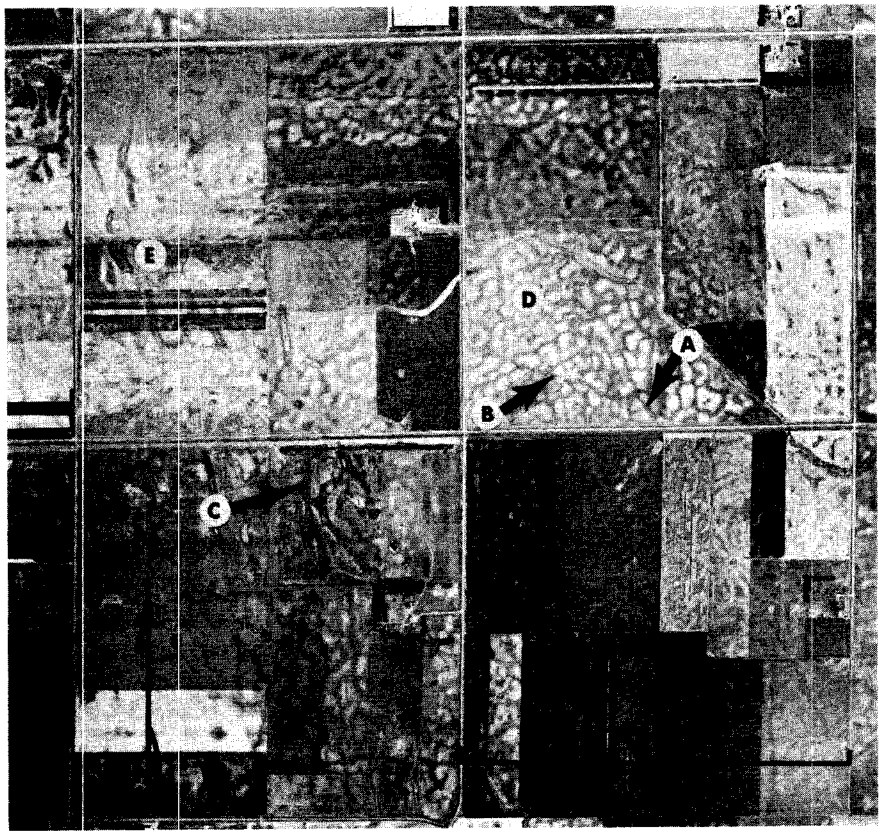


Figure 12. Patterned ground southeast of Hillsboro about 8 miles. (sections 28, 29, 32 and 33, T. 145 N., R. 49 W.). This is typical of the pattern seen on air photos east of the Hillsboro beach in Traill County. A, B, and C identify some of the more continuous lines; D and E illustrate a more random pattern.

Post Glacial History

After Lake Agassiz had drained for the last time, the present drainage soon became established. For perhaps a thousand years after the lake had drained, large amounts of precipitation that continued to fall over the area during the post-glacial pluvial cycle deepened and entrenched the streams in the Elm, Goose and Red River Valleys. On the interfluves virtually no drainage has developed; the fact that the area is well-drained is a result of the numerous canals and drainage ditches that have been constructed. In the area where the Dakota sandstone subcrops (see figure 2) there has been some sapping at the margins of sloughs that result from water that seeps to the surface. There has also been some modification of the landscape by farming processes. Some of the beach ridges have been plowed over and cultivated so often that they can no longer be recognized. It is only because Upham (1896) recognized them before intense farming practices became commonplace in Traill County that we know they once existed.

ECONOMIC GEOLOGY

In the discussion of the sand and gravel of Traill County, the occurrence and extent of the deposits was covered. Gravel has been in short supply in Traill County, but there are several deposits that have not yet been developed. Many of these are too limited in extent for anything more than local markets, but some of the larger beaches may contain gravel in sufficient amounts for county-wide consumption.

Most of the water used by the communities and farmers of Traill County comes from gravel and sand aquifers within the glacial materials. The best aquifer in the county is the Hillsboro aquifer which lies beneath the Hillsboro beach in many places, the Galesburg delta aquifer that occurs in the Galesburg delta sediments of southwest Traill County and the Elk Valley delta aquifer of northwest Traill County. Part 3 of this bulletin, which will be published at a later date, will consider the aquifers in detail and will discuss the quality and availability of the water in them.

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