DESCRIPTION OF CASSELTON AND FARGO QUADRANGLES.

By Charles M. Hall and Daniel E. Willard.

GEOGRAPHY.

Position and extent.—The Casselton and Fargo quadrangles lie between the meridians of 96° 30′ and 97° 30′ west longitude and between the parallels of 46° 30′ and 47° north latitude, and cover one-half of a square degree. Each quadrangle is about 34½ miles long from north to south and a little less than 24 miles wide from east to west, and together they have an area of about 1640 square miles. These quadrangles embrace portions of Cass, Richland, and Ransom counties, N. Dak., and Clay and Wilkin counties, Minn. Fargo, a city of about 10,000 inhabitants, the largest city of North Dakota, and the center of trade for the Red River Valley, is located in the eastern part of the area, where the main lines of the Northern Pacific and Great Northern railways cross the Red River into North Dakota.

The area is of special importance, as it represents a typical section across the so-called valley of the Red River, including a small extent of prairie upland on the west. It also includes the eastern margin of the Cretaceous artesian basin, where the water-bearing formations rise to within 200 to 300 feet of the surface, and are most easily studied through the numerous deep wells. Moreover, it also exhibits the characteristic features of the Quaternary artesian well areas so frequently found within the Cretaceous basin in the Red River Valley. Within it are also found the water horizons yielding only tubular or dug wells, which constitute the only source of water supply over a large part of eastern North Dakota and western Minnesota. The description of these water resources applies to a large extent to the entire area from Bigstone Lake to the international boundary line.

RELIEF.

Red River Valley.—The Red River Valley includes the greater part of the Casselton and Fargo quadrangles. During the latter part of the Glacial epoch it was a lake which has been called the Glacial Lake Agassiz, and which has been described by Mr. Warren Upham in Mon. U. S. Geol. Survey, Vol. XXV. The topography therefore is exceedingly simple, two-thirds of the area being level plain. From the middle of the valley, if this plain may be called a valley, the view is interrupted only by the groves planted by the early settlers around their farm buildings and by the trees along the streams. This plain is so level that in many places the tops of buildings and trees are seen on the horizon, no physiographic feature being great enough to be detected by the eye. This flatness is due to the fact that this region is one of topographic youth and has not been eroded (See Topographic Atlas U. S., folio 1, "Physiographic Types", U. S. Geol. Survey).

The general altitude of the level plain is about 900 feet above tide. On both sides of the Red River, which flows from south to north across the plain, the land rises with a gentle slope of from 1 to 4 feet per mile. Toward the western border of the old lake bottom the surface rises in a series of north-south ridges—the beaches of the old lake at its different stages. In the northern part of the area there is a rise of 200 feet in about 5 miles to the upper or highest level of the old lake. Beyond this the rolling prairie merges into the low morainic hills just west of this district. The highest part of the area discussed is in the northwest corner of the Casselton quadrangle, where the elevation is 1200 feet.

In the southern half of the Casselton quadrangle there is a sudden rise of about 60 to 70 feet within 2 or 3 miles from the lake bottom to a sand plain almost as level as the old lake bottom itself. This plain extends from a little north of the Maple River to beyond the southern boundary of the quadrangle. It is broken by the Maple and Sheyenne valleys. The Sheyenne River has eroded a gorge from 100 to 140 feet deep across the plain. On both sides of the Sheyenne Valley is a series of hills or dunes ranging from mere undulations to huge mounds 130 feet high.

The great depression or level plain through which the Red River flows was the pre-Glacial valley of a large northward-flowing stream. The excavation of this great valley began after the deposition of the Cretaceous sediments, probably when the great post-Mesozoic uplift of the western part of the continent rendered the former sea bottom dry land. The pre-Glacial Red River Valley therefore probably was eroded after the close of the Cretaceous period and during the Tertiary uplift. This old valley was deeply mantled with drift, borne southward by the moving mass of ice, and the present river flows on the top of this, many feet above the level of the older river. After the ice retreated this mantle of drift became the bottom of the Glacial Lake Agassiz.

The Manitoba escarpment, which limits the Red River Valley on the west, is composed of Cretaceous shales and was formed by the erosion of the valley to the east. If these strata once continued over the whole southern portion of the Red River Valley in North Dakota and Minnesota, as seems probable, they have been largely removed by erosion. In the axial portion of the Red River Valley, in the latitude of Fargo, the shales and sands do not generally have a total thickness of more than 150 feet, as determined by borings. However, in the western portion of the Casselton quadrangle, their thickness is unknown, as the deepest borings, which do not exceed 600 feet in the Casselton quadrangle and 800 feet or less in the adjoining quadrangle to the west, have not reached the granite and reveal successive layers of shale and sand.

DRAINAGE.

Red River.—The Casselton and Fargo quadrangles are drained by the Red River and its tributaries—the Buffalo on the east and the Wild Rice, Sheyenne, and Maple on the west. The Red River is approximately in the center of the Red River Valley. It enters the Fargo quadrangle from the south, at an altitude of 900 feet above tide, and flows in a tortuous course, the general direction of which is a little west of north. At the northern boundary of the quadrangle it has an altitude of 860 feet. In its winding course the river has a length of not less than 80 miles in the quadrangle, and it has a fall of not over 6 inches to the mile. The channel is from 200 to 300 feet broad and from 20 to 60 feet deep, and, like all meandering streams, usually has one steep bank and one more gently sloping. In many places the banks have been built up by silt deposits and there is a gentle slope for a short distance away from them. The channel of the main stream is sufficient in ordinary seasons to carry off the drainage of the land, the usual capacity at Fargo being not far from 25,000 cubic feet per second. However, when the melting of deep snows is hastened by rainfall, the present channel is entirely inadequate and the river has been known to overflow its banks and to reach in places a width of 15 miles. In recent years floods have occurred in 1897, 1893, 1882, and 1881. They occur at the melting of the spring snows in April, when the water is highest. At times heavy June or July rains will cause a rise in the river, but usually the midsummer floods do no serious damage. The spacing of the tributaries of the Red River seems to have been determined by the streams which entered the valley as the water of the lake receded. All of the perennial streams tributary to the Red River have their sources outside the area of ancient Lake Agassiz, and usually show every evidence of having been much larger. They have few affluents and usually receive the drainage from only a narrow area on both sides. As a result there are between the rivers broad areas which have little or no definite drainage. The only drainage ways in the areas between the principal rivers are coulees from 20 to 40 feet deep near the river and a mile or two in length. These carry water only after heavy rains or while the snow is melting, remaining dry at other times. This arrangement of the streams is due to the extreme youth of the drainage system.

When the erosion of the lacustrine deposits begins, it proceeds rapidly. In 1895 a wagon road was graded east of the Red River between secs. 30 and 31, Oakport Township (T. 140, R. 48), for a distance of about 6 miles. The farmers at once began to drain their fields into the roadside ditch, which was deepened and broadened by erosion so rapidly that within four years the road had been destroyed for nearly a mile from the river and a channel 80 feet wide and 25 feet deep had been cut.

The three perennial streams, the Buffalo, Wild Rice, and Sheyenne rivers, rise outside of the Red River Valley, but within the valley bottom their channels and meandering courses are not unlike those of the Red River. They have been lowered to their present places by the recession of the lake.

Buffalo River.—This stream rises in the lake region in middle Becker County, Minn. It enters the Red River Valley 1½ miles south of Muskoda station, where it cuts through the sand and gravel beds of the upper Herman beach and the delta of its own deposit. It enters the Fargo quadrangle 3½ miles east of Glyndon, and about 3 miles northwest of Glyndon is joined by the North Branch. It then takes a meandering course nearly parallel with the Red River, which it enters at Georgetown, 7 miles north of the quadrangle. The stream is seldom affected by floods, except in the spring, when all watercourses are congested. It is not much affected by rains on account of the sandy soil and the lake region at its source, but it maintains a fairly good flow during dry seasons, being fed by numerous springs along its sides.

Wild Rice River.—This stream has its source among the morainic hills near the southern boundary of North Dakota. It enters the Red River Valley in eastern Sargent County, crossing the Sheyenne delta for a distance of 24 miles in a direct line. It receives little or no lateral surface drainage in this region. It enters the Fargo quadrangle from the south within 2½ miles of the Red River, and flows north parallel with the main stream nearly 20 miles before entering it. In the spring the river is full, but after the June and July rains it is often completely dry. The fall rains start the flow again, but in winter the stream usually freezes to the bottom in many places.

Sheyenne River.—The Sheyenne River is the most interesting stream of the region. It has its source southwest of Devils Lake and flows 180 miles before entering the valley of the Red River. It occupies a valley varying from one-fourth of a mile to one mile in width and from 75 to 150 feet in depth.

After entering the valley of the Red River the Sheyenne flows northeast in a serpentine course for nearly 40 miles before joining the main stream. Although it has a drainage area of over 4000 square miles above its junction with the Maple, it is not subject to floods and does not seriously endanger the lands along its lower course, for its channel within the lowlands of the Red River Valley is large enough to hold the water as fast as it descends from the tortuous channel of the upper stream.

When the Glacial Lake Agassiz had its greatest extent it obtained its water chiefly from the ice front directly and through the Sheyenne and Maple rivers. While the lake was at its higher stages and had an outlet toward the south into the Minnesota River, the waters of the Sheyenne were carried in that direction and sediment was deposited along the margin of the lake. The diversion of the present Sheyenne River into Bigstone Lake and the Minnesota River, as a preventive of floods in the Red River Valley, is entirely impracticable, as the old channel is 150 feet above the present stream.

During most of the Glacial epoch Sheyenne River entered the lake about 12 miles south of the southern boundary of the Casselton quadrangle. The amount of sediment brought into the lake was very great and the deposit thus formed is known as the Sheyenne delta. According to Upham's estimate, this delta has an area of 800 square miles and the deposit has an average depth of 40 feet and a volume of 6 cubic miles (Mon. U. S. Geol. Survey, Vol. XXV).

The portion of the Sheyenne delta included in these quadrangles is shown on the areal geology maps. The finer clay sediment was carried far out into the lake and the coarser sandy material deposited near shore to form the delta. As the lake receded the vast delta of sand was uncovered and the river began to excavate a channel across it. Before the lake had been lowered to the fifth stage—marked by the formation of the McCauleyville beach, which is approximately the outer border of the delta—and before the river had cut a channel across the delta, the lake was receiving much less water and sediment than during its highest stages, because the water from the melting ice was diverted from the sources of the Sheyenne to other channels. If this had not been so, the delta would have extended farther into the Red River Valley in northeast Barrie Township.

During and immediately following the McCauleyville stage of the lake, the Sheyenne doubtless flowed almost directly east, across the Red River Valley, as is shown by its sharp bend to the east where it enters the valley in the southeast corner of sec. 11, Barrie Township. The old channel is again marked in secs. 8, 9, 10, and 14, Walcott Township. The volume of water could not have been great, else the stream would have followed the course first taken. On account of the levelness of the land, the river was easily diverted to the north, in which direction it flows more than 30 miles almost parallel with the Red River before finally entering it.

The Sheyenne River flows during the summer months, being supplied with water by springs, but it has been known to become completely dry. It has very few tributaries, and in the delta sand plain rarely receives surface drainage from any point more than a mile from the stream. It is believed that were it not for the great channel eroded by the glacial waters the greater part of the 4000 square miles of its drainage basin would be an area of undeveloped drainage, like the Devils Lake region and a large area between the Sheyenne and James rivers.

Maple River.—Another stream resembling the Sheyenne in origin and history is the Maple River, but its drainage area is much smaller and its valley not so deep. Like the Sheyenne and the other tributaries of the Red River already mentioned, the Maple turns northward after it enters the Red River Valley. It unites with the Sheyenne 10 miles above the junction of the Sheyenne and the Red. During dry years the bed is usually almost or entirely without water.

Near the Maple River is a peculiar topographic feature the discussion of which, because of its apparent connection with this river, has been deferred to this point. Beginning at the east side of section 19, Maple River Township, near the point where Maple River debouches into the level valley, is a winding ridge from 15 to 25 feet high that follows in general the course of the Maple River. It can be plainly traced for a distance of 20 miles. It can hardly be in any way connected with a beach line of the retreating lake, for it seems to be independent of the general topography and its crest is 945 feet above tide at the southern end and is nowhere less than 910 feet above tide. In Maple River Township the ridge contains much sand, and several sand and gravel pits have been opened. In each case there is less than 5 feet of sand and gravel. Farther north, in Durbin, Harmony, and Raymond townships, this ridge offers attractive sites for farm buildings, but in most borings for water quicksand is struck at a depth of 12 to 18 feet below the surface.

While the origin of this ridge is obscure, the suggestion is perhaps warranted that it was formed by the Maple River entering comparatively shallow water and dropping coarser materials first and the fine quicksand in the more gently moving current farther out from shore. It resembles in every respect an esker or osar, but what could confine a current in a shallow lake in one course long enough to deposit such a prominent ridge is not clear.

GENERAL GEOLOGY.

Pre-Quaternary Rocks.

ANCIENT GRANITE.

At no place in the Casselton and Fargo quadrangles is there an exposure of the stratified rocks underlying the drift, and knowledge of these rocks is therefore derived entirely from borings. Deep wells have penetrated the hard granite at depths of 252, 255, 256, 266, 286, 295, 298, and 475 feet in the Fargo quadrangle, and at depths of 411, 450, 470, and 490 feet in the Casselton quadrangle. The only pre-Quaternary sedimentary formation found in these wells above the granite is a shale containing layers of sand of Cretaceous age.

The granite basement is of unknown thickness. Little is known of its character in this area because few borings penetrate it. It is deeply buried and it does not seem likely that it will ever yield either water or valuable minerals. Its surface is shown to be somewhat uneven by the difference in depth at which it is struck in well borings, but no very accurate description of the unconformity between the old granite and the much later shale can be given.

The occurrence above the hard granite of white and green vari-colored clays, at a depth of from 5 to 50 feet, and in the deep well at Moorhead at a depth of 105 feet, shows that the granite has been decomposed and much altered and was long exposed to the action of atmospheric agencies before the submergence of the old land surface.

PALEOZOIC ROCKS.

Paleozoic strata have not been encountered in borings in the upper portion of the Red River Valley, which includes the Casselton and Fargo quadrangles, but have been observed in deep borings down the valley toward the north. At Grafton, 100 miles north of Fargo, an artesian well penetrated 317 feet of limestone belonging to the Ordovician, and 288 feet of Cambrian shales and clays (Upham). How far these strata extend southward in the Red River Valley has not been determined. Between Grafton and Fargo are several artesian wells obtaining their water supply from the Cretaceous sandstone, but none which penetrate deeper.

CRETACEOUS ROCKS.

The sedimentary rocks of the eastern portion of North Dakota and northwestern Minnesota, including the Casselton and Fargo quadrangles, were deposited in the great inland sea which during Cretaceous time occupied a large area in the interior of the continent. In the Casselton and Fargo quadrangles all the strata encountered in borings, except the granite and the surficial deposits, are shales and sandstones deposited as sediments in this great sea. The depth at which these strata are encountered westward in artesian wells shows a dip westward toward a syncline which has its western limits on the flanks of the Rocky Mountains and its southern limits in the Black Hills.

The Cretaceous shales and sandstones rest unconformably upon the granite. The great ice sheet passed over the surface of the Cretaceous strata, and the till overlying these was deposited by water from the melting ice. The upper stratified layers shown in the section of fig. 1 must not be confused with the Cretaceous formation, as they are of much later date. They were deposited upon the bottom of the Glacial Lake Agassiz at the time of the melting away of the great ice sheet, and are known as lacustrine deposits or lake sediments.

Below the lacustrine deposits water-bearing sands are encountered at various depths throughout the Casselton and Fargo quadrangles (see accompanying table of well records). The deeper sands have been generally referred to the Dakota. It is somewhat problematical whether or not the Benton underlies the drift in this portion of the Red River Valley. No fossils have been obtained in the two quadrangles from borings, and the stratified rocks do not outcrop. The exact age of the strata which form the floor beneath the drift can therefore be only provisionally stated.

The Pierre shale is excellently exposed in the Manitoba escarpment, 70 to 100 miles north of the Casselton quadrangle, where numerous small streams, descending to the Red River Valley from the west, have eroded deep canyons into the soft shale. This escarpment rises more than 400 feet above the level plain of the ancient lake bottom a few miles south of the international boundary, and 100 miles north of the latitude of Fargo and Casselton has an elevation of 1500 feet above sea level (Upham). This highland descends gradually southward to approximately 1200 feet above sea level where it crosses the western portion of the Casselton quadrangle.

About 10 miles south of the Casselton quadrangle, near the point where the Sheyenne debouches into the Red River Valley, shale outcrops in the sides of the Glacial Sheyenne Valley. It has been provisionally referred by Upham to the Benton. Shale penetrated in deep borings at several points in the upper Red River Valley, including a part of these quadrangles, has been provisionally referred to the Benton by the same authority (Mon. U. S. Geol. Survey, Vol. XXV, p. 92).

The "second clay" of drillers is encountered in the Fargo quadrangle at depths of less than 300 feet. Clays described by drillers as "light green," "decided green," "white and chalky," and "putty-like," are reported at depths of 208 to 250 feet, and in the deep well at Moorhead, at 370 feet. These clays in every case extend to the hard granite which begins at a depth of 252 to 298 feet, and in the Moorhead deep well at 475 feet. In the last-named well granite was found at a depth of 1901 feet.

In the Casselton quadrangle the "second clay" is struck at depths of 200 to 300 feet, and deeper clays, "third clay," with layers of hardpan and gravel, at depths of 300 to 520 feet. White clay is reported in the Casselton quadrangle at 292, 300, and 420 feet, with hard granite below, and hard granite at 411, 450, 470, and 490 feet. In the Fargo quadrangle flowing wells are not obtained from a fine white sand rock, the eastern limit of the Cretaceous artesian basin crossing the east half of the Casselton quadrangle. However, deep wells yielding water from a fine white sand rock are common in the Fargo quadrangle, in which the water rises nearly to the surface. If these sands are provisionally assumed to be Dakota in age, and hence regarded as the eastern continuation of the Cretaceous artesian water-bearing sands farther west, here immediately overlying the granite, it would then be natural to correlate the "second clay" of the Fargo and Casselton quadrangles with the Benton shales farther west. Until fuller field records have been obtained to the south and west and correlated with those of these quadrangles it seems of doubtful utility to attempt to definitely assert the age of the clays and sands underlying the drift and overlying the granite in the portion of the Red River Valley now being considered. That Cretaceous sediments were laid down in a shallow sea is shown by thin beds of coal in the sandstone which overlies the granite and which has been provisionally referred to the Dakota.

Quaternary Deposits.

Brief history of Lake Agassiz.—In the last great period of the earth's history preceding the present, the northern part of North America, including Minnesota and North Dakota as far west as the Missouri River, was deeply buried beneath a great sheet of moving ice. This ice sheet was not unlike the one covering Greenland to-day, and for centuries was engaged in leveling the rugged surface of a drainage basin that occupied the position of the present Red River Valley, and in adding the débris to the material already gathered farther to the north and east. This débris was deposited at the border of the ice sheet, and formed the great hills of the terminal moraines of the Coteau des Prairies and the Coteau du Missouri.

The close of this important period was marked by some change in the elevation of the land, by a change of climate, and by a gradual melting and recession of the ice to the north. This last process was not sudden, or even continuous, but was marked by a succession of pauses. Each pause was long enough to allow débris to accumulate along the margin of the ice sheet, so that, when another retreat began, a row of hills, called a terminal moraine, marked the line of the preceding pause. None of the later pauses allowed the accumulation of nearly so much material as was deposited at the southernmost margin.

Seven moraines were left by the retreat of the ice sheet before the epoch in which the surface geology of the Red River Valley was determined. The seventh moraine, known as the Dovre, was formed when the edge of the ice sheet extended north and west along the line of hills near White Rock, S. Dak., to near Lidgerwood, Lisbon, Milnor, and thence in general along the course of the Sheyenne River to Devils Lake.

As the ice melted the water filled the basin of the pre-Glacial Red River Valley until it covered an area nearly as large as all of the Great Lakes combined. This lake is called Glacial Lake Agassiz. The continued melting of the ice caused the basin to overflow and an outlet naturally was formed at the lowest point of the rim. The outlet channel formed was through Lakes Traverse and Bigstone, the course of the Sheyenne River before the last recession of the ice sheet preceding the beginning of Lake Agassiz.

Along the border of the ancient lake the action of the wind and waves formed beach lines like those on the shores of large lakes to-day, and sand and gravel were accumulated in places into great ridges. The cutting down of the outlet and the tilting of the land during this period gave rise to the formation of several well-marked beach lines running nearly parallel. Those in the upper part of the lake were five in number, called the Herman, Norcross, Tintah, Campbell, and McCauleyville, from towns of these names in western Minnesota, located on these respective beaches. After the formation of these beaches the lake found an outlet to the north as a result of the recession of the ice sheet, and many other beaches were formed, until, on the final disappearance of the ice, the Red River Valley was left approximately as it is to-day. During its highest stage the water was 250 feet deep where the city of Fargo now stands. Great icebergs could thus float down from the north and would strand where they were driven by the prevailing winds after dropping their burden of bowlders, many of which are observed along the east side of the valley. The streams flowing into the lake, vastly larger than those in the region to-day, brought a great deal of sediment. Where these streams enter the lake great deltas were often formed, like the delta of the Sheyenne. Here the sandy sediment was dropped near the mouth of the stream, the finer materials being carried out to the middle of the lake. In this way the level bottom was built up to a thickness of 60 to 70 feet.

GENERAL CHARACTER OF THE DEPOSITS.

The waters of Lake Agassiz covered the Casselton and Fargo quadrangles, with the exception of the northwest corner of the Casselton quadrangle, which is covered with till or bowlder clay of the same character as that lying beneath the stratified lacustrine sediments. The bowlder clay is composed in part of materials transported for greater or less distances by the ice, but is mainly the pulverized materials ploughed up along the course of the moving ice, as is shown by the similarity of the drift clay to the stratified clay shale below, revealed in the records of well borings.

The surface deposits, except the small area in the northwest corner of the Casselton quadrangle, are drift materials modified by the action of the waters of Lake Agassiz. Below the modified lake deposits is the till, similar in character to that of the rolling prairie beyond the area covered by the lake. The total depth of the Quaternary deposits, as determined from well borings, ranges from 150 feet in the western portion of the area to 200 to 250 feet in the axial portion of the valley. The depth varies considerably owing to the uneven pre-Glacial surface. Four types of Quaternary deposits occur. These are (a) the rolling prairie with low morainic hills; (b) the reworked drift represented in the beach ridges and other shore deposits; (c) the fine sediments deposited in the deep waters of the lake and known as lacustrine silt; and (d) the delta deposit made by the Sheyenne River.

GLACIAL TILL.

Unmodified drift.—In the northwest corner of the Casselton quadrangle is an area, about 30 square miles in extent, which lies outside the region covered by the waters of Lake Agassiz, and beyond the limits of what is known as the Red River Valley. This is an area of drift, with the rolling and undulating topography characteristic of much of the eastern half of North Dakota west of the ancient lake bottom. The 1100-foot level is in general the limit of wave action. The extreme northwest corner of the quadrangle has an altitude of 1200 feet and is thus 100 feet higher than the crest of the principal line of the Campbell beach 4 miles to the east. There is a fall of only 100 feet in about 40 miles from the Campbell shore line eastward to the Red River.

Morainic islands—An embayment of the ancient lake extended beyond the western boundary of the Casselton quadrangle. One mile east of the western edge of the Casselton quadrangle, and almost exactly midway between the north and south boundary lines, is a hill, about 2 miles in length and averaging about one-third of a mile in width, which was an island for a short time during the highest stage of Lake Agassiz. Two miles farther south a similar hill, having a north-south width of 2 miles, projected as a promontory or headland into the ancient lake, a neck of land about a mile in width connecting it with the general highland a mile to the west. These elevations are typical morainic hills, being composed of hard bowlder clay with occasional sandy or gravelly layers, and bowlders of granite, quartzite, and limestone.

Extending for a distance of 3 miles in a north-south direction between the eastern extremities of these highlands is a conspicuous gravelly beach ridge. This ridge marks the line of the "breakers" between these two highlands at the time of the second or lower Herman stage of the lake. Another segment of the second Herman beach about $2\frac{1}{2}$ miles in length lies 3 miles north of the northern extremity of the island just described and half a mile east and 20 feet lower than the highest Herman shore. Five miles farther north a feebly developed shore line representing the second Herman stage lies about the same distance east of the upper beach and is separated from it by about the same vertical interval.

Lagoons back of the beaches.—The island referred to was an island only during the period in which the lake stood at the level of the upper Herman beach. During the second or lower Herman stage of the lake the embayment west of the island was a broad and shallow overwash slough or lagoon.

Similar lagoons or sloughs existed back of the high ridges formed at different stages of the lake. The breaking of the waves where the lower part of the rolling mass of water was retarded by the friction of the bottom caused the coarser gravel and sand to be thrown down in more or less uniform layers, forming the beach ridges which have been described. The finer sand and silt were carried over the crest of the bar and settled in the still water of the lagoon. The soil of these lagoon tracts is thus frequently not only composed largely of fine sand and silt but is often impregnated with alkali derived from the continued evaporation both before and after the disappearance of the lake.

LAKE AGASSIZ SILT.

The lacustrine silt overlying the till is found over about one-half of the Casselton quadrangle and over all of the Fargo quadrangle except about 40 square miles. Its thickness is in places 70 feet and is commonly 30 to 50 feet. This lacustrine silt consists of the finest particles of rock brought into the lake by streams, or washed from the wall of ice which formed the northern shore. It was laid down in perfectly stratified layers, the upper portion being blackened and enriched by accumulations of carbonaceous matter from the decomposition of plants and animals which found a habitat in the cold waters of the lake and in the shallow marshes which existed after the disappearance of the lake. These blackened marshes in turn became dry meadows.

BEACHES OF LAKE AGASSIZ.

In the northwest quarter of the Casselton quadrangle is a tract having the characteristic topography of a wave-washed shore of a receding sea. It is about 6 miles in width and extends from the northern edge of the Sheyenne delta northward beyond the quadrangle, and has an area of a little more than 100 square miles. The western limit of this tract is the highest level reached by the waters of Lake Agassiz. In the northern two-thirds of the tract, the 1100- and 1000-foot contours are only about 3 miles apart, whereas the 900-foot contour is about 40 miles to the east near the Red River. This slope between the 1000- and 1100-foot contours is the eastern face of the Manitoba escarpment.

The region was covered by the waters of Lake Agassiz during its highest stages, and was uncovered as the lake receded. Well-marked gravelly and sandy ridges formed by the action of the waves and currents traverse the area in a general north-south direction. They are composed of whitish sand with a little clay, and gravelly places are frequent. Sand for building purposes and gravel for road construction are obtained from pits. The eastern slope, or front, of the beaches is usually steeper and higher than the western side, and a marshy tract often lies back of a ridge, drainage to the lower levels to the east being prevented by the ridges. The area is one of reworked drift and lacustrine deposits, the latter being found in places where the configuration of the shore prevented the accumulation of sand and gravel in ridges.

The highest wave-marked ridge represents the level of the lake at its greatest extent, and is known as the Herman beach. The recession of the lake was not gradual but was by stages of intermittent recession and pause. The next lower beach was the Norcross, which is represented by a ridge about 4 miles in length along the boundary between Eldred and Walburg townships, and another fragment about 2 miles in length in Wheatland Township. Fragments of beach ridges representing the upper and lower Tintah stages of the lake occur along generally parallel lines at intervals between the north edge of the Sheyenne delta and the northern limits of the Casselton quadrangle. North of Leonard village the Tintah shore is marked by an escarpment eroded by the waves in the front of the delta. That the Tintah beaches represent two stages or levels of the lake is shown by the fact that the two nearly parallel lines connecting fragments of well-defined ridges are separated by a vertical interval of about 20 feet.

The most conspicuous beach after the Herman, which delimits the lake area from the rolling drift topography to the west, is the Campbell, which extends in a general northward direction from the point where the Maple River debouches upon the level plain to beyond the limits of the quadrangle. It is in part a well-defined ridge, rising with a sharp slope on the east, or lakeward side, and falling a less amount on the west, or landward side, and in part an eroded cliff or escarpment formed in the drift clay or till by the cutting action of the waves of the lake. It is the principal boundary between the level lacustrine sediments and the reworked drift which forms the "bench" land bordering the old lake bottom. Gravel and sand pits have been opened in many places along it.

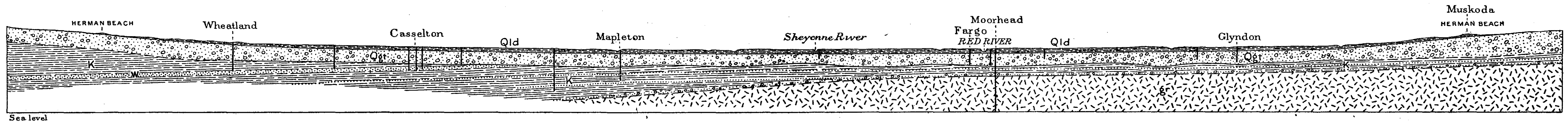

FIG. 1.—East-west sketch section across Red River Valley along Northern Pacific Railway, showing artesian wells deriving water from Cretaceous and Quaternary strata.

Qld, lake deposits; Qgt, glacial till; K, Cretaceous shale and sandstone; W, principal water-bearing horizon in the Cretaceous strata; gr, granite ("bed rock" of drillers).

Horizontal scale: 1 inch=4 miles. Vertical scale: 1 inch=1500 feet.

The McCauleyville beach, which marks the lowest stage of the lake while its waters were drained southward by the river Warren, is very feebly developed within this area. It is represented by two fragments, not exceeding a mile each in length, in Walburg and Gill townships. It is elsewhere a conspicuously developed ridge bearing sand and gravel, and traceable continuously for many miles. A prominent ridge parallel to Maple River and containing sand, gravel, and quicksand may possibly represent a later beach, but its origin seems to be due to other causes, as is described under the heading "Drainage."

The Blanchard beach, representing the next stage of the lake lower than the McCauleyville, and the highest level of the lake after its waters had begun to be discharged through a northern outlet, is shown in a low sandy swell of an area of about 16 square miles in Wilkin County, Minn., and by another broad sandy swell in Clay County, Minn., having an area of about 9 square miles. These areas, represented on the map as modified lacustrine deposits, are distinguished from the surrounding surface by the sandy character of the soil and the frequent occurrence of gravel, as well as by their elevation.

The beaches just described are found on the eastern as well as western side of the lake. The beaches representing the higher stages of the lake occur on a gentle slope that faces westward and does not reach the eastern boundary of the Fargo quadrangle. Bowlders occur in great abundance on this slope, and there are a few bowlder-strewn areas in the Fargo quadrangle. Some of these bowlders are of immense size, and their distribution along the higher shore lines of the lake suggests that they may have been carried by floating blocks of ice and stranded on the sand bars.

DELTA SANDS.

Extent and character.—The great delta plain of the Glacial Sheyenne River, composed of the coarser sediments deposited by this stream, extends over the southern third of the Casselton quadrangle and the southwest corner of the Fargo quadrangle. Upham estimates that the delta has an area of 800 square miles and an average depth of 40 feet. The northern and eastern front of the delta in Cass and Richland counties rises abruptly 60 to 70 feet from the almost perfectly level surface of the lacustrine sediments of the old lake bottom. The deposit is composed of fine sand and fragments of shale with a scant admixture of clay, so that its texture is in general loose. The surface of the plain is generally level or gently undulating. Dunes of wind-blown sand are conspicuous in places. The plain is intersected by the valley of the Sheyenne River, by which the delta was formed, and by the valley of the Maple River. Both these streams have eroded deep gorges in the delta deposit. The valley of the Sheyenne is nearly as deep as the total thickness of the delta deposit, though at no points has the underlying till been observed.

Age.—The steep front of the delta on its northeast side near the village of Leonard is marked by benches or terraces formed by the action of the waves after the waters of the lake had fallen below the level of the delta. The most conspicuous of these is the Campbell beach, which north of the delta also marks the most prominent "bench" forming the line of demarcation between the black lacustrine sediments and the reworked drift of the beach deposits. The existence of this beach along the front of the delta and below its highest level, and the occurrence of the highest or Herman beach along the western or shore side of the delta plain, show that the delta was formed by the Glacial Sheyenne River during the highest stages of Lake Agassiz, or between the Herman and the Campbell stages. The Sheyenne River therefore excavated its present deep valley in its own delta during the stage when the lake was being drained southward by the River Warren.

Springs of the delta.—The loose texture of the delta deposit allows the ready absorption of the waters of rainfall and melting snows. There is little erosion because the surface waters are so readily taken up by the soil. The waters percolate downward until they are checked by more clayey strata in the delta or by the hard impervious till beneath the delta deposits. The ready percolation of the waters and the impervious beds of clay make springs common along the delta front and in the deep channels of the rivers. On the lake bottom beyond the delta the hydrostatic pressure of the waters derived from higher levels in the delta causes the water table to rise to the surface and considerable areas are rendered boggy marshes.

The northeast front of the delta, about midway between the Sheyenne and Maple rivers, near the village of Leonard, is intersected by several deep coulees which have been formed by the action of springs bursting out from the delta. These may fittingly be called "traveling springs," since they travel backward into the plateau as a result of the action of their own waters in removing the erodible materials out of which they emerge. The same phenomenon is observed in the springs which head the coulees along the valleys of the Sheyenne and Maple rivers. The spring half a mile west of Leonard village has eroded a gorge 2 miles in length with a maximum depth of 70 feet. Other coulees in the vicinity formed in the same manner are half a mile to nearly 2 miles in length. Such springs occur in the banks of the Sheyenne River outside the Red River Valley for 150 miles, in Ransom, Barnes, Griggs, Nelson, and Eddy counties, where the river has cut deeply into the soft Cretaceous shales that underlie the drift.

DUNE SANDS.

The surface of the Sheyenne delta is marked by dunes. The most important dunes on the portion of the delta included within the quadrangles under consideration are in a tract from 3 to 10 miles in width along either side of the Sheyenne River. The dunes occur on the grandest scale in the neighborhood of the larger lateral coulees. Wherever the turf becomes broken by erosion so as to expose the sands, or where the covering of grass is thin, the lightness of the soil permits the scooping out of hollows and piling of sand into hills.

Geologic Structure.

The structure section shown in fig. 1, across the Red River Valley from western Minnesota to the western limit of the Casselton quadrangle, shows the granite immediately underlying the Cretaceous shales and sands. The Cretaceous formations have a westward dip toward the great synclinal basin in which the latest formations within North Dakota were deposited as sediments in the great inland sea.

The Cretaceous strata in the Manitoba escarpment indicate the post-Cretaceous erosion by which the great pre-Glacial Red River Valley was formed as a trough across the eastern edge of the great syncline. The glacial deposits, till and lacustrine sediments, represent the later work of the Glacial epoch.

In all parts of the Casselton and Fargo quadrangles borings have reached the Cretaceous shales and sands, and, except in the western third of the area, the hard granite. The lowest of these Cretaceous strata, and in the eastern portion of the area perhaps the only one, is probably the Dakota formation. Farther west and beyond the Manitoba escarpment the Benton, Niobrara, and Pierre formations are encountered in ascending order.

Immediately west of the Casselton quadrangle the deepest borings do not go below the Cretaceous sandstone, but it may be supposed that at some distance farther west successively older formations would be encountered at still greater depths, and finally the granite basement at the bottom.

In the western portion of the Casselton quadrangle and a large adjacent area the occurrence of artesian water, supplied from a sandstone formation, is due to the synclinal basin which extends westward from the region of the Red River to the Rocky Mountains and southward to the Black Hills. Flowing wells from the Cretaceous sandstone horizon are obtained at depths of 200 feet near the eastern limits of the artesian basin in the Casselton quadrangle, at depths of 400 to 500 feet in the western portion of the quadrangle, at depths ranging from 650 to 800 feet 30 miles farther south and west, and at a depth of 1500 feet still farther west, in the valley of the James River.

The Cretaceous formation outcrops along the eastern edge of the Rocky Mountains and in the Black Hills, and the water is supposed to be derived from these regions. Here the rains penetrate the porous sandy formation lying at the surface at altitudes of from 4000 to 6000 feet above sea level, and traverse the sandstone layers to the eastern portion of the syncline. At Jamestown and Devils Lake the water-bearing formation is at about sea level. The Cretaceous artesian water-bearing horizon rises to about 700 feet above sea level on the eastern side of the syncline.

The accompanying cross section (fig. 1) of the Red River Valley shows the structure along the line of the Northern Pacific Railway. It shows the black lacustrine deposit of fine sediment to a maximum depth of 60 to 70 feet in the axial portion of the Red River Valley, and thinning toward the western portion of the lake bottom. Below this occurs the bowlder clay or till to a depth of 150 to 200 feet. Then follow the Cretaceous shales and sands, which rest unconformably upon the granite. The top of the shale is very uneven, as is shown by the inequalities in its depths from the surface. At the top of the drift a layer of hard clay is often encountered, and below this water is generally obtained. This often rises nearly to the surface. The hardpan, as the layer of hard clay at the bottom of the drift is called by the drillers, was formed by the concentration of the salts dissolved out of the overlying clay and out of the rocks through which the water has passed.

ECONOMIC GEOLOGY.

Soils.

Lacustrine silt.—Probably there are few regions in the world in which the soil is more fertile than in the Red River Valley. The soil consists of very fine rock flour, ground and pulverized by the great ice sheet and deposited in Lake Agassiz. Only the finest assorted sediments were deposited in the deeper portions of the lake, as the coarser materials were thrown down when the current of in-flowing streams was slackened by the still water. This rock powder is known as lacustrine silt. When wet and compacted it has much the character of clay, but differs from clay in that it contains fine sand, fine powder of limestone, and carbonaceous matter, and is not coherent.

Gumbo areas.—Upon the level bottoms are tracts of very compact and heavy soil, varying in area from a few square yards to a few square miles and known as "gumbo spots". The water percolates very slowly through this soil, which cracks and forms hard prism-shaped blocks when dried by the intense heat of summer. This soil is very sticky when wet and hence not readily worked. Owing to its tendency to bake into hard blocks and its impermeability to water, which renders drainage difficult and frequently causes accumulation of alkaline salts, the gumbo areas are not desirable for farming purposes.

River alluvium.—Along the rivers, beyond the area of the Sheyenne delta, is a mantle of river alluvium over the original fine lake sediments. This has a thickness of several feet at the river banks and thins to an attenuated sheet at some distance from the streams. This material is the fine overflow deposit from the rivers and is slightly coarser than the lacustrine sediments. It is coarser near the river banks because the heavier particles were first deposited. A cross section of the alluvial deposits therefore would show a wedge in which the alluvium is coarsest at the base and gradually becomes finer away from the river as it merges into the lacustrine silts. The land slopes away from the rivers and, while dry and suitable for farming near the stream, is not infrequently too low and wet for this purpose at a little distance.

These alluvial soils are among the most productive of the region. Their looseness renders them capable of more easily taking up the moisture of the summer rains and the drainage from the melting snows and spring rains. It also permits greater freedom of natural underdrainage, so that the soil is less impregnated with alkaline salts than the lacustrine sediments generally.

Subsoils.—The subsoils have the same general character as the surficial soil from which they have been derived by the action of the atmospheric agencies and the addition of organic matter. The subsoils, however, show distinctly the mode of their deposition from water, being in definite strata or layers. Many of these layers are of a fine-grained clay loam, approaching clay in character, but are not so heavy that they are not penetrated by water. They are generally sufficiently porous to permit surface water to percolate slowly to lower depths and to allow underground water to rise by capillary action. This quality is favored by the atmospheric and organic agencies which produce soil, and is of great importance in determining the value of the lands for agricultural purposes, as it renders natural and underdrainage possible and permits the slow rising of the waters during dry seasons from the permanent water table below. These stratified subsoils differ from the unstratified till in the region outside the lake bottom, and also from the till underlying the stratified deposits, chiefly in the assorted and stratified character of the materials.

The deeper till consists of pre-Glacial soil and the broken and pulverized rock shoved along the bottom and carried in the ice of the moving glacier. It consists of clay, bowlders, gravel, and sand. The gravel and sand often occur in locally stratified layers or beds. The clay in its deeper portions is a dark blue, becoming brown nearer the surface, where acted upon by the atmosphere. At a depth where it is not penetrated by vegetable roots and burrowing animals, and is beyond the active changes of heat and frost, this bowlder clay is a firm and compact substance, offering a high resistance to the percolation of water.

Water table.—The permanent water table is high in this region, owing principally to two causes—the almost complete imperviousness of deeper subsoil or till to water, thus preventing underdrainage, and the levelness of the land, by reason of which the surface water flows toward the streams very slowly. The soil and subsoil are sufficiently porous to allow a very slow percolation, and the deeper clay acts as a vast dish holding the water.

Alkali in the soil.—The study of alkali in the soil is of great importance in this area, as in all the adjacent portions of North Dakota and Minnesota. In some localities the alkaline salts in the soil become a hindrance to agriculture. The percentage of salts in the soil is found by analysis to increase with the depth. Not infrequently water is obtained abundantly from shallow wells, but it is so highly impregnated with salts as to be unfit for drinking or even for the use of stock or for steam boilers. Therefore water from shallow wells is not commonly used for any purpose.

As the surface water evaporates and deeper ground water rises by capillary action alkaline salts are brought to the surface and carried to the streams by melting snow and spring rains wherever there is surface drainage. Through concentration from continued evaporation, low places toward which the surface drainage flows and from which the waters can not escape, become in time what are known as "alkali spots." "Gumbo spots" are often of this character, the subsoil being so compact that there is practically no underdrainage. The amount of alkali gradually increases and, as a result, these places become unproductive.

Because of the removal of the soil, alkalies, and other salts by surface waters, the waters of all the streams contain alkaline and other salts, and because there is alkali in all the soils and subsoils, also in the deeper till, all the well waters contain some mineral impurities. While the waters may be soft and suitable for washing purposes and for drinking, there are no pure waters. In most of the deeper wells the amount of alkaline and other salts does not make the water unsuitable for domestic and general agricultural purposes.

As all the soils and subsoils are of drift origin, the ultimate origin of the alkaline and other mineral substances was in the stratified rocks of the pre-Glacial land surface. The salts are therefore those that were carried in the waters of the ancient seas on the bottom of which these rocks were originally deposited as sediments.

While the alkali in the soils is sometimes a detriment because it makes the water unwholesome and occasionally renders small areas unproductive, on the whole the alkaline and other mineral salts in the soil add greatly to the productiveness of the land, as, when present in not too great amount, they furnish necessary plant food.

Water Supply.

SURFACE WATERS.

Streams.—The area considered in this folio is traversed by the Red River and several tributaries, each entrenched in a well-defined channel. The largest streams are never dry, and the smaller only during dry seasons, but, owing to the general levelness of the region, their currents become very sluggish during the summer, and the water, which receives organic matter from the banks along their courses, is therefore not suitable for household purposes without filtering and boiling. It is, however, used for stock. The Red River supplies the cities of Fargo and Moorehead with water for sprinkling streets and lawns, fire protection, and laundry purposes, but not for culinary or drinking purposes. Streams supply water to the comparatively few persons who live near them. Outside the cities of Fargo and Moorehead probably fully nine-tenths of the population is dependent upon wells for a water supply for all purposes, while not more than one-tenth to one-twentieth could, without great labor and inconvenience, obtain their farm water supply from streams. The Red River, with its principal tributaries, the Sheyenne, the Wild Rice, and the Buffalo, and the secondary tributaries, the Maple, North and South branches of the Buffalo, and Deer Horn and Whiskey creeks, are the only perennial streams, and but few coulees intersect the intervening lands.

Springs.—In the level bottom of the Red River Valley springs are extremely rare. The water seeping under the heavy lacustrine clays along the borders of the valley is effectually held down by the impervious clay, and furnishes water for the Quaternary tubular artesian wells when the clay is penetrated in drilling. As the river valleys become deeper by erosion, springs break forth from the banks bounding the valleys, the waters being conveyed to the surface along the horizontal layers of porous gravel and sand. Such springs now exist in the deep valleys of the Red River, in the deep valley of the Sheyenne before it debouches upon the level plain of the bottom of Lake Agassiz beyond its own delta, and in the valley of the Buffalo.

Springs occur upon the generally level plain in two portions of the area. They owe their origin to hydrostatic pressure from the waters penetrating higher ground, which causes the water table to rise to the surface. These two areas are in the eastern portion of the Fargo quadrangle and central portion of the Casselton quadrangle. In the eastern area the water falls as rain or snow upon the sandy slope of the eastern side of the Red River Valley from 8 to 15 miles east of the Fargo quadrangle, and bursts out upon the nearly level surface of the lower land of the lake bottom. In the southwestern area a springy tract is due to the waters which soak into the sandy soil of the Sheyenne delta and rise to the surface a few miles east, upon the level plain which borders the delta.

WELL WATER.

Sources of supply.—In this area the problem of an adequate water supply from wells is of the greatest importance, since, on the great majority of farms, as well as in the smaller towns, all water, save only that caught upon the roofs of buildings and stored in cisterns (an amount barely sufficient for strictly household purposes), must be obtained from wells. The supply for drinking and culinary purposes for the cities of Fargo and Moorehead is also derived from deep wells.

Over considerable areas flowing wells can be obtained from shallow depths, and an inexhaustible supply of fairly good water can be obtained with but little lift in pumping.

The wells of this region may be grouped into four classes: (a) shallow or seepage wells, (b) bored or tubular pump wells, in which the water is raised by pressure, (c) artesian wells deriving their supply from sand and gravel beds in the drift, and (d) artesian wells deriving their supply from the Cretaceous sandstone.

SHALLOW OR SEEPAGE WELLS.

There are comparatively few wells of this class, and they are of little interest either from a geologic or an economic standpoint. They are, however, of interest as showing the height of the soil water table, and the fluctuations in its level during seasonal changes. The water in such wells is often strongly alkaline and unfit for domestic use. The waters of the shallow wells, however, differ greatly in quality, even in wells separated by very short distances and differing but little in depth. This circumstance shows the variability in the structure and character of the material deposited on the bottom of the ancient Lake Agassiz. Frequently, dug wells having a gravelly bottom furnish good water. When, however, the water is derived from a bed which contains a mixture of clay, it is very likely to be strongly alkaline and may contain other unpleasant or injurious impurities. The examination of waters from wells having clay bottoms indicates that the sediments deposited upon the bottom of the Glacial Lake Agassiz contained alkaline and other substances which render the water impure.

Two exceptions to the general conditions regarding shallow wells are worthy of note. These are in the depth of the wells and character of the water on the sandy area of the Blanchard beach, in Wilkin County, Minn., and on the Sheyenne delta plain in Richland County, N. Dak., along the course of the Maple ridge before described. On these sandy tracts the surface wells are from 12 to 20 feet deep and furnish inexhaustible supplies of very excellent water. The water is usually obtained in sand or fine gravel, is commonly soft, and is as pure as any water in these quadrangles. This is due to the fact that the sandy deposits act both as reservoirs and as filters for the waters which fall upon the surface as rain and snow. The clay which underlies the beach sand prevents the water from percolating to lower depths, and the surface slopes so little that the water is held in the sand reservoir of the beach. On the delta plain clayey layers in the deposit make the downward percolation of the waters slow. The sands, both of the beach and of the delta, were effectually washed by the waters of the lake during the time of their deposition, and thus were rinsed of the soluble salts such as impregnate the drift and lacustrine deposits generally.

DEEPER TUBULAR PUMP WELLS.

Tubular pump wells are obtained in nearly all parts of the Casselton and Fargo quadrangles, as shown on the artesian water maps, and furnish probably three-fourths of all the water used by the inhabitants. By a tubular pump well is meant one made by boring with an auger, the tubes lining such holes ranging in diameter from 2 to 30 inches. Frequently a hole is dug with a spade to a depth of 12 to 30 feet and then an auger is used till the water-bearing bed is reached.

Tubular wells range in depth from 20 to 200 feet, and the water often rises to within 2 to 8 feet of the surface, and sometimes stands even with it. A generalized section of a tubular well would show black soil from 2 to 8 feet from the surface, followed by stratified dark silt layers to a depth of 30 to 70 feet, and below bowlder clay or till. The bottom of the drift is generally reached at depths not exceeding 200 feet, though the horizon between the drift and the shale can not always be clearly distinguished owing to the similarity between the bowlder clay and clay shale.

The water of tubular wells is derived from layers of sand in the lacustrine deposits, from gravel and sand at the horizon between the lacustrine silt and the till, from gravel and sand strata in the till, from the bottom of the drift, and not infrequently, according to the drillers' reports, from the "soapstone"—the drillers' term for the Cretaceous shale clay.

From whatever horizon the water is derived the same general conditions prevail—a compact and impermeable layer or bed of clay overlies the water-bearing stratum, and no sign of water appears until the bottom of this clay is reached. The water rushes up the tube often with considerable force, and it is reported on good authority that, in wells in which a digging had first been made and a hand auger used for the deeper boring, it is sometimes with difficulty that the well digger is able to avoid being drowned before he can be lifted out of the well. The supply of water is practically inexhaustible, it often being impossible to lower the water in the tube or digging to any appreciable extent even with the use of a windmill or steam pump. Sometimes the water can be lowered appreciably by persistent pumping, the water resuming its original height in the well within a short time after pumping ceases.

QUATERNARY ARTESIAN WELLS.

Definition.—The difference between the so-called "tubular" wells, in which the water rises nearly or quite to the surface but does not flow, and a Quaternary artesian well, in which the water flows over the top of the tubing, is one of lifting pressure or head merely. The wells in this region show every gradation in head from those in which the water rises very little in the tube, but into which it enters very readily, to those in which there is a flow sustained by good pressure.

Distribution.—Flowing wells are obtained at depths ranging from 40 to 200 feet in several areas in Clay and Wilkin counties, Minn., and in the northern part of Cass County, N. Dak., and at a depth of from 80 to 175 feet in Davenport and Leonard townships, Cass County. (See fig. 2.) The pressure in these wells is not strong and the flow is subject to variation. In some cases such wells have ceased to flow entirely, and have to be pumped. It is likely that in many cases the cessation has been due to faulty construction in the well tubing or to infiltration of sand, and not to any real loss of pressure due to the head.

A well in sec. 28, Davenport Township, at a depth of 80 feet, yielded a strong flow of nearly 1000 barrels when first drilled. In the northern part of the same section a well 120 feet deep yields only a weak flow, and one 87 feet deep has ceased to flow. A well in the southeast corner of sec. 20 and one 148 feet deep in sec. 34 yield weak flows. In sec. 11, Leonard Township, a weak flow was obtained from a depth of 104 feet, and in sec. 3, in a well 175 feet deep, the flow was vigorous at first but soon became very light and furnished barely enough water for household and farm demands.

Character of the water.—These wells vary not only in the depth at which water is obtained but also in the quality of the water. In most cases the water is fairly good for general purposes, though often hard. In none of these wells is there the characteristic saltiness which is uniformly present in the deeper artesian wells that obtain their supply from the Cretaceous sandstone. Shallow artesian wells also occur in a few places immediately west of the Casselton quadrangle, in Buffalo Township. One of these shallow flowing wells is only 37 feet in depth.

Source of the water.—The water in these shallow flowing wells, like that in a great number of tubular wells in these quadrangles, is obtained from beds of glacial gravel and sand. The great variation in the depth of these wells within short distances indicates that the water-bearing beds lie not only at different depths but also in comparatively narrow zones or belts, rather than in broad, widely extended sheets. In the area of flowing wells in the southwestern portion of the Fargo quadrangle the wells vary in depth between 40 and 134 feet within a distance of less than 2 miles, and in one section in Spring Prairie Township, in the northeast corner of the Fargo quadrangle, three flowing wells have depths of 100, 125, and 145 feet. This indicates that a distinct reservoir supplies the water to each well. The marked variation in the depths of the water beds in tubular wells where the water rises to within a few feet of the surface but does not flow is similarly explained. Four wells in sec. 34, Elmwood Township, are 90, 110, 117, and 201 feet in depth, and the water rises respectively to within 4, 9, 10, and 16 feet of the ground. Similar diversities in depth characterize the whole area.

It has frequently been observed that in boring a well within a few rods, or even a few feet, of a well which had furnished an abundance of water but which had choked with sand or otherwise become disused, a thinner gravel or sand bed was encount-at about the same depth as the water-bearing bed in the first well, but no water, or but a scanty supply, was obtained. Sometimes no trace of the bed that yielded the water in the first well was found in the second boring. It seems probable, therefore, that the gravel or sand beds are not continuous over large areas, but thin out rapidly. It would seem, however, from the abundant supply of water and the strong head in most of the tubular wells, and the Quaternary artesian wells, that the beds extend for considerable distances in some direction.

The higher lands outside the Red River Valley, where frequent sandy and gravelly tracts occur, and where the surface drift is often loose and porous, furnish a suitable gathering ground. Here the rain water penetrates the porous soil and is conducted through the gravel beds to the lower levels. The pre-Glacial valley occupied by Lake Agassiz formed a basin or trough in which the glacial materials were deposited, and thus porous tracts of gravel and sand may have been so placed as to afford conduits or underground channels which convey the water from the higher lands outside the valley to the lower levels beneath the lake floor. The compact and impenetrable clay above and below the porous sandy or gravelly layers effectually prevents the dispersion of the waters, and thus when a vertical boring from the level lake floor passes through the compact clay into the saturated sands and gravels the water in these layers immediately rises.

Some borings are recorded which penetrated to the granite and no considerable amount of water was obtained. This is explained by the narrow areal extent of the water-bearing layers, such borings having penetrated no beds of gravel or sand of such extent as to contain any large amount of water, or those penetrated did not extend to the surface so as to receive a supply from rainfall.

CRETACEOUS ARTESIAN WELLS.

The western two-thirds of the Casselton quadrangle lies within the Cretaceous artesian basin. In this part of the quadrangle strong flows are obtained at depths ranging from 250 to more than 500 feet, as shown on the artesian water maps. The water is obtained in all cases from a fine-grained, loose sand. It is generally believed that the formation from which the water is obtained is the Dakota.

The water in these wells is generally salt and not suitable for irrigation purposes, though it is not found to have any injurious effects upon animals that drink it, and is agreeable to the taste after one has become used to it. The water is generally not so hard as that obtained from the more shallow Quaternary flowing wells or the tubular pump wells.

The wells vary considerably in depth within short distances. This seems to be due to the occurrence of alternating layers of sandstone and shale. In some cases a sufficient flow is obtained in the first sand, and in other cases the second sand layer is penetrated; not infrequently more than one water-bearing bed is struck in the same boring.

In sec. 10, Walburg Township, two flowing wells about 40 rods apart are 265 and 440 feet in depth. Four miles north, in sec. 26, Gill Township, water was obtained first at 262 feet, but insufficient in amount, and another flow in the same boring was struck at 405 feet. In sec. 32, Amenia Township, two flowing wells one-fourth mile apart are 350 and 430 feet deep. Five miles southeast, in sec. 21, Casselton Township, two beds from which water flowed over the surface of the ground were struck at depths of 350 and 425 feet. In the southwestern part of Walburg Township within a radius of one mile occur 5 flowing wells with depths of 240, 414, 430, 434, and 460 feet.

Granite has been struck in four places near the eastern edge of the Casselton quadrangle, at depths of 411, 460, 470, and 475 feet, and very little water, or none at all, was obtained. The records of these borings, so far as obtainable, do not show the occurrence of the characteristic water-bearing sandstone.

The pressure of the Cretaceous artesian wells increases toward the west. In the zone of the shallower wells of this class, those having depths ranging from 200 to 300 feet, the pressure is not great, and the water in general does not rise more than 5 or 6 feet above the surface. As the depth at which the water is obtained becomes greater toward the west, the pressure increases. In about the center of the Casselton quadrangle is a zone in which the calculated height to which the water might be carried, as determined from the well pressures, is 1000 feet above sea level, or about 15 to 20 feet above the surface. The 1000-foot contour traverses nearly centrally the zone of wells of 300 to 400 feet depth. The 1100-foot contour traverses nearly midway the zone of wells of 400 to 500 feet depth, and lies about 5 to 6 miles west of and nearly parallel with the 1000-foot contour. The height of the land in this zone averages about 1050 feet above sea level, and the water rises approximately 50 feet above the surface. From 3 to 5 miles farther west is the 1200-foot contour, which, in a general way, runs parallel with the 1100- and 1000-foot contours and is near the western limit of the Casselton quadrangle. The western boundary of this district coincides roughly with the 1100-foot contour, though its northern end is 40 to 50 feet higher. Thus, in the western portion of the Casselton quadrangle the calculated height to which the well pressure would raise water is from 50 to nearly 100 feet above the surface.

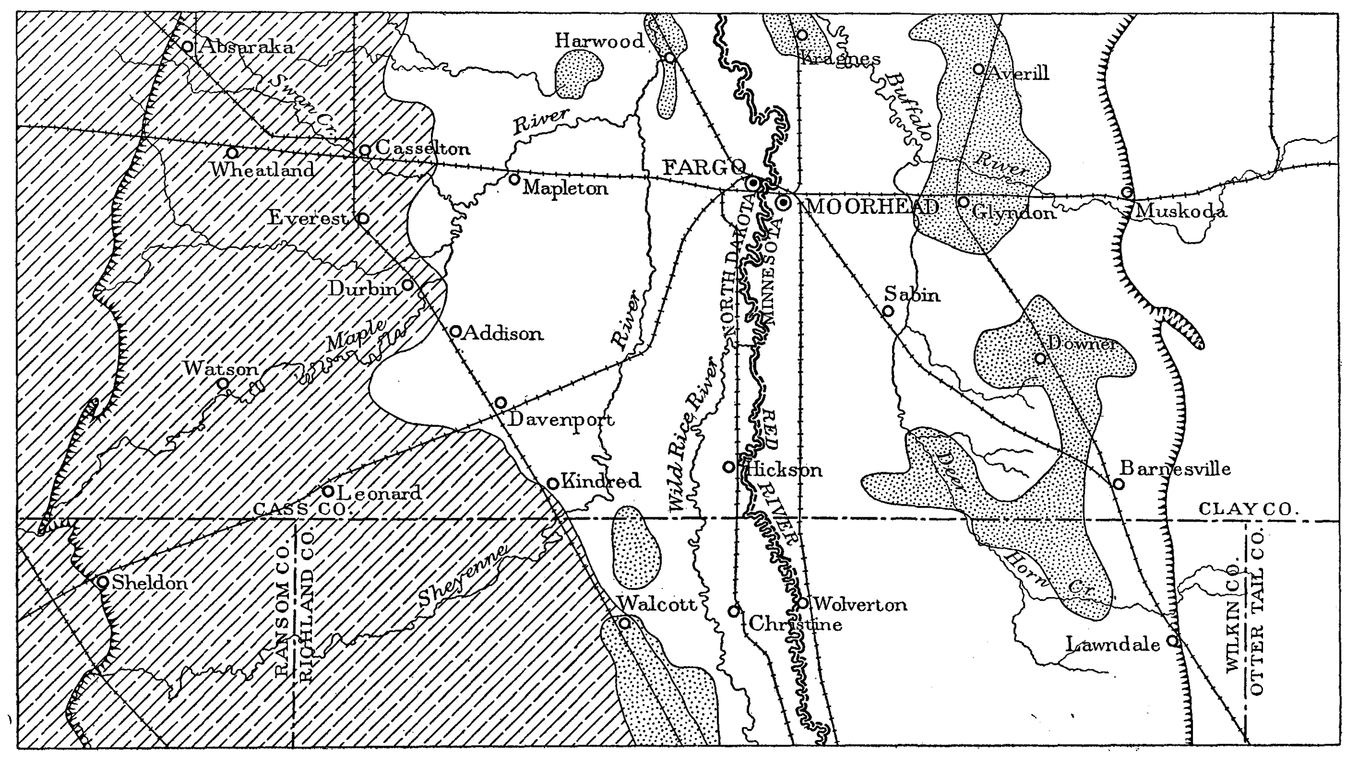

FIG 2.—Map showing underground water resources of Fargo and vicinity.
Ruled area, Cretaceous artesian basin where strong flows may be obtained at 300 to 600 feet depth; dotted areas, Quaternary artesian basins which yield light-flowing wells at 100 to 200 feet depth. Eastern and western boundaries of Red River Valley shown by hachured lines.
Scale: 1 inch=8 miles.

DESCRIPTION OF WELLS.

The following notes on wells not already described are given for the sake of the aid they may give in locating additional wells. Since the distribution of the water horizons, particularly in the Quaternary deposits, is very irregular, it does not seem possible to generalize this material, though the records have in each case a local value.

In sec. 7, T. 137 N, R. 46 W., water was obtained at 216 feet, and rises to within 6 feet of the surface. An accurate log of this well could not be obtained, but it was reported that green clay was struck at 208 feet, and hard granite at 258 feet. No samples of rock were preserved from this well, but the hard rock at the bottom seemed, from the description, to be granite, and the green clay is thought to represent an overlying mass of decomposed granite. The water, which is of poor quality, is derived from a layer of coarse gravel and sand in the upper layers of rotten granite. The water penetrates through the porous drift on the highland lying east of the Red River Valley, and is conveyed in the weathered granite underneath the heavy drift clay to the lower plain of the lake bottom. The hydrostatic pressure is sufficient to lift the water nearly to the surface.

The log of a well in sec. 8, T. 137 N., R. 46 W., about one mile from the well described in the preceding paragraph, is given below.

Log of well in sec. 8, T. 137 N., R. 48 W.

	Feet.
Clay	0–60
Blue clay	60–128
Gray clay	128–160
Second blue clay	160–215
Green clay (decidedly green)	215–266
Granite at 266 feet.	

No water was obtained in this well. The occurrence of bowlders down to 128 feet indicates that the drift extends to this depth. The first 60 feet of clay represents the lacustrine sediments. The age of the gray clay that extends from 128 to 215 feet can not be determined with certainty. The "clay" between 215 and 266 feet is described by the driller as "decidedly green," and is probably decomposed granite.

In sec. 34, T. 140 N., R. 47 W., a well not completed at date of visit had been drilled to a depth of 140 feet. Water was obtained from gravel and rose to within 20 feet of the surface. The log is as follows:

Log of well in sec. 31, T. 140 N., R. 47 W.

	Feet.
Clay	0–100
Gravel, varying coarse and fine, with water all the way	100–140

The upper portion of the clay is a lacustrine deposit and the lower portion is till. The gravel is probably drift, and not the Cretaceous sand.

The log of a well in sec. 15, T. 138 N., R. 47 W., is shown in fig 3.

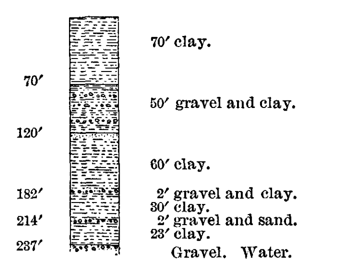

FIG. 3.—Section of well in W ½ sec. 15, T. 138 N., R. 47 W.

The water in this well rises to within one foot of the surface. The first 70 feet of clay is probably formed of lacustrine sediments. The gravel and clay from 70 to 120 feet are drift deposits, and the bottom of the drift may be represented by the water bed. The similarity between the till and the shale, when mixed and ground by the drill, is so great that they can with difficulty be distinguished. The water in the well rises to within one foot of the surface, also 3 miles east and 4 miles north of this well are flowing wells of low pressure and moderate flow.

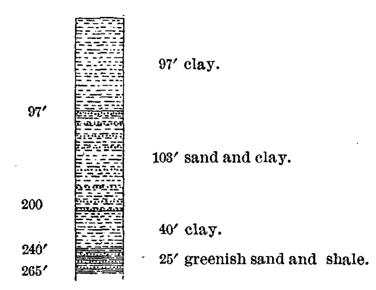

FIG. 4.—Section of well in N. ½ sec. 34, T. 138 N., R. 47 W.

From the log shown in fig. 4 it is impossible to distinguish the clay of the lacustrine silt from the underlying till, and this from the underlying shale. These altogether have a thickness of 240 feet. The 25 feet of "greenish sand and shale" may represent Cretaceous sand and rotten granite mixed by the drill.

In sec. 31, T. 137 N., R. 47 W., a well 150 feet in depth penetrated only clay and quicksand, according to the log reported:

Log of well in sec. 31, T. 137 N., R. 47 W.

	Feet.
Clay	0–100
Quicksand	100–150

Water was struck at a depth of 150 feet. The quicksand probably represents the lower portion of the drift.

Fig. 5 shows a log of a well in sec. 36, T. 141 N., R. 48 W.

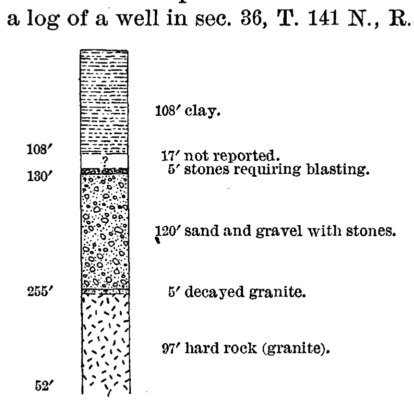

FIG. 5.—Section of well in E. ½ sec. 36, T. 141 N., R. 48 W.

The hard layer containing stones (125–130 feet) is probably at the bottom of the drift, and the underlying sand and gravel may be considered the Cretaceous sediments overlying the granite.

The old city well at Fargo (T. 139 N., R. 48 W.) has a depth of 209½ feet, water being obtained from 50 feet of sand, which overlies a white chalky rock at the bottom. The chalky rock was penetrated to a depth of 3½ feet only. The water from this well is softer than that from many wells of lesser depth, and is not as hard as that from a bed which was struck in this boring below hardpan at 96 feet. This sand is interpreted to be the same as that from which flowing wells are obtained farther west, in the district of the shallower Cretaceous artesian wells, the white chalky rock perhaps representing the Benton. The water rises nearly to the surface and its estimated yield is 1000 barrels per day. This well is one from which water is supplied to city consumers for domestic use, the water being pumped and hauled away in wagons to be delivered about the city. As much as 500 barrels per day are reported to have been hauled away. Below is the log of this well:

Log of old city well at Fargo, T. 139 N., R. 48 W.

	Feet.
[Material not reported]	0–96
Hardpan with small bed yielding water at 96 feet.	
[Material not reported]	96–156
Sand	156–206
White chalky rock	206–209½

The log of the new city well at Fargo (T. 139 N., R. 48 W.) is as follows:

Log of new city well at Fargo, T. 139 N., R. 48 W.

	Feet.
Soil	0–7
Yellow clay	7–22
Quicksand and alkali water	22–26
[Material not reported]	26–147
Water and gravel at 147 feet.	
Sand and stones	147–216

The water is derived from gravel at a depth of 147 feet, sand and stones occurring below this to a depth of 216 feet. No record has been obtained of the rock penetrated from 26 to 147 feet, but it may be presumed that it was lacustrine silt and till, and that the horizon of the water supply is at the bottom of the drift or in the upper layers of the Cretaceous sand.

One of the most remarkable feats of drilling recorded in this region is the Moorhead, Minn. (T. 139 N., R. 48 W.), deep well, drilled in 1888 and shown in fig. 6. According to the log kept by Mr. Andrew Holes, a citizen of Moorhead, hard granite rock was struck at a depth of 475 feet, and, despite the opinion of geologists that all the odds were against the probability of any large water supply being obtained in the hard granite, the drilling was continued to the great depth of 1426 feet into the hard granite, or to a total depth of 1901 feet from the surface.

The section derived from the notes of Mr. Andrew Holes and from rock samples secured by him is shown in fig. 6.

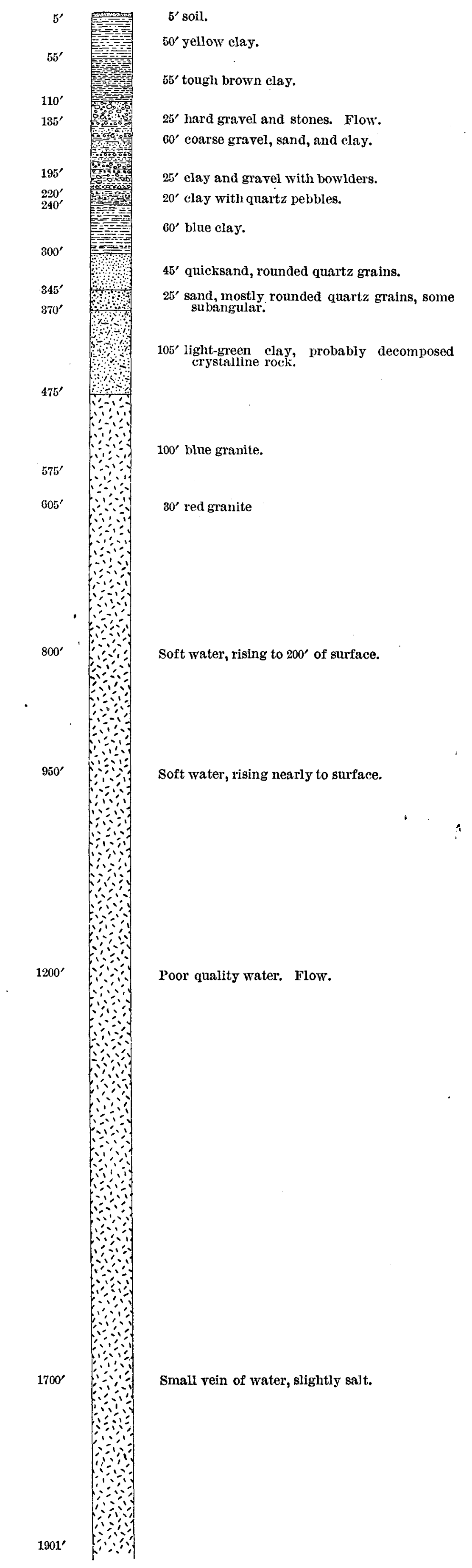

FIG. 6.—Section of deep well at Moorhead, Minn., T. 139 N., R. 48 W.

The bottom of the drift is marked by 25 feet of clay (195 to 220 feet) containing bowlders. Below this is 155 feet of clay and sand, which represents the entire thickness at this point of the Cretaceous strata. Twenty-five feet of sand at the bottom of this series is thought to be of sedimentary origin. The light-green clay, 370 to 475 feet, probably represents the decomposed upper portion of the granite. Therefore, in this axial portion of the Red River Valley the total depth of the drift is 220 feet and that of the Cretaceous strata is 150 feet. Including the 105 feet of clay referred to the granite, the boring penetrated more than 1500 feet of granite.

The water-bearing gravel struck in the drift, at 110 to 135 feet, from which the water rose to the surface, was the most successful water bed encountered. At a depth of about 800 feet, or more than 400 feet below the top of the granite, a bed containing soft water was struck, and another at about 950 feet, also furnishing soft water, which would have been a recompense for the drilling thus far. The bed of salt water at about 1700 feet has been noted in the log.

In sec. 29, T. 138 N., R. 48 W., five holes have been drilled, and no water obtained in any. A whitish clay 22 feet in thickness was struck at 162 feet, which is described by the driller as putty-like in character. Below this is about 100 feet of "green chalky shale or clay," which may represent the Benton, and granite at 286 feet. The generalized log of the five wells, as nearly as could be ascertained, is as follows:

Generalized log of 5 wells in sec. 29, T. 138 N., R. 48 W.

	Feet.
[Material not reported]	0–162
Whitish putty-like clay	162–184
Green chalky shale or clay	184–286
Granite	286–

In sec. 3, T. 135 N., R. 48 W., a well drilled to a depth of 275 feet did not yield water. From the meager record which was obtained it was impossible to determine the depth of the drift. No sand was encountered that suggests the Dakota water-bearing sands. The section is shown in fig. 7.

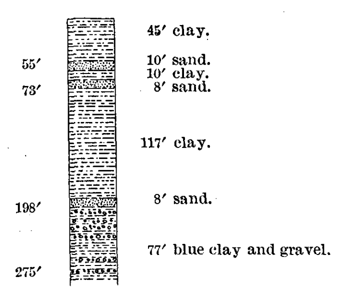

FIG. 7.—Section of well in N. ½ sec. 3, T. 135 N., R. 48 W.

No water-bearing sand or gravel was struck in the well shown in fig. 8 The hard rock is thought from the description of the driller to be granite. Several days were spent in an attempt to penetrate the hard rock, but it was possible to drill only 5 or 6 inches in a day.

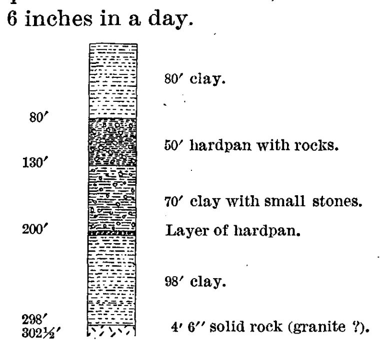

FIG. 8.—Section of well in E. ½ sec. 15, T. 141 N., R. 50 W.

On the Douglas farm, in sec. 9, T. 140 N., R. 50 W., is a well of which the section shown in fig. 9 was furnished by the owner, Mr. W. B. Douglas.

This well furnishes an abundant supply, derived, however, from the 10-foot layer of quicksand that extends from 60 to 70 feet. No water of any importance was obtained below this.

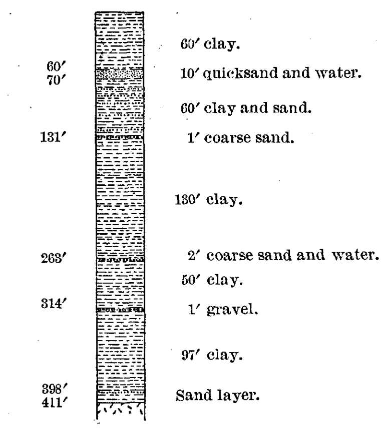

FIG 9.—Section of well in SW. ¼ sec. 9, T. 140 N., R. 50 W.

In sec. 16, T. 138 N., R. 50 W., a well drilled to a depth of 425 feet shows the following log:

Log of well in sec. 16, T. 138 N., R. 50 W.

	Feet.
Clay	0–64
Dry sand and mixed clay, with bowlders	64–100
Clay	100–336
Water-bearing bed at 336 feet.	

Most of the bowlders encountered are reported as occurring between 60 and 100 feet. Water rises to within 20 feet of the surface.

In sec. 6, T. 137 N., R. 50 W., a well was drilled to a total depth of 350 feet without encountering any water.

On the Bond farm, in sec. 30, T. 140 N., R. 51 W., a well was drilled to a total depth of 292 feet, but no record of the formations penetrated was obtainable. A good pumping supply was struck at 180 feet. Below 180 feet stones and sand were encountered. Between 225 and 280 feet a flow was struck. A flow of 400 barrels per day was obtained at 290 feet. At 292 feet, below the vein of flow, a white clay substance was encountered, the depth of which was not determined, as drilling ceased.

On the Dickinson farm, in sec. 12, T. 139 N., R. 51 W., three holes were drilled, the deepest being 425 feet, but no definite logs could be obtained. The driller reports that below 200 feet the material penetrated was mostly fine, hard sand. The deepest hole was abandoned at 425 feet, in clay. No water was obtained. Water from the Maple River is used for the farm supply.

In sec. 12, T. 138 N., R. 51 W., three wells were drilled, having the following depths: 365 feet, 391 feet, and 470 feet. Alling Sieverson, driller, Davenport, N. D., reports the following log:

Log of well in sec. 12, T. 138 N., R. 51 W.

	Feet.
Soil	0–2
Yellow clay	2–12
Blue clay	12–72
Hardpan and small water-bearing beds at 72 feet.	

The driller thinks granite was struck at 470 feet.

At Addison, T. 138 N., R. 51 W., the city well was drilled to a depth of 452 feet and abandoned, no water being obtained. Stones and hard substances reported from 130 to 200 feet. Soft rock, easy drilling, from 200 to 420 feet. At 420 feet a white substance was struck that gave a milky appearance to the water. At 450 feet hard rock, thought to be granite, was encountered.

At the Detmer farm, 10 miles southwest of Addison, a well was drilled to a depth of 491 feet. Two hundred feet of sand and gravel with thin layers of hardpan are reported to have been penetrated. A small flow was obtained at 332 feet. Soft rock was passed through from 332 to 490 feet. One foot of hard rock, thought to be granite, was penetrated at 490 feet. Above the hard granite was a layer, 40 feet, of what was thought to be rotten granite, same as that at 420 to 450 feet at Addison, described above.

A well in sec. 15, T. 137 N., R. 51 W., was drilled to a depth of 465 feet, but did not get flow. Hardpan and a little water were struck at 82 feet. Driller reports penetrating "100 feet of solid stuff," thought to be shale, sand, and gravel. Drill was lost, and the well abandoned.

On the Hocking farm, sec. 34, T. 141 N., R. 53 W., a well was drilled to a depth of 364 feet. When first struck the water rose 26 feet above the surface. Enough combustible gas is emitted with the water to be burned in the house in a gas burner for illuminating purposes. Three flows were struck in this well—at 150, 250, and 364 feet.

On the Trott farm, sec. 10, T. 140 N., R. 53 W., a well 418 feet in depth is reported to flow 4000 barrels per day. The log is as follows:

Log of well on Trott farm in sec. 10, T. 140 N., R. 53 W.

	Feet.
Gravel	0–3
[Material not reported]	3–50
Gravel	50–55
Blue clay	55–150
[Material not reported]	150–260
Weak flow at 260 feet, 30 barrels per day.	
[Material not reported]	260–350
Hardpan but no water at 350 feet.	
[Material not reported]	350–396
Hardpan	396–397
Clay	397–418
Fine white sand, penetrated 8 inches at 418 feet.	

Fig. 10 is a section of a deep well, known as the Budke well, in sec. 24, T. 139 N., R. 54 W., Howes Township, Cass County, N. Dak. The log was obtained from the driller, Mr. B. Hassig. The lower horizon of the drift is interpreted to be as shown in this record, probably at about 150 feet.

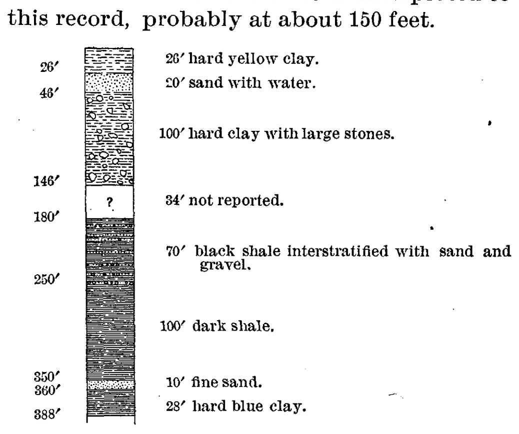

FIG. 10.—Section of well in W. ½ sec. 24, T. 139 N., R. 54 W.

This well has proved a very unfortunate enterprise to the owners of the property. It has ejected quicksand till an area of 20 to 40 acres has been buried in sand. The farm buildings had to be removed. A large reward has been offered for the effectual stopping of the well, and while repeated efforts have been made to "plug" it, by hammering old rags, tin rubbish, and clay into the boring, it continues to deliver water and fine sand.

In sec. 26, T. 139 N., R. 53 W., a well struck a flow of dirty water at 262 feet. At 405 feet a flow was struck which yielded 1000 barrels per day at first. The water from this bed was piped inside the larger tubing, and water was used from both beds, but separately. The two flows now yield 500 barrels per day. The water is somewhat muddy, soft, and contains some salt. The temperature is reported to be constant at 59°.

In sec. 36, T. 139 N., R. 53 W., a well was drilled to a depth of 330 feet. It flowed at the rate of 50 to 60 barrels of oily water per day. Hardpan and some water are reported to have been struck at 80 feet. The water from this bed was softer than surface water, and contained some salt. Water in small quantity was struck at 260 feet.

In a boring at Chaffee, sec. 15, T. 138 N., R. 53 W., a well was drilled to a depth of 420 feet, and flows were obtained at five different horizons—287, 325, 378, 404, and 420 feet. Hardpan is reported from 80 to 90 feet, and again from 231 to 250 feet. A large flow was obtained at a depth of 325 feet, from 40 feet of sand. A dark layer with bits of brown coal is reported below the 325-foot flow, with sand to the main flow at 404 feet.

In sec. 33, T. 138 N., R. 53 W., a flow was struck at 434 feet yielding 1000 barrels per day. The same dark layer is reported above the water-bearing sand as in the Chaffee well, described in the last paragraph. A well in sec. 33, T. 138 N., R. 53 W., is said to yield 500 barrels of clear water per day. Flows are reported at 300, 404, and 476 feet.

A well on the Staples farm, sec. 12, T. 140 N., R. 54 W., was drilled to a total depth of 514 feet, and flows with a pressure of 20 pounds. The well was drilled in 1888. It is 3 inches in diameter to 180 feet, 2 inches in diameter from 180 to 350 feet, and 1¼ inches in diameter from 350 to 514 feet. Water is reported at 180 feet and rises to within 1 foot of the surface. A small flow was struck at 500 feet, and below this thin layers of "hardpan" with increasing flow. At 514 feet the drill dropped suddenly 2 feet, and operations ceased. The driller reports the material as blue clay all the way below the surface soil.

A well in sec. 2, T. 137 N., R. 54 W., shows the following record: First flow at about 360 feet, the water muddy. Second flow at about 499 feet, water also muddy. Third flow at 520 feet, from sand, water clear. Hardpan struck at 390 feet. Soft rock below 390 feet. Total depth of well, 520 feet.

April, 1904.

NOTE.—The field work for this folio was done by Prof. Charles M. Hall, deceased, and a few pages had been written by him. The field notes of Professor Hall formed the basis from which the report was written.

D. E. W.