# DESCRIPTION OF THE HERMAN, BARRETT, CHOKIO, AND MORRIS QUADRANGLES.

By Frederick W. Sardeson.

## INTRODUCTION.

### GENERAL RELATIONS.

The area here described lies between parallels 45° 30′ and 46° and meridians 95° 45′ and 96° 15′ and includes the Herman, Barrett, Chokio, and Morris quadrangles, comprising 834.83 square miles. It is in western Minnesota and includes the greater part of Grant and Stevens counties and small adjacent parts of Douglas, Pope, and Big Stone counties. (See fig. 1.) Morris, near the center of the quadrangle of that name, is the principal town in the area.

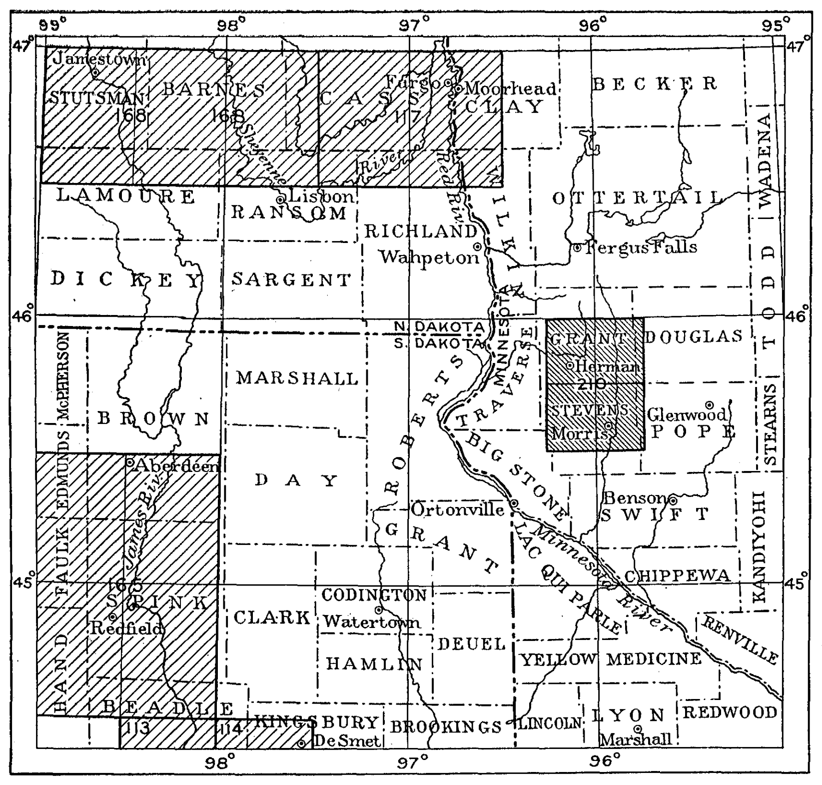


FIGURE 1.—Index map showing location of Herman-Morris district, Minn. The area described in the Herman-Morris folio is shown by the darker ruling (210). Published folios that describe other areas, indicated by lighter ruling, are as follows: 113, Huron, S. Dak.; 114, De Smet, S. Dak.; 117, Casselton-Fargo, N. Dak.-Minn.; 165, Aberdeen-Redfield, S. Dak.; 168, Jamestown-Tower, N. Dak.

In its general geographic and geologic relations the area forms a part of the geologic province known as the Glaciated Plains, which lies between the Laurentian Upland on the north and northeast, the Appalachian province on the east and southeast, the Ozark province on the southwest, and the Great Plains on the west. The quadrangles lie near the middle of this part of the Glaciated Plains, only a few miles from the southwestern limit of that part of the Laurentian Upland that is commonly called the Lake Superior Ranges or simply The Ranges. The bedrock beneath the quadrangles consists largely, if not wholly, of rocks of the same kind as those of The Ranges, but inasmuch as it is thickly overlain by glacial drift and the topographic features are wholly of glacial origin and not at all affected by the bedrock, the boundary is so drawn as to include these quadrangles wholly in the Glaciated Plains.

### OUTLINE OF THE GEOGRAPHY AND GEOLOGY OF THE REGION.

#### RELATIONS.

The general region in which the quadrangles are situated lies approximately in the center of North America, at the meeting place of the divides which separate the drainage basins of Hudson Bay, the Gulf of St. Lawrence, and the Gulf of Mexico. It is also approximately in the center of the great area of low altitude and slight relief that occupies the interior of the continent from the Arctic regions to the Gulf of Mexico. It comprises parts of three geologic provinces—the Laurentian Upland, the Glaciated Plains, and the Great Plains (see fig. 2)—and hence displays considerable diversity in geologic structure, topographic form, and drainage pattern.

#### RELIEF.

The general altitude of the region is not great, although it lies in the interior of the continent at the head of three drainage systems. The surface of Lake Superior is only 600 feet above sea level, and a tract several miles wide along its southern shore is not much higher. The lake, however, lies in a rather deep depression, and nearly all the land surface of the Laurentian Upland within this region stands 1,000 feet or more above sea level and much of it at an altitude of more than 1,500 feet. The crests of some of the ranges, which in general trend northeastward, reach an altitude of 2,000 feet, and the Mesabi Range stands 2,200 feet above the sea.

Although they reach an altitude of 2,000 feet in places along their western margin and in the Turtle Mountains plateau on the international boundary, the Glaciated Plains elsewhere lie considerably lower. In North Dakota and South Dakota and eastern Nebraska their surface slopes in general eastward to a level of about 1,000 feet along the Missouri and to considerably less in the valley of Red River. In the area east of this line the surface is somewhat higher, reaching 1,600 feet above sea level about the sources of the Mississippi and 2,000 feet in southeastern South Dakota, on the Coteau des Prairies. From this culminating area there is a general easterly and southeasterly slope across southern Minnesota and northern Iowa to the Mississippi.

The Great Plains lie in general higher than any other part of the region. From an altitude of 2,000 feet or less along their eastern margin their surface rises gradually but steadily westward, and in the southwest corner of the region shown in figure 2 it lies more than 3,000 feet above sea level. The surface is diversified, especially in South Dakota, by buttes or isolated knobs, which rise above the general level, but only a few of these knobs are in the region here considered.

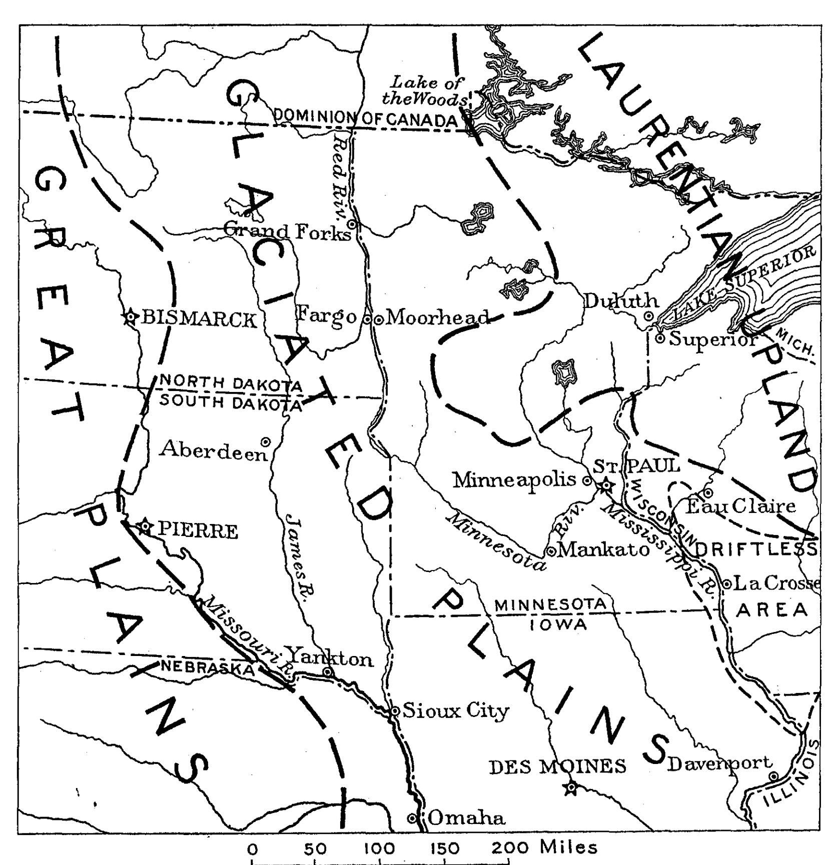


FIGURE 2.—Geographic provinces of Minnesota and adjacent regions. The Herman-Morris district is 150 miles northwest of Minneapolis and lies wholly in the Glaciated Plains.

Except in its northeastern part, about Lake Superior, where some of the ranges rise several hundred feet above the general level, the upland in the region is flat or gently rolling. It is traversed, in the Laurentian Upland and Glaciated Plains, by belts of hilly country that mark the position of glacial moraines, and near the courses of the main streams it is much dissected by the drainage. The larger valleys are several miles wide and 300 to 500 feet deep. Considerable areas of broad, level country remain in many of the interstream areas, and much of Red River Valley is the nearly level bed of an extinct glacial lake. Although of diverse origin and lying at different altitudes, all these level tracts are commonly associated under the generic name "prairie."

#### DRAINAGE.

As has been stated, the region includes parts of three great drainage basins—those of the Nelson, the St. Lawrence, and the Mississippi, which discharge respectively into Hudson Bay, the Gulf of St. Lawrence, and the Gulf of Mexico. Indeed, the basin of the Missouri is so very large and is so completely unrelated to that of the upper Mississippi that it might be regarded as a fourth. Furthermore, Mississippi River, St. Louis River (the ultimate head of the St. Lawrence), and Red River (one of the two ultimate heads of the Nelson), all rise within the region, two of them in Minnesota. The region is thus one of the great centers of radiating drainage on the continent.

Northeastern North Dakota, the extreme northeast corner of South Dakota, northern Minnesota, and the adjacent parts of Canada are drained by Red River and its tributaries into Lake Winnipeg, which discharges through Nelson River into Hudson Bay. Northeastern Minnesota and a little of northern Wisconsin are drained into Lake Superior, part of the St. Lawrence system. The rest of Minnesota, except the extreme southwest corner, the greater part of Wisconsin, and the eastern two-thirds of Iowa are drained directly into the upper Mississippi, and the remainder of the region mapped in figure 2 is drained into the Mississippi through the Missouri. The State of Minnesota lies in part of each of the four drainage basins.

The divide between the basins of Nelson River and of the St. Lawrence crosses the international boundary not far northwest of Lake Superior and trends a little south of west about one-third of the distance across Minnesota. It is continued in the divide between the basins of the Nelson and the Mississippi, which crosses Minnesota south of Red Lake, thence turns southward and passes between Traverse and Big Stone lakes, and thence takes a general northwesterly but rather devious course across the northeast corner of South Dakota and nearly through the center of North Dakota. The divide between the St. Lawrence and the Mississippi drainage crosses northern Wisconsin and turns northward in eastern Minnesota to join the other two in the Giants Range near Hibbing, Minn., at the meeting point of the three basins. Although in general they traverse higher ground, the divides are not, except in northern Wisconsin and northeastern Minnesota, along ranges of mountains or high hills. In much of the region, especially in northern and western Minnesota, the divide traverses flat country and there is an irregular belt, several miles wide, some of which may be drained either one or both ways, according to changing local conditions, and some of which is drained into lakes and sloughs without outlets and thus not into either basin.

As the greater part of the region is drift covered, the drainage is nearly everywhere youthful and in much of the region is incomplete. The southern and western parts of the Glaciated Plains within the region were covered by the earlier drift sheets, and the drainage in those areas, although developed wholly on the drift surface, has reached a fairly advanced stage, and the areas are, on the whole, well drained. The remainder of the Glaciated Plains and the Laurentian Upland were covered by the later drift, except in the Driftless Area, and in these areas the drainage is still very youthful and much obstructed by the drift. Lakes and ponds abound, and much of the country is swampy or marshy. Parts of the country are so flat that comparatively low accumulations of drift have caused flooding of considerable areas, and in the district along and just north of the international boundary there is a network of irregularly shaped lakes that are joined by straits which are virtually parts of the lakes themselves.

#### GEOLOGY.

The hard rocks of the region range in age from pre-Cambrian to Cretaceous and include both sedimentary and igneous rocks, some of them highly metamorphosed and others virtually unaltered. All the igneous and all the greatly metamorphosed rocks are of pre-Cambrian age. Their distribution in the region is shown in figure 3 (p. 2).

The Laurentian Upland within the region is underlain almost entirely by pre-Cambrian rocks representing both the Archean and the Algonkian systems and all the series into which those systems have been divided, so that the region about Lake Superior has been recognized as one of the best in North America for the study of pre-Cambrian rocks and is the one in which they have been studied in greatest detail. The igneous rocks include both intrusive and volcanic types and the highly metamorphosed sedimentary rocks include some of the richest deposits of iron ore on the continent. Beneath the drift, in a part of the Glaciated Plains, lie pre-Cambrian rocks, which are exposed in places along Minnesota River and in several areas in southwestern Minnesota and eastern South Dakota. Undoubtedly rocks of the same age underlie the entire region at great depth, but elsewhere they are covered by younger stratified rocks.

In southeastern Minnesota and southwestern Wisconsin, in the adjacent parts of Iowa and Illinois, and in the lower part of Red River Valley, chiefly in Canada, the Glaciated Plains within the region are underlain by stratified rocks of Paleozoic age, ranging in age from Cambrian to Carboniferous.

The remainder of the Glaciated Plains within the region and all that part of the Great Plains which is included in the area shown in figure 2 are underlain by stratified rocks of Cretaceous and Tertiary age.

The whole region, except parts of South Dakota and Nebraska and the Driftless Area, was covered by ice at one time or another during the Pleistocene epoch and received deposits of glacial drift. These deposits consist in part of till—a heterogeneous mixture of rock waste transported by the ice and remaining practically as the melting ice left it—and in part of stratified drift or outwash—sheets of gravel, sand, and silt laid down by streams that flowed from the melting ice or in lakes that were formed for a time at the margin of the glacier while it was melting. The greater part of Red River Valley is occupied by deposits laid down in the bed of such a vanished lake.

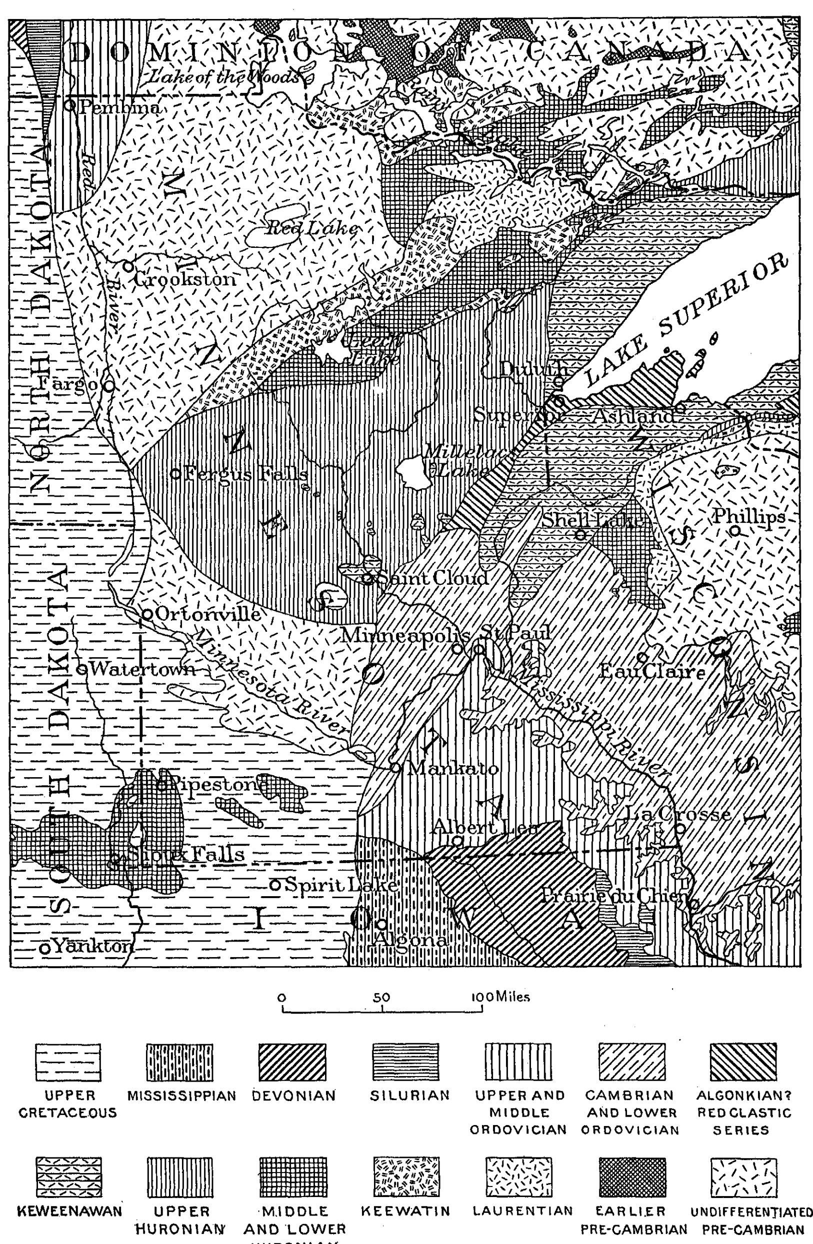


FIGURE 3.—Geologic map of Minnesota and adjacent regions showing the distribution of rock formations at the surface. In much of the area the bedrock is deeply covered by glacial drift. (From the geologic map of North America, U. S. Geol. Survey, 1911, somewhat modified.)

In parts of the region the drift is hundreds of feet thick and completely obliterates the details of the underlying bedrock topography; in other parts it forms a sheet of irregular thickness, generally filling the hollows and leaving the rocky ridges bare. At many places this sheet has been cut through and the underlying hard rock exposed by postglacial streams. At many other places the drift is accumulated in hilly or hummocky tracts, in which there are many undrained hollows. These tracts are the terminal or recessional moraines of the several ice sheets. Beyond these moraines—that is, on the side that was away from the edge of the ice sheet when they were formed—the valleys then existing were filled completely or to a great depth by sand and gravel washed out from the melting ice.

The surface of the Glaciated Plains as a whole is nearly everywhere formed by drift and exhibits a typical drift topography. The Laurentian Upland was also glaciated and is partly covered by drift, which, however, is discontinuous and thin, so that in this region large areas of hard rock are exposed and the topography is that of a surface formed of hard rocks. The boundary between the two provinces has been drawn along or near the line or narrow zone that separates the two sorts of surface.

The pre-Cambrian rocks of the Laurentian Upland and those underlying the drift in the Glaciated Plains have been greatly deformed and metamorphosed. The stratified rocks have been thrown into great folds, have been more or less faulted, and have been considerably invaded by igneous rocks. They now lie in large part in belts that trend northeastward, and the more resistant beds stand up to form the ranges of the Lake Superior district. The Paleozoic rocks of the upper Mississippi district lie nearly flat but dip gently southward or southwestward, so that successively younger beds overlap on the older ones from north to south. (See fig. 3.) Those in Red River Valley dip westward in a similar fashion, the older beds outcropping on the east and being overlain by successively younger strata toward the west. The Cretaceous strata of the western part of the region lie nearly horizontal but dip very gently westward toward the center of the Great Plains. Along their eastern margin they overlap both the pre-Cambrian and the Paleozoic rocks, but the overlap is nearly everywhere covered by drift.

## OUTLINE OF GEOLOGIC HISTORY.

The history of the region during pre-Cambrian time is long, complicated, and obscure, and only the general features of it are known, for later events have destroyed a large part of the record and younger deposits have concealed much of the remainder. Part of the time the surface was beneath the sea and was receiving sheets of sediment derived chiefly from neighboring lands; part of the time it was land and was undergoing denudation in some districts while in others volcanic material was being erupted on the surface or the streams were spreading sheets of alluvial material over the low-lying areas. Periods of quiet alternated with periods of profound deformation during which the rocks were folded, mashed, and greatly altered, and great mountain ranges, generally trending northeastward, were formed and attacked by denudation.

At the beginning of the Paleozoic era most of the region seems to have been land, though a part of it may have been submerged early in the Cambrian period. The period including early and middle Cambrian time was in general, however, a period of subaerial denudation, during which the surface of the greater part of the region was reduced to comparatively slight relief. In late Cambrian time the land slowly sank and the sea, encroaching from the south, spread over southeastern Minnesota and most of Wisconsin, so that Upper Cambrian strata were deposited over that area. Until late in the Paleozoic era the northeastern and central parts of the region shown in figure 2 appear to have formed a peninsula, which projected southwestward into the Paleozoic sea that occupied much of the present interior of the continent. The land was constantly undergoing slow warping and tilting, and the position of the shore line shifted back and forth over a considerable stretch, but probably at no time was the peninsula wholly submerged. During the Silurian period the sea retreated southward, probably into Illinois, but in Devonian time it returned to southern Minnesota. Finally, near the end of the Carboniferous period, all of eastern North America was uplifted, and much of it was greatly deformed, and the sea was driven out of the region.

The uplift near the close of the Paleozoic era left this region far inland and perhaps at a considerable altitude. During the Triassic and Jurassic periods it was undergoing denudation and was probably greatly reduced in altitude, perhaps to a region of slight relief lying near sea level. No record of this time now seems to be preserved in the region. Early in the Cretaceous period the sea again occupied a large part of the Great Plains, and early in Upper Cretaceous time it encroached eastward into western Minnesota and Iowa and some sediments of upper Cretaceous age were deposited in those States. Before long, however, renewed uplift of the land caused the sea to withdraw permanently from the region.

Near the beginning of the Tertiary period the Rocky Mountain region was uplifted and greatly deformed, and before the uplift ceased the Great Plains had been tilted eastward and the drainage of a large area in the interior of the continent took a new course. The streams of this area, which flowed in general westward during the Mesozoic era, now flowed in another direction, probably not greatly different from the present one. The uplift in this region was sufficient to cause the streams to cut down their valleys and to develop essentially the present bedrock topography.

At the beginning of the Quaternary period there was a great change in the climate of northeastern North America. Immense sheets of ice and snow accumulated in Canada and spread outward in all directions, grinding down the surface over which they passed, picking up and carrying along quantities of rock débris, and, when they melted, leaving the surface changed and nearly everywhere covered with a blanket of transported material. The Keewatin center was on the western side and the Labradorean center on the eastern side of Hudson Bay, and there may have been another center—the Patrician — southwest of the bay. Ice sheets from one or another of the centers invaded the United States several times—at least five times, according to the view generally accepted. At their greatest extent they reached central Missouri and southern Illinois and Indiana. At times between the several invasions the ice melted, perhaps altogether, and the climate became as mild as it is at present, or even milder, and the land was inhabited by plants and animals.

Minnesota was invaded by each ice sheet in turn but was probably never wholly covered by any. (See fig. 4.) Each sheet came from a different direction, as shown by the striae on bedrock, covered a somewhat different area, and left a characteristic deposit of drift. In the latest or Wisconsin glacial stage the State was twice invaded by the ice—first by a sheet coming from the north and later by two sheets, one coming from the northeast and the other from the northwest, each leaving a drift deposit of distinctive color.

One of the most interesting events in the history of the region occurred near the close of the Pleistocene epoch. When the margin of the last ice sheet had melted back past the divide between the streams now flowing to the Mississippi and those now flowing to Lake Winnipeg, a lake called Lake Agassiz was formed between the ice front and the higher land on the south. It eventually reached an enormous size and for a long time discharged southward into the Mississippi basin through a large river which flowed in the valley of the present Minnesota River. This river has been named River Warren by Upham, who has described the history of the lake.[1] A

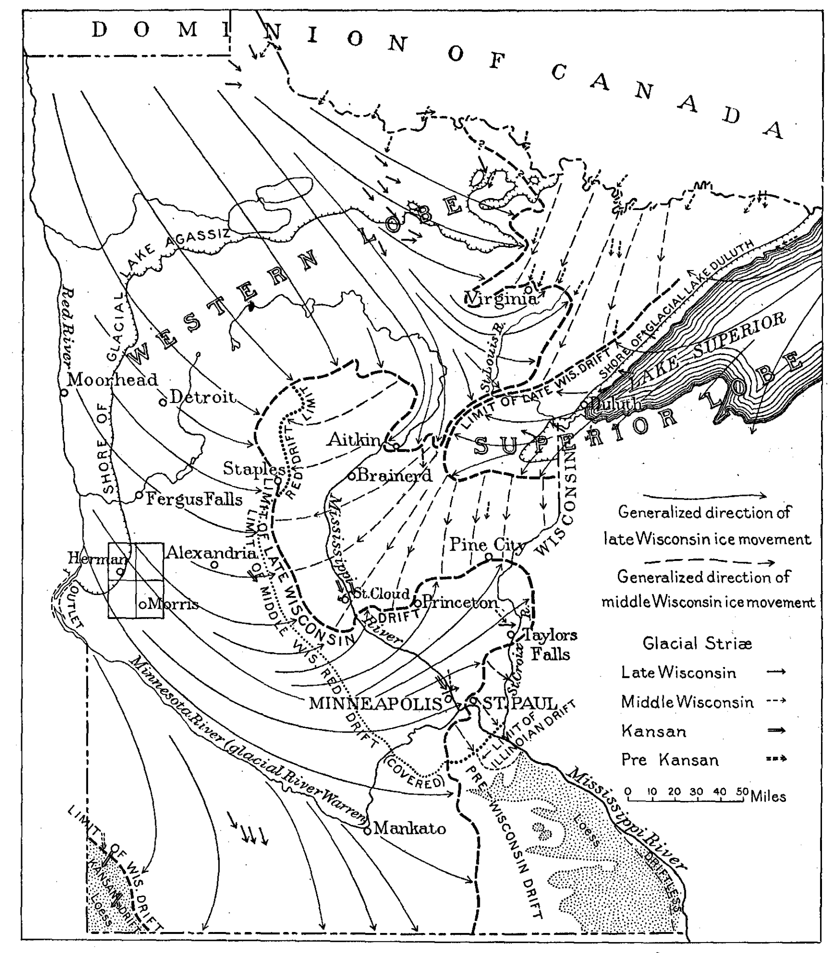


FIGURE 4.—Map of Minnesota showing the maximum extent of the glacial ice sheets, direction of ice movements, and shores of glacial lakes. By Frank Leverett.

similar glacial lake, called Lake Duluth, filled the Lake Superior basin about this time and at first discharged southward through St. Croix River into the Mississippi.

The northeastern part of the continent was apparently depressed by the great weight of the ice and snow that thus accumulated on it, and as the ice gradually melted the land slowly rose, approximately to its former position. The northern part of this region was therefore lifted more than the southern part. During the existence of Lake Agassiz the cutting down of its outlet, the changes in its size and shape due to the continual melting back of the ice dam, and finally the shifting of the outlet from a point where it discharged southward into the Mississippi basin to a point where it discharged eastward into the basin of Lake Superior resulted in the formation of a number of beaches that mark the position of the shore of the lake at different stages. On account of the greater uplift of the land toward the north the northern parts of each of these beaches now stand at a higher altitude than the southern parts.

After the ice disappeared from the region and Lake Agassiz had been drained the conditions became practically the same as those now existing, and slow weathering and denudation has been going on ever since.

## CLIMATE AND VEGETATION.

In the region where the quadrangles lie the summers are warm and the winters are prevailingly cold. The temperature varies greatly from day to day, and the winds are variable. The climate is influenced most by the westerly winds. On many days the skies are clear and the sunshine is bright. The average annual rainfall is about 23 inches. The rainfall is greatest during the growing season in spring and summer. Seasonal rains and general storms are supplemented in summer by thunderstorms, some of which cover an area so small that not all the region receives equal rainfall at the same time. A few local storms are accompanied by a heavy and destructive fall of hail. Some snow falls during the winter and early in the spring.

The land in the quadrangles, in its wild state, was nearly all prairie, but in places that were naturally protected from fires it was forested. Some tracts of wild land or unplowed prairie, such as sec. 27, Roseville Township, still remain covered with rosin-weed and wild grasses. A large proportion of the original woodland is preserved. On the east side of Barrett Lake there is a large grove of burr oak, linden, ash, ironwood, swamp maple, and elm, besides small fruit trees, shrubs, and vines. Small groves of oak grow on the east or south side of other lakes, on islands or in marshes, and in the hilly belt, and willow and cottonwood grow isolated at many places near streams and lakes. Artificial groves planted around farmhouses show that trees will thrive when protected from fires.

[1] Upham, Warren, The glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, 1896.

## TOPOGRAPHY.

### RELIEF.

*General character.*—The area is in greater part the northern extension of the prairie region of the Minnesota Valley, but its northeast corner is crossed by the western border of the Leaf Hills region and its northwest corner lies in Red River Valley—the flat bed of glacial Lake Agassiz. Seen in wide extent the region has the appearance of a level or gently undulating plain, but a near view shows that its surface is marked with knolls and kettles, ponds and swamps, plains and obstructed valleys—the result chiefly of the unequal deposition of glacial drift.

The average altitude of the surface throughout the southern, central, and central-northern parts of the area is not far from 1,150 feet above sea level. From this general level the surface rises to the hilly morainic belt in the northeast corner and descends to the lake plain in the northwest corner. The highest point in the area, which is in the northeast corner of the Barrett quadrangle, on the line between secs. 12 and 13 in Erdahl Township, is a little more than 1,390 feet above sea level, and the lowest part, along the western side of the Herman quadrangle, a little south of its northwest corner, lies just below 1,010 feet.

The area includes three chief topographic divisions—the hilly belt in its northeastern part, the prairie upland, which occupies nearly all of it, and the lake plain in its northwestern part. The otherwise even surface of the lake plain is broken by two lines of beach ridges, and the prairies are crossed by several valleys, the larger fairly broad and flat or terraced and the smaller mostly knolly. These ridges and valleys constitute minor features of the relief.

*The hilly belt.*—A belt of morainic hills lies along the eastern side of the Barrett quadrangle, east of Erdahl and of Chippewa River, and extends southward into the Morris quadrangle to the point where the river leaves it. Only the western or inner margin of this morainic belt lies within the area. It includes several hills that stand more than 1,300 feet above sea level and many well-marked undulations, knolls, and ridges, as well as abundant boulders. These features are found not only among the highest hills but also at lower altitudes in the belt, which includes also many basins or kettles. Some of the larger basins contain deep ponds and lakes. The hilly belt is clearly separated from the prairies, even where the valley of Chippewa River does not intervene.

*The prairie upland.*—The somewhat undulating plain that occupies the greater part of the area contains widely separated knolls and ridges whose slopes are not generally steep and many low, broad swells. Where the surface is nearly flat there are shallow basins or kettles, many of which contain small swamps or are wet in rainy seasons. Some basins occur on sloping ground, though few of them hold water, and even where the surface rises distinctly above the general level there are low knolls and intervening kettles. For example, the conspicuous prominence on which School No. 21 stands, 4 miles west of Hancock, is covered with low knolls and shallow basins, though only the basins at the top of the prominence contain swamps or small meadows. In addition to the minor knolls and basins there are everywhere broader ridges and depressions, which are sufficiently marked to be shown by the contour lines on the topographic maps. For a few miles west of the Pomme de Terre Valley the general surface is diversified by knolls and ridges that approach in sharpness of outline the morainic hills.

On the other hand, at some places where the surface deposits consist of outwash gravel instead of till, especially in an area about 3 miles west of Fish Lake in the Chokio quadrangle, in a broad tract south of Mustinka River about 4 miles northeast of Herman, and in a belt extending southward from Burr Lake to a point east of Moose Island station, the surface is flat or only gently sloping and bears few if any knolls or ridges.

*Valleys.*—The general continuity of the prairie upland is broken by valleys that are 20 to 50 feet deep and about a mile wide. Although these valleys are lower than the adjacent upland, not all of them are now occupied by streams, and only one, the valley of Chippewa River, has been cut to any great extent by the stream that occupies it. They are, in fact, old valleys that were partly masked but not wholly filled by a drift sheet. Their bounding slopes and, to a considerable extent, their bottoms are morainic in appearance, being pitted by kettles and deep basins containing lakes and swamps.

A valley of this sort extends northeastward from a point south of Pomme de Terre Lake, in the Barrett quadrangle; another extends eastward from Barrett Lake to Sylvan Lake and thence across Chippewa River; a third begins at a point in the Pomme de Terre Valley 3 miles south of Barrett and extends past Spring, Elk, and Lower Elk lakes and across Chippewa River into sec. 6, Solem Township; and a fourth extends from Pomme de Terre Lakes, in the Morris quadrangle, eastward to Chippewa River at Swan Lake Church. Other valleys extend from points near the North Star Mill eastward to Scandia Lake and northward to Swan Lake, and from a point 4 miles southeast of Morris to Long Lake and thence eastward along the railroad.

All the valleys just described lie east of the Pomme de Terre and extend from that stream to the Leaf Hills. Their sharp knolls and deep basins are similar to those of the morainic belt, and they look like low extensions or arms of that belt across the upland prairies. In soil and other features, however, they are like the prairie upland.

A similar valley lies west of the Pomme de Terre, extending from a point a mile north of the mouth of Mud Creek westward to the creek and thence along its course toward Alberta; another such valley is occupied in part by Wintermute Lake; and a third extends from the north side of the Pomme de Terre Lakes toward the northwest corner of the Morris quadrangle.

The valley of the Pomme de Terre is bordered on both sides chiefly by steep slopes or bluffs, but at some places, as west of Barrett Lake, by a group of knolls. The Mustinka Valley is likewise bordered in part by bluffs and in part by groups of knolls, and from it extend other valleys—one to the south side of Round Lake, another past Jones Lake to the south end of Cormorant Lake, and a third to Burr Lake. Many subordinate branches of these valleys merge into the prairie upland so gradually that no sharp boundary can be drawn between them.

The valley of Chippewa River from Sylvan Lake southward, all that part of the Pomme de Terre Valley that lies within the area, the valley of the lower part of Mud Creek, and that of the Mustinka down to the point where it passes the Norcross beach are flat-bottomed, range in width from a few hundred yards to a mile or more, and are floored with gravel and alluvium. The surface of these valleys is flat or gently sloping or is terraced in places but is rarely uneven or knolly. A knoll in the Pomme de Terre Valley southeast of Morris is crossed by the railroad and highway.

*The lake plain and beaches.*—The low plain in the northwestern part of the area, in the western half of the Herman quadrangle and the northwestern sixth of the Chokio quadrangle, is a small part of the bed of glacial Lake Agassiz. Its regularly even surface, on which there are a few broad swells but no knolls or ridges other than the beach ridges described below, slopes gently from an altitude of about 1,090 feet above sea level along the eastern margin of the plain to 1,010 feet in the northwest corner of the Herman quadrangle. In this area the plain is divided into three belts or strips by two beach ridges. The surface of the part of the plain that lies east and southeast of the highest or Herman beach is less uniform than that of the rest of the plain.

As the plain across which they extend is flat the beach ridges, although nowhere more than 20 feet high, are everywhere conspicuous. The Herman beach, which runs southward west of Herman across the Herman quadrangle and across the northwest corner of the Chokio quadrangle, appears to be a practically continuous level-topped ridge. The Norcross beach is not continuous but recurs at intervals from north to south across the western part of the Herman quadrangle. At some places it is only a low swell; at others, as at Norcross, it is a fairly sharp ridge.

### DRAINAGE.

*Direction of drainage.*—The run-off of the northwestern part of the area flows by way of Mustinka River to Bois de Sioux River, a tributary of Red River, and thence by Nelson River to Hudson Bay; that of the eastern and southern parts flows through Chippewa and Pomme de Terre rivers to the Minnesota, and thence by the Mississippi to the Gulf of Mexico. The subcontinental divide between the two drainage basins enters the Barrett quadrangle northwest of Thorsborg and takes a general southerly course across the quadrangle, passing west of Long, Eide, Cormorant, and Patchen lakes. In the Morris quadrangle it turns southwestward, passing just south of Harstad Slough and entering the Chokio quadrangle near Donnelly, which stands practically on the divide. From Donnelly it runs southwestward, passing northwest of Chokio, and leaves the Chokio quadrangle near the southwest corner. The lowest point on the divide within the quadrangles is a little more than 1,100 feet above sea level at a place 2 miles southwest of Donnelly. It is noticeable that the divide does not traverse the highest land in the area.

Along the divide, as well as in other places, some bodies of water lie in basins so deep that they do not overflow, and others overflow only after a succession of wet seasons. After several consecutive dry seasons the small streams and finally even the lakes, ponds, and sloughs dry up. There is thus an irregular belt along the divide of varying width from year to year, that is not at all times tributary to the rivers.

Much of the area is artificially drained by extensive ditches, the effect of which is to make the small streams more regularly and frequently intermittent by preventing the ponding of water in the basins through which they run. As the region is relatively flat, the ditches are extended even to the divides. As the lines of artificial drainage run in the same general direction as those of the natural drainage that they displace, the divides are very little changed in position by the ditches but are everywhere made more apparent.

*Streams.*—Chippewa River enters the east side of the Barrett quadrangle in Evansville Township, where it at first flows rapidly through the hilly belt from Albert Lake to Peterson Lake. It then takes a general southerly course for 18 miles, descending 105 feet in that distance, and leaves the east side of the Morris quadrangle in the northern part of New Prairie Township. It is about 20 feet wide and 2 feet deep and flows over a gravelly bed throughout its course. Its banks are low except near Albert Lake. At some places its flood plain is only 100 feet wide and its channel is 3 to 10 feet deep, but a large part of its course is through meadows and lakes.

Pomme de Terre River enters the area in Pomme de Terre Lake and flows almost directly south through the Barrett and Morris quadrangles, descending 110 feet in 35 miles. It is 40 to 60 feet wide. Part of its course is between low banks in a valley that is only two or three times as wide as the stream, and the remainder is through swamps and lakes. The valley is floored throughout its length by gravel, though at a few places the bed of the stream is on till.

Mud Creek is the chief tributary of the Pomme de Terre from the west. Near its mouth, 3 miles south of Morris, it flows in a channel 10 feet wide within a valley 150 feet wide and 15 feet deep. It is fed by several springs that are 4 to 6 miles above its mouth. Farther up the valley the stream is intermittent, but at times of flood it receives water from points as far away as the southwest corner of the Chokio quadrangle and also from a point 4 miles east of Donnelly. Unlike the Chippewa and the Pomme de Terre, the creek receives waters from no lakes that tend to control the flow and the turbidity, and it is therefore somewhat muddy.

Mustinka River enters the Herman quadrangle from the north in Elbow Lake Township and flows southward for 9 miles, then turns abruptly and flows westward through the middle of the quadrangle to the west border, descending more than 80 feet in the distance. The stream is about 20 feet wide between banks about 5 feet high and meanders in a valley that is 200 feet or more wide. West of the Herman beach it flows in such a valley as far as the Norcross beach, west of which it flows between low banks in a channel cut in the flat prairie, without any valley or well-developed limit to its flood plain. In very high flood part of the stream overflows northwestward from the NE. ¼ sec. 10, Gorton Township, across secs. 17 and 18 to Rabbit River.

Fivemile Creek, near Herman, and Twelvemile Creek, in the northwestern part of the Chokio quadrangle, are tributaries of the Mustinka. Intermittent streams and drainage ditches, carrying water from artesian wells in North Ottawa Township in the northwestern part of the Herman quadrangle reach Rabbit River, which is a tributary of Bois de Sioux River.

*Lakes and sloughs.*—Except in the tract west of the Herman beach the area contains many lakes and ponds, sixty of which have been named and nearly three hundred others are unnamed, most of them being locally called sloughs. Pomme de Terre Lake, part of which lies outside this area, is larger than any lake that lies wholly within the area. Cormorant Lake and Long Lake, in the Barrett quadrangle, and Swan Lake, in the Morris quadrangle, are each more than 2 miles long, and fifteen others are a mile or more long. All are shallow. The level of the lakes along Pomme de Terre and Chippewa rivers is constant, but that of most of the others varies greatly between cycles of years of more and cycles of years of less rainfall, as well as from season to season.

The shores of these lakes above the level of high water are steep, but most of them have a low, more or less gravelly beach, which extends from the high-water line toward the low-water line. In many places raised gravelly beaches separate the lakes from adjacent swamps. One such beach, on the southeast side of Cottonwood Lake (Herman quadrangle), is more than 100 feet wide and 10 feet high. The slope facing the lake is gentle, but the slope facing the swamp is steep, and the top of the divide between the two is forested. Lake Hattie (Chokio quadrangle) has a high gravelly beach at its west end. Between Elk Lake and Lower Elk Lake (Barrett quadrangle) there is a double barrier of raised gravelly beach. The bottoms of these lakes are nearly flat, as is well seen in the basins of dry lakes.

The lakes are prevailingly round, and very few contain islands. They are exposed to the winds of the open prairie, and their banks are of clay that has been easily eroded when frequent changes of level of the lake have destroyed the protecting vegetation. Therefore the waves have cut away exposed points and projecting shores and have transported sand and gravel alongshore to make raised beaches, and the lakes have at the same time become wider, more rounded, and shallower.

The so-called sloughs are lakes that are either small or shallow and grown full of sedges and rushes, or that dry up too frequently to be inhabited by fish, or that are notably alkaline, but in other respects they are like the lakes. Even some of the large lakes have been dry in exceptional seasons.

The bed of Lake Hattie is said to have been dry in September, 1895. Some of the lakes have been artificially drained. A large, irregular lake called Moose Island Lake, which has been mapped by Warren Upham[1] as lying 2 miles southwest of Donnelly in 1888, has now disappeared, but its shores remain as an escarpment that surrounds fields and meadows. Its general outline is indicated by the 1,100-foot contour on the topographic map, which also shows the ditches by which the lake was drained. A lake that once extended from a point 1 mile west to another 2 miles south of Chokio and another lake in secs. 31 and 32, Baker Township, have also been drained. Pullman Lake, near Herman, has been drained since the topographic map was made.

*Marshes.*—Grassy marshes, both large and small, are abundant in the area. Some occupy the beds of naturally or artificially drained sloughs or lakes, and many little ones that are distributed over the till plain occupy glacial kettles, most of which are small and shallow but may hold water for some time, for the clay of the till plain is too impervious to allow the water to sink away quickly. As not much peat grows in the area, the marshes are simply intermediate in character between the prairie on the one hand and the sloughs on the other. Artificial drainage has already converted much marsh to prairie or field. In the gravelly tracts, marshes are found only in basins that are as low as the level at which ground water stands under the plain. Along the Chippewa and Pomme de Terre valleys the many marshes are all practically at river level.

The lake plain west of the Herman beach now contains few marshes, having been artificially drained by ditches.

### CULTURE.

In 1910 Morris, the county seat of Stevens County, had a population of 1,685, and Elbow Lake, the county seat of Grant County, a population of 771. The other towns in the area are Herman, Hancock, Hoffman, Chokio, Barrett, Donnelly, Norcross, and Erdahl. The country outside the towns is rather sparsely populated, and the farms are large, averaging in area more than 240 acres. Several lines of the Northern Pacific, the Great Northern, and the Minneapolis, St. Paul & Sault Ste. Marie railway systems enter or cross the area.

Agriculture and trade are the chief industries in the area, which contains numerous broad grain fields. Many lake basins and marshes have been drained and converted to fields, and the remaining wild or unplowed prairie is used for growing hay or for pasture. Manufacturing is practically limited to a few flour mills. Morris is the site of a State agricultural school, a branch of the State University.

The early explorers and traders who penetrated the area crossed it in canoes along the rivers. Settlement followed the building of the railways and began after 1870. The river called the Pomme de Terre by the French traders had been known as the Tipsinah by the Indians, on account of the abundance along it of the prairie turnip or tipsinah (*Psoralea esculenta* Pursh).

## DESCRIPTIVE GEOLOGY.

### GENERAL CHARACTER OF THE ROCKS.

The exposed rocks of the area are all surficial deposits of Quaternary age and comprise unconsolidated till, gravel, sand, and silt, in part glacial and lacustrine deposits of Pleistocene age and in part alluvial deposits of Recent age. The bedrock beneath the surficial deposits consists everywhere, so far as known, of crystalline rocks of pre-Cambrian age, chiefly Archean granite. Bedrock is not exposed anywhere in the area but has been reached in several well borings at depths ranging from 42 to 480 feet. Some of these records are included in the accompanying table.

### ROCKS BENEATH THE DRIFT.

The bedrock, so far as it is known in this area, is like the Archean rock that outcrops along Minnesota River near Ortonville, about 18 miles southwest of the southwest corner of this area. In the well records it is called granite. At the Norcross well red granite was found. The railway well in Herman, as reported by Upham,[2] penetrated 57 feet into "Archean rocks, being quartzose granite with red feldspar, white micaceous quartzite, and mica schist of several varieties." One well near Chokio penetrated 8 feet into granite. As the granitic rocks are hard and seldom yield water the bedrock is not sought for by drillers nor is it, when struck, penetrated any farther than is necessary to prove that it is granite in place. Knowledge of the Archean rocks beneath the quadrangles is therefore meager. Somewhat younger crystalline rocks, which might be expected to be associated with the Archean rocks, are not proved to be entirely absent, and, in fact, the white quartzite mentioned by Upham may be of this class and be Algonkian.

The surface of the granitic rocks, where it is encountered in drilling, appears to be fresh, not weathered or rotted. Wherever Cretaceous strata have been recognized in this part of Minnesota the surface of the underlying granite is weathered and decomposed, and the absence of such a decomposed zone at the surface of the granite beneath these quadrangles indicates that the Cretaceous strata also are absent and have not been mistaken, in well logs, for glacial drift. The known Archean rocks beneath the area are immediately overlain by glacial drift.

### FORM OF BEDROCK SURFACE.

The well borings show that the bedrock surface is not level nor parallel with the present surface of the ground. (See figs. 5, 6, and 7.) The accompanying table shows the depths of several wells that reach bedrock, and also the depth of three wells that did not reach bedrock, which are included in the table because they show the great depth to bedrock at some places. The table shows that the bedrock surface lies lower in the southeastern part of the area at Hancock than in the southwestern part, south of Chokio, although the altitude of the present surface is the same at the two places. It also shows that the bedrock surface is highest at a place north of Herman, although the land surface at that place is not so high as at Hancock. The deep well at Elbow Lake indicates conditions similar to those at Hancock, although the elevation of the surface is somewhat higher. Three neighboring wells near Herman show a descent of 90 feet in the bedrock surface where the present surface has a descent of only 6 feet.

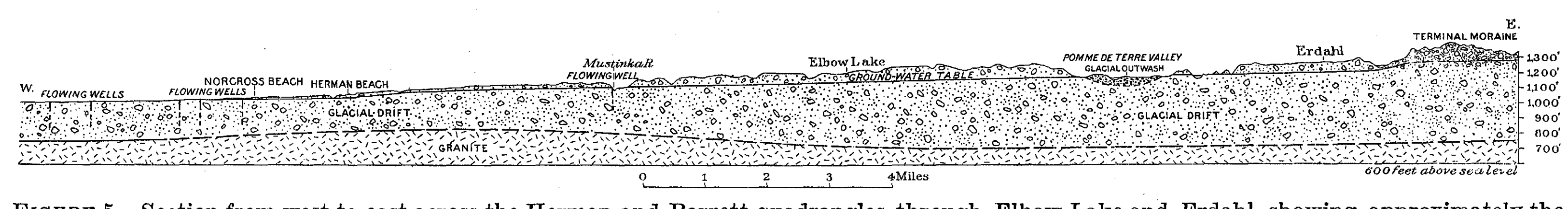


FIGURE 5.—Section from west to east across the Herman and Barrett quadrangles through Elbow Lake and Erdahl, showing approximately the thickness of the glacial drift and the depth to bedrock. The ground-water table (the approximate surface of standing water in the drift) is shown by the continuous heavy line.

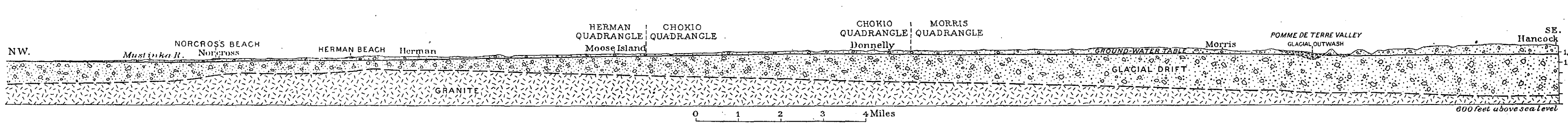


FIGURE 6.—Section along the Great Northern Railway through Norcross, Herman, Donnelly, Morris, and Hancock. The ground-water table is shown by the continuous heavy line.

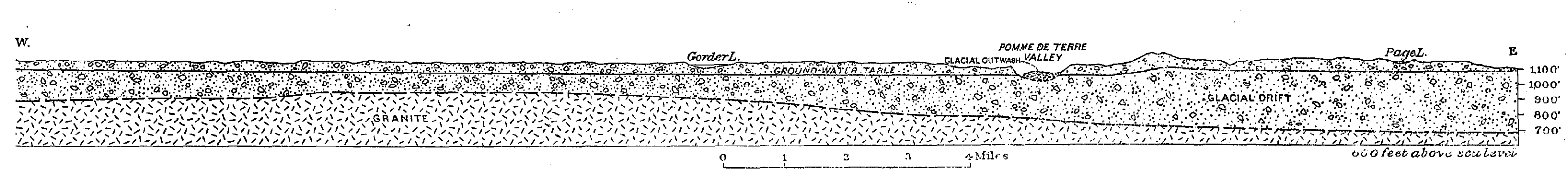


FIGURE 7.—Section from west to east 1 mile north of the southern boundary of the Chokio and Morris quadrangles. The ground-water table is shown by the continuous heavy line.

*Relation of bedrock surface to present surface as found by well borings in the quadrangles.*

| Locality. | Depth of well. | Depth to bedrock. | Altitude of land surface above sea level. | Altitude of bedrock surface above sea level. |
|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Hancock village (south edge of the area) | 480 | 480 | 1,160 | 680 |
| Elbow Lake village (north edge of the area) | 450 | ------- | 1,220 | ([a]) |
| Baker Township: NE. ¼ sec. 26; 4 miles southeast of Chokio | 200 | 200 | 1,160 | 960 |
| Everglade Township: SW. ¼ sec. 5; 6 miles northwest of Chokio | 118 | 110 | 1,080 | 970 |
| Eldorado Township: SW. ¼ sec. 27; 8 miles north of Chokio | 160 | 160 | 1,080 | 920 |
| Logan Township: SE. ¼ sec. 32; 5 miles southwest of Herman | 233 | ------- | 1,057 | ([b]) |
| Herman railway station | 189 | 132 | 1,072 | 940 |
| Logan Township: NE. ¼ sec. 13; near Herman | 100 | 100 | 1,078 | 978 |
| Logan Township: E. ½ sec. 12; 1 mile north of Herman | 42 | 42 | 1,072 | 1,030 |
| Gorton Township: NW. ¼ sec. 34; one-half mile southeast of Norcross | 138 | 138 | 1,042 | 904 |
| Gorton Township: NW. ¼ sec. 27; one-half mile northeast of Norcross | 150 | ------- | 1,045 | ([c]) |
| Average | 205+ | 170+ | 1,097+ | 898+ |

[a] Less than 770 feet above sea level. [b] Less than 824 feet above sea level. [c] Less than 895 feet above sea level.

Many wells in the Chokio and Morris quadrangles not listed in the above table are 200 feet deep and yet do not reach bedrock, and it is probable that its surface in these two quadrangles lies as deep as it is in the well at Hancock. In any case the bedrock surface has a general slope from west to east, in the direction opposite to the slope of the present surface of the land, which is from east to west. The relief of the bedrock surface is at least 350 feet. The relation of the drift to bedrock is shown in the sections in figures 5, 6, and 7.

### QUATERNARY SYSTEM.

#### PLEISTOCENE SERIES.

##### GENERAL RELATIONS.

The glacial drift, which covers the entire area, ranges in thickness from 40 to 500 feet and has an estimated average thickness of more than 250 feet. It comprises at least two drift sheets, of Kansan and Wisconsin age, respectively, and possibly a third, of pre-Kansan age. These drifts are all nearly alike and consist mainly of an unconsolidated heterogeneous mixture of rock fragments of many kinds and sizes, comprising boulders, cobbles, pebbles, sand, rock flour, and clay, either all mixed together or more or less assorted into separate deposits. The greater part of the drift consists of till or boulder clay—a nearly unassorted mixture of rock fragments of all sizes, most of them more or less rounded pieces of fresh rock. Another large part consists of assorted coarse or fine gravel, sand, silt, or clay. The assorted deposits lie upon, in, or beneath the till in various forms and amounts.

Fresh drift, in which the original rock fragments are not decomposed, is close beneath the soil in all parts of the area, so that its top is exposed in many places, even in shallow excavations for roads or ditches. In a few railroad cuts and in a few outcrops along streams and about the shores of lakes the drift is exposed to a greater depth but nowhere to more than 40 feet, so that the greater part of its thickness in the quadrangles is known only from well borings. The best exposures are along the Great Northern Railway from a point southeast of the Pomme de Terre Valley to Morris; along the Minneapolis, St. Paul & Sault Ste. Marie Railway on the east side of Chippewa River, between Barrett and the east side of the Pomme de Terre Valley, and north of Elbow Lake; also along the drainage ditches northwest of Alberta and the ditch west of Herman; and on the shores of Barrett Lake.

The till consists chiefly of a mixture of rock flour and clay, and although boulders are common they form but a small part of the whole. The boulders include both crystalline and sedimentary rocks. Among the crystalline rocks are red and gray granites, gneisses, dark schists, and some green, bluish, and black fine-grained rocks; among the sedimentary rocks are light-buff, yellowish, and gray limestones. The granites and limestones are most abundant. The cobbles and pebbles that occur in the till and that compose a large part of the outwash gravels include pieces of shale in addition to the same types of rock as the boulders. Much more than half the pebbles are limestone, about one-third are granite or other crystalline rocks, and among the rest are shale, chert, flint, and vein quartz. Some gravels or assorted deposits consist mostly of pebbles, whereas others contain few pebbles and much coarse sand, which is mainly composed of clear quartz grains but includes also many small fragments of limestone, feldspar, chert, shale, and fine-grained crystalline rock.

Beds of gravel and coarse sand are found in the glacial outwash overlying the till, and lenses of different sizes and forms are also penetrated in most places by wells that pass through the till. There are also many deposits of fine sand or quicksand within the till, either in distinct beds or in irregular patches. Some silt occurs on the surface of old lake beds.

The drift as a whole appears to have been derived from the same general source, for it is made up of the same kinds of material throughout. It is all calcareous or gray drift as distinguished from the less calcareous or red drift of some other parts of the State, its abundant limestone pebbles and fragments of Cretaceous shale being characteristic of the gray drift of Minnesota. Some of the limestone boulders contain fossil corals and shells such as are found in the Ordovician, Silurian, and Devonian limestones of Manitoba, so that the limestones of the drift presumably came from that region. The glaciers that brought the drift evidently approached the area from the north and doubtless originated in the Keewatin glacial center, in the region west of Hudson Bay.

[1] Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, pl. 49, 1888.
[2] Upham, Warren, Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 503, 1888.

### PRE-KANSAN DRIFT.

The pre-Kansan drift is widely distributed in the region but only as remnants, for it had been greatly eroded before the next drift sheet was deposited. It is not known to exist in these quadrangles, but its preservation, at least in part, beneath the younger drift is not improbable in places where the whole drift is now thickest. As seen elsewhere in the region the pre-Kansan is a dark-colored till containing proportionately much clay, little sand, and few pebbles and boulders. The freshly exposed till is blue-black in its deepest layers, dark buff in the leached and partly oxidized portion, and reddish brown in the weathered and oxidized subsoil zone. Because of its dark color and clayey character it is readily mistaken in well records for Cretaceous beds. Where the oxidized zone and leached top portion was swept away by the next oncoming glacier, the remaining material can with difficulty be distinguished from overlying Kansan till. The pre-Kansan includes very little outwash or intercalated gravel beds.

### KANSAN DRIFT.

Although nowhere exposed in the quadrangles, the Kansan or "old gray" drift sheet undoubtedly underlies the Wisconsin drift throughout nearly or quite the whole area, but north of Herman, where the bedrock lies less than 50 feet below the surface, it may be everywhere absent. The Kansan consists largely of till but contains also beds of silt, sand, and gravel. It is blue-black except near its top, where a zone about 30 feet thick has been leached and partly oxidized and is buff. Except where removed by later glaciation this zone marks the top of the sheet. The till is hard and somewhat consolidated so that it may be distinguished from the Wisconsin "young gray" drift, even in well borings. The Kansan drift sheet is at some places 300 or even 400 feet thick and comprises the greater part of the whole drift of the quadrangles. The old, partly buried valleys, described under the heading "Topography," were eroded in the surface of the Kansan drift and are masked or only partly concealed by a veneer of Wisconsin drift and possibly of Iowan drift, which, however, has not been recognized in Minnesota.

### WISCONSIN DRIFT.

*General character.*—The Wisconsin or "young gray" drift is found throughout the four quadrangles, but its average thickness is less than 50 feet. It is characteristic gray drift, containing proportionately much clay and numerous limestone boulders and pebbles. In its deeper part it is blue-black or dark gray, but its uppermost 15 to 20 feet is leached and partly oxidized and is yellowish buff.

The distribution of the different forms of drift in this sheet—terminal moraine, ground moraine, drift masking the buried valleys, kames, outwash deposits, lake silts, and lake beaches—corresponds notably to the surface features, many of which owe their form and position directly to such distribution.

*Terminal moraine.*—The drift of the tract east of Erdahl and of Chippewa River, which is mapped as terminal moraine and which includes many knolls and basins of different forms and sizes, is characteristically heterogeneous. Some knolls are all till; others contain more or less gravel, sand, silt, or clay. The till is of irregular thickness, but it covers the surface of the knolls and nearly everywhere underlies the basins. The number of boulders in the till differs greatly from place to place but as a whole is great. Where the assorted drift is exposed in cuts it has been warped and crumpled and in part mixed into the till. The till sheet and boulders were deposited directly from the ice while it was melting, whereas the assorted drift was spread out in horizontal beds near the front of the glacier by small temporary streams that flowed from the ice. The irregular knolls and crumpled drift are the characteristic result of the oscillation of the ice front across the morainal belt as the result of the varying relation between the rate of the advance of the glacier and that of the melting back of its margin.

The small knolls and basins are clearly due to irregularities in the deposition of the till of the moraine. The larger hills are also accumulations of till, and at least a part of their height is due to the piling up of Wisconsin drift, but the whole moraine may rest on an uneven surface of Kansan drift, either old terminal moraine or dissected ground moraine.

*Ground moraine.*—The ground moraine of the quadrangles resembles the terminal moraine in being composed chiefly of till and in having boulders scattered over its surface, but it differs from it in having fewer and less abrupt knolls and ridges and wider, shallower basins and in containing fewer boulders. Beds of more or less crumpled assorted drift in the till indicate that it was deposited in part near the margin of the glacier in much the same manner as the terminal moraine, though it was as a whole overridden by the ice. The knolls were probably formed during a relatively short period when the ice was disappearing from the area.

The amount of assorted drift in the till of the ground moraine is roughly proportional to the unevenness of its surface. Gravel and sand occur at the surface at very few places except in the outwash plains and lake beaches which overlie the till and which are described below. A few excavated knolls now show gravel or sand beds, which, in greater part at least, lie within the till. Assorted drift within the till appears to be encountered in wells most commonly and most abundantly at depths of 30 to 40 feet. In the level parts of the till plain many wells have encountered no gravel or coarse sand within 200 feet of the surface but instead beds of silt or of quicksand. Stratified drift beneath the upper till is found most frequently in the low and rough belts that occupy the masked or buried valleys already described.

In these masked valleys the till is in places as much as 40 feet thick and generally rests on abundant gravel, which in turn rests on a lower deposit of older till that lies in what are evidently valleys cut in the surface of the Kansan drift before the Wisconsin drift was deposited. The knolly surface is due not so much to unequal deposition of the till as to the uneven surface of the underlying gravel, which appears to have been thrust into knolls and ridges while a nearly uniform sheet of till was being laid down upon it.

*Kames.*—A small group of kames on the north boundary of Hodges Township (Morris quadrangle), at the corners of Framnas and New Prairie townships, includes several steep-sided knolls consisting of gravel and boulders.

*Glacial outwash.*—The tracts of glacial outwash deposited during the recession of the margin of the Wisconsin ice from the region lie along the present river valleys in succession from south to north. Those along Mustinka River and its tributaries are isolated from one another, those along Chippewa River are partly joined together, and those along Pomme de Terre River form a continuous, more or less overlapping succession. The outwash lies on an uneven surface of till, so that although each deposit has a comparatively flat top, the thickness of the outwash is far from uniform and is in places at least 75 feet. The deposits lie not only in the bottoms of the valleys but also on the slopes of their sides, so that those that are piled highest are not necessarily thicker than the lower ones.

These outwash deposits consist principally of gravel, but they everywhere contain sand, even where the gravel is very coarse. At some places, however, as in the tract 6 miles north of Chokio, the pebbles are so small and few that the deposit appears at first sight to be all sand. The deposit northeast of Herman is mainly sand on its west side but is coarse gravel and cobbles on its east side. At other places the coarse gravel and cobbles occur on the west side of a tract, as southeast of Hoffman, west of Hancock, and at Barrett and Sylvan lakes. At many places the gradation from fine to coarse material is regular between adjacent parts and between successive beds. The outwash is in part well assorted and stratified or cross-bedded, but it is in part also poorly assorted.

### LACUSTRINE DEPOSITS.

*Minor lacustrine deposits.*—At a few places deposits of brown loam or of stratified silt and clay lie on the till plain. Such deposits are exposed on the road in the S. $\frac{1}{2}$ secs. 15 and 16, Erdahl Township; in the NE. $\frac{1}{4}$ sec. 20, Elk Lake Township; north of the southeast corner of sec. 12, Morris Township; and in part of the SE. $\frac{1}{4}$ sec. 24, Morris Township. They are only a few feet thick and of small extent and appear to have been deposited in temporary ponds at the margin of the ice before the formation of Lake Agassiz.

*Silt of Lake Agassiz.*—The area once covered by Lake Agassiz is underlain by a moderate thickness of till, in which is included gravel, sand, and silt. It is like the ground moraine except that it has a more even surface and the till is in part overlain by lake deposits, consisting of sand and brown loam. Although a large part of the old lake bottom remains a bare till surface, large areas are covered by a thin deposit of silt or loam, and along Fivemile Creek, in sec. 33, and along the west side of secs. 28, 21, and 16, Logan Township, the silt is several feet deep. A narrow area which borders on the east the Herman beach deposits of glacial Lake Agassiz is underlain by till that has a flat surface and is thinly covered with silt. This narrow belt is part of an area that was temporarily occupied by a lake that lay at the edge of the ice when the ice sheet covered the northwest corner of the quadrangles, and is regarded as an early stage of Lake Agassiz. As shown on the geologic maps this belt passes south through the center of the Herman quadrangle, widening southward and spreading out into a broad area in the northwest corner of the Chokio quadrangle. The soil in this strip is loamy and in places also sand and loam lie between the soil and the till. In parts of secs. 31 and 32, Eldorado Township, the brown loam beneath the soil is several feet thick.

*Herman beach of Lake Agassiz.*—The Herman beach, or "The Ridge," as it is called, runs southward across the Herman quadrangle west of Herman and across the northwest corner of the Chokio quadrangle. It is continuous except where it is crossed by streams or other drainage lines, and even at some such places parts of the ridge overlap without leaving an actual break or gap between the two sides of the stream. The beach stands a few feet above the surface on either side but appears twice as high on the west or lakeward side as on the east or landward side, for the western slope includes both the thickness of the beach and the depth to which the till was excavated by the waves of the lake while the beach was being made. At most places the beach deposit, which consists of gravel and sand, is more than 10 feet thick and is in general more than 300 feet wide. The gravel is such as would be formed by the washing and sifting out of pebbles from the till. South of Fivemile Creek the ridge is sandier than it is north of the creek.

The beach forms either a single ridge or in places two, three, or four more or less distinct ridges, of which the outer or easternmost one is highest. West of Herman, on the south line of sec. 15, Logan Township, the beach has two ridges. The lower one is of gravel about 10 feet deep and the higher is chiefly sand about 15 feet deep. On the north line of secs. 15 and 14, Logan Township, the beach is a single ridge 16 feet high on the west side and 8 feet high on the east side and has a maximum thickness of 13 feet of gravel. Where the ridge is cut through by the Great Northern Railway, near Herman, it consists of 6 feet of gravel resting on a low ridge of till. (See fig. 8.) The beach is there 300 feet wide. In sec. 1, Logan Township, a well on the beach penetrated 18 feet of sand and gravel overlying the clay or till.

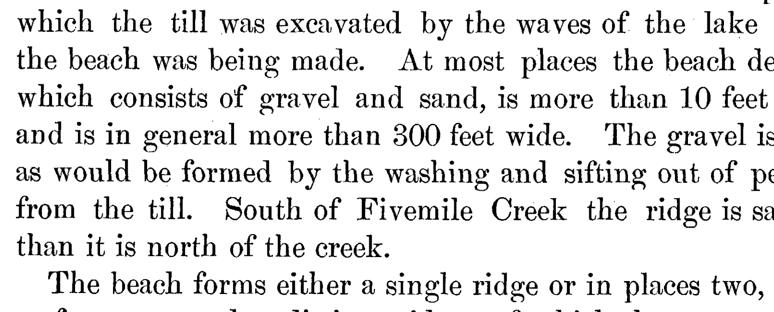


FIGURE 8.—Section through the Herman beach along the Great Northern Railway near Herman, Minn. The beach gravel here surmounts a hill of till.

*Norcross beach of Lake Agassiz.*—The Norcross beach is west of the Herman beach and roughly parallel to it. It is not continuous across the area and in other ways it is not so strongly developed as the older beach. At a point half a mile south of Norcross it is a prominent rounded ridge of gravel, 8 feet high on the east side and 13 feet high on the west side. The ridge ends somewhat abruptly on the south, but another part begins a mile away. In the southwest corner of sec. 8, Logan Township, the beach is a gravel ridge 9 feet high. The ridge extends northward from Norcross to Mustinka River, and north of the river it is continued for 3 miles as interrupted low sandy ridges and farther north it is absent for 2 miles. Beyond this break there are isolated sandy gravel ridges, and at the north boundary of the quadrangle the beach is a well-defined gravel ridge.

### RECENT SERIES.

*Alluvium.*—The alluvial deposits along streams consist of thin beds of sand, alluvial soil, or muck, only 2 or 3 feet thick except where the streams flow through ponds or former lake basins and where, as a rule, there is a thicker deposit of muck or loam. The smaller streams have correspondingly narrow alluvial borders.

Alluvial fans have been formed at the mouths of ravines along steep slopes, but most of them are too small or too thin to be mapped. Such fans occur, however, notably on the east side of the Mustinka Valley, in sec. 14, Elbow Lake Township; on the east side of the Pomme de Terre Valley for a mile north of Barrett Lake; and for 3 miles north of the south margin of the Morris quadrangle. They are more numerous in the Pomme de Terre Valley than elsewhere but are not noted there at many places where they might be expected, owing to the dominance of erosion along streams.

*Lacustrine deposits.*—Wherever the lakes or sloughs are bordered by dry banks these are wave-cut and lined by sandy or gravelly beaches, and the beds of those that have been drained show a foot or more of clay or muck. The numerous marshes contain deposits of muck and in some places a growth of plant roots that resembles peat. Peat does not occur in notable amount, however, and most of the marshes might be considered merely patches of very thick wet soil.

## GEOLOGIC HISTORY.

### PRE-CAMBRIAN TIME.

The earliest event recorded in the rocks of this area was the irruption of the bodies of granitic rock that are believed to underlie the whole region and to be of Archean age. Nothing is known, however, of the conditions under which they were formed or of their relation to the land surface of that time. Presumably they solidified at some depth below the surface and were afterward laid bare through the erosion of the overlying rocks, whatever those may have been. However, they appear to have been considerably deformed and more or less metamorphosed.

During a part of Algonkian time the region was probably submerged beneath the sea and received sediment derived from the neighboring land, as the present distribution of the

Algonkian rocks of Minnesota indicates that they probably once covered this area. In the region on the northeast, south of the area now occupied by Lake Superior, great sheets of lava were poured out on the old land surface. The lava did not extend far west into Minnesota, but the irruption of igneous rock seems to have extended to the general region in which the area lies, and some of the dikes of dark volcanic rock exposed in the Minnesota Valley were probably intruded at that time. Dikes of the same age presumably cut the granitic rocks underlying the area. At the close of pre-Cambrian time the region seems once more to have been dry land and undergoing subaerial denudation.

### PALEOZOIC ERA.

The area here considered appears to have been land during a large part if not the whole of the Paleozoic era, as is shown in the accompanying table, which gives the relative age of the existing formations and of those that were perhaps once present but that have been removed by erosion if they were present, thus indicating the submergence and emergence of the area. Marine sedimentary formations of Upper Cambrian, Ordovician, Silurian, and Devonian age are found in southeastern Minnesota or in adjacent States and also north of the region, in Canada, but none are found in central and southwestern Minnesota, a region which appears to have been a peninsula extending into the Paleozoic sea. Whether the peninsula was at any time submerged and strata were deposited over it can not now be determined.

*Relative age of existing Archean and Quaternary formations and the intervening formations probably once present but removed by erosion in the Herman, Barrett, Chokio, and Morris quadrangles.*

| Age. | | Sedimentary formations. |
|---|---|---|
| Cenozoic era. | Quaternary period. | Deposited and still existing. |
| | Tertiary period. | None deposited. |
| Mesozoic era. | Upper Cretaceous epoch. | Deposited but eroded. |
| | Lower Cretaceous epoch. | Probably none deposited. |
| | Jurassic period. | |
| | Triassic period. | |
| Paleozoic era. | Carboniferous period. | |
| | Devonian period. | |
| | Silurian period. | |
| | Ordovician period. | Probably deposited and eroded. |
| | Cambrian period. | None deposited. |
| Proterozoic era. | Algonkian period. | Deposited but eroded. |
| | Archean period. | Formation still existing. |

In late Cambrian time the sea on the south extended as far north as Taylors Falls, Rush City, Monticello, and Cambria, as shown by the exposure near those places of what are evidently shore deposits. The shore line gradually shifted its position and in early Ordovician time appears to have been near Shakopee and Mankato, though during part of that period the sea may have extended to St. Cloud and Redwood Falls. Afterward the land rose, and the sea retreated southward. In Silurian time the shore appears to have been far to the southeast, outside the limits of the State, but in Devonian time a slight subsidence again allowed the sea to encroach on southeastern Minnesota. During the Carboniferous period the slow rise of the land drove the sea southward once more, until it finally disappeared from the upper Mississippi basin. Owing to the overlap of the Cretaceous strata and to the thick cover of glacial drift nothing is known of the position of the western and northwestern shores of the peninsula during the era.

It is barely possible that the region may have been covered by the sea, at least as far as this area, at some time during either the Ordovician or the Devonian period, for in a well drilled for the railway at Herman a bed of limestone 7 or 8 feet thick was encountered before the granite was reached.[1] N. H. Winchell, however, believes that this limestone is only a mass of boulders in the drift, brought presumably from Manitoba, and his belief is supported by the fact that no limestone has been encountered in other wells at Herman.

### MESOZOIC ERA.

The uplift that brought the Carboniferous deposition in the Mississippi Basin to a close affected a large part of North America and left Minnesota in the interior of a great land area and probably at an altitude of 1,000 to 2,000 feet or more above sea level. The surface, however, must have been smooth or gently rolling, much like that of the present Great Plains. Throughout the Triassic and Jurassic periods and the early part of the Cretaceous period the surface of the area was being reduced by subaerial denudation. The surface was thus lowered several hundred feet at least, and, in common with that of a great surrounding region, it was probably at least once reduced nearly to base-level and thus again formed a low-lying, nearly featureless plain. The climate was probably rather moist, and the surface of the granitic rocks was deeply weathered and decomposed into a clay containing scattered angular grains of quartz.

In Lower Cretaceous time the region on the west, now the Great Plains, was depressed, and a new interior sea occupied that area. The streams of the Minnesota region then flowed westward into that sea, and the waste of the land was carried out and spread over the sea floor. Subsidence continued into Upper Cretaceous time, and the sea advanced into western Minnesota, spreading over the older rocks a thick sheet of sand and clay that now forms the Dakota sandstone and the Benton shale. Some fresh-water sediments were deposited along the courses of the streams or in small lakes, and some brackish-water sediments were deposited in lagoons and estuaries. At and near their margins the Upper Cretaceous deposits were therefore probably rather irregular both in thickness and in character.

No such strata have been encountered in wells in the area here considered, though patches of them may exist beneath the drift in places where wells have not been sunk to bedrock. Whether the entire area of the quadrangles was submerged beneath the Upper Cretaceous sea and received such deposits can not therefore be certainly determined, but what is known of the occurrence of remnants of the Cretaceous strata in neighboring areas indicates that it was probably submerged. It seems fairly certain that such strata once covered at least that part of the bedrock surface which now lies less than 1,100 feet above sea level and that these strata have been largely or wholly removed by later erosion.

The Upper Cretaceous submergence was brought to a close by renewed uplift, and the sea withdrew westward and finally wholly disappeared. By the close of Cretaceous time the area was again far inland and subaerial erosion was once more actively reducing its surface.

### CENOZOIC ERA.

#### TERTIARY PERIOD.

In early Tertiary time several brackish or fresh-water lakes still occupied parts of the area that were formerly covered by the interior Cretaceous sea, but they lay hundreds of miles west and southwest of this area. A progressive uplift of most of the interior of the continent that was going on affected this area in common with the surrounding region. The uplift was much greater on the west, and the land surface was thus tilted to the east, standing at altitudes ranging from 6,000 feet along the eastern base of the Rocky Mountains to less than 1,000 feet in the Mississippi basin. A new system of drainage was developed everywhere in the region, and the new streams flowed not from east to west but rather in the general direction in which the present rivers run. Whatever strata had been deposited in the area during the Upper Cretaceous submergence were largely if not wholly removed, and new valleys were cut to depths several hundred feet below the horizon of the base of the Cretaceous strata. Where the granitic rocks were exposed they were still further weathered and cut into by erosion, and in all probability the present features of the bedrock surface in the quadrangles were formed chiefly at this time. From what is known concerning this area and Minnesota generally the Tertiary denudation evidently left the exposed granitic rock relatively fresh and not deeply decomposed.

#### QUATERNARY PERIOD.

##### PLEISTOCENE EPOCH.

###### PRE-KANSAN TIME.

The history of the earliest Pleistocene glacial stage in the area is obscure, as whatever record of it may exist is buried deeply under younger deposits. The pre-Kansan drift, where observed in Iowa and southern Minnesota, has, however, the calcareous nature and other general characters of the gray drift deposited by the Keewatin ice sheet, and the ice that left it doubtless crossed the quadrangles as it moved southward from the Keewatin center of accumulation west of Hudson Bay. The pre-Kansan ice sheet is believed to have been entirely melted away from the region, so that an interglacial stage—the Aftonian—preceded the advance of the Kansan glaciation. During the Aftonian stage, as well as during the Kansan glaciation, the record of the pre-Kansan glaciation was exposed to destructive agencies and was largely removed.

###### KANSAN STAGE.

*Advance of the glacier.*—As neither the Kansan or old gray drift nor the bedrock on which it rests is exposed in these quadrangles, the manner in which the Kansan ice sheet advanced and the length of time during which it remained must be inferred chiefly from the general relations of this drift to that of the surrounding region. The general direction in which the ice moved is known, however, because the samples of the Kansan drift from well borings show it to be gray drift of the Keewatin glacier and because the direction of movement here must have corresponded in general to that of the ice lobe as a whole. Striations on the bedrock surface beneath the Kansan drift in southern Minnesota show that the general direction of movement of the ice in that region was east of south, and the extent of the drift sheet shows that a large tongue or lobe of the ice sheet covered the region. The thickness and wide extent of the drift indicate long, intense glaciation.

*Disappearance of the ice.*—It is not known whether the margin of the Kansan ice sheet melted back steadily, leaving a more or less uniform drift sheet, or whether there were intervals of readvance, so that thick terminal moraines were formed, but the latter is thought to have been the more probable procedure. The retreat of the ice front as a whole was doubtless in general northward, but the part that receded across this area is believed to have faced east rather than south and to have retreated westward. Such a north to south trend of the ice margin is suggested by the uneven thickness of the Kansan drift and by the direction of the interglacial valleys.

The position of a Kansan terminal moraine may be inferred from the trend of a prominent elevation coinciding with the great thickness of the Kansan drift in a north to south belt extending through the Barrett and Morris quadrangles east of the Pomme de Terre Valley and including it. The differences in thickness of the Kansan drift are, of course, not all due to the formation of a terminal moraine but are due in part to erosion of the surface of that drift during the following interglacial stage and in part to irregularities in the bedrock surface. The present course of the Pomme de Terre Valley thus appears to have been determined by the establishment of a drainage line along the retreating margin of the Kansan ice sheet rather than by the direction of a preglacial valley in the bedrock. Mustinka and Chippewa valleys also appear to coincide with glacial border-drainage lines of pre-Wisconsin age. (See fig. 9.)

###### INTERGLACIAL TIME.

Between the Kansan and the Wisconsin glacial stages a long time elapsed during which the Kansan drift was exposed to weathering and erosion. While its surface was being dissected by streams so that its thickness was appreciably modified, its upper part was being leached by surface water, and soil was being formed on it by weathering, and the region was probably in general habitable for plants and animals. The depth and extent of the erosion and the deep leaching of the drift show that the interglacial time was long.

*Erosion of interglacial valleys.*—The chief interglacial valleys are followed by existing streams and therefore may be conveniently called by the names of those streams. The main ones are only partly filled by Wisconsin drift, but some of the smaller ones are so nearly obstructed that no streams flow in them. As already stated, the excavation of the Pomme de Terre Valley was probably begun by a border-drainage stream of the Kansan ice sheet while that sheet was melting. In interglacial time the main valley was enlarged and deepened and tributary valleys were developed. That the Pomme de Terre Valley was once deeper than it is now appears from the depth of the gravel deposit that forms the present floor of the valley. At Morris the city wells in the middle of the valley penetrate gravel for their entire depth—65 feet. This gravel, which is Wisconsin glacial outwash, is deep throughout the length of the valley.

Tributaries of the Pomme de Terre were numerous in interglacial time, and their courses are shown in figure 9. Those on the east side of the river extended back across the present course of Chippewa River. From the north side of Barrett Lake eastward to Sylvan Lake one of the old valleys can be easily recognized, though obstructed by Wisconsin drift. Where it is crossed by Chippewa River that stream is prevented from flowing directly though Sylvan Lake to Barrett Lake only by a narrow dam of Wisconsin outwash gravel, as is shown on the geologic map of the Barrett quadrangle. When the interglacial stream followed this old valley to the Pomme de Terre the present course of Chippewa River was not a continuous drainage line. In fact, several tributaries of the Pomme de Terre headed east of the present Chippewa Valley and controlled the drainage of that belt. The course of one such tributary is marked by the trough in which lie Turtle, Spring, Elk, and Lower Elk lakes, and thence it extended across the course of the present Chippewa to a point east of Hoffman. A tributary valley in the area east of Pomme de Terre Lakes drained the part of the Chippewa Valley between the vicinity of Hoffman and a point south of Swan Lake Church. A tributary near North Star Mill drained the tracts now occupied by Scandia and Swan lakes, and another extended from a point 3 miles southeast of Morris northeastward to the site of Long Lake and thence eastward

[1] Upham, Warren, Minnesota Geol. and Nat. Hist. Survey Final Rept., vol. 2, p. 503, 1888.

along the railway. A branch of this valley extended southeastward west of Hancock. These tributary valleys are still very distinct, although they are obstructed by Wisconsin drift and are not occupied by streams.

The interglacial Chippewa Valley within this area was not only greatly influenced but was probably for the greater part determined by drainage along the melting margin of the Kansan ice sheet. (See fig. 9.) It was thus made while the present course of the Pomme de Terre was still covered by the Kansan ice. Early in the development of the Pomme de Terre Valley the Chippewa Valley was invaded by the developing tributaries of the Pomme de Terre, and its drainage was diverted.

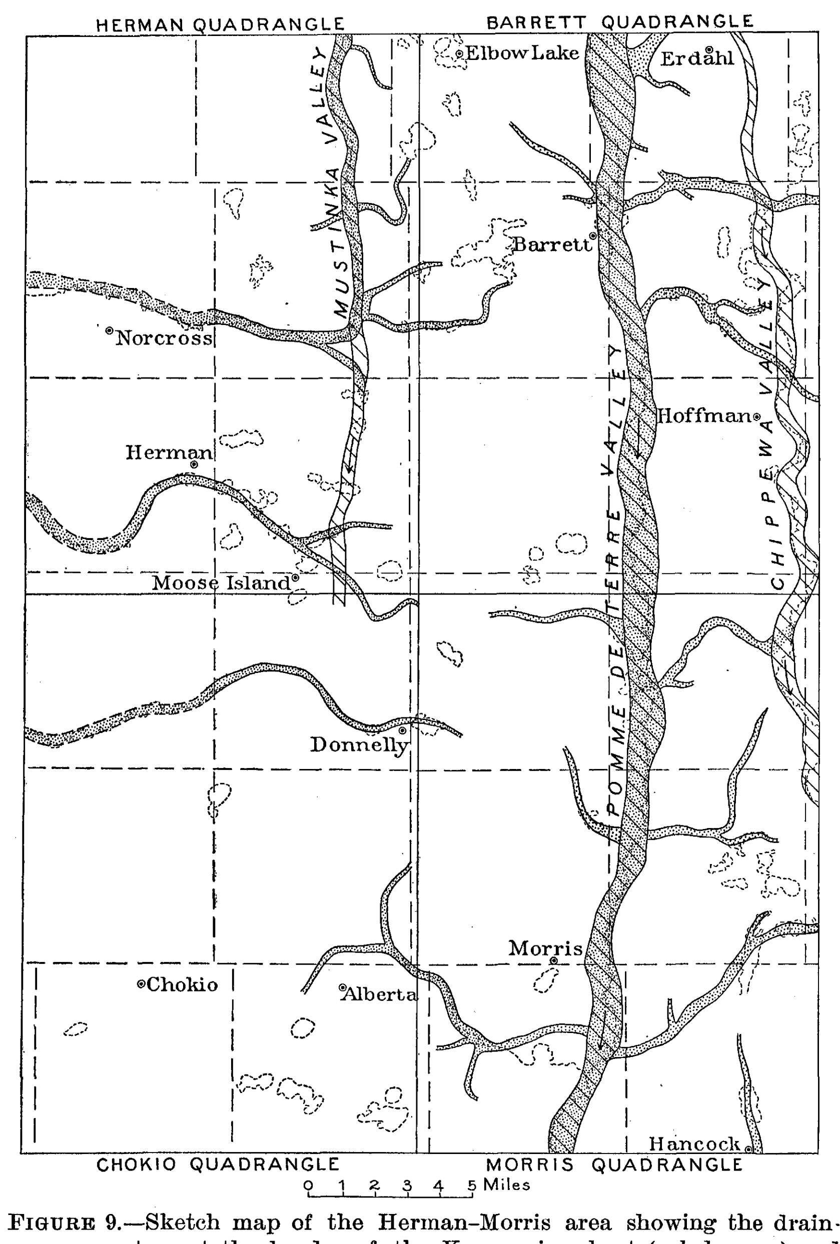


FIGURE 9.—Sketch map of the Herman-Morris area showing the drainage system at the border of the Kansan ice sheet (ruled areas) and later interglacial drainage (dotted areas). The border-drainage stream down Chippewa Valley was the first to form as the Kansan ice sheet receded westward, then the one down Pomme de Terre Valley, and later the one down Mustinka Valley.

On the west side of Pomme de Terre Valley there were interglacial tributary valleys at Long Lake north of Barrett; at the north end of the Pomme de Terre Lakes, extending to the northwest corner of the Morris quadrangle; at Wintermute Lake; and at Mud Creek. The old course of the Mud Creek valley appears a mile north of the present mouth of Mud Creek and extends westward. It has several minor branches.

The development also of that part of the Mustinka Valley that trends from north to south was probably begun as a Kansan border-drainage course, and for this reason it runs transverse to the general slope of the land surface. The entire valley is older than the Wisconsin drift, which lies in it. The Mustinka Valley, when traced 15 miles northward from the place where it enters this area, leads to Otter Tail River. The Mustinka drainage begins a short distance from the Otter Tail, but the valley in which it lies extends in fact beyond that stream as the valley of Pelican River. The valley has the same general direction, depth, and width north of this area as it has for the first 10 miles of its length within the area. As a Kansan glacial border-drainage course, this valley did not follow the present route of the Mustinka toward Norcross; it extended southward along the line marked by the basins of Burr, Johnson, Ohlsrud, and Niemakl lakes. (See fig. 9.) Whether it then joined the pre-Wisconsin valley of Mud Creek or whether it continued in a southwesterly direction is not determined. During the interglacial time, however, streams flowing in the direction of the Bois de Sioux Valley on the west appear to have eroded their valleys back to the border-drainage course of the Mustinka and diverted the stream. (See fig. 9.) The western or lower part of the Mustinka was in that way established nearly where it is now. The location of another interglacial valley is indicated by the chain of lakes extending northwest toward Herman from Cottonwood Lake to Pullman Lake and thence continuing in the direction of Fivemile Creek. Small interglacial tributaries of the Mustinka were located west of Elbow Lake; others extended southwest from the basin of Round Lake, also from Huset Lake, and from the south side of Cormorant Lake through Jones Lake. The main controlling valley is traceable westward along the Mustinka for only a few miles, down to the plain that once contained glacial Lake Agassiz, where it is quite obliterated within this area.

*Erosion and weathering.*—Although the whole surface of the Kansan drift may have been dissected by erosion and its original thickness may have been appreciably modified before the end of interglacial time, the thickness of the material removed can not be determined. In one place the bedrock appears to have been swept bare, possibly because the Kansan drift on it was originally thin. North of Herman, as noted in the table on page 4, the bedrock is only 42 feet from the surface, probably because no Kansan drift remained at that place when the Wisconsin drift was deposited. The amount of erosion there and elsewhere can, however, be only estimated from a general comparison of the pre-Wisconsin with the post-Wisconsin valleys, on one hand, and of the depth of leaching of the old till with that of the young till, on the other.

The Kansan drift was originally dark bluish gray, but the oxidized and partly leached part of it is brownish buff. In borings there is frequently reported as much as 30 feet of oxidized brownish till between the unoxidized bluish-gray till of the Kansan drift and the overlying Wisconsin drift. Apparently the old till was leached fully twice as deeply as the young till. As both the surface leaching of the till and the erosion of the valleys were deeper then than now, it is inferred that the surface of the Kansan drift was correspondingly more eroded than the surface of the Wisconsin drift has been.

### WISCONSIN STAGE.

*Advance of the ice.*—During the last glacial stage these quadrangles were again covered by an ice sheet. A long, narrow lobe of the Keewatin glacier, which has been variously designated as the Minnesota, the Iowa, or the Des Moines lobe, advanced southeastward up the Red River valley, through the Minnesota Valley to southern Minnesota, and thence southward to central Iowa. Its southwestern margin lay along the Coteau des Prairies escarpment in northeastern South Dakota, and its northeastern margin lay along a curved line passing through the eastern halves of Wadena and Todd counties, Minn. The width of the lobe, measured on a line drawn southwest through these quadrangles at right angles to its axis, was 125 miles. The lobe was narrow in proportion to its length, and the quadrangles were covered by its lateral rather than its central part. The general direction of movement was east of south along the axis of the lobe, but from the axis the ice spread laterally toward the margins, and the invasion of the area here considered, lying east of the axis, was probably from west to east. The margin of the glacier ascended gradually from the lower land on the west to the higher land on the east, covering successively the valleys of Mustinka, Pomme de Terre, and Chippewa rivers.

Either during the advance of this lobe or during a retreat preceding a readvance gravel was washed into the eastward-trending valleys that had been formed during interglacial time. The thickness of this gravel is so great that it is interpreted as made up of successive accumulations by outwash during slow transgression or oscillation of the ice border rather than as interglacial stream deposits.

The beginning of the last glacial invasion was in early Wisconsin time and its end was in late Wisconsin time. The work of this ice lobe is best expressed in features developed during its retreat, but there may have been considerable deposition during its advance. The glacial lobe maintained for a long time an oscillating margin east of these quadrangles while it built the great terminal moraine, 10 to 20 miles wide, that extends from Fergus Falls and Glenwood to Minneapolis. A small part of this moraine lies within the quadrangles, east of Erdahl and of Chippewa River.

*Retreat of the ice border.*—After the building of the great terminal moraine east of Erdahl the south end of the ice lobe in Iowa and southern Minnesota was melted away so that its margin receded northward — in this region to the divide between Minnesota and Bois de Sioux rivers. At the same time the lateral border appears to have receded westward, rapidly and without notable readvance, to and beyond the west border of the area here described. Various positions of the retreating ice front are shown in figure 10 (p. 8). The Chippewa, Pomme de Terre, and Mustinka valleys were thus successively reopened to drainage.

*Glacial outwash deposition in Chippewa Valley.*—As the margin of the ice melted back from the terminal moraine, water began to flow between it and the moraine, and thus the course of Chippewa River was again established. From the beginning the drainage line consisted rather of a chain of lakes along the ice front than of a stream valley. Into this border-drainage belt streams from the melting ice brought gravel and sand, which was deposited along it. These glacial outwash deposits are not continuous but lie in patches evidently formed in succession along the valley. Those patches that lie wholly on the east side of Chippewa River are in general older than those that are crossed by it; those that lie wholly on the west side are, with one exception, still younger. The patch at Sylvan Lake is evidently the first one formed and its highest or eastern part is oldest. The other patches in succession down the valley were evidently deposited in like manner, and the patch near Swan Lake Church, in the Morris quadrangle, is evidently the youngest.

As the retreat of the ice border uncovered the basins in front of it so that the stream could finally take the lowest course between them, Chippewa River formed its present valley. It flows in part over glacial outwash, in part between the outwash and the till surface, and in part over till. The effect of the ice front on the course of the stream appears from the circumstance that no very great obstruction would be necessary in several places to divert the stream from its present course. Obstruction by an ice wall on the west side of the valley must, in fact, account for the turning of the stream into Peterson Lake instead of through Sylvan Lake to Barrett Lake, or, again, for its not flowing through Elk Lake to the Pomme de Terre. In the valley east of Hoffman only the sweep of the border drainage prevented the entire obstruction of the valley, which would later have turned the river's course into and through Elk Lake. The obstruction by the ice wall likewise explains why the drainage did not go by way of Swan Lake instead of eastward.

The outwash in the southeast corner of the Morris quadrangle is part of a great gravel plain of the Chippewa Valley, which, as far as it lies in this area, was formed later than the outwash farther north.

*Glacial outwash deposition in Pomme de Terre Valley.*—The interglacial valley of the Pomme de Terre was not obliterated by the Wisconsin ice lobe, although it was covered by the ice for some time and received therefrom a deposit both of till and of outwash. The till sheet was not thick enough to fill the valley, and the depression was occupied by glacial drainage when the ice melted from it and streams flowing from the ice washed gravel and sand into it. The history of the abandonment of the Pomme de Terre Valley by the ice and its partial filling by outwash deposits is somewhat different from the history of the Chippewa Valley.

During its melting the ice withdrew first from the Chippewa Valley and later from the Pomme de Terre Valley. The general direction of marginal retreat was at first from east to west, so that the trend of the ice margin was from north to south. Later, when the end of the lobe had melted back near this area, the ice front retreated more rapidly along the south border of the area than along the north border, so that the trend of the margin shifted to a point west of south—that is, although the margin as a whole retreated most rapidly at the extreme end of the lobe on Minnesota River, at the same time in this area that part which was nearer the end of the lobe retreated faster than that which was farther from it. The change in the trend of the ice margin greatly affected the Pomme de Terre Valley. As this valley extends from north to south and as the trend of the ice margin had diverged toward the west (see fig. 10), the valley was freed from ice gradually from south to north, so that each part in turn received drainage and outwash from the margin of the ice. The bottom of the valley is therefore occupied by gravel and sand nearly continuously from south to north.

The trend of the ice margin in successive positions is shown by certain features of the deposit. Parallel ridges on gentle slopes show where the margin stood while each ridge was being formed. In secs. 26, 27, 34, and 35 of Darnen Township, near the south side of the Morris quadrangle, such ridges trend N. 30° E., and similar ridges as far north as Pomme de Terre Lakes show the same trend. Southeast of Barrett seven parallel marginal positions, shown by ridges and slopes of the outwash, trend S. 20° W., or in the same direction as the river flows at the railway bridge. North of Barrett Lake the trend of the ice margin appears to have been nearly due north.

The drainage from the melting ice did not flood the whole valley, but the glacial river followed a narrow course, in places less than 500 feet wide, along the line of the present stream. Part of this course coincides with the trend of the ice margin at the back of the outwash, as near the south side of the Morris quadrangle; part lies between the front of the outwash and the east side of the valley, as near Morris; and part lies across the outwash and through lakes and the basins of former lakes now occupied by marshes and meadows. Some of the original course of the glacial stream was later abandoned. An old course that was occupied by at least part of the glacial river runs 4 miles southward from the southwest end of Perkins Lake and joins the present river's course. It is obstructed now by an ice rampart at the lake shore, and some such obstruction probably caused the diversion of the glacial stream to the course which the river now follows.

*Glacial outwash deposition in Mustinka Valley.*—As the edge of the ice retreated across what is now the subcontinental divide in this area—the watershed between the Mustinka and Pomme de Terre valleys — and then gradually withdrew to lower altitudes in the Red River basin, standing water must have gathered in front of the ice, although for some time the area covered by it was not great. Its drainage may at first have escaped through Mud Creek to the Pomme de Terre, but later it passed westward along the margin of the ice. During the early part of this stage streams from the ice deposited first the outwash that forms the plains southeast and northeast of Niemakl Lakes, next the deposits north of Ohlsrud and Johnson lakes, then the outwash along the Mustinka Valley, only four small remnants of which remain, and finally the larger areas, one northeast of Herman and one 5 miles north of Chokio. Much greater streams flowed at the same time from the ice north of this area into the Pomme de Terre Valley.

The interglacial valley of the Mustinka had not been obliterated by the deposits from the Wisconsin ice, and as the ice margin retreated the valley reappeared. It received very little drainage until the ice margin north of this area had retreated from the head of the Pomme de Terre Valley to the place where the head of the Mustinka Valley intercepted Otter Tail River. Then, while the ice there still blocked the course of drainage toward the west, water from the ice and from Otter Tail and Pelican rivers swept southward through the Mustinka Valley, which was distinctly eroded and terraced, especially in the northern part of the Herman quadrangle, where the stream occupied the entire width of the valley. It there left its bottom strewn with large boulders, showing that its current was swift.

#### TIME OF LAKE AGASSIZ.

*Early high stage of ice-border lake.*—Ponded waters began to form along the edge of the ice sheet as soon as it had melted back across the divide between the Minnesota and Red River drainage basins, which crosses the Herman and Chokio quadrangles. Parts of these quadrangles and a considerable area to the west, extending nearly to Graceville, were thus covered by water. This ponding occurred while the front of the ice lay at the line marked "ice border (D)" in figure 10 and for some time before it had retreated to that position. The presence of the water is shown by the smoothed-over topography and by thin deposits of silt loam on the till. These deposits occur up to an altitude of fully 1,090 feet, or about 20 feet higher than the Herman beach of Lake Agassiz, and the height of the water was controlled by that of the lowest available line of discharge across the divide into the Minnesota drainage basin. When the ice border had retreated sufficiently to open a passage to Lake Traverse the ponded waters of the Herman and Chokio quadrangles took that course and were drawn down to the level of the Herman beach of Lake Agassiz.

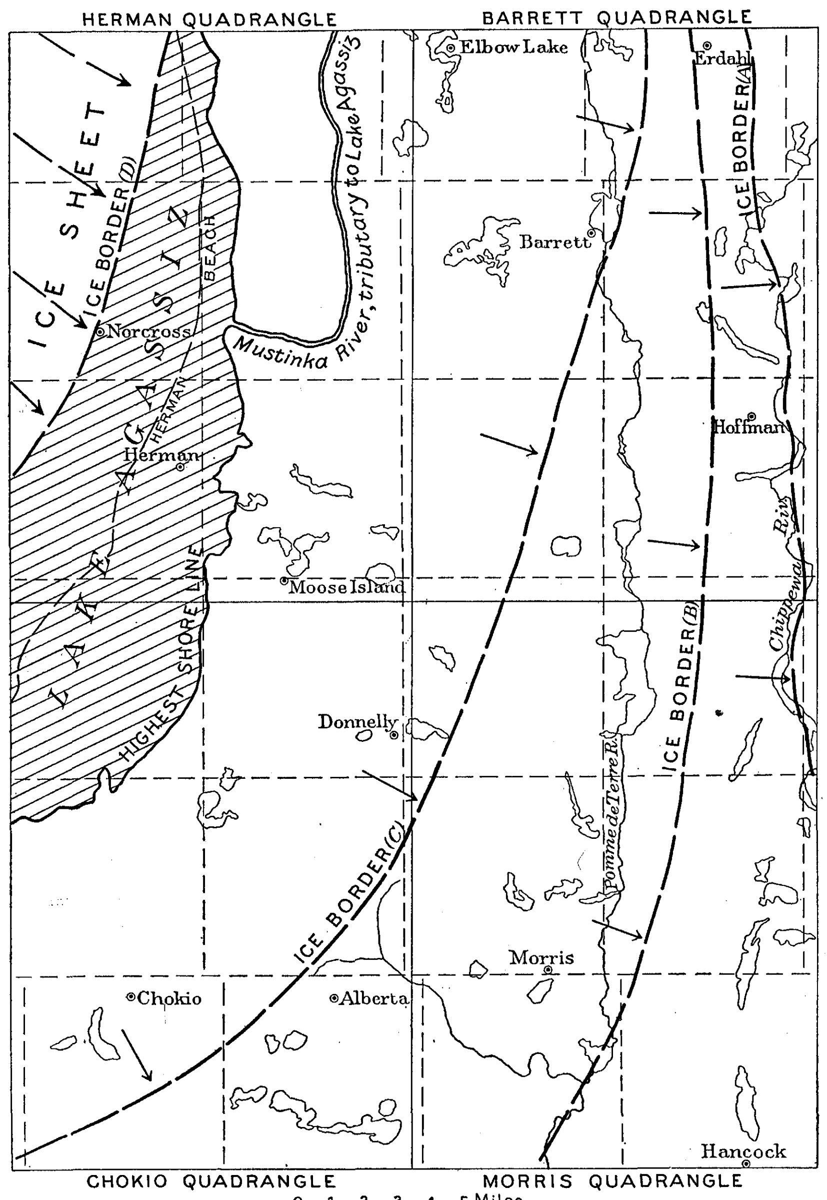


FIGURE 10.—Sketch map of the Herman-Morris area showing an early ice-border stage of Lake Agassiz at the time the ice border stood at Norcross, as shown by dashed line D. Earlier positions of the ice border in the area are shown by other dashed lines, and their relative ages are indicated by the letters A, B, C. The streams and lakes that probably existed at the same time are also indicated. The ice border had receded far beyond this area when Lake Agassiz built the Herman beach.

The failure of the ponded waters of the Herman and Chokio quadrangles to form a definite beach at the higher level may be due to the shallowness of the water, which may have been insufficient for wave development, and to the relatively short period that the waters were held at this stage. Silt deposition would naturally be rapid, as the waters from the melting ice were probably heavily silt-laden.

*Herman stage of Lake Agassiz.*—The Herman beach was formed during practically a single stage of Lake Agassiz. The level of the lake fell repeatedly as the outlet was deepened, but it fell only a few feet while the Herman beach was being formed. Farther north the beach divides into two or more distinct beaches, the highest of which is the oldest. In the Herman quadrangle it has either one, two, three, or four crests. Where it has more than one crest, as it has for 4 miles north of Mustinka River, the outer (easternmost) one is the highest and corresponds to the crest of the single beach, and the second, third, and fourth are each successively built upon the slope in front of the preceding one, thus showing that the shore line had retreated slightly before the inner parts of the beach were formed. The beach as a whole is thus widened on its western or inner side. It is not, however, regarded as more than one, for all the parts grade into one another and are intimately connected.

The effect of the gradual falling of the lake level or the rising of the shore is evident both where the beach is single and where it is multiple. West of Herman gravel is deposited down the slope of the beach, even on ground that had been eroded while the waves were making the crest of the ridge. Where the beach is multiple, the successive decrease in height from the outer to the inner ridge is still clear evidence that the level of the lake was falling. The form of the beach was in fact everywhere influenced by the gradual retreat of the waters. Whether a single or a complex beach was made in this area was determined by the form of the surface on which the shore line rested and by the direction of storm waves, as is evident where one form of shore merges into another. For example, north of Fivemile Creek, where one beach was built like a spit in front of the other (see fig. 11), the two distinct ridges merge northward into one ridge having a double crest and still farther northward into a single ridge.

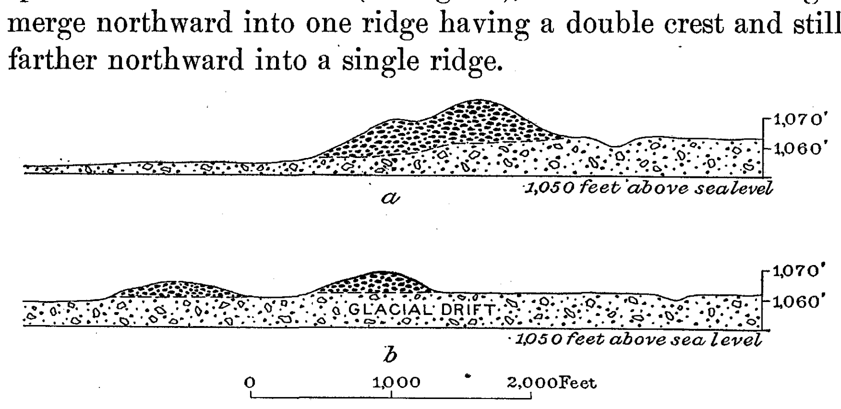


FIGURE 11.—Sections of the Herman beach at a spit in secs 15, 22, and 27, Lyon Township; *a*, northern section, where the beach is double crested; *b*, southern section, where the beach and spit are separated. The beach sand and gravel rest on glacial drift.

A differential uplift of the whole region also affected the form of the beach. Less than 10 miles north of this area the Herman beach separates into a higher and a lower beach. Farther north there is also a third one, and still farther north, east of Crookston, Upham has noted a fourth Herman beach. While the Herman beach was being formed differential uplift of the land took place, so that the position of the lake shore was changed more in the area to the north than in these quadrangles. The part of the beach in these quadrangles, however, is east rather than north of the outlet of the lake and the slight change in water level here while the beach was being formed should be ascribed to lowering of the outlet rather than to differential uplift.

The present difference in altitude of the top of the beach at Collis, west of the Chokio quadrangle, and at Hereford, 2 miles north of the Herman quadrangle, is 10 feet. The two points are 35 miles apart, and the uplift across these quadrangles has therefore amounted to nearly 1 foot in 3 miles, measured north-northeastward. This uplift took place after the higher part of the beach was made, but it had already begun while the lower parts were being formed.

The Herman beach was interrupted or broken through by several inlets to the lake where the present drainage lines cross it. In fact, the beach in its earliest stage was merely a row of isolated shores, islands, and bars, until excavation near the shore, aided by alongshore transportation by waves, made a continuous beach. It still remained incomplete where inlets interfered with shore building, as on the south side of secs. 19 and 31, Elbow Lake Township; between secs. 19 and 30, Delaware Township; in secs. 11 and 34, Logan Township; and in secs. 5, 18, and 19, Eldorado Township. The front of the beach, especially at the original inlets, shows that the prevailing winds and storms came from the northwest. At the north side of the Herman quadrangle the beach is divided into three parts, the second and third of which extend out from the first as spits. North of Fivemile Creek a second beach springs from the first one in the same manner. All the spits were built from north to south, evidently by waves driven obliquely along the shore by a northwest wind. For the same reason, where Mustinka River, Fivemile Creek, and other drainage lines crossed the beach, its divided ends overlap, the overlap being to the south.

*Norcross stage of Lake Agassiz.*—The Norcross beach is much less perfectly formed than the Herman beach and represents perhaps half as much time in the duration of Lake Agassiz. It was formed only a very short time after the Herman beach. The highest part of the Norcross beach is 10 feet lower than the base of the Herman beach, and the difference in altitude between the base of one and the base of the other is fully 20 feet. The subsidence of the water and the retreat of the shore between the periods in which the two beaches were built was relatively so rapid that no intermediate beaches were formed. The reason for the rapid subsidence of the water was probably a change in the conditions at the outlet of the lake. That it was not due to differential uplift is indicated by the relation of the beaches in the region north of these quadrangles, where the Herman beach separates into four beaches. The Norcross beach there likewise divides into two beaches, and the vertical interval between the lowest Herman beach and the highest Norcross beach is no greater there than here. Measured by the rate of differential uplift the time that intervened between the formation of the Herman and the Norcross beaches therefore appears to have been short.

At the north side of the Herman quadrangle the Norcross beach is only a mile from the Herman beach, but at Norcross it is 3 miles and where it leaves the west side of the quadrangle it is 4 miles from the other beach. The divergence in trend was of course determined largely by the difference in slope of the lake bed, but at Norcross the beach lies somewhat farther out than the general slope might have determined, because of the presence of a slight morainic ridge, which appears to be crossed by the Herman beach near the north side of the quadrangle and which appears again at and beyond Norcross. This moraine probably marks the position at which the ice margin stood during the highest stage of the lake. Moreover, the beach is most prominent at Norcross because of a low till ridge on which it rests. The till there has been cut from 3 to 5 feet deep up to the shore, and gravel and sand from it have been thrown shoreward from 1 to 10 feet high over the original surface. The gravel is cross-bedded and shows that the storm waves swept landward over it.

The Norcross beach in this area represents a single stand of the lake, which was not held long enough or else the slope of the lake bed along parts of the shore was not steep enough to permit erosion by storm waves to build a continuous beach. Where the beach crosses the northern boundary of this area there was a clearly marked shore, now shown by a narrow gravel ridge and a sand-covered flat about 40 rods wide in front of it. That shore ended a mile farther south. Still farther south, although two short, low sandy ridges were built and the sandy flat extended southeastward for 3 miles, the shore was like the reed-grown borders of recent lakes. It was evidently marshy for a stretch of more than a mile where there is no trace of a shore. For 3 miles north of Mustinka River sand is spread over the flat, and there are three disconnected strips of sandy beach, like the shores of the present lakes that are clear in winter and reed-grown in summer. From the south side of the river through Norcross there was a high, clearly defined shore with a gravel beach. South of Norcross the gravel beach ended abruptly in an area that was probably occupied by a marsh that bordered the lake for a mile. Thence a low gravelly shore continued southwestward.

Mustinka River had the same relation to the Norcross beach that it had to the Herman beach. It flowed into the lake and interrupted the building of the beach, although the force of the waves formed by the prevailing northwest winds extended the beach southward somewhat against the direct course of the river.

*Disappearance of the lake.*—After the Norcross beach had been formed the level of Lake Agassiz fell rapidly to the level of the Tintah beach, which lies just outside the area. While the shore of the lake was receding still farther northward several more beaches were made, each representing a stage in the lake level during the gradual lowering of its outlet, until the end of the Pleistocene epoch, which is marked, in this region, by the disappearance of the lake because of the final melting away of the ice barrier north of it. From the time when the lake withdrew its shores from these quadrangles the record of changes here is not distinguishable from that of the Recent epoch.

#### RECENT EPOCH.

Since Lake Agassiz and the glacial rivers disappeared from this region the surface has undergone slight changes. The top of the drift has been lowered everywhere at least a few inches, because of the dissolving away of limestone pebbles in the formation of subsoil and soil by weathering. Weathering and land wash together have also reduced slightly the knolls and slopes. Along certain drainage lines and around lakes and ponds the results of erosion are notable.

The rivers have changed their valleys very little in Recent time. For example, the course of the Mustinka west of the Norcross beach is almost wholly Recent. Its channel there is 20 to 30 feet wide, and its banks stand only about 5 feet above the water, and it affords a measure of the erosion that has occurred since the lake disappeared from that area. East of the Norcross beach the Mustinka meanders in the channel of a glacial river, which, east of the Herman beach, lies in an interglacial valley. Only the glacial channel of that valley has been lowered a few feet by the work of the Mustinka in Recent time. Pomme de Terre River has likewise eroded a channel about 5 feet in depth within the limits of the channel of a glacial river, and outside that narrow erosion valley the Recent stream has had no effect on the great interglacial valley in which it flows. Chippewa River has made slight though somewhat unequal reduction along its course. The deepening of the three valleys by Recent erosion is small compared to that effected by glacial and interglacial streams. Mud Creek has an erosion valley 150 feet wide and 15 feet deep in places, as on the line between secs. 22 and 23, Darnen Township. In contrast with the interglacial valley in which it flows its own valley is small. Perhaps less than 5 feet of the depth of this valley has been cut in Recent time. Fivemile Creek, in Logan Township, and Twelvemile Creek, in Eldorado Township, have small erosion valleys from 1 to 12 feet deep. The probable average depth of erosion in them is 5 feet.

Certain drainage lines that are due to Recent erosion between basins in drift-filled valleys in this area have been cut in a few places to a maximum depth of 20 feet. The sides of the large valleys are bordered by spurs formed by erosion between glacial knolls to a depth of 5 to 10 feet. In sec. 18, Darnen Township, a very distinct lake basin has been drained by a ravine leading to Mud Creek.

The cut bank on the east shore of Elk Lake is 40 feet high, and the banks on the southeastern and northwestern shores of Barrett Lake are 30 feet high. Worm Lake has banks 20 feet high, and nearly all the lakes show much cutting along the shores. The effect of wave erosion is even more evident from the rounded form of the basins in which the lakes and sloughs lie than from the height of their banks.

## ECONOMIC GEOLOGY.

### MINERAL RESOURCES.

The mineral resources of the quadrangles consist of road materials and building materials obtained from the boulders, gravel, sand, and clay of the glacial drift, and, more important than these, of the water resources and the rich soil.

#### ROAD MATERIALS.

Gravel suitable for use as road material is found in abundance in the glacial outwash along Pomme de Terre, Chippewa, and Mustinka rivers, near Ohlsrud and Cottonwood lakes, and in some parts of the Herman and Norcross beaches. Small beds of gravel occur in the glacial till in many places. On the shores of Lake Hattie and of Cottonwood and Fish lakes there are extensive beds of gravel, and many small deposits occur on existing lakes or on the sites of former lakes.

The largest gravel pit now developed is that of the Great Northern Railway, on the east side of Pomme de Terre River in the NW. ¼ sec. 18, Erdahl Township, where many acres have been stripped and a thickness of gravel measuring 10 to 20 feet has been removed down to ground-water level. The gravel is covered by 2 or 3 feet of soil and subsoil and generally consists of the imperfectly assorted mixture of pebbles and sand that is commonly found in such deposits. In this pit, however, the material is coarse—that is, the proportion of sand is small and some pebbles are 2 inches in diameter. Near this pit there are other extensive deposits of glacial outwash, some of which contain coarse gravel or cobbles and others consist chiefly of sand. Large gravel pits on the Minneapolis, St. Paul & Sault Ste. Marie Railway, near Barrett, and on the Great Northern Railway, below Morris, appear to have been used at one time by the railways. Large gravel pits east of Morris are owned and worked by the town.

The glacial outwash gravels afford an inexhaustible supply of road material and are suitable for use without crushing or screening. The gravel differs in fineness from place to place, but there are usually many acres of one kind in one place. Along the Pomme de Terre Valley the ground water, which stands at nearly the same height as the river, submerges a large part of the gravel. Dredging can not profitably be employed, however, except to obtain material of high grade that lies convenient to a railway. Most of the coarse gravel deposits, such as those along Mustinka River, near Sylvan Lake, north of Barrett Lake, below the Pomme de Terre Lakes, and in sec. 26, Darnen Township, are not conveniently situated for railways. Numerous small pits supply all necessary material for surfacing wagon roads and streets, nearly all of which are on clay ground and need such surfacing.

The sand deposited in Lake Agassiz, except that in the beaches, is too fine for use in making roads. Some of it is quicksand. Good sand may be obtained by screening any of the gravels.

#### BUILDING MATERIALS.

*Stone.*—Boulders from the drift may be employed as building stone and are generally used for making foundation walls in the region. Most of the boulders are of light-colored limestone and red or gray granite, though some of dark-colored crystalline rock are also found. The granitic and other crystalline boulders and cobbles are suitable for making ornamental walls. There is not a great variety of stone among them, however, and the supply is rather small. Most of the boulders are about a foot in diameter; a few are as large as 6 feet in diameter. The granite and fine-grained crystalline boulders are generally well rounded, but many of the limestone boulders are flat.

The boulders are found in the till, and in some places where the land has not been cultivated they remain sparsely strewn over the surface. In other places they are either piled in heaps for use or, where the fields are most cultivated and houses are most numerous, they have in large part been used and are scarce.

*Sand and gravel.*—The abundant gravel and sand have already been mentioned under "Road materials." When properly screened they are also used with cement in making concrete. The sand consists largely of good "sharp" or rough and angular grains of quartz. The gravel, on the other hand, consists in large part of pebbles of limestone, which, except where the material has been leached, are fresh, hard, and strong. A few pebbles of greenish shale that occur in the gravel are objectionable, as they tend to swell and finally to split off or break out in spots on the surface of the concrete.

*Brick clay.*—Bricks were formerly made at a clay pit on the north side of the road in the NE. ¼ sec. 24, Morris Township, 3 miles northeast of Morris. A laminated or water-laid till is now seen in the pit. The bricks formerly made there are said to have been cream-colored or slightly red. At Elbow Lake bricks are made of the same kind of clay. The kiln is between the Minneapolis, St. Paul & Sault Ste. Marie Railway and the east end of Worm Lake. The bricks are light red, porous, and of low weight. The presence of limestone pebbles in the clay causes some of the bricks to effloresce if they are exposed to the weather too soon after being made.

### WATER RESOURCES.

#### SURFACE WATER.

*Water power.*—Pomme de Terre River falls 110 feet in crossing the area. At the outlet of Barrett Lake it is held by a dam that gives a head of 4 feet of water, and the power developed is used in driving a flour mill. The water power of the North Star Mill, on the Pomme de Terre 6 miles above Morris, is not now in use. The former dam was 6 feet high. Another dam, about 6 feet high, near Morris, in the NW. ¼ sec. 12, Darnen Township, is also not now used, the flour mill that was formerly run by the power developed there having been burned. The water power at all these mills has been supplemented by steam power. Although no data are available on the stream flow in the quadrangles, the records from adjacent areas, together with the fall, indicate that the available water power amounts to less than 500 horsepower.

The Chippewa mill, on Chippewa River, formerly stood on the north side of sec. 1, Elk Lake Township, but no water power is used there now. At that place the river has a fall of 30 feet in a short distance. Chippewa and Mustinka rivers are both small within these quadrangles and are not now used for power.

*Quality of water of lakes and streams.*—All the water in the lakes and streams is more or less hard and alkaline because of the chemical composition of the clay in the gray drift. The quality of the water in each one varies because of freshening in seasons of heavy rainfall and concentration at times of excessive evaporation. The water of the rivers and of the lakes through which the rivers flow is the best, but even this water is somewhat discolored because of the growth of vegetation in it and because of drainage from meadows. However, the streams and ponds are not used or needed for supplying drinking water, except for animals, and are valued less as sources of water supply than for the wild fowl and fish that inhabit them.

#### GROUND WATER.

*General features.*—By ground water is meant the water intermingled with soil and rock in the ground, and by ground-water table is meant the level at which this water stands in the ground or to which it rises in wells. The ground-water level is highest in the northeastern part of the area and lowest in the northwestern part, as shown on the geologic maps. It conforms broadly to the general surface and is not much influenced by local hills and valleys. Hence, in parts of the Chippewa, Pomme de Terre, and Mustinka valleys and of the basin of glacial Lake Agassiz the water from the deeper parts of the drift will rise a little above the surface. In these valleys, therefore, flowing wells have either been drilled or could be obtained, as shown on the geologic maps.

Most of the lakes and sloughs are higher than the level to which the ground water will rise in wells. For example, the level of the ground-water table in the region about Cormorant Lake is 25 to 50 feet lower than the surface of the lake. Such lakes and sloughs are filled by the rains, and their water is kept from sinking into the ground by impervious beds below them. Hence they supply very little water to neighboring wells, most of the water that is caught in the lakes being returned to the air by evaporation. The artificial draining of the lakes should therefore not affect the wells unfavorably. On the contrary, as the lake beds are commonly broken up and made pervious when they are drained, the supply of ground water should be increased by drainage.

The water that percolates to the ground water below passes slowly downward, generally through the nearly impervious clay, but wherever local lenses or layers of pervious sand or gravel are included within the clay the course of the water is influenced by them, and at some places where gravel beds exist water no doubt flows directly or obliquely downward, or even rises again under certain conditions. Most of the gravel and other pervious beds lie nearly horizontal or rather they dip slightly in the direction of the slope of the land and may give a very oblique course to descending water, which is prevailingly in the direction of the slope. Below the general plane of ground water the flow is slow from places where the plane is high to those where it is low. The sheet of water as a whole flows slowly, but beds of gravel doubtless give more speed as well as oblique direction in many places, so that there is movement of water also in the lower water-bearing zone.

Few notable springs occur in this region, and all are evidently seepage springs, being supplied by water that has entered the ground and has found an outlet before reaching the general water table. A series of small springs on the east side of the Mustinka Valley in the N. ½ sec. 14, Elbow Lake Township, are just at the height to which artesian water rises in neighboring wells (1,110 feet above sea level). A spring near the east shore of Barrett Lake (S. ½ sec. 6, Elk Lake Township), which flows 5 gallons a minute, is also at a low altitude. Springs were noted in the bottom of ravines in the SE. ¼ sec. 19, Erdahl Township; in the NE. ¼ sec. 25, Sanford Township; and larger ones near Mud Creek in the NW. ¼ sec. 16 and in the NW. ¼ sec. 29, Darnen Township.

*Surface wells.*—Many wells in this area that depend on surface water were once used but have been abandoned because they often failed in seasons of drought or were not equal to increasing demand. Some such wells, however, are still in use. In many shallow wells there is liability to contamination of the water, and some have therefore been abandoned.

Distinction may be made between shallow wells in gravel and those in till. The glacial outwash gravels that lie at the surface in the Pomme de Terre Valley are filled with water to a level controlled by the river, and wells sunk into them find an adequate supply of water. As the ground is porous all these wells may be liable to contamination, especially from areas that lie upstream. Besides the wells at the farmhouses on the glacial outwash deposits that are shown on the maps, the wells at Barrett and those at the Morris waterworks draw their supply from gravel beds in the Pomme de Terre Valley. Wells at farmhouses along the Chippewa Valley likewise penetrate glacial outwash gravels which are saturated below the level of Chippewa River and which yield abundantly. The ancient shore gravels of the Herman beach also contain water near their base and supply several shallow wells dug near houses on the beach.

Practically all the wells in the till draw water from irregular and discontinuous bodies of gravel, sand, or silt that are interbedded with the till. Most of the water-bearing beds are underground reservoirs that are filled more or less directly with rain water. Such beds may be pumped dry in time, or they may become empty because of flow from them to lower beds or to the dried-out till around them. As the water descends or flows off from one gravel bed to another, some shallow wells that penetrate water-bearing beds that are continually replenished may be practically inexhaustible. A few wells are supplied from flowing underground streams. For example, a well at a house in the NE. ¼ sec. 17, Erdahl Township, which is 45 feet deep and contains 2 feet of water, is supplied by a stream that flows near the bottom of the well.

Because of the conditions described some wells that fill nearly to the surface of the ground may be easily pumped dry, though others which contain but a few feet of water yield an adequate supply.

*Wells drawing from levels below the water table.*—Many wells in this region draw water from beds of gravel, sand, or silt in the glacial till. All the clay of the till below the ground-water table is saturated with water, but as it is very fine grained and close textured it yields little or none to wells. The deep beds of gravel and sand yield water, which rises in the wells to the ground-water table and therefore has artesian head.

The water table everywhere lies above the bedrock, and therefore there is everywhere a zone of saturated drift. Moreover, beds of gravel or sand of sufficient extent to yield water are so abundant that failure to find water in the drift is exceptional. However, these beds are so irregular in distribution and size that two or more deep wells sunk only a few rods apart may strike different water-bearing beds and obtain very different quantities of water. For this reason the depth to which a well must be sunk to find an adequate supply of water can not generally be predicted. The bedrock is nearly everywhere too impervious to be water bearing, but in some places it may have open joints, which serve the same purpose as a bed of gravel in carrying water or collecting it from the till. In a well in the SW. ¼ sec. 5, Everglade Township, water was found only after the drill had passed 8 feet into the granitic rock under the drift.

More than half the deep wells now in use get water from beds of gravel or coarse sand that yield freely, but many wells are stopped in beds of fine sand or silt, either to save the cost of sinking them deeper or because they have struck bedrock without finding gravel. A screen is commonly attached to the casing of such wells to prevent the silt or sand from entering with the water. These screens may become coated with calcareous deposits and in a few years may thus become entirely clogged.

When an old well is sunk deeper and reaches a water-bearing bed at or below the ground-water table, the head of water generally falls nearly to the lower water level, even if the water from the higher beds is admitted to the well. If the deep water-bearing bed is relatively weak the height to which the water rises in the well may fluctuate greatly with alternating wet and dry periods.

There is reason to believe that good wells are more commonly obtained in high than in low places, for the height of a tract may be due to some extent to underlying lenticular beds of gravel and sand, which bear water, as shown in figure 12.

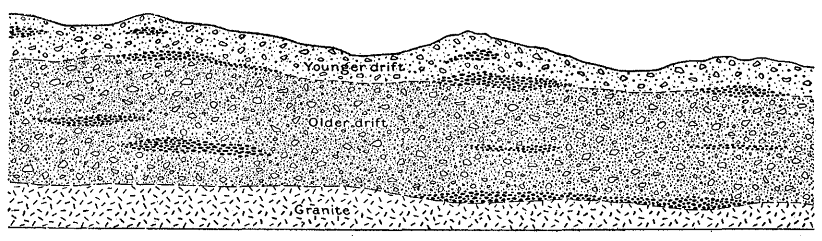

FIGURE 12.—Ideal section showing underground conditions that favor successful wells on high ground. The higher ground is believed to be more generally underlain by gravel deposits (darker lenses in the figure) than the lowlands, and most of the gravel beds are water bearing.

*Municipal supplies.*—All the towns of the area have deep wells except Morris and Barrett, where the wells are shallow. A well 450 feet deep supplies the entire town of Elbow Lake, yielding 40,000 gallons a day without notable lowering of its head. Herman is supplied in the same way by wells 140 feet deep, and Donnelly by one well 125 feet deep. The town well at Hoffman is 75 feet in depth, that at Chokio 80 feet, and that at Norcross 150 feet. The waterworks at Hancock is supplied by a well that is sunk to a depth of 480 feet but that receives no water below the depth of 117 feet, where there is a strong inflow.

*Flowing wells.*—Wells flow because the surface of the land on which they are sunk stands below the plane of artesian head, or below the height to which water rises in wells from the pervious beds within the till. The water which is derived from rainfall on a neighboring high catchment area passes through pervious beds with a movement as fast as friction permits toward lower land. It passes almost horizontally from tracts where the water table is high to where it is lower, its flow being most rapid through the pervious beds, to which it is in large part confined by the nearly impervious beds of till. The water thus flows horizontally under certain surface depressions, although it has artesian head enough to overflow the top of a well sunk to the water-bearing beds.

Where the bottom of the Mustinka Valley enters the Herman quadrangle it is a little below the level to which the artesian water rises, the water in the only deep well in the valley there standing 1,110 feet above sea level, or 10 feet above the level of the water in the river. The same condition occurs on the Mustinka east of the Herman beach, where the water in a deep well stands 1,076 feet above sea level, or 25 feet above the river. There are no deep wells in the Pomme de Terre Valley, but flowing wells could perhaps be obtained in some parts of it. A flowing well that has a head of 1,085 feet above sea level was drilled on the south side of sec. 20, Elbow Lake Township.

In certain districts in the northwestern part of the Herman quadrangle all the deep wells overflow. One of these districts is north of Mustinka River, in Gorton and North Ottawa townships, and extends several miles north of the Herman quadrangle; the other is south of the river, in Gorton and Logan townships, and extends westward a short distance beyond the Herman quadrangle. In the northern district there are more than 20 flowing wells, which range in depth from 20 to 165 feet and have 1 to 10 feet head above the ground; in the southern district there are 5 flowing wells, which range in depth from 100 to 150 feet and have 1 to 3 feet head. The head of the flowing wells in the two districts ranges from 1,012 to 1,042 feet above sea level. The best wells have a flow of about 10 gallons a minute. Some of them have been flowing without restraint for 10 to 20 years, but the rate of flow is said to have decreased somewhat in that time. A few wells that barely overflowed at first have lost head, and the water level in them is now 1 to 4 feet below the surface.

## SOILS.

*General character.*—The soil of the region is derived wholly from materials of glacial origin. The differences in the soil are chiefly those that have resulted from original differences in the drift and from subsequent drainage. The chief differences are in the proportion of clay and sand, the amount of humus, the surface drainage, the underground drainage, the thickness of the subsoil, and incidentally the presence of alkali.

The drift contains a great variety of mineral substances and makes a rich soil. The present rich soil was obviously formed by the weathering and decomposition of the surface of the drift and by the addition to it of vegetable mold or humus. The underlying drift is a like source of future soil. At many places there is a distinct subsoil of weathered drift, which is like the soil except that it contains no humus. The soil and subsoil have together an average thickness of 2 feet. The most notable difference between the subsoil and the fresh drift is that the fresh drift contains an abundance of calcium carbonate. Wherever the surface drainage is rapid the soil and subsoil are thin and the carbonate-bearing zone lies near the top of the ground and may in certain small tracts be turned up by the plow. At the foot of the slopes and in numerous small sloughs the soil is generally thick and the carbonate-bearing drift lies 3 to 6 feet or more below the surface.

Where water percolates through the soil from below and evaporates at the surface, a concentrate of "alkali" is left in the soil and alkali land is formed. Wherever an excess of alkali has long interfered with the growth of vegetation the soil may be poor from lack of humus. The alkali may, however, appear in thick mucky soils where the conditions of drainage have been changed. It disappears likewise where tiling, deep plowing, and the addition of coarse fertilizer have allowed rain water to leach the soil downward. No attempt is made to represent the distribution of the alkali land on the accompanying maps, as the alkali spots are of irregular shape and small extent, though widely distributed.

*Loam on gravel and sand.*—The soil on the glacial outwash plains and the glacial lake beaches is a mixture of sand and clay and ranges from light to heavy loam. It has been formed from weathered gravel and sand, such as it now rests upon. The clay came from the weathered gravel, especially from limestone pebbles but in part also from grains of calcite, dolomite, hornblende, feldspar, and mica, in the sand. The soil is black from its content of humus and is 6 to 18 inches thick. Even where this soil is on flat ground it is well drained except in low meadow land along rivers. The soil itself is good, but where it is thin the porous ground under it makes it dry in times of drought; where the soil is thick and the amount of humus in it is great such dryness is much less apparent.

*Loam on till.*—In the part of the area once covered by Lake Agassiz that lies west of the Herman beach there is loamy soil in places where the lake deposited fine sand. This soil is mostly rich in humus. It rests either immediately on till or on 1 to 6 feet of very fine silt above the till. The black soil is 6 inches to 3 feet deep and ranges from light loam to muck. As the till is rather clayey and the surface of the land is flat much of this area required drainage by ditches. The part that needed artificial drainage is in general occupied by the better soil.

*Loam and clay soil on till.*—The soil of that part of the bed of Lake Agassiz that lies outside or east of the Herman beach is variable from place to place. The most characteristic soil of this part of the lake bed is a thick black loam that rests on till, but at some places the soil rests on sand or loam that lies above the till and in other places it consists of clay formed in part or wholly of weathered till.

*Clay soil on till.*—The soil of the greater part of the old bed of Lake Agassiz in the Herman quadrangle and the soil of nearly all the till surface in all four quadrangles consists of clay formed of weathered till containing much humus, and it differs according to the topography. On a steep slope it may be only a few inches deep and the protruding boulders and the pebbles that are turned up by the plow may make the land look stony. At the foot of the slope, however, the soil may be several feet deep. The prevailing or ordinary till surface, on which knolls and low, broad swells are interspersed with kettles and sloughs, has a rich black soil, which is about a foot deep on well-drained land but from 2 to 6 feet deep in the kettles and sloughs. The beds of drained lakes have a rich mucky soil of uneven depth.

As the till under the soil is nearly impervious artificial drainage is needed to prevent the flooding of crops in the bottoms of old sloughs and kettles in wet seasons, and as the soil of the sloughs is fertile such drainage is becoming more common. Although the bottoms of most of the sloughs and lakes stand above the level of ground water, the till or clay of which they are formed prevents the water from sinking. Vertical drainage has not yet been successfully employed; the only effective methods of drainage are surface ditching or tiling close under the soil.

March, 1916.