DESCRIPTION OF JAMESTOWN-TOWER DISTRICT.

By Daniel E. Willard.

INTRODUCTION.

Location.—The district here described is bounded by meridians 97° 30′ and 99° west longitude and by parallels 46° 30′ and 47° north latitude. It comprises the Jamestown, Eckelson, and Tower quadrangles, which have an area of about 820 square miles each, or a total of about 2460 square miles. Portions of Cass, Barnes, Stutsman, Ransom, and Lamoure counties, North Dakota, are embraced within the area. (See fig. 1.) The eastern boundary coincides very nearly with the Red River valley, and the western boundary lies at the eastern edge of the Missouri Plateau.

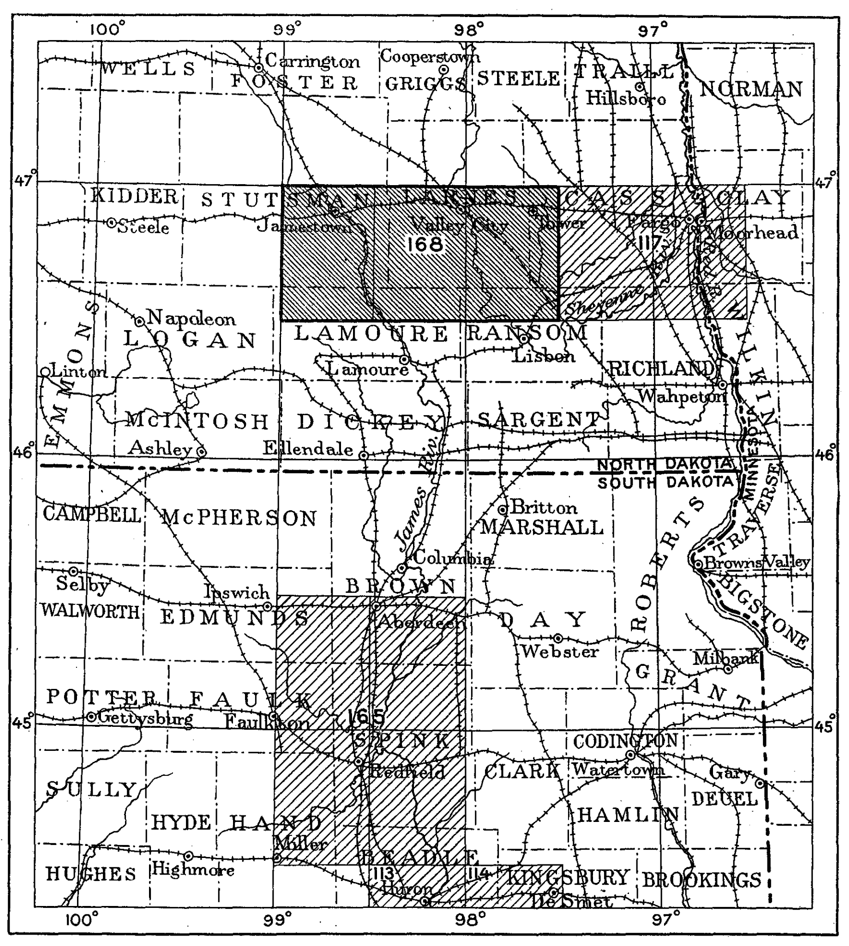

FIGURE 1.—Index map of the vicinity of the Jamestown-Tower district.

Scale, 1 inch = 50 miles.

Darker ruling, area of the Jamestown, Eckelson, and Tower quadrangles. Published folios indicated by lighter-ruled areas, as follows: Nos. 113, Huron; 114, De Smet; 117, Casselton-Fargo; 165, Aberdeen-Redfield.

The largest settlement in the area is Jamestown, Valley City and Tower being next in size. All three towns are on the main line of the Northern Pacific Railway, which crosses the northern portions of the district.

General relations.—Eastern North Dakota is embraced in the Great Plains, lying between the Rocky Mountains and the Mississippi Valley. The greater part of it is between 1000 and 1500 feet above sea level. It is crossed by the indefinite divide that separates the waters of the Gulf slope from those of the Hudson Bay slope, and is drained mostly by Red River but partly by James River, a branch of the Missouri. It lies within the glaciated area of North America, and its surface features show the characteristics of a drift-covered region. The country is generally level, but presents broad slopes, with escarpments due to preglacial erosion, which in places rise 300 to 400 feet above the plains lying to the east. Further diversity of topography has been produced by the excavation of the deep, steep-sided valleys of Missouri, James, and Sheyenne rivers. Between the morainal ridges occur gently rolling plains of till, or nearly level plains due to the filling of glacial lake basins. The Red River valley is a notable example of lake-bed topography, being the western part of the floor of the ancient glacial Lake Agassiz. The Herman beach, the highest shore line of that lake, crossed the eastern boundary of the Tower quadrangle near its middle point.

TOPOGRAPHY.

Relief.—The surface of the district is a gently undulating plain, in places nearly flat, the eastern part having an elevation above sea level of about 1100 feet. The small portion of the bed of glacial Lake Agassiz contained within the area is crossed by the 1060-foot contour, and the valley of Sheyenne River, in the extreme southeast corner of the area, is excavated nearly to the 1000-foot contour. A broad swell called Alta Ridge east of Valley City rises above the 1500-foot contour at a few points. West of Alta Ridge the surface declines 100 feet or so, in places directly to the crest of the bluffs forming the east side of the Sheyenne Valley and elsewhere to the nearly flat Lanona Plain, several miles in width, which terminates on the west in the sharply cut valley of the Sheyenne. The eastern slope of Alta Ridge declines rather steeply 200 feet or more to the gently undulating plain of the Maple River basin.

The valley of Sheyenne River extends along the boundary between the Tower and Eckelson quadrangles, swinging eastward in a broadly sinuous course near the southwest corner of the Tower quadrangle. It is a steep-sided trench about 200 feet deep, with a generally flat bottom averaging about one-half mile in width.

The valley of James River enters the area near the center of the northern boundary of the Jamestown quadrangle and leaves the area in the southwestern portion of the Eckelson quadrangle. Its depth varies from 100 to 150 feet and it is steep sided and flat bottomed. Lateral valleys of similar form enter the Sheyenne and James valleys at intervals and give to the plains adjacent to these valleys a deeply trenched appearance. Here and there wide troughs of ancient waterways also cross the broad, gently rolling plains of the interstream divides.

The western portion of the area rises by moderately steep slopes about 300 feet to the eastern margin of the Missouri Plateau. The slope of this plateau is broken by numerous deep coulées which give to the landscape a somewhat rugged appearance.

The south-central portion of the Tower quadrangle, the eastern third of the Eckelson quadrangle, and the east-central and southwestern portions of the Jamestown quadrangle are rolling in character. The hills have the rough and irregular outlines of morainal deposits from the great ice sheet, and small lakes and undrained sloughs are of common occurrence.

Drainage.—The greater part of the land embraced in these quadrangles has no surface drainage whatever, the waters from rains and melting snows being absorbed or evaporated. Shallow lakes without outlets and undrained sloughs are numerous. Several ancient channels occur within the area, but these in no sense drain the areas they cross.

The continental watershed between the Hudson Bay drainage basin and that of the Gulf of Mexico crosses the area from Bears Den Hillock, in T. 135 N., R. 58 W., northwestward to T. 137 N., R. 60 W., and thence northward through Rs. 60 and 61 W., between Eckelson and Fox lakes. This divide illustrates well the undrained character of the glaciated prairie regions and the delicate balance between the drainage systems. Although Sheyenne and James rivers flow in nearly parallel courses for 180 miles and the relief of the land between their valleys is generally 20 feet or less, yet the Sheyenne ultimately discharges into Hudson Bay and the James into the Gulf of Mexico.

Sheyenne and James rivers are the principal streams of the area. Their valleys are out of all proportion to the streams that now occupy them, there being barely sufficient water to maintain them as flowing streams during the summer season.

The drainage area of the Sheyenne embraces approximately 10,000 square miles, yet the volume of water discharged into Red River is estimated to be less than that which flows through Valley City, nearly 150 miles up the stream. The loss is due to evaporation and absorption as the stream meanders sluggishly over the broad, flat bottoms of the ancient valley which it traverses. The crest of Alta Ridge, which lies 4 to 5 miles to the east, parallel with the Sheyenne Valley, is about 300 feet above the bottom of the valley, yet no modern stream channels to carry away the water from the region have been cut between this crest and the shoulders of the bluffs which immediately border the river.

Several broad and deep valleys enter the valley of the Sheyenne from the west, but each is occupied only by an intermittent stream, insignificant in size even in times of heavy rain, and the only land that is really drained is that comprised in short, deep gorges which broaden out rapidly toward the Sheyenne as they deploy upon its flood plain.

The drainage basin of the James, from its source to the southern boundary of the Jamestown-Tower district, covers more than 5000 square miles, yet the volume of water in it is not sufficient to maintain a current during the summer season. A United States gaging station a few miles south of the district was abandoned because there was not sufficient current to turn a water meter. Large channels, ancient waterways, enter the valley from the east and west, but except in the Pipestem and in a few miles of the lower portion of Beaver Creek, no water passes down these channels except in times of flood.

In periods of heavy rains and melting snows a system of ancient channels is occupied by Maple River and its tributaries, but ordinarily, though these constitute the drainage system for an area of more than 1000 square miles, the run-off is insufficient to maintain a permanent stream. The occurrence of springs along its banks alone prevents the Maple from entirely drying up during the summer seasons.

Although the plain of the bed of glacial Lake Agassiz lies immediately east of the area and is 400 feet lower than the crest of Alta Ridge and 200 feet lower than the general level of the eastern portion of the area, still there are no eastward-flowing streams corresponding to this fall of 400 feet in a distance of 15 miles. On the west the Missouri Plateau rises 300 to 400 feet above the plain of the drainage basin of the James, but though this slope is serrated by coulées, many of which are deep and broad in their lower courses, yet none of them have the appearance of channels eroded by modern drainage.

GENERAL GEOLOGY.

GENERAL RELATIONS.

The surface of the Jamestown-Tower district is thickly covered by glacial drift, which forms a continuous mantle except in the slopes of the deep valley trenches. Beneath the drift lies soft dark Cretaceous shale into which Sheyenne and James rivers have eroded their valleys 50 to 150 feet. The shale outcrops in the slopes of these valleys where not obscured by talus of glacial material from above, and it has been penetrated by many deep wells.

The lower limit of the glacial drift is in many places difficult to recognize, owing to the similarity between the glacial clay and the shale on which it lies. Bowlders occur in the drift, but drillers seldom report the depth at which the last bowlders are encountered. Numerous springs on the steep slopes along the river valleys indicate approximately the position of contact between the shale and the drift. Below the shale are sandstones, or a succession of sandstones and shales, of Cretaceous age, which attain a thickness of 300 feet or more and contain the artesian water supplying many deep flowing wells in all parts of the area. In parts of eastern North Dakota this sandstone series lies on granitic rocks of pre-Cambrian age. At the Jamestown Asylum an underlying limestone which may be Carboniferous was penetrated 19 feet.

CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

The lowest sedimentary formation recognized in the Jamestown-Tower district consists of 200 or 300 feet of light-colored soft sandstone in beds 10 to 50 feet thick, separated by deposits of shale. It lies several hundred feet below the surface and is known only from well records. It has been regarded as the Dakota sandstone, but some of the water-bearing beds may belong in the Colorado group. The greatest known thickness of the sandstones is at Valley City, where 300 feet have been penetrated by wells. In borings at the Jamestown Asylum the amount appears to be only 206 feet, with limestone at the base.

In the eastern portion of the Tower quadrangle the top of the sandstone series lies about 500 feet below the surface, or about 550 feet above sea level. To the west the depth increases gradually, owing to a gentle dip in that direction and also to increased elevation of the land. West of Jamestown, where the surface rises more abruptly toward the Missouri Plateau, the depth increases rapidly, so that the sandstone is 1700 feet under the highest lands on the west margin of the district. The two wells that are farthest west in this area are the Jamestown city well, 1476 feet deep, altitude 1410 feet; and the well in sec. 7, T. 136 N., R. 64 W., 1435 feet deep, altitude 1525 feet. Thus from R. 54 to R. 64 W. the rise of the land is about 400 feet, while the increase in depth to the water-bearing sandstone is about 1000 feet. This indicates a westward dip of the water-bearing sandstone of about 600 feet in a distance of about 70 miles, or about $8\frac{1}{2}$ feet per mile. (See fig. 6.) The dip is nearly uniform and the upper surface of the sandstone appears to pass below sea level along a northeast-southwest line a short distance east of the Jamestown Asylum, and to be about 175 feet below sea level in the extreme northwest corner of the district. The depth to the sandstone is shown in the list of wells on page 10, but a number of these wells penetrated some distance below the top to find water in satisfactory volume with sufficient head to flow. The well drillers have furnished very few data as to the character and relations of the sandstones.

COLORADO AND PIERRE SHALES.

The meager exposures in the slopes of the river valleys and the records of deep wells indicate that the shales beneath the glacial drift are of blue-black color and that they contain a few thin deposits of sand. In the lower part of the shale the well drillers report lime concretions and thin layers of hard rock, which they call "iron ore."

Probably the shale exposed at the surface in this area and for some distance below is Pierre shale; the underlying shales extending to the Dakota sandstone doubtless include the Benton and Niobrara strata of the Colorado group. No fossils have been found in these lower shales within this area, so their age can only be inferred from their position above the Dakota sandstone and from their relations in neighboring regions. Upham[a] found the distinctive Montana fossils *Inoceramus sagensis* and *Baculites ovatus* in an outcrop of the Pierre shale on the western slope of a hill near the west line of sec. 33, T. 139 N., R. 58 W., 8 miles south of Valley City and about 1½ miles west of Sheyenne River. The elevation above sea level at this place is 1350 feet, or about 175 feet above the river. The following well records show the character and thickness of these shales:

Record of well in the SE. ¼ sec. 13, T. 140, R. 55.

	Feet.
Soil and clay } glacial drift	150
"Hardpan" } glacial drift	10
Blue-black soft shale	446
	606

Record of the railroad well at Tower City.

	Feet.
Soil	50
Clay	375
Soft sandstone	25
Very soft clay	115
Mud	100
"Hardpan" (gravel and rock)	50
	715

Record of well in the NW. ¼ sec. 19, T. 136, R. 58.

	Feet.
Soil, sand, and clay (drift)	8
Dark shale	40
Light-gray shale	320
Hard dark shale	100
Sandstone	2
Hard dark shale	300
Iron pyrites	1
Softer dark shale	100
Shale, with layers of sand rock from 6 to 10 inches thick	50
	951

Record of well at Nome, N. Dak., in sec. 13, T. 137, R. 57.

	Feet.
Soil, sand, and clay	40
Yellow clay	20
Bluish gravelly clay	48
Tough bluish clay	162
"Iron ore"	1
Blue clay with thin iron-ore layer at 356 feet	128
Iron ore; softer below	5
Blue clay with fine sand	300
Hard clay	10
Sand and clay mixed; first flow	42
Hard iron layer	½
Clay with thin hard layer at base	27½
Clay with fine sand	46
Sand and clay alternating; thin iron layer; second flow at top	35
Clay and sand; third flow at top	22
Sand with main flow	1
	888

Record of artesian well at Jamestown Asylum, sec. 6, T. 139, R. 63.

	Feet.
Blue clay	42
Fire clay, impure	49
Quicksand	20
Shale with limestone fragments	100
Light-colored shale	150
Dark shale	200
Light and dark shale with limestone layers	398
Sandy shale	40
Sand	10
Blue shale with hard limestone layers	290
Quicksand with shale and limestone layers	175
Hard sand rock	7
Sand rock with 4-gallon flow	24
Limestone (Carboniferous ?)	19
	1524

The Dakota sandstone is supposed to begin with the quicksand beneath the 290-foot bed of blue shale, at a depth of 1299 feet, and the base of the drift probably is not far below the surface, so that the Pierre and Colorado shales are more than 1200 feet thick.

Record of artesian well at Jamestown, N. Dak.

	Feet.
Soil, clay, and gravel (glacial at top)	120
Light shale	905
Blue shale with pyrites	275
Sandy shale	85
Sand rock; small artesian flow	10
Shale and pyrites	55
Hard sand rock	8
Soft sand rock with 460-gallon flow	18
	1476

The shales extend from 120 to 1450 feet in depth in this well, a thickness of 1330 feet.

[a] Upham, Warren, The glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, 1896, p. 92.

QUATERNARY SYSTEM.

PLEISTOCENE DEPOSITS.

GENERAL CHARACTER AND RELATIONS.

The surface formations of the Jamestown-Tower district, except on the slopes of the Sheyenne and James valleys already referred to, are deposits made directly from the melting ice sheet or secondarily from the flood waters resulting from the melting ice. These deposits of unconsolidated material are grouped together under the general name of drift. While stratified deposits of sand, gravel, and clay are of common occurrence, much of the drift is unassorted. The unassorted material consists generally of a matrix of clay in which are embedded rock fragments of various sizes, shapes, and lithologic characters.

This clay is very similar in character to the blue clay resulting from the disintegration of the underlying shale, and indeed it appears that it was from this shale that the clay of the drift was very largely derived.

While the arrangement of the materials of the drift is in large part heterogeneous, yet from the abundance of stratified materials in the deposit, especially in certain parts of the area, it is evident that considerable water must have taken part in the original deposition or in the rearrangement of the deposits.

The depth of the drift deposits over the area ranges from a thin remnant of bowlders to a deposit 100 feet or more thick. The drift presents a minimum thickness on the upper flat plain of the west bluff of the Sheyenne Valley from Valley City to Oakville, where it is represented by little else than scattered bowlders resting upon or embedded in the deeply weathered Cretaceous shale. A maximum thickness occurs on Alta Ridge, where well borings have reached shale at a depth of about 120 feet. The Sheyenne and James valleys have been eroded deeply into the shale, and although the shale has been largely concealed by the talus of drift that has fallen down the valley sides, yet the sections of the drift thus revealed show its thickness in those localities to range from 20 feet down.

The stony material of the drift ranges in size from coarse gravel to bowlders 2 or 3 feet in diameter, though the large bowlders are not generally abundant except in Alta Ridge and in the slopes of the Sheyenne and James valleys, in proximity to morainic deposits. In the latter situation bowlders from 6 inches to 3 feet in diameter literally form a pavement over considerable areas. Bowlders gathered in heaps from the tilled fields on Alta Ridge show sizes averaging a foot in diameter.

The till beds are relatively free from stony materials, as shown by exposures in valleys and sections of the drift in railroad cuts and wells. Out of 200 well records 10 only were reported as containing any considerable amount of stony material.

Granitic rocks, dark basic intrusives, and quartzitic rocks make up the major portion of the stony material of bowlder size. It is estimated that perhaps 10 per cent of the bowlders are limestone. At some places shale bowlders and cobbles are found in the terraces and drift deposits. On the whole the foreign material of the drift constitutes a very small fraction of the glacial deposits. While small fragments of crystalline rocks may be seen upon minute inspection of the sand and clay beds, almost the entire body of the till is of local origin.

Probably no impressions in the nature of grooves or striæ have been retained in the fragile Cretaceous shales which formed the floor beneath the moving ice; at least none were discovered. Subangular pebbles and small bowlders with polished facets bearing well-marked glacial grooves and scratches occur in the body of the glacial deposits of this area, although not as abundantly as in corresponding situations in Illinois or Wisconsin.

The arrangement and direction of the terminal moraines indicate a west-southwestward movement of the ice sheet. (See fig. 2.) The region of Archean rocks about 400 miles to the northeast seems to have been the source of the foreign material that has found lodgment in the drift of the district.

Lenticular pseudostratified masses of porous travertine-like limestone in which are included drift pebbles and cobbles, the whole presenting the structure of an ordinary conglomerate with a limestone matrix, were found in several places embedded in the drift. One occurrence is in Madigan Coulee, sec. 4, Spring Township (T. 135 N., R. 57 W.), on the side of the valley near to and above a ledge of outcropping shale. Another is on the north bluff of Sheyenne River, sec. 12, Fort Ransom Township (T. 135 N., R. 58 W.), in a gravelly mass of drift near its contact with the shale, exposed by a road cut leading into the Sheyenne Valley. The most notable occurrence, however is in the Glens of Kathryn, sec. 23, Oakville Township (T. 137 N., R. 58 W.), where an area of several hundred square rods, broken by deep gorges and hills and supporting a dense growth of small timber, is covered with large blocks and irregular masses of this limestone, scattered confusedly over the surface.

Evidences of more than one stage of growth and decadence of the continental glacier have been found in this area, but the history of the stages of glaciation and deglaciation can not at this time be fully written, owing to the fact that the earlier glacial deposits are so thoroughly commingled with the later drift, or so completely buried by it, that only an incomplete distinction can be made.

Evidence of deglaciation and the formation of soil and the accumulation of vegetal matter, and of the subsequent advance of the ice and burial of these deposits, is afforded by the reports of peaty, mucky, and lignitic matter encountered in digging or boring for water at depths of 20 to 40 feet below the present surface. Evidence of a period of erosion, which was in turn followed by a period of destruction of the landscape features developed, is afforded by certain topographic forms that are best explained by assignment to an earlier invasion of the ice sheet. These are described below. There are in this district several series of small lakes or lakelike basins which occupy long depressions but are individually separated by low hills or hummocks of drift. Among the most prominent of these are the lakes and lakelike basins forming the Eckelson, Sanborn, and Fox Lake series, in the Eckelson quadrangle, described below.

A notable chain of lakes whose interpretation is in doubt but which may be described here is the Alice group, in the northern part of the district. These lakes seem to bear no relation to a preexisting valley, and therefore do not belong in the class referred to above. That they are related in origin to the deglaciation of the region seems certain.

These depressions range in dimensions from 20 rods in diameter to half a mile in width and 1½ miles in length. Their sides are steep, composed mainly of till, and are in many places bordered with cobbles and bowlders. The bottoms are flat and lie about 20 feet below the surrounding plains. Some of the depressions join; some are separated by low bars of gravel and sand, and others by ridges of till. Hills and ridges from 10 to 50 feet in altitude having gentle slopes and presenting the characteristics of terminal moraines rise close to the sides of some of the lakes. More commonly, however, the lakes are surrounded by a nearly level or very gently undulating plain, the depressions occurring as pits in a generally even surface. There is no definite alignment of the hills with reference to the longer axis of the lake-pitted plain.

DEPOSITS OF THE WISCONSIN STAGE.

GROUND MORAINE.

Deposits formed and overridden during the advance of the glaciers are known as ground moraine. When the final melting took place such drift as remained in the body of the ice or upon its surface was let down upon the subglacial deposits. Generally such additions of englacial and superglacial drift are not very clearly distinguishable from the drift deposited beneath the ice. Besides the definite terminal moraines formed during the deglaciation of the area, scattered marginal deposits also occur at many places within the ground-moraine tract. Many of the ground and terminal moraines merge into each other so that the two can not be clearly distinguished. Gently undulating till plains occur among hills of terminal-moraine character.

Many isolated symmetrical hills rise with gentle slopes from 10 to 25 feet above the nearly level surface of the ground moraine. These are characterized by a core of ordinary unassorted till surrounded and overlain by irregularly stratified but rather definitely assorted gravel and sand beds. The gravel is cherty and calcareous in composition, and the individual pebbles are not well rounded. Elevations of this character are known as gravel-capped hills. Ravines in their slopes reveal their structure and their availability as a source of excellent road metal, as well as of sand and gravel for other constructive purposes.

The great body of the ground moraine is made up of a fine-grained compact aluminous clay, with which are intermingled grains of quartz, particles of silt, and angular fragments of crystalline rocks. Widely scattered throughout this clay matrix are pebbles, cobbles, and bowlders of various lithologic characters not unlike those of the terminal moraines of this area, elsewhere described. The whole is unstratified as compared with the definite assortment of water-deposited material, yet where sections of considerable thickness are exposed an irregular and crude bedding may be distinguished. Beds of varying thickness and attitude consisting of definitely stratified sand and gravel are interlaminated with the more massive and heterogeneous body of the till. The clay matrix is dark slaty gray in color and is generally known as the blue clay of the region.

Oxidation has changed the upper 5 to 20 feet to a light-yellow color. The thickness of the till sheet, as estimated from well records, varies from 100 feet to a fraction of an inch. Of the body of the till more than 90 per cent, of both the ground-moraine and the terminal-morainic tracts, seems to have been derived from the subglacial burden of the ice sheet. This material was supplied to the glacier from the underlying Cretaceous shales at no great distance from its present place of lodgment.

The very small number of bowlders scattered over the ground moraine would seem to indicate that the superficial and englacial load of the glacier at the time of its recession was relatively small. Almost all the bowlders are rounded masses of the more refractory fragments of the granitic and other crystalline formations which are found in place 400 miles distant in the Canadian provinces to the northeast. Bowlders whose characteristics indicate a Paleozoic origin are found, but their number is comparatively small.

TERMINAL MORAINES.

Distribution.—The area is traversed in a generally north-south direction by several well-defined moraines. The extreme southwest corner of the district includes a small tract of the Second or Gary moraine, as mapped by Todd,[a] and the extreme eastern portion is traversed by the east side of a loop of the Eighth or Fergus Falls moraine, as mapped by Upham.[b] Extensive tracts of roughly rolling surface lie between the moraines indicated, with much larger areas intervening which are moderately rolling or undulating. (See fig. 2.) Kamelike hills are distributed irregularly or in patches upon the otherwise gently rolling plains.

Altamont and Gary moraines.—The extreme southwestern part of the district is the most roughly morainic portion of the entire area. R. 66 W. extends into the region of the Altamont and Gary moraines, the earliest, the most extensive, and the roughest of the whole series of terminal moraines formed during the Wisconsin stage of glaciation.

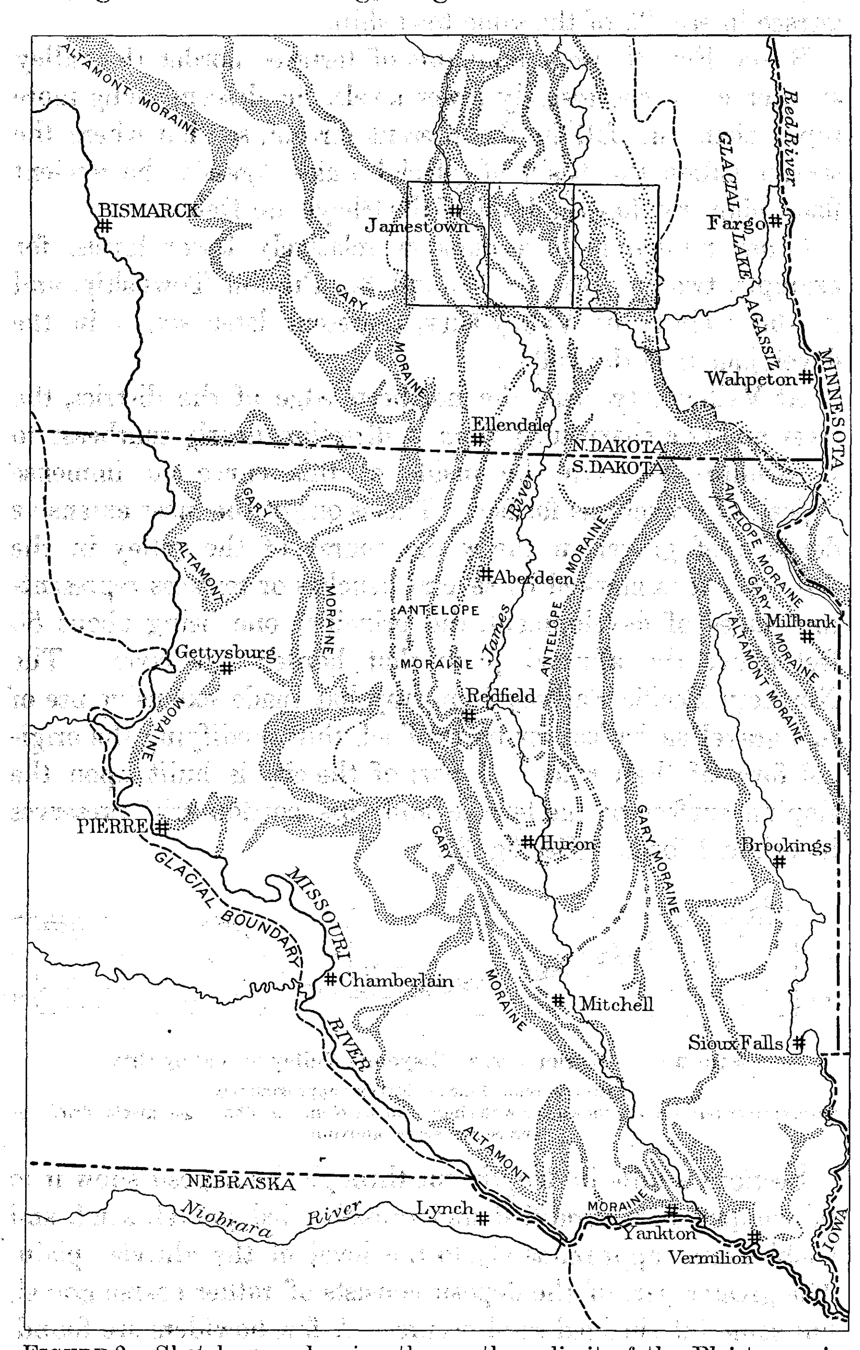

FIGURE 2.—Sketch map showing the southern limit of the Pleistocene ice sheet and the distribution of moraines of the Dakota glacial lobe in North and South Dakota. Compiled largely from maps by J. E. Todd, Warren Upham, and the author.

The location of the Jamestown, Eckelson, and Tower quadrangles is shown by rectangles.

Close upon the northwestern border of the district rise very rugged morainic hills. Within 1 mile north of the northwest corner, in secs. 23 and 24, T. 141 N., R. 66 W., the topography takes on abruptly the roughest and most irregular outline. Steep and stony hills, close set as if packed together to economize space, deep ponds at different levels within short distances, long ridges, and short, steep rounded hills give to the landscape a wild and fascinating aspect in comparison with the long and broad swells and gently undulating contour of the plain to the southeast. This great moraine swings to the west from the northwest corner of the district and extends southward through the western part of R. 66 W. and R. 67 W., reappearing in Tps. 135 and 136 N., R. 66 W.

Antelope moraine.—The central part of the Jamestown quadrangle is marked by morainic hills, but they are generally of a subdued type. Tps. 136, 137, 138, and 139 N., Rs. 63 and 64 W., are rolling or hilly in places, the hills locally becoming definitely morainic. Many hills, however, have the smooth symmetrical outlines of kames. This portion of the Jamestown quadrangle is crossed by several ancient drainage channels, and these are exceedingly crooked. The generally subdued character of the morainic hills, their occurrence scattered over so large a territory with broad interspaces of undulating land between, the crooked and interlocking character of the ancient channels, and the absence of a definite trend in the arrangement of the hills may be explained as the work of an earlier invasion of the ice sheet, the hills having been overridden by a later advance of the ice and thus smoothed and subdued in their outlines. The crookedness of the drainage channels that carried away water from the later ice would be thus explained by the difficulty of cutting channels across a buried moraine. These hills were represented by Todd as belonging with the Third or Antelope moraine, with which he also placed the scattering low morainic and kamelike hills in Tps. 140 and 141 N., Rs. 64 and 65 W.

Kiester moraine.—The Fourth or Kiester moraine enters the area by two branches in T. 135 N., Rs. 60 and 61 W., at the central part of the southern boundary of the Eckelson quadrangle, and extends in a northwesterly direction to the western part of T. 138 N., R. 62 W., thence northward parallel with the James River valley to the southwestern portion of T. 139 N., R. 62 W. From this point the moraine is probably to be regarded as extending to the north and west through Tps. 140 and 141 N., R. 63 W., embracing the broad tract of low, rolling hills between the valleys of the James and Sevenmile Coulee.

This moraine is from 1 to 2 miles in width through much of its course in this area and is made up in larger part of low, rolling hills. It is crossed by drainage channels which carried water from the edge of the ice sheet during the next (Waconia) stage of deglaciation. Bowldery morainic hills occur in the region between the two large channels in Tps. 139 and 140 N., R. 62 W. The channel that discharges northward in T. 139 N., R. 62 W., was supplied principally by waters that came from the east, but also by waters from the south and west, as is shown by branches entering from these directions. It was compelled to discharge toward the north because the ice still lingered on the east bank of the James Valley and east of Sevenmile Coulee in Tps. 139 and 140 N., R. 62 W.

The Kiester moraine is a well-defined range of hills in Greenland and Montpelier townships (T. 137 N., Rs. 61 and 62 W.). Southward from sec. 36 in Greenland Township to secs. 5 and 6 in Gladstone Township (T. 135 N., R. 60 W.) the moraine is traversed by a large southward-discharging ancient channel, and the topography is much less rough. In Gladstone and Grand View townships it reaches a width of 6 miles, and the hills are high and rugged. Two arms of the moraine, each about a mile wide, extend southward beyond the limits of the present area, inclosing an intramorainic tract about 4 miles in width. North of the large ancient channel which enters the James Valley in sec. 30, T. 138 N., R. 62 W., the moraine is less rugged, the hills having smooth and subdued outlines, but the tract is only from 1 to 3 miles in width. Farther north and west, between the James Valley and Sevenmile Coulee, the hills are kamelike and are spread upon a gently undulating plain.

Between the Kiester moraine and the Waconia moraine, next to be described, occurs a series of morainal hills of subdued aspect, many of which have a kamelike character and wherever observed in section are composed of stratified sand and gravel. This tract of hills was mapped by Upham as the Fifth or Elysian moraine.

Waconia moraine.—The most conspicuous terminal moraine in this district crosses the Eckelson quadrangle in a generally northwest-southeast direction. It varies in width from 1 to 5 miles, and some of the hills comprised within its belt rise more than 100 feet above the plain upon which they stand.

In the southeastern part of the Eckelson quadrangle the moraine is in two parts. One of these enters the district in Black Loam Township (T. 135 N., R. 59 W.), where it is a little more than a mile in width and consists of moderately rolling drift knolls. It first trends northwest, but at the northeast corner of T. 135 N., R. 60 W., it makes a turn at right angles, extending thence northeastward 10 or 12 miles to western Oakville Township (T. 137 N., R. 58 W.), where it again swings to the northwest.

In western Oakville Township the moraine is cut by the broad and well-defined ancient channel which extends from Keyes Lake southeastward to the Sheyenne Valley. The main morainic belt is here joined by a small but very distinct moraine from the southeast, locally called the Svenby moraine, the highest hills of which rise 100 feet above the adjacent plain. From Oakville Township the main moraine extends northwest and north to Hobart Lake, with a width of 1 to 2 miles. For about 10 miles west from Hobart Lake the morainic tract is from 5 to 6 miles wide and comprises the steepest and highest hills and the most typical knobs in the area. The moraine continues northwestward from the vicinity of Fox Lake and is 7 or 8 miles in width where it leaves the area. In this vicinity the hills are high and many hollows contain water.

In the northeastern portion of the Eckelson quadrangle, in the region lying between the main belt of the Waconia moraine and the Sheyenne Valley, are several small morainic areas from 1 to 4 square miles in extent. A few isolated morainic hills or small areas of low morainic hills occur also along the line between Rs. 58 and 59 W. These small areas were by Upham included with the Seventh or Dover moraine. A region of rough terminal-moraine topography lies in sec. 17 and the eastern part of sec. 18, Valley Township (T. 140 N., R. 58 W.), and in secs. 12 and 13, Hobart Township (T. 140 N., R. 59 W.). A tract embracing portions of secs. 4, 5, 6, 7, 8, 9, 17, and 18, Hobart Township, and another embracing portions of secs. 25, 26, 27, 34, 35, and 36, of the same township, are roughly rolling and have the appearance of terminal moraines. Southward from this region through a tract 3 or 4 miles wide bordering the Sheyenne Valley the country is very sparsely covered with drift, there being in many places little more than a stray scattering of bowlders. Westward toward the Waconia moraine the drift is more prominent. This region is further considered under the heading "Deglaciation" (p. 7).

The entire west front of the Waconia moraine in the district is fringed with channels representing ancient drainage. One of these extends from Keyes Lake southeastward to the Sheyenne Valley, traversing the region bordering the moraine on the west. It is joined by two large branches, one from the vicinity of St. Marys Lake, in secs. 17 and 20, T. 139 N., R. 59 W., and another from the northern part of T. 138 N., R. 59 W. This second branch represents a reversed waterway, the drainage being now from the west side of the moraine toward the Sheyenne through the large coulée that heads in the moraine. The two branches that enter the coulée from the north and south among the eastern low hills of the moraine probably originally conveyed water across the present axis of the moraine to the main channel of this ancient drainage system in sec. 13, T. 138 N., R. 60 W.

The arrangement of the channels of ancient drainage from this moraine in Rs. 61 and 62 W., as compared with those in Rs. 59 and 60 W., agrees with the position of the ice front suggested by the moraine. The fanlike arrangement of the head branches of the large drainage channel in Rs. 59 and 60 W. indicates a broad embayment in the ice front in southern Heman and southwestern Green townships (T. 139 N., Rs. 59 and 60 W.), with a prominent tongue of the moraine projecting southward on the boundary between Rs. 60 and 61 W. This tongue of the moraine marks the divide between the Sheyenne and James valleys, and hence the continental divide at this point. To the west of this tongue of the moraine is another large embayment extending northwestward beyond Goose Lake to Spiritwood. This embayment is traversed by four large ancient channels which extend southwestward to the James, each channel having branches of the broad, flat-bottomed type that characterizes the district.

Fergus Falls moraine.—The Fergus Falls moraine varies from 4 to 7 miles in width. It enters the Tower quadrangle from the north through the central part of Noltimier Township, and passes due south to the eastern part of Fort Ransom and western Spring townships. Thence from the limits of the Tower quadrangle it continues southward close against the western bank of the glacial Ransom River, maintaining its southerly course to the boundary of the State in R. 58 W.

The interruption in the morainic topography represented by Sand Prairie and the terraced region in eastern Bear Creek Township are referred to under the history of Sheyenne River. (See p. 7).

The crest of the Fergus Falls moraine is represented by a main ridge extending from Noltimier to Thordenskjold Township through the central part of the western half of the morainic belt. It forms also the divide between Sheyenne and Maple rivers. The ridge is continuous through a distance of 9 miles in Norman and Cuba townships, and its summit, a mile in width, is gently undulating with slight relief. In Alta and Noltimier townships the crest is narrow and interrupted by deep sags and by hills with an altitude of 20 to 60 feet. Southward from northeastern Thordenskjold Township the moraine has been eroded away by glacial Sheyenne River, leaving no traceable crest. Three culminating points, however, stand out in relief and mark its course—Standing Rock, a conspicuous elevation in sec. 6, Preston Township; a sharp drift ridge a mile in length in sec. 31, Preston Township; and Bears Den Hillock, in Fort Ransom Township. The last is the highest point of the continental divide in this area.

The outer or western face of the moraine is fairly well defined from Noltimier Township to southern Cuba Township by the broad, nearly level topography and sandy character of the Lanona Plain. From Cuba Township to the village of Oakville it coalesces with the bluff of the Sheyenne Valley and its heading coulées. Southward from sec. 26, Oakville Township, through a distance of 5 miles, the level plain of Sand Prairie replaces the western slope of the moraine. In Fort Ransom Township the western slope merges into an outwash plain of sand and gravel declining gently to Bears Den Hillock Creek one-half mile west of the Tower quadrangle.

The inner or eastern face of the moraine from Noltimier Township to a point $1\frac{1}{2}$ miles west of the village of Fingal

[a] Todd, J. E., The moraines of the Missouri coteau and their attendant deposits: Bull. U. S. Geol. Survey No. 144, 1896.

[b] Op. cit., p. 160.

presents a roughly rolling surface, the closely aggregated hills rising to an altitude of 10 to 50 feet and being generally grouped in ranges having a north-south alignment. Many undrained depressions occur on this northern half of the moraine.

The morainic tract in southeastern Oriska, eastern Springvale, and northern Binghamton townships, although nearly continuous with Alta Ridge, is to be correlated with a terminal morainic belt extending from western Oriska southeastward through central Springvale, Clinton, and Pontiac, to eastern Liberty Township. In the northwestern half of this moraine, where it diverges from Alta Ridge to the southeast, the hills and ridges of drift have a relief of 15 to 30 feet, are closely aggregated, and assume with the intervening undrained depressions a distinct north-northwest and south-southeast trend. A drainage channel from the front of this part of the moraine originates at the village of Fingal, continues southward through secs. 20, 30, and 32, Binghamton Township, and enters a branch of Maple River in sec. 5, Raritan Township. The southeastern half of the moraine, that portion in Binghamton, Clinton, and Pontiac townships, presents a much less rugged type of terminal topography. The swells and ridges rise with gentle slopes to an altitude of 20 feet above the inner bordering plain. A few scattering elevations exhibit a relief of 25 to 35 feet. Prominent hills with rounded contours and elongated form showing the water-assorted structure of kames are in this portion of the moraine closely associated with drainage channels.

From Fingal southward the eastern border of the main Fergus Falls moraine is ill defined. The whole tract broadens out and the hills are scattered and low, ranging from 10 to 20 feet in altitude and being separated by shallow undrained depressions and patches of low till plains. Some of the depressions assume the nature of steep-sided pits from 10 to 30 feet in depth and from a few rods to nearly a mile in diameter. Good examples of such marked depressions are found in northeastern Preston Township.

The Fergus Falls moraine as here described is understood to have been formed as a continuous series of deposits from the ice front when it lay along the slopes and crest of Alta Ridge and southward to Bears Den Hillock in Fort Ransom Township. While this belt of morainic topography in the western part of the Tower quadrangle evidently marks one continuous marginal deposit of the glacier, the drift deposits themselves do not constitute a topographic feature so well marked that its boundaries are clearly and sharply defined. The exact location of these lines is in a measure arbitrary.

An alternative correlation strongly suggested by topographic relations and glacial drainage would make this moraine diverge in Thordenskjold Township from its southward course as above described, and bend away in a broad curve to the southeast, thus including the morainic belt extending through Moore, Liberty, Fuller, and Casey townships. Part of the moraine extending into Shenford Township and partly buried by the Sheyenne delta deposits is referred to later (p. 5). From this point the moraine appears to curve southward and thence to continue in a southeasterly direction.

The Eighth or Fergus Falls moraine was considered by Upham to run southward through Ayr and Buffalo townships, in the northeastern part of the Tower quadrangle, into the northwestern part of Howes Township, thence westward in a broad curve through adjacent parts of Hill, Springvale, and Binghamton townships to Cuba Township, and thence northward through Alta and Noltimier townships.

This mapping made the deposits define the south end of a distinct narrow lobe of the ancient glacier, while the moraine in Norman, Thordenskjold, Raritan, Preston, Moore, Liberty, and Casey townships was not mapped. The moraine on the west side of Sheyenne River in Bear Creek and Fort Ransom townships, here regarded as the Fergus Falls moraine, was by Upham made to diverge thence sharply to the southeast and correlated with his Seventh or Dover moraine.

The most easterly morainic tract enters the district at the northeast corner and passes southward through the eastern portion of the Tower quadrangle to the vicinity of the town of Enderlin. This tract is about $1\frac{1}{2}$ miles in width and includes the region of the Alice chain of lakes. (See p. 2.)

The northern third of this morainic tract has an altitude 100 feet greater than that of the hills of its southern extension and about 60 feet greater than that of the ground moraine and the Maple Valley to the west. From these facts, together with the records of well borings, which show the drift to have a thickness of about 65 feet, it is apparent that this part of the moraine lies on the summit of a preglacial ridge.

The surface of the moraine is strongly undulating, the hills rising 10 to 40 feet above the general level. Shallow undrained depressions are common. Farther south the hills are more widely separated and the slopes are less abrupt. A striking feature of the morainic deposits in Buffalo, Howes, and Eldred townships, and also, though less conspicuous, in Clinton, Pontiac, and northern Binghamton and Springvale townships, is an arrangment of the hills and till ridges in short ranges having a definite north-northwest and south-southeast trend.

KAMES AND ESKERS.

A number of hills or elongated elevations whose structure and composition show them to be the marginal deposits known as kames occur in the western portions of Buffalo, Howes, Eldred, and Highland, northeastern Liberty, western Moore, northern Thordenskjold, Norman, western Cuba, and Alta townships in the Tower quadrangle. They are not distinguished from the moraines shown on the areal geology map. There are also several small groups of kames northwest and southwest of Griswold, in the Eckelson quadrangle, which are shown on the geologic map. Two groups of these hills, which are typically developed and are used as a basis of description, occur in the NW. $\frac{1}{4}$ sec. 5 and the SE. $\frac{1}{4}$ sec. 8, T. 138 N., R. 54 W. (Eldred Township).

The deposits forming these hills have an irregular stratification and a fairly definite assortment of material, including sand and gravel, together with beds of bowldery till. The narrowing and widening of the beds, crossed obliquely by delicately laminated stratification dipping at various attitudes and mingled with the coarser materials of the drift, indicate that both water and ice were concerned in their formation. The two groups referred to in Eldred Township extend noticeably in a north-northwest and south-southeast direction, and this fact is general for most of those that have an elongated form in the eastern portion of the quadrangle. Those in the four townships last named have no distinct axial trend.

A long, narrow ridge regarded as an esker extends southward for a mile from the railroad in sec. 23, 2 miles west of Tower. This ridge is nearly straight and nearly even on its top. It rises about 6 feet above the adjacent plain. Other ridges more irregular in form occur in this immediate neighborhood. The latter are more kamelike, however, and are not regarded as true eskers. They probably partake somewhat of the nature of both eskers and kames.

DEGLACIATION.

TERRACES AND STREAM DEPOSITS.

Sheyenne River.—Sheyenne River is bordered by terraces along much of its course through the district. The first and highest terrace formed is the nearly flat Lanona Plain, which borders the valley continuously on the east, through adjacent parts of Noltimier, Valley, and Alta townships, and the townships immediately to the south, southward to a point 9 miles below Valley City. Farther south in Oakville Township remnants occur on either side of the river, being represented by characteristically flat-topped hills.

This highest terrace was the flood plain of the glacial Sheyenne River at the time when the margin of the ice sheet was forming the morainal deposits on Alta Ridge and its southward continuation, in Preston, Bear Creek, and Fort Ransom townships and southward beyond the district.

This terrace, which is in places 4 to 5 miles in width, has been slightly dissected by subsequent erosion by the tributaries of the present stream, but through most of its extent in this area the original surface is little modified. The highest parts of the Lanona Plain have an elevation of 1420 feet above sea level, or more than 200 feet above the present Sheyenne River. Certain hills rising above this plain were surrounded by the waters which flooded the plain.

In Oakville, Bear Creek, and Fort Ransom townships is a broad, nearly level plain, locally known as Sand Prairie, the surface configuration, superficial structure, and composition of which indicate that it has been covered by a shallow body of water. In secs. 2 and 11, Bear Creek Township, the sand plain extends to the brink of the valley, here 1400 feet above sea level. Some higher portions of the plain have an elevation of 1420 feet. Sand and gravel are reported in well diggings at depths of 6 to 40 feet. The sharply trenched modern coulées of Sheyenne River, in sec. 35, Oakville Township, and sec. 2, Bear Creek Township, expose a continuous line of contact where sand and gravel beds aggregating 40 feet in thickness are seen to rest upon glacial till. Well borings in these and adjoining sections immediately west indicate that stratified gravel and sand overlie the till to a depth of 15 to 40 feet.

From these and similar data collected in the vicinity it appears that a deep sag in the underlying till plain extends from sec. 2, Bear Creek Township, west by south through a distance of perhaps 3 miles. This depression was doubtless eroded by the waters of the upper Sheyenne at the Lanona stage, when the glacial drainage escaped by way of Bears Den Hillock Creek. Later this channel was silted up to the present level of the Sand Prairie plain with the stratified deposits above referred to.

To the south Sand Prairie merges into the broad bottom of the valley of Bears Den Hillock Creek, by which it is connected with the plain of the bottom of glacial Lake Dakota. It reaches a width of about 5 miles in Oakville Township and has an average width of about 3 miles.

A second terrace, or ancient flood plain, of Sheyenne River is represented by a flat plain which borders the valley on the west in adjacent parts of Bear Creek and Preston townships. This terrace, which has an elevation of 1380 feet above sea, or approximately 200 feet above the present stream, and an area of about 4 square miles, was formed after the ice front began its recession from the moraine on the west, and therefore marks a later stage of the river than that represented by the Sand Prairie and Bears Den Hillock Creek channel. A well-defined channel traverses this terrace from north to south through secs. 12, 13, and 23, Bear Creek Township. In secs. 26 and 35, Bear Creek Township, this channel has been much deepened and broadened by the later erosion of a deep coulée, but farther south, in sec. 35, Bear Creek Township, and secs. 2 and 11, Fort Ransom Township, the ancient channel may be traced as a distinct troughlike depression high up on the steep side of the present Sheyenne Valley, 186 feet above the present stream. Below Fort Ransom the present valley of the Sheyenne swings eastward, but the old channel extends southward in secs. 14 and 15, Fort Ransom Township, and continues beyond the district. This channel, here a broad and well-defined valley called River Ransom, extends southward close to the east side of the moraine in R. 58 W., and broadens out 20 miles south of the district into the gently undulating plain representing the bottom of an ancient lake in Sargent County known as glacial Lake Sargent.

Another terrace is crossed by a channel running from sec. 12, Bear Creek Township, through secs. 18 and 19, Preston Township. The bottom of this channel is below the 1360-foot contour, and therefore 20 feet below the channel just described. It is probably represented farther north by traces on the valley slope in sec. 36, Oakville Township, and by a slightly higher terrace in sec. 25 of the same township.

Below Fort Ransom remnants of terraces border the valley at intervals at successively lower levels, the descent being more rapid than the fall in the present stream, so that where the stream enters the basin of glacial Lake Agassiz the ancient flood plain reaches the level of the Sheyenne Delta.

Other remnants of terraces at relatively lower levels, for example, two in secs. 18, 19, and 30, Preston Township, and in the vicinity of Valley City, represent later stages in the development of the valley.

At Valley City, near the northern edge of the district, the river makes a sharp turn from a direction nearly southeast to west-southwest. On the inside of this curve an immense deposit of gravel was formed. This is one of the most extensive deposits of gravel in the whole course of the valley in the district. It is marked by several benches or terraces representing stages of development, the principal one being about 50 feet above the alluvial plain that borders the river. The Northern Pacific Railway Company has made extensive use of this gravel as ballast for its roadbed, thus modifying the original form of the terrace. A part of the city is built upon the sloping surface of the terrace, and this portion still preserves its original form. (See fig. 3.)

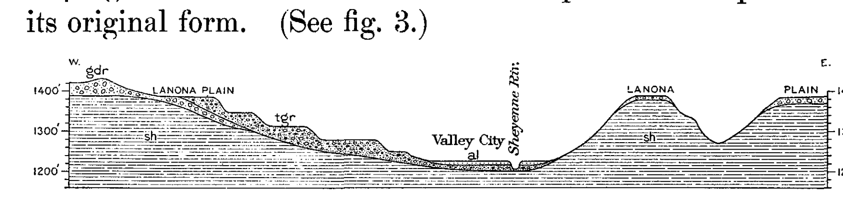

FIGURE 3.—Section across Sheyenne Valley at Valley City.

Horizontal scale, 1 inch = 4000 feet approximately.
Several river terraces are shown below the high Lanona plain. sh, Shale; gdr, glacial drift; tgr, terrace gravels; al, alluvium.

Sections a mile in length cut through the deposit show it to be composed of stratified and cross-bedded gravel, sand, and cobblestones approximately to the level of the alluvial plain. The greater part of the deposit consists of rather coarse gravel, but some interbedded sand occurs. A few bowlders are found. A thin soil, barely sufficient to sustain a scattering growth of grasses, covers most of the surface of the terrace.

Another finely developed terrace, comparable in height to the one just described, laps around and below the point of the bluff immediately south of Valley City, extending almost to the east bank of the river where the stream makes the wide detour to the west.

The broad bottom of the valley is covered with alluvium, comprising the later flood-plain deposits of the river while it yet received the drainage from the melting ice sheet and deposits formed during the present stage of the stream. The thickness of these deposits varies from 4 to 12 feet, as shown by wells and other natural and artificial excavations. Through this material the stream now meanders in a channel about 12 feet in depth. At some points the stream has cut away the alluvium and exposed the underlying shale. In many places beds of coarse gravel underlie the finer materials, and where such deposits are encountered the bed of the stream is marked by slight rapids.

Many abandoned and silted-up segments of channels persist in the tilled fields of the lowest terrace or flood plain. They usually present the form of oxbows, and apparently when occupied by the stream were not essentially different from the present channel, above which they lie at a height of 8 to 20 feet. In the west half of sec. 17 and the east half of sec. 18, Preston Township, there are three such concentric successively abandoned channels, all articulated with a sharp conformable bend in the present stream. The outer one of these three oxbows traverses about three-fourths of the terrace between the bluffs. It lies about 15 feet above the present river. At the upper and lower limits of such silted-up reaches of the valley the recent stream is sinking its channel into new material, the beds of Cretaceous shale.

These aspects of the river and its lowest terrace indicate that an earlier stream, with tortuous windings and heavy burden, deposited its load along the bottom of the valley in the form of a wide flood plain, which the modern river has carved into terraces and is now steadily removing.

The texture of the alluvium ranges from fine silt to coarse sand and gravel, well stratified in all its exposures. The preponderating constituents are sand and silt, the latter dark in color owing to the associated organic matter. The organic matter, together with the bitter salts from the shales, renders the water of many wells on the river bottom lands unfit for use.

Sheyenne River Delta.—A tract of about 25 square miles of the deposits of glacial Lake Agassiz occupies the southeast portion of this area.

The shore line of Lake Agassiz enters the Tower quadrangle in sec. 4, Highland Township, passing thence southward to sec. 13, Casey Township. The margin of the delta formation in Highland Township, through a distance of 5 miles, is marked by a prominent ridge of irregularly stratified sand and gravel, the Herman beach or barrier. Southward through Sheldon and Casey townships the beach ridge is not well developed, the littoral deposits consisting of broad sheets of sand overlying the till. Northward from sec. 4, Highland Township, through the marginal tier of sections to sec. 21, Howes Township, the gently undulating topography and superficial structure indicate slight wave action and the presence of embayments of quiet waters outside (west) of the Herman barrier beach during its occupancy by the lake waters. The altitude of the shore line through this quadrangle is approximately 1085 feet.

The surface of secs. 4, 5, 8, 9, 16, 17, and 20, Highland Township, is flat. Throughout the remaining portion of the Sheyenne River Delta, except where deeply trenched by Sheyenne and Maple rivers, the topography is very gently undulating. Slight ridges of dune sand occur in secs. 17 and 20, Sheldon Township.

The Sheyenne River Delta deposits vary in thickness from a few inches to 60 feet. In the southeast corner of the district the Sheyenne Valley, here one-half mile wide and about 50 feet deep, is sunk into till or unmodified drift. The bottom of the valley is filled to a depth of 10 feet with an alluvium of gravel and silt.

In Shenford and the adjoining parts of Casey, Liberty, and Sheldon townships glacial drift is exposed in many places at the surface. The delta deposits merely fill depressions between morainic hills. The topography and structure of this part of the delta plain is markedly different from that to the north in Highland and Sheldon townships. The elevations are rounded knobs and ridges with bowldery till exposed on the crests and flanked by water-deposited sand and gravel. Numerous depressions bordered by slopes steeper than would be expected in such situations lie among the hills and ridges. Till is exposed along the sides of these pits, and their bottoms are built up with sand and silt.

From these appearances it seems reasonable to conclude that a portion of a moraine provisionally correlated with the tract extending northwestward to Thordenskjold Township has in this region been inundated by the waters of Lake Agassiz. The morainic hills have been subdued and the intervening depressions partly filled by the waves and currents of the shallow waters covering the delta. Well borings in sec. 17, Sheldon Township, penetrate 20 feet of stratified sand and reach stony clay beneath. A well in the bottom of the Maple Valley, sec. 31, Highland Township, is dug through 16 feet of gravel to blue clay.

Maple River.—The valleys of Maple River and its tributaries within the Tower quadrangle bear evidence of having been once occupied by streams much larger than the present small intermittent creeks. Extensive gravel deposits lie in the valleys and well-defined terraces occur at several places above the point in southwestern Highland Township where the stream enters the basin of glacial Lake Agassiz. Good exposures of stratified gravel were observed at intervals in the main valley as far north as sec. 3, Clinton Township. In sec. 15, Clinton Township, a terrace which stands about 10 feet above the bottom of the valley has a width of 40 rods. One in sec. 22 is about 30 rods wide, and one in sec. 33 has a width of 60 rods. A well on a terrace in sec. 28 of the same township penetrated 18 feet of sand and gravel. In sec. 31, Clinton Township, a terrace of shaly gravel occurs in a tributary valley. Below the junction of this branch with the main channel several good exposures of stratified gravel occur in terraces. A layer of alluvial soil a foot or two in thickness covers many of the terraces, but wells almost invariably show gravel and sand below. In some places, however, wells or other excavations on a terrace reveal clay material, probably till, showing the terrace to be one of erosion.

The village of Enderlin is built upon a gravelly plain which is about 15 feet higher than the bottoms, or alluvial flat, along the present channel of the river. About 10 feet higher than the plain on which the city stands are other well-defined gravel terraces, and the sides of the valley show pockets and shoulders of stratified sand and gravel 30 feet above the terraces.

In sec. 31, Highland Township, and sec. 1, Liberty Township, Maple River broadens its valley to a width of half a mile as it reaches the ancient delta plain of the Sheyenne. The highest or Herman shore of Lake Agassiz was probably near the western line of sec. 32, Highland Township, though no beach is now traceable. Here till is exposed in the sides of the valley, the channel having been eroded below the lake deposits, but not so far as to reach the subjacent stratified shales.

James River.—The James Valley resembles the Sheyenne Valley in general character, but is less wide and less deep, though its sides are marked by well-defined gravel terraces. The valley is about 100 feet deep, and the bottom is throughout a deposit of sand and gravel of late glacial age, overlain in the lower portion by alluvium of the postglacial stream. The valley is intrenched deeply in the shale, though exposures of the shale are not common. The terraces are remnants of the ancient flood plains and are composed largely of gravel and sand.

The drift covers the region to a depth of 10 to 20 feet, as shown by excavations for wells and in recently eroded banks of ancient channels. In sec. 1, T. 140 N., R. 64 W., and sec. 31, T. 141 N., R. 63 W., 4 miles north of Jamestown, occurs the most extensive exposure of shale observed in this area—a long hogback ridge lying within the valley parallel with the course of the stream. Shale outcrops also high on the valley side opposite.

In secs. 30 and 31, T. 141 N., R. 63 W., well-defined terraces occur on either side of the valley. From this point southward to the point where the valley is joined by that of the Pipestem at Jamestown the river valley is narrow, its bottom being at many points but a few rods across. At Jamestown a broad, level plain having a gentle slope toward the valley extends for some distance away from the brink of the valley and is in places thickly strewn with bowlders. This is regarded as a terrace plain flooded by the commingled waters of the James and the Pipestem during the earliest stage of these streams. In the southern part of sec. 4, T. 139 N., R. 63 W., is a small fragment of a very distinct terrace having a sandy and gravelly surface.

These are the only high terraces along this valley in the area, except that in some places the bluffs that immediately overhang the valley are flat on their tops, apparently representing the action of the broad stream in its earliest stage.

In secs. 5, 6, 7, 8, 11, 12, and 13, T. 139 N., R. 63 W., are large gravelly terraces that are much lower in relation to the valley than those already described. Their position in relation to tributary stream channels, together with their gravelly and sandy character, gives them the aspect of deltas modified by the large glacial river. The one farther up the stream slopes gradually toward the river and has its highest part toward the mouth of the large coulée that enters the valley from the south. The other terrace slopes also toward the axis of the present valley, but its position opposite to the mouth of the large Sevenmile Coulee suggests that it was formed by deposits from that tributary, largely modified by the current of the main stream.

About 9 miles farther south, in sec. 30, T. 138 N., R. 62 W., a large ancient channel enters the valley of the James, bordered by terraces of gravel 20 feet or more above the modern alluvial flood plain. This terrace continues into the main valley and appears on the opposite side of the river as a high gravelly plain.

In secs. 6, 7, and 18, T. 138 N., R. 63 W., a gravelly plain extends fully 2 miles upon the east side of the valley bottom at about the same altitude as all the lower terraces described.

Extending from sec. 32 to sec. 14, T. 136 N., R. 62 W., is a broad, low sandy terrace more than half a mile in width in places, and opposite to this, in secs. 34 and 3, are fine examples of higher terraces which are bowlder strewn and contain considerable shale. These terraces on the east side are evidently the result in large part of the deposition of materials transported by ancient streams that entered the valley of the James at this point.

Terraces occur also along several of the ancient channels that are tributary to the James and Sheyenne valleys. The most notable of these are along the large ancient channel known as Sevenmile Coulee and its northward-flowing tributary 3 miles to the east. In the Sevenmile channel well-defined terraces occur at different levels. The lower terrace plain forms a broad, nearly level platform occupying a considerable part of the bottom of the valley and is composed largely of coarse gravel and sand. The higher terrace is approximately 30 feet higher than the lower terrace and borders the adjoining prairie, into which it gradually merges. The higher terrace is locally strewn with bowlders, and in places is somewhat gravelly in character.

In T. 140 N., R. 64 W., embracing parts of secs. 2, 3, 10, and 11, in a sharp bend in the Pipestem Valley, is a fine example of a terrace marking a higher stage of the stream. The highest part of the terrace is 60 feet above the modern flood plain, the surface of the terrace plain sloping rather uniformly toward the present stream. This terrace is crossed by an ancient channel about two-thirds of the way from its lowest point toward the highest portion, and nearly opposite the mouth of and parallel in direction with a coulée that enters the valley from the other side. In modern drainage systems streams tend to straighten themselves by cutting across projecting points, leaving oxbow channels. Here, on the contrary, the cut-off channel was abandoned and an oxbow developed as the main channel. The stream adjusted itself by finding an easier course by the longer journey around the bend than that across the neck.

Well-defined gravel terraces occur at two places on Bone Hill Creek. In sec. 1, T. 135 N., R. 63 W., the broad, level terrace is 20 feet or more above the modern stream and is composed largely of gravel and sand. In sec. 32, T. 136 N., R. 64 W., a terrace a third of a mile in width lies 10 to 15 feet above the alluvial flood plain of the modern stream and consists largely of sand at the surface.

On the lower Beaver terraces occur on both sides of the valley in secs. 3, 4, and 10, T. 137 N., R. 63 W., and again on both sides of the ancient channel in sec. 32, T. 138 N., R. 64 W.

At the place of intersection of three ancient tributaries of the large stream that once discharged southward into the Sheyenne, or into the lake covering Sand Prairie, are broad bowlder-strewn terraces occupying the spaces between the mouths of these channels. These are broad sandy terrace plains, and they merge into the adjacent gently undulating prairie.

PREGLACIAL VALLEYS.

Several large valleys which have the appearance of ancient watercourses enter the Sheyenne Valley from the west. These were evidently avenues of escape for the waters of the receding ice sheet during late glacial time and were doubtless enlarged by the erosion of these waters, but their size indicates that they were avenues of erosion at an earlier time.

One of the largest of these ancient channels enters the Sheyenne Valley in secs. 14 and 23, T. 137 N., R. 59 W. Its lower 15 miles is occupied by an intermittent stream. The bottom in its upper course is broad and flat, and old stream deposits mark its flood plain. Broad gravel terraces occur along its course. In the northern part of Tps. 138 and 139 N., R. 60 W., the old channel is traceable as a distinct landscape feature locally called a slough. It contains no stream in this portion. Northward from this point it appears to be a part of an ancient valley in which now lie Keyes Lake and the Eckelson Lakes, in Tps. 139, 140, and 141 N., R. 60 W. An ancient channel extending in a northeasterly direction from Keyes Lake, in Tps. 139 and 140 N., R. 60 W., probably conveyed glacial water from the region south of Sanborn to this old channel. This, however, appears to be a channel of glacial drainage and not an older filled valley.

Another large valley extends from Valley City, sec. 29, T. 140 N., R. 58 W., southwestward to sec. 21, T. 139 N., R. 59 W., and becomes lost among the hills and sloughs of the terminal moraine.

In sec. 26, T. 141 N., R. 59 W., a deep coulée heads back upon the prairie and continues as a traceable watercourse to the vicinity of Sanborn Lake. This lake and the chain of lakes extending southward to Sweetwater Lake may represent an ancient channel, perhaps of Sheyenne River at an earlier stage. This channel is not now occupied by any stream but is a slough narrowing and widening irregularly and could not be traced south of the Northern Pacific Railway at Sanborn. It has no direct connection with the slough extending southwestward from the vicinity of Sanborn Lake, and it is not connected with Sanborn Lake. If Sheyenne River discharged across this region at some time before the present valley began to be excavated, this ancient waterway, with the depression southward in which lie the Sanborn chain of lakes, may represent the old filled valley of the Sheyenne.

Fox, Rose, Goose, and Mud lakes occupy a long depression broken by intervening drift knolls, from T. 141 N., R. 61 W., southward through Tps. 140 and 139 N., R. 61 W. Thence the depression continues to the south and west as a well-defined channel, being joined by a large branch in sec. 14, T. 138 N., R. 62 W., till it debouches into the James Valley in sec. 30, T. 138 N., R. 62 W., as a broad and deep ancient channel.

Another example of what appears to be a blocked drainage channel extends northward from sec. 9, Spring Township, through Preston, Thordenskjold, and Norman townships (Tps. 135, 136, 137, and 138 N., R. 58 W.), a distance of 15 miles. The southern 5 miles of this ancient watercourse, which is locally known as Madigan Coulee, is a steep-sided ravine or gorge having a depth at its mouth of more than 100 feet, the sides being outcropping shale with overlying talus of the same material. Very little drift exists along the bottom or sides of this gorge. Ten miles north from the head of this gorge the depression continues, though there is no continuous modern watercourse. In secs. 14, 11, and 2, Preston Township, the depression contains several lakelike basins with intervening hills of morainal type. Thence it continues northward through secs. 30 and 31, Raritan Township, and secs. 25 and 36, Thordenskjold Township, thence being interrupted by a rolling hilly topography to secs. 23 and 14, Thordenskjold Township; thence extending 3 miles northward in a broad lakelike depression, beyond which it may be traced 4 or 5 miles, in Norman and Binghamton townships, as a flat till plain interrupted by rolling hills.

The Eckelson Lakes occupy a valley 50 to 60 feet deep extending from the northern part of T. 139 N., R. 60 W., northward through T. 140 N., and thence continuing for several miles beyond the north line of this district as a slough interrupted here and there by low drift hills.

The lower portions of the open channels are of such size as to suggest that they were carved upon the landscape at an earlier time than the stage of general deglaciation of the continent. So also the long north-south parallel valleys in which lie five prominent chains of lakes, between Valley City and Jamestown, compel the suggestion that they are valleys of erosion of an earlier time.

It is difficult to get away from the idea that all these valleys were once joined into a kind of system, and were then dismembered and separately developed by the advance and subsequent retreat of the glacier. The most obvious explanation of such chainlike series of lakes or basins, and also of such large valleys now occupied by insignificant intermittent streams or none at all, would seem to be that valleys, representing a period of erosion, had been blocked or partly filled by drift deposits during a subsequent period of glaciation and destruction of landscape features.

GEOLOGIC HISTORY.

Inasmuch as the only rocks older than glacial drift either exposed or encountered in drilling deep wells in the district are the shales and sandstones of the Cretaceous system, the records of the earliest geologic events are very meager. However, as during later Mesozoic and Cenozoic time generally uniform conditions appear to have prevailed throughout the surrounding region, some inferences may be drawn from other areas. In wells at Fargo, 30 or 40 miles east of the Jamestown-Tower district, granite was encountered at depths of 300 to 400 feet immediately below Cretaceous shales and sand, so that it is probable that for a long time prior to the incursion of the Cretaceous seas land stretched away eastward. The western limits of this land are not known, but not improbably it included the Jamestown-Tower district.

CRETACEOUS EVENTS.

During the latter half of the Cretaceous period the sea covered what is now the region of the Great Plains and the Rocky Mountains as far west as the Wasatch Range and extended from the Gulf of Mexico to the Arctic Ocean. The incursion of the sea over this area was due to the relative sinking of the land. As this took place the waters advanced and the waves and currents washed and sorted the sediments brought down by the streams. The coarser sands and gravels were left near the shore, but the finer silts were widely distributed over the sea bottom. As the sea gradually deepened and the shore line advanced, the silts covered up the sands; the sands were cemented together as sandstone; and the silts were compacted into shales. Varying conditions caused more or less commingling and interbedding of sand with the silts, so that numerous beds of sand or sandstone and of arenaceous shales are now encountered in drilling into the ancient deposits. Still further submergence, extending as far eastward as central Minnesota and Iowa, was marked by the deposition of the Colorado and Pierre shales. The long duration of this period is indicated by the thick deposits of fine sediments which accumulated.

TERTIARY EVENTS.

At the close of the Cretaceous period the land permanently emerged, and the sea never again covered the interior of the continent. During the Tertiary large areas farther west were covered by fluviatile and lacustrine sediments, but in this part of the State no deposits were formed during Tertiary time and its history during that time was one of erosion.

During the Tertiary period the climate was probably much warmer and moister than now, so that the region abounded in animal and vegetable life. In the later Tertiary a large stream probably flowed southward somewhere near the present position of James River. Doubtless tributaries of this or other streams drained the district, cutting rapidly into the soft beds of shale and sculpturing the land surface into hills and valleys.

To the east was developed the broad ancient valley now traversed by Red River. The rapid westward rise of the present land surface in the eastern part of the Tower quadrangle and farther east marks the location of the western slope of this great valley. This slope, formed by the cut-off edges of the Cretaceous strata, has been called the Manitoba escarpment. In the Jamestown-Tower district it is so mantled with drift that no exposures of the shale occur, though the character of the underlying rock is revealed by well borings.

Alta Ridge is a broad, drift-mantled preglacial ridge extending two-thirds of the length of the Tower quadrangle. It was probably fashioned by erosion during late Tertiary time, but whatever river valleys may have existed on the ancient land surface are now hidden by the thick mantle of drift.

The extreme western portion of the district lies upon the sloping edge or face of the Missouri Plateau. The highest part of the area, that in the southwest corner, is traversed by the 2000-foot contour, and the lowest point, in the Sheyenne Valley, by the 860-foot contour. There is therefore a rise of 1100 feet in a distance of 72 miles along the southern boundary of the district. This gives an indication of the extent of Tertiary erosion in this region. The broad plain lying between the Missouri Plateau and Alta Ridge represents a high, broad valley of preglacial erosion, while east of Alta Ridge was carved a still deeper valley that was later occupied by the glacial Lake Agassiz.

QUATERNARY EVENTS.

PLEISTOCENE HISTORY.

PRE-WISCONSIN GLACIATION.

The opening of the Quaternary period was marked by a change in climatic conditions such that during the colder seasons snow fell in large amounts over a large part of northern North America. So great were these snowfalls and so meager, comparatively speaking, were the opportunities for their melting during milder seasons, that vast amounts accumulated over an area millions of square miles in extent, producing immense ice sheets comparable in character to the present ice cap of Greenland, but much more extensive.

There appear to have been two centers of this accumulation, one in Labrador and one west of Hudson Bay. From these centers the ice moved out in radial directions with a movement such as is now observed in the mountain glaciers of various parts of the earth. The spreading of the ice sheet from these centers caused their coalescence, so that during their greatest extent they covered the whole continent approximately as far south as the line of Ohio and Missouri rivers. (See fig. 4.)

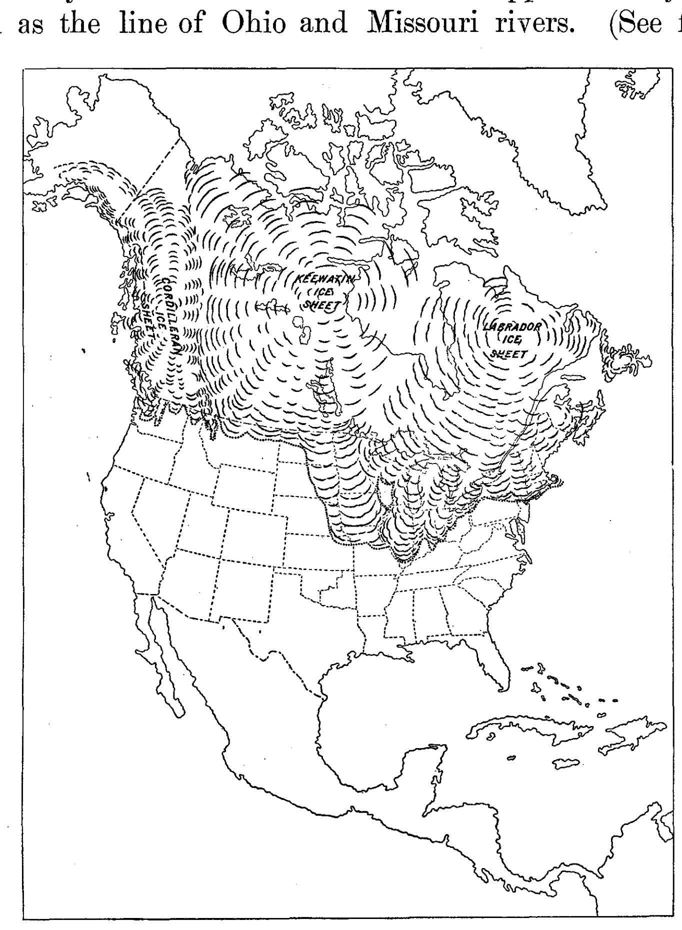

FIGURE 4.—Map of area covered by the North American ice sheet of the Pleistocene epoch at its maximum extension.
Shows the approximate southern limit of glaciation, the three main centers of ice accumulation, and the driftless area within the border of the glaciated region.

At this stage all that part of North and South Dakota lying east of Missouri River was covered by the ice sheet, which was probably hundreds and perhaps thousands of feet in thickness.

As has already been indicated, the study of the deposits formed by these great glaciers shows that the glaciation of northern North America was not confined to a single stage of growth and decadence of the ice sheet. It appears that stages when the climatic conditions were favorable to the development of such continental glaciers alternated with milder intervals when the ice sheets wasted away, until large tracts previously covered with ice were again in condition for the return of animal and vegetable life. During these intervals soils were developed and the glacial deposits spread over the land were sculptured by new river systems. The return of glacial conditions over most of the area previously glaciated destroyed many of the newly developed topographic features and buried the whole in a new deposit of drift.

Just how many successive stages of glaciation and deglaciation marked the region in which the Jamestown-Tower district lies is not certainly known. Some evidences of an interval of deglaciation have been considered elsewhere (p. 2).

WISCONSIN GLACIATION.

The extent of the ice sheets in this region during the Wisconsin stage of glaciation is shown in figure 2. Northeastern Minnesota was covered by the Lake Superior lobe of the Wisconsin ice sheet. Sweeping southwestward and southward about the west end of this lobe another great glacier bifurcated at the head of the Coteau des Prairies into two great lobes, one of which, known as the Minnesota Glacier, passed from the broad ancient valley of Red River southeastward and then southward, traversing western and southwestern Minnesota and north-central Iowa as far south as the location of Des Moines. The other lobe, known as the Dakota Glacier, moved down the James River valley on the west side of the Coteau des Prairies to the line of Missouri River, spreading out on the west to and upon the Plateau du Missouri. The limits of these glacial lobes are marked by the Altamont terminal moraine. The Tower quadrangle is located about 40 miles in a north-northwesterly direction from the head of the Coteau des Prairies, where the Minnesota and Dakota lobes separated.

Doubtless the advance of the glaciers of the Wisconsin stage was attended by many interesting events, but the record is imperfect and little more than the bare fact of the advance is known. When the ice melted away the débris borne within it and that accumulated at its base were left spread over the surface of the land as a mantle of drift, the bulk of which constitutes the ground moraine. To the action of these glaciers and their attendant waters, and especially to the deposition of the drift, is due in large measure the difference between that part of the State east of Missouri River and the lands to the west, so that on the whole the glaciation of this region was an advantageous preparation for the advent of civilized man.

DEGLACIATION.

The progress of the final melting of the ice sheet which covered this region was marked by intervals of halt, or possibly even of readvance, as climatic conditions varied from time to time. The successive positions of the ice front during these stages of halt are marked by marginal accumulations of drift constituting more or less definitely ridged terminal moraines. The heaping up of drift in reentrants in the ice margin, the pushing together of piles of débris, and the unequal settling of the deposits, due in part to the burial and subsequent melting of great masses of ice from the disintegrating glacier, resulted in the ridged, humpy, and pitted surface characteristic of these moraines.

The Dakota glacial lobe which occupied the James River valley appears to have melted away somewhat more rapidly than the Minnesota lobe, so that the retreating ice front approached the present area from a west-southwest direction. The first marginal deposit within the area indicating a halt in the progress of glacial wasting is the moraine in the extreme western portion of the district, known as the Second or Gary moraine. This moraine here lies upon the Missouri Plateau and is closely associated with the First or Altamont moraine. The high plateau front served as a wall or dam to hold back the ice in its forward movement. The great amount of material in these outer moraines and the large size of the hills indicate that the edge of the great ice sheet probably remained in this part of the eastern plateau top for a considerable time. In its maximum advance the ice sheet thus fully crossed the Jamestown-Tower district.

After the formation of the large moraines that traverse the east side of the Missouri Plateau the recession of the ice front left the whole front of the plateau in the district freed from the ice. There is no well-defined moraine between the plateau front and the James Valley, although scattered morainic hills occur, and in the central part of the Jamestown quadrangle a morainic district indicates that the ice lingered in its retreat and locally may have advanced. The systems of ancient channels that traverse the region indicate that the retreat was slow. The steep and high hills in T. 134 N., R. 64 W., have a terminal-moraine character. The ice front probably extended approximately northwestward from the big bend on Bone Hill Creek in T. 136 N., R. 64 W., covering the lower Pipestem. This is shown by the broad channel in western T. 137 N., R. 64 W., by the similar large channel in Tps. 138 and 139 N., R. 65 W., and by the system of ancient channels in T. 140 N., R. 65 W.

This complex system of drainage channels extends south and east entirely across the Jamestown quadrangle from its northwest corner and is connected with the James Valley by three large cross channels.

In the western part of T. 134 N., R. 64 W., in secs. 17, 18, 19, and 20, is a broad flat-bottomed ancient channel, across which runs the insensible divide between Bone Hill and Beaver creeks. The portion of this channel where the divide occurs forms part of the large trunk channel by which the waters from the melting ice in the morainic district in Tps. 137 and 138 N., R. 64 W., and also the drainage from the west and north escaped, probably along the edge of the waning ice sheet toward the southeast. It is probable that the upper Beaver was connected with this channel in T. 138 N., R. 63 W., if, as seems likely, the lower Beaver was still covered by the ice when the ice front was near Eldridge, in T. 140 N., R. 65 W.

In the western part of T. 140 N., R. 65 W., is a system of ancient channels which now discharges to the north and east into the Pipestem. The main trunk extends due north through secs. 32, 29, 20, 17, 8, and 5, thence turning almost due east to enter the valley of the Pipestem by a large channel in sec. 36, T. 141 N., R. 65 W. Its head channels rise in the high morainic hills in the central part of T. 140 N., R. 66 W., the main one extending southeastward from sec. 23, through secs. 25 and 36, to sec. 31, T. 140 N., R. 65 W., where it turns eastward into sec. 32. From this southern bend of the ancient channel a large valley extends to the north on both the east and the west sides of the moraine in northern sec. 31, sec. 30, and southern sec. 19. A distinct long morainic hill or ridge lies close to and parallel with the main trunk in secs. 29, 28, 20, 21, 17, 16, 9, and 8, T. 140 N., R. 65 W. From this bend a large channel also extends southward through secs. 6, 5, 8, 17, and 28, T. 139 N., R. 65 W., continuing as the upper main channel of the Beaver. The divide between the northward-flowing system and the head of the Beaver is so very faintly discernible as to be easily mistaken. The modern drainage from the upper channel to the west of the moraine, in secs. 31, 30, and 19, passes eastward in secs. 31 and 32 by a small channel that lies close to the north side of the Northern Pacific Railway track, the ancient channel being nearly blocked by the railroad grading.

The earliest drainage channel in this region extended southeastward from the central part of T. 140 N., R. 66 W., crossed the present low divide in sec. 6, T. 140 N., R. 65 W., and continued to the southeast as the present main channel of the upper Beaver.

From T. 138 N., R. 64 W., southward the upper Beaver discharged southward by the lower part of the channel of the south branch of the Beaver, crossing the low indefinite modern divide in western T. 137 N., R. 64 W., and continuing by Bone Hill Creek to James River. This composite ancient drainage system, together with the terminal-moraine hills in Tps. 137 and 138 N., R. 64 W., and T. 140 N., R. 65 W., and the low morainic or kamelike hills, indicates that the edge of the great ice sheet lay in a generally north-northwest and south-southeast direction across the central portion of the Jamestown quadrangle.

In sec. 1, T. 140 N., R. 65 W., the Pipestem Valley makes a sharp bend toward the north. From this bend a large tributary coulée extends back into the plain to the southeast, presently passing an insensible modern divide and descending in a southeasterly direction to the NW. $\frac{1}{4}$ sec. 34, T. 140 N., R. 64 W., where it turns to the north of east, entering the valley of the Pipestem just above the point where that stream debouches into the James. The Pipestem evidently occupied this channel at the time when the rolling morainic hills in southern T. 141 N., R. 64 W., and in northern T. 140 N., R. 64 W., were being formed. This region marks a halting place of the edge of the ice in its recession from this part of the continent. Moreover, the relations of the drainage systems to the low rolling kamelike hills indicates that the recession was slow.

At the next stage of recession of the ice front the lower Pipestem and probably all of that portion of the James Valley lying within the Jamestown quadrangle was uncovered. There are no definite moraines from the James Valley eastward to the large moraine that crosses the Eckelson quadrangle, but there are low morainic and kamelike hills, indicating a slow recession of the ice, with deposits formed at or near the margin. The old channels as well as the moraines indicate the stages of the ice recession. South of the morainic ridge crossing the southwestern portion of the Eckelson quadrangle are several channels eroded by waters flowing from the edge of the ice sheet at the time this morainic ridge was being formed. The crooked ancient channels that interlace among the low hills in Tps. 139 and 140 N., R. 62 W., indicate that they were formed during the time that the adjacent moraine was being built, the waters escaping to the lower places and ponding until escape was found from one depression to another and a channel ultimately eroded.

The next important moraine after the Gary is the Sixth or Waconia moraine of Upham,[a] which crosses the Eckelson quadrangle from a point near its southeast corner to its northwest corner. It marks the first definite and lengthy halt in the ice front during its retreat after the formation of the Gary moraine. The region traversed by this moraine is marked by several series of lakes or lakelike depressions, in part in line with old channels. The topography probably was outlined as subdued morainic hills built during an earlier stage of glaciation and subsequently overridden by the ice. The Waconia moraine was accumulated on the old surface in the next recession.

The blocked channels represented by Fox Lake, Eckelson Lakes, Sanborn, Round, and Sweetwater lakes, Hobart Lake, the now open channel from central Green Township to the Sheyenne at Valley City, the one from sec. 9, Skandia Township, to the Sheyenne, the one immediately south and connecting with this by a depression through secs. 15, 14, and 24, Skandia Township—all were formed at the same time and were continuous with the channels farther south with which they were in alignment. They all carried water away from the ice front when it stood close to and along what is now the west bluff of Sheyenne River. The subdued remnants of the moraine formed at this time and subsequently overridden by the ice and then depleted by the floods of water issuing from the retreating glacier may now be traced from sec. 8, Oakville Township, northward along the west bluff of the Sheyenne to the north boundary of the district at Ivan.

A readvance of the glacier at this stage buried the channels and partly obliterated them, until the ice front lay along the Waconia moraine as far north as St. Marys Lake, in southwestern T. 139 N., R. 59 W., where it turned sharply to the west, passing close to Keyes and Mud lakes; at Mud Lake a bend in the ice front carried it around the heads of the two ancient channels immediately southeast of Spiritwood; thence it continued to the northwest corner of the district.

Then came the final retreat of the glacier from this region. As the ice uncovered the ground the water from behind and east of the Waconia moraine flowed southward and eastward into a channel that later became the glacial Sheyenne River; in thus flowing to the Sheyenne it subdued the earlier overridden moraine along the west bluff and reopened the channels now rising in the Waconia moraine and flowing to Sheyenne River. When these channels were originally formed the drainage was westward, but on the retreat of the ice, after blocking all westward exits with morainic débris, the drainage was reversed and led eastward in the reopened channels until it met the ice front and followed that southward, perhaps at the stage known as the Lanona flood-plain stage. The ancient blocked channels represented by Hobart Lake and the lakes to the west of it were never reopened, because the ice was not melted from the line of the Sheyenne until after the uncovering of the blocked channels.

The hills from sec. 8, Oakville Township, northward along the Sheyenne past Valley City, have the appearance of an overridden and subdued moraine; the relief is of morainic magnitude, but the slopes are gentle and subdued in the line of what was considered to have been the edge of the melting glacier.

The retreating ice front approached the Tower quadrangle from a westerly direction. The first marginal deposit within this area indicating a check in the progress of glacial wasting is the moraine stretching across the western part of the quadrangle on the preglacial Alta Ridge. The trend of this moraine shows that the ice front was retreating in a direction nearly eastward and that at this time the western lobe of the ice sheet had almost if not quite disappeared.

At length there ensued another increase in the rate of wasting, a decrease in the rate of forward movement of the ice, or a combination of both, so that the glacial front was melted back from this terminal moraine.

As has been shown, morainal deposits, largely in the form of disconnected hills and ridges of stratified drift, are scattered over the whole area of the ground moraine east of the main moraine. The general trend of their axes seems to indicate a gradual shifting of the retreat to a more northeasterly direction—that is, to a direction normal to the prevailing trend of these features. The character and distribution of these deposits suggest a general stagnation or disintegration of the ice sheet that afforded opportunity for the assortment and localized deposition of the drift by streamlets on and near the melting ice. Many of these hills are typical kames and are thought to have been deposited by streams of glacial water debouching at the ice front, in reentrant angles or in crevasses and other cavities in the ice. The continued melting at length freed the Tower quadrangle from ice and in due time the whole continental ice sheet disappeared. Recent time for this area dates from the final disappearance of the glacier and of the waters resulting from its melting.

SHEYENNE RIVER.

The melting of so vast an accumulation of ice resulted in great floods of water along the lines of all streams leading away from the ice front. The deposition of so great an amount of glacial débris over so large an area caused an entire rearrangement of the drainage system of the glaciated area. Old valleys were filled up, and the outflow of glacial waters established new streams which were gradually shifted from place to place as the ice fronts changed their positions, until the final disappearance of the glacial floods, when drainage was established along the present lines. This shifting of drainage lines is well illustrated by the streams of the Jamestown-Tower district.

Outlet to James River.—While the ice front stood at the moraine on Alta Ridge and its southward continuation west of the river in Ransom County, glacial waters from the front and from a considerable distance to the north escaped southward along the western front of the moraine. The present Sheyenne Valley not then having been excavated, this water followed sags in the surface of the drift until it reached the James River valley by way of Bears Den Hillock Creek. As Sheyenne River follows in a general way the course taken by these waters southward to Ransom County, this glacial stream may be conveniently referred to as the glacial Sheyenne River. The flood plain of this stream has been described as the upper terrace bordering the Sheyenne Valley. In the northwestern part of the Tower quadrangle it is known as the Lanona Plain (see fig. 3); farther south it forms Sand Prairie, which lies in southern Oakville, Bear Creek, and Fort Ransom townships. Between these tracts all but slight remnants of this ancient flood plain have been cut away by later erosion.

At this stage we may picture the glacial margin as resting on the ridge of débris on Alta Ridge, its surface rising at first steeply, then more gently, and stretching away to the east and north in a vast sheet of ice. To the west was the drift plain recently exposed, its bare surface gradually becoming mantled with a new growth of vegetation. Near the glacial front was the broad river flowing southward to join James River, its waters burdened with sand and silt brought to it from the neighboring slope of ice and drift by innumerable rivulets of glacial water.

North of Fort Ransom the river had located itself approximately along the line of the present valley and began cutting downward. The bed of the ancient channel in eastern Bear Creek Township has an elevation about 1360 feet above the sea, 50 or 60 feet lower than the level of Sand Prairie, its earlier flood plain. The terrace in sec. 25, Oakville Township, corresponds in elevation with this ancient channel and may represent its northward continuation. With this also are perhaps to be correlated the cols and notches northeast and southeast of Valley City, which are marked on the geologic map as old channels. With the deepening of the valley the notching of its lateral slopes by tributaries began, initiating the coulées now found.

That the deep valley of the Sheyenne is in its main features due to the eroding waters escaping from the wasting ice front as it lay along the summit of Alta Ridge is evident from its tributaries, which rise in the eastern slope of the moraine and have deeply trenched it to the level of the alluvial plain. In some places, where the river departs widely from the ridge, these channels show an advanced stage in the development of terraces and river flats; in others, where the moraine stands close to the shoulders of the valley, they are short and steeply trenched. Examples of the former are the valleys cut into the Lanona Plain; of the latter, those in the vicinity of Daily and 6 miles north of that place.

Outlet of Lake Sargent.—When the ice front was melted back from that part of the moraine in Bear Creek and Fort Ransom townships, a sag in the morainal crest allowed the waters of the glacial Sheyenne River to cross to the east side of Alta Ridge, where they found a lower outlet southward across the broad, flat terrace in eastern Bear Creek and western Preston townships. The ancient channel, known as River Ransom, formed at this stage, has been traced from sec. 12, Bear Creek Township, southward across Fort Ransom Township, and beyond the bounds of the district. Continuing southward along the east side of the moraine for 20 miles, the stream mingled its waters with those of glacial Lake Sargent.

About 3 miles above Fort Ransom, in sec. 36, Bear Creek Township, occurs the narrowest and most canyon-like stretch on the river in the Jamestown-Tower district, if not on its whole length. It is locally known as the "Jaws." This is interpreted to be the place where the river crossed the axis of the moraine, causing a narrowing of the valley and an increase in the fall in its bed below. The valley slopes and the channels eroded in the alluvial plain show a larger proportion of bowlders in this narrower portion than elsewhere in the valley. The shifting to the east of the divide which now separates the Gulf drainage from that flowing to Hudson Bay dates from the time of this crossing of Alta Ridge.

It seems likely that by the time of the formation of the moraine which extends from western Fuller Township north-northwest through eastern Preston and Thordenskjold townships the river had abandoned the old channel leading southward from Fort Ransom, as the general land surface to the east is as low as the bottom of this channel. The deep tributary channel known as Madigan Coulee, which extends from sec. 9, Spring Township, northward to the moraine in eastern Preston Township, became the principal avenue of drainage from that portion of the moraine to the Sheyenne, which thereafter followed its present course through Spring Township. The broad terrace in secs. 11, 12, and 13, Spring Township, indicates that the level at which the waters ran was below that of River Ransom.

The topography in Fuller and southern Moore townships is morainic in character, but it is not of the sharply rolling type such as commonly characterizes terminal-moraine belts. The hills are subdued in form and are less closely set than those of the morainic districts to the north and west. They appear to be a type of hills such as might be formed during a slow recession of the ice when the ice edge was slowly receding.

[a] Op. cit. pp. 143-145.

Such a condition would have been sufficient to determine the course of the river along the line of the ice front. The trend of the moraines to the south beyond the present area is in a generally south-southeasterly direction.

Outlet of Lake Agassiz.—From the time of its abandonment of the River Ransom channel, the Sheyenne followed its present course to the point where it enters the basin of glacial Lake Agassiz, about 10 miles south of the southeast corner of the district.

Glacial Lake Agassiz is the name given to the body of water which flooded the broad basin of Red River as the Minnesota glacial lobe melted northward. As the ice front retreated the area of ponded waters was extended until they encroached on the southeastern part of the district (Tower quadrangle) in the townships of Highland, Sheldon, Shenford, and Casey. Where recognizable in Highland Township the elevation of the highest or Herman shore line of this glacial lake is approximately 1085 feet above the sea, so that the part of the Sheyenne River valley within the Tower quadrangle may have been eroded to its present depth while yet the stream discharged its waters into this lake. The material derived from the erosion of this valley, together with much glacial sand and silt contributed by the drainage from the melting glacier, was spread out upon the lake bottom in the great delta deposit already described (p. 5).

Glacial Lake Agassiz discharged by the way of Lake Traverse, Bigstone Lake, and the Minnesota River valley until the glacial front had been so far melted back that a lower outlet to Hudson Bay was opened. During this time the southern outlet was steadily cut down, and the water sank to lower and lower levels. As it lowered, Sheyenne River was extended across its delta deposit to the retreating shore line, until it reached the southeast corner of the Jamestown-Tower district, where it now flows through a sharply cut valley about 50 feet in depth. With the disappearance of glacial Lake Agassiz the stream became tributary to Red River.

The erosion of the Sheyenne Valley was practically completed before that of the tributary valleys, and probably while yet it received the drainage from the melting ice in this area and to the north. This is shown by the occurrence of alluvial fans or aprons of gravelly material sloping from the mouths of the tributary valleys toward the axis of the main valley. These deposits have been dissected by the streams now flowing in the valleys. This material was derived from the erosion of the coulées and possibly directly from the drift at the melting ice front. As the deepening of the valleys continued the streams cut through the deposits previously made. Generally these valleys are much out of proportion to the rivulets that now flow through them.

MAPLE RIVER.

Maple River has a history somewhat similar to that of the Sheyenne in its relations to the shifting of the ice margins. Extending from a point northwest of the village of Fingal southeastward to the southwest corner of Pontiac Township is a channel in whose bottom and banks gravel is exposed. In sec. 26, Raritan Township, a similar channel joins this from the west. Other channels lead from these to the channel in Moore Township, now occupied intermittently by the south branch of Maple River. This latter channel, though traversed by very little water except in the spring, is well defined, with abrupt slopes 30 to 40 feet high in northern Moore Township and 15 to 30 feet high in southern Moore and Fuller townships. It is continuous from the village of Enderlin to sec. 20, Fuller Township, where it reaches the Sheyenne as a hanging valley about 75 feet above the present stream. At present, however, only 1 or 2 miles of this channel drains to Sheyenne River; much of it is fine level meadow, the divide being imperceptible.

These channels appear not to be due to recent erosion, and were probably formed by the discharge of glacial waters to Sheyenne River while the glacier extended west of the present main valley of the Maple. The two channels in Raritan Township and the course thence to the Sheyenne may represent the first two stages in the development of Maple River. A third stage may be represented by a discharge southeastward by way of the valley heading in eastern Binghamton, through Pontiac Township to Enderlin, and thence by the south branch of Sheyenne River. A fourth stage, in which the stream was still discharging to the Sheyenne, marked the opening of the main channel and upper tributaries to the vicinity of Tower City. The fifth stage resulted when the ice receded still farther, opening the channel east of Enderlin. The waters of glacial Lake Agassiz encroached upon the district, and the stream discharged into this lake. This resulted in a reversal of the drainage in the valley of the south branch and the abandonment of the outlet by this channel to Sheyenne River. Probably as long as the ice front stood near its head while the stream was discharging into the lake, contributions of glacial sediments were made to the great delta of Sheyenne River, but when the ice disappeared from the region and the lake was lowered by the cutting down of its outlet, the Maple also was extended across the delta to the retreating shore line, and its channel in the delta deposits was eroded. The stream now joins Sheyenne River northwest of Fargo, 30 miles east of Buffalo.

ECONOMIC GEOLOGY.

WATER SUPPLY.

The water supplies of the Jamestown-Tower district consist of surface water derived directly from rainfall or melting snow and underground waters obtained from wells of various kinds. The surface waters are streams, lakes and ponds, and springs. The underground waters are reached by shallow dug wells, artesian wells, and tubular wells.

SURFACE WATERS.

STREAMS.

Streams furnish only a small portion of the water required for agriculture in the district. The comparatively few persons residing near the streams obtain from them the necessary supply for stock and laundry purposes, but the water is unfit for drinking or cooking. Some water is obtained from springs that flow from the steep banks on the valley sides, or from shallow wells dug in the gravelly or sandy flood-plain deposits of the valleys.

SPRINGS.

Springs occur along all the valleys of Sheyenne and James rivers and of their deeper tributary channels, their common position being at the contact of the shale with the drift. They furnish, however, only a small proportion of the water supply of the area. Their occurrence and distribution are such that they are available only to a few who live in the valleys, and the volume of most of them is inadequate for the demands of house and farm.

LAKES AND PONDS.

Many small lakes occur in this area, but they are of little importance as a source of water supply for either agricultural or domestic purposes, owing to the mineral matter they hold in solution. The water of most if not all of the lakes is not suitable for stock to drink, and many of them are so highly mineralized that but little vegetation grows close to their basins.

UNDERGROUND WATERS.

SHALLOW DUG WELLS.

In most portions of the Jamestown-Tower district sufficient water for farm and domestic uses is obtained from wells a few feet deep. On the Lanona Plain east of Valley City wells 12 to 18 feet deep yield plenty of water; on the lower lands along the foot of Alta Ridge west of Oriska wells from 16 to 24 feet deep are required; on the sandy plain of the Sheyenne Delta in the southeast corner of the district the depths are 10 to 16 feet; and on Sand Prairie, in the southwest corner of the Tower quadrangle and the southeast corner of the Eckelson quadrangle, the depths are 6 to 10 feet. In these localities the topography of the drift is such as to cause the ground-water table to be near the surface. In all these places the water enters the soil in the immediate neighborhood of the wells. In the Jamestown quadrangle, north and east of Jamestown, Cretaceous shale is encountered in dug wells at depths of 15 to 20 feet, but many of these wells yield water of good quality. In some wells the water occurs at the base of the glacial drift at its contact with the underlying shale, and here and there wells penetrate the shale itself. The depth to the base of the till is shown in figure 5. Quicksand is encountered in some wells; in others the water is derived from coarse sand or gravel.

In many places the water from shallow dug wells is not of superior quality, owing to the presence of mineral matter derived from the soil through which the water has percolated. There are noteworthy exceptions, however, as, for instance, the unusually pure water which the shallow wells of Sand Prairie yield in large amount. The shallow wells on the plain of the Sheyenne Delta also furnish water of superior quality. Many dug wells which penetrate gravel yield good water and plenty of it, but where the water is closely associated with shale or clay it is likely to be inferior. The explanation of these different conditions is probably to be found in the underdrainage of the soil in which the wells occur. In Sand Prairie the surface soil is underlain by water-bearing sand and gravel, which were sorted and washed by the glacial Sheyenne River. Relatively few wells have penetrated below this sand and gravel stratum, partly because plenty of water is obtained in it and partly because of the presence of much quicksand. The underlying material is either bowlder clay or shale, which restrains the water from percolating downward, while the slight general slope of the plain permits a slow lateral movement. To this underground flow is attributed the purity of the shallow-well waters. The purity of the waters from the shallow wells of the Sheyenne Delta and part of the Lanona Plain is due to this same condition; the loose texture of the delta materials allows the ready penetration of the water from the surface, and the lateral flow is sufficient to prevent the concentration of salts. At Lanona station, however, a well about 15 feet deep furnishes water in abundance, but of very poor quality. This is because the subsoil is clayey, the topography is such that surface waters can not easily escape except by evaporation or percolation into the soil, and the structure of the plain is not such as to afford ready lateral underdrainage. On the east side of Alta Ridge there is considerable variety in the quality of the waters, due to the varying conditions of the drift. Where the gravel beds are of considerable thickness the wells generally yield good water, but where the gravel or sand layer is thin, or where there is much blue clay associated, the water is alkaline.

TUBULAR WELLS.

Bored or tubular wells from 40 to 250 feet deep form one of the principal sources of water supply in this region. They differ from shallow wells in that most of the water is derived from rain that penetrates the earth at some distance away. In a number of the tubular wells the water rises nearly to the surface of the ground, and at some places it flows into reservoirs that have been excavated to receive it. In sec. 17, T. 136 N., R. 56 W., where no water could be obtained in a dug well, a sufficient supply for general farm and household purposes was furnished by a tubular well 32 feet deep, all in drift. It is located on a round knoll, and the water rose so near to the surface that a horizontal pipe sunk in a shallow trench affords a running stream which is conducted to a milk house and trough on the adjacent lower ground. Another well about 4 miles east of this one flows at some seasons of the year, but at others must be pumped. Both wells yield large volumes of water.

A flowing tubular well in sec. 14, T. 140 N., R. 55 W., is 58 feet deep, and others along Maple River in Tps. 139 and 140 N., R. 55 W., range in depth from 25 to 48 feet. These wells are all in the drift and their flow is evidently determined by the local topography. Many springs occur along the valley of the Maple and its tributaries, the water flowing underground from the higher porous soils in the near-by regions to the valley, where it breaks out along the banks and bottom. The land 3 miles east and 5 to 6 miles west of the flowing wells referred to is 60 feet higher than the prairie along the river, and farther west it is still higher. Thus the intake area is sufficiently extensive to give a constant flow to wells which tap the water-bearing bed. These wells have been flowing for about twelve years, with no signs of diminution.

The water-bearing stratum tapped by tubular wells is usually either a permeable layer in the body of the drift or lying at its

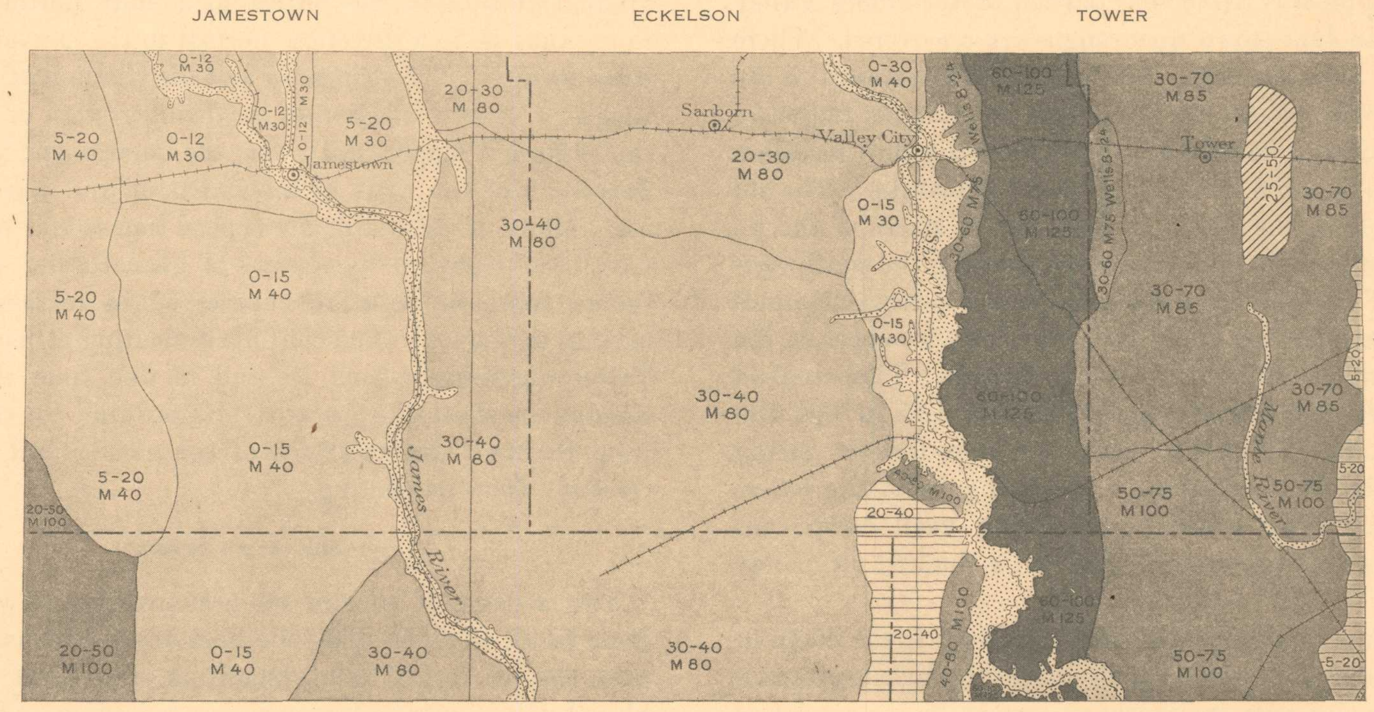

FIGURE 5.—Sketch map of Jamestown, Eckelson, and Tower quadrangles, showing depth to base of till.

Water can generally be had from sand at the bottom of the till. Average range of depth indicated by figures. M = Maximum. Dotted pattern represents alluvium and terrace gravels, 10–60 feet deep; horizontal ruling, lacustrine and delta deposits; diagonal ruling, areas in which shallow flowing wells occur in the till.

base on the Cretaceous shale; but in some places it is a porous layer in the shale. Ordinarily the water-bearing bed is overlain by compact blue clay which serves as a cap to hold the water under considerable pressure. When this clay is pierced by the drill or auger the water rises, often with considerable force, until the hydrostatic level is reached. The water-bearing bed is so porous that the water readily passes through it for great distances.

Water from tubular wells is usually palatable and wholesome, especially when they are frequently pumped, but if allowed to stand long in the well it often becomes brackish and stale, acquiring a disagreeable odor and taste and becoming so mineralized that it is unfit for domestic use. This undesirable effect probably results from the action of the water, which generally contains some alkaline or other salts, upon the clay in which the well has been bored. Also, at many wells where the water is allowed to stand in reservoirs or cisterns excavated about the mouth of the well, or where the well is partly dug and partly bored, the water stored is bad. This trouble is generally overcome by the use of windmills, which by constant pumping keep the water in circulation.

Many tubular wells penetrate the shale which underlies the drift, though the exact line between the blue clay of the unoxidized drift and the blue clay shale below is not easy to ascertain. The "soapstone" often recorded by the driller is usually the shale below the drift. In some localities good water is obtained from layers of sand in the soapstone or shale, but in others it is claimed by drillers that if no water is struck before the soapstone is reached, none will be found.

The region along the crest of Alta Ridge is one in which few wells of large capacity and good quality have been obtained. The collecting ground is not extensive, and thick deposits of water-bearing sand or gravel rarely occur in the blue clay of either the drift or the shale in the 200 to 250 feet that have been penetrated. Along the foot of the steeper sloping sides of the ridge abundant supplies of water are obtained in shallow wells. The ridge itself is a preglacial hill, probably of Pierre shale, with its crest 200 feet higher than the plain 10 miles to the east about Tower City and nearly 300 feet higher than the bottom of the Sheyenne Valley 6 miles to the west. The conditions therefore seem to be unfavorable for shallow tubular wells in this region, and it is necessary to bore for the deeper artesian waters.

the surface in pounds by 2.3 (the height in feet of a column of water 1 inch square weighing 1 pound) and adding the result to the altitude of the land. By this means it is found that the head is 1632 feet at Jamestown, 1350 to 1500 feet at Valley City, and 1300 feet at Tower, which indicates a gradual decline to the east. This diminution is due to the fact that the water enters the porous beds in highlands far to the west, passes underground beneath this region, and leaks out under the surficial deposits in Red River valley.

In all parts of the region the head increases with the depth, that is, lower flows have progressively greater pressures. This is clearly illustrated at Valley City, 1200 feet above sea level, where the 850-foot and 892-foot wells have pressures of 55 to 64 pounds, indicating a head of about 1350 feet, while an 1150-foot well developed 120 pounds pressure, indicating a head of 1500 feet. The smaller head indicates that no flow is available from the upper part of the sandstone in the highlands adjoining Valley City. Accordingly, a well on land about 180 feet higher 2 miles northeast of Valley City had to be sunk 1250 feet to reach a flow which has about 8 pounds pressure, corresponding to a head of 1400 feet. An 1160-foot boring on slightly higher land in sec. 4, T. 140 N., R. 57 W., has water which rises within 60 feet of the surface, indicating a head of 1360 feet. Doubtless a deeper boring would reach a water-bearing stratum with greater head—probably sufficient to afford a flow.

PRESSURE.

All pressures so far reported are given in the list of artesian wells, which shows that they vary greatly from place to place. The pressure is a direct manifestation of head. At a given locality, as explained above, the pressure increases with depth of well and diminishes with height of land. For instance, in a district where the head is 1400 feet, a well on land 1300 feet above sea level would show a pressure of about 43 pounds, whereas in a well reaching the same stratum from land 100 feet higher—that is, with an altitude of 1400 feet—the water would rise just to the surface, with no pressure or flow. Leaks in casings either underground or at the surface cause variation in observed pressure or flows from wells. Pressures often are not measured by accurate gages, and at some wells they are read too soon to show maximum amounts. Where a well has a weak flow, considerable time must elapse after the well is closed before the ultimate pressure is shown by the gage.

in parts per million: Calcium (Ca), 58; magnesium (Mg), 15; sodium and potassium (Na + K), 670; bicarbonate radicle (HCO_3), 250; sulphate radicle (SO_4), 1098; chlorine (Cl), 222.

FLOW AREA.

The area of artesian flow is limited on the west by the high slopes extending along the western margin of the district. To judge by the head of the flow at Jamestown (1632 feet) and of the well 2 miles northeast of Floyd (1670 feet), after making allowance for the slight rise in head toward the west, the limiting altitude is slightly above the 1720-foot contour line. Accordingly, it is so shown on the Jamestown artesian water map. This is based on the deepest flow known, which at Jamestown is at the bottom of the water-bearing sandstones.

Alta Ridge reaches an altitude of 1500 feet on either side of the railroad and is too high to obtain the first and second flows that are available in wells in the adjoining regions. This has been demonstrated by several wells which reach the water-bearing sandstones and obtain a supply that rises nearly to the surface, but does not overflow. Probably by boring deeper the wells would reach the stratum showing the 1500-foot head in the deep well at Valley City and obtain a surface flow. The area in which this condition exists is shown by a special pattern on the Tower artesian water map. The table-lands at altitudes of 1350 to 1500 feet for some distance west of Valley City are too high to obtain flows from the upper and middle water strata, which have a head of only 1350 feet at Valley City, but no doubt could obtain flows from the deeper stratum. The regular rise of the head to the west probably is such that the line of 1500-foot head runs a short distance east of Eckelson, and as most of the land in this zone is less than 1500 feet in altitude, flows may be expected at moderate depths from this locality westward.

FIRST AND SECOND FLOWS.

The water-bearing sandstones appear to lie in widely extended sheets separated by deposits of shale or clay. The first or highest sandstone yields the water known as the first flow, and the next yields the second flow. Still lower beds yield a third flow in most places. Owing to variations in the thickness of the shale there is considerable local difference in the interval between the first and second flows, but ordinarily 100 to 120 feet is the amount, and at Valley City the lowest flow is

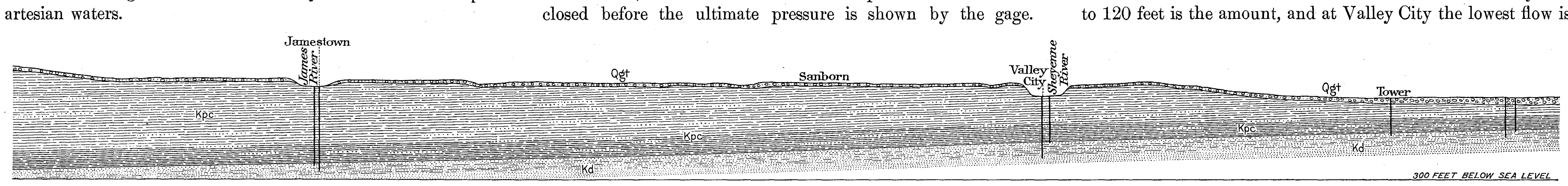

FIGURE 6.—Section across the Jamestown, Eckelson, and Tower quadrangles, near the line of the Northern Pacific Railway, showing the westward dip of the strata and wells penetrating to the Cretaceous sandstones.
Horizontal scale, 1 inch = 5 miles approximately. Vertical scale, 1 inch = 2000 feet.
Kd, Dakota and associated water-bearing sandstones; Kpc, Pierre and Colorado shales with sandstone layers and concretions; Qgt, glacial till.

Tubular wells ranging in depth from 150 to 200 feet have been put down in a wide area in the Eckelson quadrangle, but they have not been altogether successful. On this account many of the deeper artesian wells have been sunk.

In the northern and western portions of the Jamestown quadrangle shallow wells do not furnish a sufficient supply for farm and household purposes, so that tubular wells have been bored. These range from 100 to 300 feet in depth, and many of them yield only a small water supply, under so light a pressure that the cost of pumping is considerable. At many ranches in this region the supply is obtained wholly or in part from springs that break out in the deep coulées on the eastern slope of the Missouri Plateau.

ARTESIAN WELLS.

The entire area of the Jamestown-Tower district is underlain by sandstone which contains a great volume of water under considerable pressure. This sandstone, which averages 300 feet or more in thickness, is overlain by a thick body of shale and dips gently toward the west. (See fig. 6.) The depth to the sandstone, as shown on the artesian water maps, is about 500 feet at the eastern margin of the district. Owing to the westward dip and the rise of the land in the same direction, the depth gradually increases to 1300 feet near James River and to more than 1800 feet along the western margin of the district. The head or pressure of the water is sufficient to afford flows in all of the region except on the high plateau along the western margin of the district and possibly on part of Alta Ridge east of Valley City. The limits of the flow area are shown on the artesian water maps. Many wells ranging in depth from 500 to 1570 feet have been sunk, and nearly all obtained a flow of 20 to 300 gallons a minute, depending on the size of casing and local pressure. A list of the wells from which reports were obtained is given on page 10.

HEAD.

The head of artesian water is the height to which it will rise, and it is usually expressed in figures of elevation above sea level. The head is calculated by multiplying the pressure at

Some of the pressures given in the table are inaccurate estimates. The highest amount reported is 150 pounds at Enderlin, which is probably erroneous. The deep well at Jamestown showed 115 pounds. Many wells in lower lands, especially those drawing from the second flow, have pressures of 35 to 60 pounds, while those in higher lands or drawing from the first flow show pressures considerably less. The shallower wells at Valley City, as above noted, have pressures of 55 to 64 pounds; the 1150-foot well to the deeper flow has one of 120 pounds.

POWER.

The artesian pressure might be utilized extensively for power, as in South Dakota, where it runs electric-light plants, flouring mills, pumps, and other machinery. In this district, however, it is used for power only in the shops of Davidson Brothers, at Valley City, where a 4-inch well with a pressure of 60 pounds develops 4 to 5 horsepower. It is suggested that the power of artesian wells might be utilized for pumping water from Sheyenne River for irrigation of the lower slopes and bottom lands bordering that stream.

CHARACTER OF THE WATER.

Most of the water from the deep artesian wells is slightly salty, but in general it is suitable for domestic purposes as well as for stock and other farm uses. It has not yet been demonstrated that these waters can be used successfully for irrigation; the water from some wells applied to gardens and lawns has given good results, but the water from others has been observed to be disadvantageous to vegetation in places where the drainage was not free.

It is found that the water from the first flows is mostly soft and slightly salty, but locally it contains a slight tinge of iron. The second-flow water is generally somewhat hard. The water from an 1140-foot well at Valley City is hard and salty. According to J. A. Dodge, the Jamestown well contains, in parts per million: Calcium (Ca), 148; magnesium (Mg), 31; sodium and potassium (Na + K), 514; bicarbonate radicle (HCO_3), 229; sulphate radicle (SO_4), 1069; chlorine (Cl), 224. According to E. G. Smith, the well at the asylum near Jamestown contains

300 feet below the first flow. As explained above, the lower flows have a higher head or pressure, and accordingly in some areas which are too elevated for flows from the first water-bearing sandstone, the wells are sunk to the second or deeper horizon. Often in such places no attention is given to the first sandstone, and the water which comes to the surface is called the first flow, although it is from the bed yielding the second flow on lower lands. In many places also the upper bed of sandstone does not yield a flow of satisfactory volume and the well is sunk deeper to the second flow.

Unfortunately, in most areas the water of the lower flows is so hard or high in mineral content as to be unsatisfactory for domestic use. The first Jamestown well, 3½ inches in diameter and 1476 feet deep, yielded a 460-gallon flow from sandstone beginning at a depth of 1458 feet. The pressure was 115 pounds. A small first flow was found in sandstone from 1385 to 1395 feet. A deeper boring to 1570 feet found a salty first flow at 1305 feet, a soft second flow at 1426 to 1445 feet, below a hard cap rock, and a very small additional flow at 1460 feet. From 1460 to 1570 feet no more water was obtained. The asylum well, on the plain 2 miles southeast of Jamestown and 83 feet higher, was sunk 1524 feet, finally penetrating 19 feet into limestone. It found only a 4-gallon flow under 48 pounds pressure (70 pounds according to another report) in sand rock extending from 1481 to 1505 feet. Water probably occurred in some quicksand above, but was not under sufficient head to afford a flow on the high land.

VOLUME.

While the volume of the artesian water appears to be very great, and no diminution is yet noticeable, it is most important that the water should not be wasted. The number of wells is rapidly increasing and if water is allowed to run from so many outlets the final result will be a great depletion of the supply, possibly not in a few years, but surely in time to come. Several large wells near together about Valley City appear to have decreased the head somewhat, and this means diminished volume. Often, however, when wells appear to be failing, it is due to faulty construction, sand filling, or corrosion of the casing.

Representative artesian wells in Jamestown-Tower district.

TOWER QUADRANGLE.

Location.				Depth (feet).	Pressure (pounds).	Flow (gallons per minute).	Remarks.
Quarter.	Section.	Township N.	Range W.				
SW	34	141	54	614	20	25	
SW	25	141	55	645	40	30	
Buffalo		140	54	743	50	55	
SE	19	140	54	628	18	40	
Tower		140	55	716	53	25	Claynearly to bottom
SE	13	140	55	606			
SW	16	140	56	860	40	30	
SE	20	140	56	873	35	40	
SW	33	140	56	830	35	25	Reported 730 feet deep.
SE	30	140	56	890	35–40	25	
NE	4	140	57	1160		0	Water to —60 feet, pumped.
NE	12	140	57	1120	20	25	
NE	35	140	57	1196	8+	8	First flow at 900 feet; rather salty.
SW	14	140	58	1250	10±	7	Diameter 2 inches to 1 inch.
Valley City.		140	58	875	40–50	38	Soft salty water; diameter 2 inches.
NE	6	139	54	678	18	12	
NW	18	139	54	606	11	11	
SW	20	139	54	536			
NE	21	139	54	425			
NE	1	139	55	597	30	35	
SW	34	139	55	560			Another flow at 545 feet.
NW	22	139	55	630	40	32	
SW	23	139	55	587	15	18	
NE	12	139	57	1020	15+	20	Flow began at 950 feet.
SW	20	139	57	1300	0		Second sand, water rises to —30 feet. Water at 1100 feet; main supply at 1200 feet; diameter 2 inches.
SW	31	138	54	577	35	Many.	Diameter 1 inch.
SW	4	138	55	660		Many.	
NE	19	138	56	950	25	60	
NW	25	138	57	985	20	60	
NE	27	138	57	950	20	60	
SW	21	138	57	955	20	30	
NW	29	138	57	1050	15	3	
NW	30	138	57	1015	16	5	
SW	12	138	58	970	14	25	
NE	12	138	58	1000	None.		No flow.
NW	24	138	58	1050	60	85	
NW	5	137	54	500		Many.	Diameter 2 inches.
SW	4	137	54	500		Many.	
NE	8	137	54	513		Many.	
SE	32	137	54	515		Many.	
NE	2	137	53	514	50	Many.	Diameter 1½ inches.
SW	1	137	56	950		Many.	Diameter 1¼ inches.
SW	3	137	56	900	65	25	Mineral water, soft; diameter 1¼ inches.
NE	11	137	56	750		Many.	Stopped flowing.
NE	17	137	56	772		3	Soft salty water; diameter ¾ inch.
SE	17	137	56	800–900			
SE	13	137	56	800–900			
NE	12	137	57	800–900			
SW	2	137	57	980	Strong.	Many.	Diameter 1¼ inches.
NW	12	137	57	985	Good.	Many.	First flow at 895 feet; slightly salty.
NE	12	137	57	835	60	Many.	First flow at 700 feet; slightly salty; diameter 1¼ inches.
Nome		137	57	888	60		
Enderlin		136	55	700	150	Many.	Diameter 2 inches.
Enderlin		136	55	640	150	Stopped.	
Enderlin		136	55	660		Stopped.	
SE	8	136	55	700	100	Many.	Diameter 1¼ inches.
	14	136	56	800–900			
SW	22	136	56	870	75	Many.	Diameter 1½ inches.
SW	28	136	57	889	50	3	First flow, good water; diameter 1¼ inches.
SE	29	136	57	922		8	Slightly salty; diameter 1½ inches.
SW	28	136	57	1066			
NE	22	136	57	800	85	Many.	Diameter 1½ inches.
SE	21	136	57	1120	40	50	First flow at 1000 feet; soft water, not salty.
SW	16	136	57	950		30	Slightly salty.
	33	136	57	800–900			
NW	16	136	57	800–900			
NW	10	136	57	1100		Many.	Flow also at 800 feet; slightly salty; diameter 1½ inches.
SW	24	136	57	850		7	
NW	14	136	57	835		Many.	Slightly salty.
SW	21	136	58	900±	65–100		
NE	8	135	55	730		Many.	
NE	15	135	55	600±		Many.	
NE	5	135	56	850			
NE	7	135	57	880	25±	12	Flow at 860 feet.
NE	5	135	57	850		Many.	
SW	14	135	57	945		Many.	Principal flow at 900 feet; second flow.
SE	1	135	58	900		40	Diameter 1¼ inches.
NE	1	135	58	900		3	
SW	2	135	58	1070		Many.	
SW	14	135	58	855		Many.	

Representative artesian wells in Jamestown-Tower district—Continued.

ECKELSON QUADRANGLE.

Location.				Depth (feet).	Pressurse (pounds).	Flow (gallons per minute).	Remarks.
Quarter.	Seation.	Township N.	Range W.				
Valley City.		140	58	1150	120	225	Hard and salty.
Valley City.		140	58	992	55–60	350	Soft and salty; diameter 4½ inches; flow from 875 feet.
Valley City.		140	58	900	64	250	Soft and salty; diameter 2 inches; flow from 850 feet.
SE	28	138	58	912	20–25	20	Diameter 2 inches.
SW	24	138	62	1380	80	60	Second flow.
SE	32	137	59	1150		9	Slightly salty water.
NE	26	137	59	1020	15	30	
NW	32	137	59	1195			Diameter 1 inch.
Litchville		137	60	1160	65		Diameter 3 inches.
NW	19	136	58	950			
NW	30	136	58	940			
	3	136	59	990			
NE	26	136	59	975	50	10	Soft, slightly salty water; diameter 1¼ inches; flow at 150 feet.
NW	30	136	59	1075	75		
SW	2	136	60	1090	60		
NW	10	136	60	1085	60		
SW	24	136	60	1075			
SW	14	136	60	1080	60		
SE	11	136	60	1085			Flow at 1060 feet also.
NW	26	136	60	965			
	32	136	61	1160	Many.	45	Soft, slightly salty water.
SE	30	136	61	1150±	65±		
NE	24	136	62	1200	65	Many.	Salty water.
SW	18	135	59	1012	60	Many.	Soft water, slightly salty.
NE	3	135	59	995	75	40	Soft water, slightly salty; diameter 2 inches.
SE	10	135	59	1018	75	12	Salty water.
	2	135	59	990	75		
SE	5	135	61	1150±	65±		
NE	2	135	61	1060		35	Salty water.
SW	3	135	62	1100±	75	Many.	
NE	9	135	62	1100±			

JAMESTOWN QUADRANGLE.

Jamestown.				1476	115	460	Main flow begins at 1458 feet.
Jamestown.				1570			No flow below 1460 feet; main flow 1426–1445 feet.
Asylum		139	63	1542	48	177	Flow at 1520 feet.
SW	1	138	63	1460	60	40	
NW	9	138	63	1360	60	40	Diameter 2 inches; flow at 1343 feet.
SW	6	136	62	1224		21	First flow at 1125 feet; diameter 1½ inches; medium water.
SE	12	136	63	1300	0	Few.	
NW	7	136	64	1435		16	Gas also; diameter 1½ inches.
SE	22	136	63	1284			Much gas.
NW	20	136	64	1337	60	Many.	Much gas; diameter 1½ inches.
SW	18	135	62	1200±	Many.	Many.	

SOILS.

GEOLOGIC RELATIONS.

The soils of these quadrangles are such as have been formed, either directly or indirectly, by the action of the great ice sheet. The soil types in the different parts of the area conform to the geologic conditions under which they have originated, and the proper study of their geologic character is therefore most important and fundamental for the development of the crop resources of the region.

The soils may be conveniently grouped into three classes—(*a*) those that have resulted from materials deposited directly by the melting ice of the great continental glacier; these include the characteristic soils of the morainic areas, recessional deposits, or kame hills, and also the soils of the rolling prairie, or ground moraine, which are usually silt loams resulting from the grinding processes of the great ice mass; (*b*) those deposited by waters from the melting ice sheet, either in running streams or in still bodies of water such as lakes; and (*c*) those derived directly from the disintegration of the shales exposed at the surface.

DRIFT SOILS.

The soils of this group, as already indicated, are of three general types. Those on the morainic deposits are not uncommonly rather stony, though bowlders large enough in size or abundant enough in quantity to render the land unprofitable for cultivation are rare. Owing to their position and looseness of texture the higher portions of the morainic lands are so drained of their finer material by rain wash as to be less valuable for agricultural purposes. Most of the morainic hills, however, are capable of cultivation, being in this respect in marked contrast with the earlier moraines in some sections to the west.

In the higher portions of the morainic tracts are the ever-present sloughs or small lakes. Though the topography of the district is morainic, it is not in general strongly so, and the waste land due to small lakes and sloughs is not nearly as great in amount as in many other morainic regions in the State. Many valuable hay meadows and pasture lands are to be found on the bottoms of these depressions.

The hills which have been referred to as kames play an important rôle in the classification of the soils. In the localities where these deposits occur the soil is generally a sandy loam varying to a gravelly loam. The subsoil is also usually sandy or gravelly, consisting as a rule of definitely stratified sand and gravel with an admixture of clay. The soils of these ground swells are therefore light in character and not the most suitable for crop production. These hills furnish the finest places for building sites, owing to the excellent sanitary conditions that are provided by nature. Water of good quality and abundant quantity is obtained from wells on many of these hills where a few rods away, on the surrounding lowlands, only water of poor quality, alkaline in character and small in amount, can be had.

The soil varying from silt loam to sandy loam covers the greater part of the district, being the surface portion of the glacial deposit which forms the generally nearly level or undulating land surface. The character of this soil is determined by the character of the drift from which it is derived, and the character of the drift is determined by the kinds of rock that the great ice sheet passed over. The rock beneath the drift in this region and in the adjacent region to the north is shale, which disintegrates into clay, and the soil is therefore somewhat clayey in character. The silt has been derived from the grinding to powder of the hard rocks which were carried by the great ice mass.

ALLUVIAL AND LACUSTRINE SOILS.

Stream deposits in these quadrangles are mostly represented by materials that were transported by the running waters of streams vastly greater than any that now exist. Modern stream deposits occur upon the low bottom lands of the Sheyenne and James valleys, along the lower courses of the Maple, and in the channels of the larger tributaries of the James. The more extensive deposits of these streams were left by the glacial flood waters. River gravel, which may or may not be covered by finer alluvium, occurs in the bottoms, and gravelly terraces, the remains of ancient flood plains, mark the deposits of earlier stages of the rivers.

An important soil feature in the Sheyenne Valley is the material that has been carried in by lateral tributaries and distributed in the form of alluvial fans, or washed down the sides of the valley and spread out in broad aprons bordering the valley sides. Nearly all the tributaries that enter the Sheyenne from the east are short, few of them extending more than 1 to 2 miles from the main valley; their sides and bottoms are, however, generally steep. Many of these side coulées are eroded into the shale which underlies the drift, but drift has usually fallen upon the slopes of the tributary streams and of the main valley, so that the hillsides have in many places much the appearance of drift hills, and the soils have somewhat the nature of drift soils.

In the southeastern portion of the district parts of Casey, Shenford, Sheldon, and Highland townships are included in the area covered by the waters of glacial Lake Agassiz and the delta of Sheyenne River. This delta has been described elsewhere (see p. 5), and need be referred to here only in reference to the character of the soils making up its surface. The delta, being a deposit from the glacial Sheyenne River, is composed in considerable part of drift materials assorted and arranged by the waters of the lake. Its soil is loose in texture, and in places is of sufficiently sandy character to be blown by the wind into dunes. Only a small portion of the silt-covered area of glacial Lake Agassiz falls within the district, in Eldred and Highland townships.

DISINTEGRATED SHALE.

In a considerable portion of the Sheyenne Valley from Valley City southward to Oakville the shale is not covered with a mantle of drift. The soil is therefore that formed from the disintegration of the shale. It is a compact and heavy soil, and is subject to cracking into prismatic blocks during the dry season of summer. This type of soil, classified by the United States Department of Agriculture as Hobart clay, is very similar to that locally known in the Red River valley as gumbo and classified by the United States Department of Agriculture as Fargo clay. This shale is the source from which it is thought the Fargo clay was originally derived.

February, 1909.