DESCRIPTION OF THE MITCHELL QUADRANGLE.

By J. E. Todd.

GEOGRAPHY.

General relations.—Eastern South Dakota is in the Great Plains province, in the broad, indefinite zone wherein these plains merge into the prairies of the Mississippi Valley. It is comprised within the area of glaciation, and most of its surface features show the characteristics of a drift-covered region. The country is mainly level, or presents low rolling slopes rising out of broad expanses of plains. The principal elements of relief are long ranges of low hills, due to morainal accumulations left by the ice along lines marking various pauses of glacial advance and retreat. Further diversity of topography has been produced by the excavation of the valleys, especially that of the Missouri, which has cut a trench several hundred feet deep, mostly with steeply sloping sides. Between the moraines there are rolling plains of till and very level plains due to the filling up of glacial lakes. Upper James River Valley presents a notable example of this lake-bed topography.

Location.—The Mitchell quadrangle embraces the quarter of a square degree which lies between parallels 43° 30′ and 44° north latitude and meridians 98° and 98° 30′ west longitude. It measures approximately 35 miles from north to south and 25⅛ miles from east to west, covering about 863 square miles. It includes portions of Davison, Aurora, Sanborn, and Jerauld counties, S. Dak., and lies almost entirely in James River Valley.

Topography.—The general surface of the quadrangle is a nearly smooth plain that slopes northeastward and is broken only by the beds of streams, which have banks of moderate height. The highest elevation is in the central part of T. 101 N., R. 63 W., where the altitude is 1680 feet above sea level. The lowest elevation, 1220 feet, is in the James River bottom, in T. 104, R. 60.

Extending across the quadrangle from the northwest corner to the southeast is a morainal belt whose western border coincides with the upper portion of Firesteel Creek and the upper course of Enemy Creek and continues southeastward along an old stream channel past the center of T. 101, R. 60. The eastern border of this belt is less definitely marked, but corresponds to a line that begins where the western boundary of Sanborn County enters the quadrangle, and extends southeastward past Mitchell. This morainal belt consists largely of short, low ridges trending southeastward and rarely rising more than 15 feet above the surface. The general belt is from 6 to 8 miles wide, and may be separated into three or four divisions with more level areas between. It is traversed by numerous old, flat-bottomed channels, which become especially noticeable toward the south.

The country lying southwest of the moraine has a smooth surface except in Aurora and Truro townships, where the land rises to the south and breaks off sharply into the head of Lake Andes Creek. Toward the northeast is an almost level plain, trenched at intervals by the larger streams. In an area comprising several square miles lying north of Letcher there are a number of lake beds, some of the depressions having a depth of 10 to 15 feet.

The whole surface of the quadrangle is, naturally, covered with grass only, except in the immediate vicinity of James River and at a few points along Firesteel Creek, where groves of stunted cottonwood, maple, ash, and elm are found. The grasses are usually short except in the alluvial flats along the streams and waterways and in the more important lake beds.

Drainage.—The drainage of the area has been greatly influenced by an ice sheet which occupied it in Pleistocene time, as will be more fully explained in a later portion of this text.

The principal stream is James River, which, however, has only about 10 miles of its course in this quadrangle. It crosses the northeast corner, and reenters the quadrangle in a short curve a few miles north of Mitchell. Its trench is about 100 feet deep, and has abrupt sides and an alluvial bottom about half a mile wide. James River drains the whole quadrangle with the exception of a small area in the southwest corner, which is tributary to Lake Andes Creek.

Of the tributaries of James River, Firesteel Creek is the principal one, and the only one that contains running water the year round. This, however, is found only for a few miles of its course. The stream enters the quadrangle near the northwest corner and flows southward, swerving gradually to the east and dividing into two or three channels, which reunite when it turns more directly eastward and passes north of Mitchell. Its trough has abrupt sides, but varies greatly in depth, being not more than 30 feet deep toward the north, and nearly 100 feet at the southeast, near Mitchell. It also varies much in breadth, owing to difference in the hardness of the underlying rock at different points.

Enemy Creek rises in a southeastward-trending valley that starts from the eastern bend of Firesteel Creek near the middle of T. 104, R. 63, and keeps a southeasterly direction to the middle of the western boundary of Lisbon Township (T. 102, R. 61). Here the stream turns nearly due east, abandoning its old valley, and after a crooked course leaves the quadrangle about 4 miles south of Mitchell. Considered as a whole the valley of Enemy Creek is strikingly anomalous. In some places it has a depth of 50 to 60 feet and a breadth of a quarter of a mile; in other places it flows through open meadows, where its banks are only a few feet high. This stream receives short tributaries from the west, mainly from a network of deep valleys in Lisbon Township. The valleys of these tributaries have abrupt sides, and are in fact channels cut into the chalk by streams of an earlier period. Their courses were determined by the position and movement of the ice sheet, as will be explained later.

Two branches of Twelvemile Creek traverse Tobin and Rome townships in an easterly direction, and a third, having the same direction, lies near the south line of Rome Township. The valleys of these streams are connected with one another and with Enemy Creek by shallow cols marking cross channels having a southeasterly course.

Morris Run, or Dry Creek, is a dry valley which starts northwest of Letcher, turns first southwest and then southeast, and keeps quite closely a southeastward course for 12 or 15 miles, when it leaves the quadrangle a short distance before it enters James River. This channel has no running or standing water except in spring or after a severe storm. Its trough rivals that of Firesteel Creek in size, especially in its lower course.

Most of Aurora Township (T. 101, R. 63), Truro Township, and the southwest corner of Baker Township are drained southward by streams occupying numerous deep ravines and valleys and emptying into Lake Andes Creek, which empties into Lake Andes, in Charles Mix County.

GENERAL GEOLOGY.

The surface of eastern South Dakota is in large part covered with a mantle of glacial deposits, consisting of gravel, sand, silt, and clay, of varying thickness, which is described under the heading "Pleistocene system."

The underlying formations of eastern South Dakota are seldom exposed east of Missouri River, though they outcrop in a few of the hills where the drift is thin, and some of the streams afford natural exposures. The numerous deep wells throughout the region have, however, furnished much information as to the underground structure. They show that extensive sheets of clays and sandstones of Cretaceous age here lie on an irregular floor of quartzite and granite of Algonkian and possibly Archean age. Under most of the region this floor of old rocks lies more than a thousand feet deep, but it gradually rises to the surface northeastward. There is also an underground quartzite ridge, of considerable prominence, that extends southwestward from outcrops in southwestern Minnesota to the vicinity of Mitchell, S. Dak.

Next to the quartzite the lowest sedimentary formation is a succession of sandstones and shales termed the Dakota formation, which underlies the greater part of the area and furnishes large volumes of water to thousands of wells. It reaches a thickness of 300 feet or more in portions of the region, but thins out and does not continue over the underground ridge above referred to. It is overlain by several hundred feet of Benton shales, with thin sandstone and limestone layers, and a widely extended sheet of Niobrara formation, consisting largely of chalkstone toward the south and merging into limy clays northward. These formations rise in an anticlinal arch of considerable prominence where they appear at the surface along the underground ridge of quartzite, but they dip away to the north and west and lie several hundred feet deep in the north-central portion of the State. In the Missouri Valley they rise gradually to the southeast and reach the surface in succession, the Dakota sandstone finally outcropping in the vicinity of Sioux City, Iowa, and southward. Above the Niobrara is the Pierre shale, which extends in a thick mantle into eastern South Dakota, lying immediately under the drift in the greater portion of the region, except in the vicinity of the higher portions of the anticlinal uplift above referred to. Doubtless it was once continuous over the entire area, but was extensively removed by erosion prior to the Glacial epoch. Probably the Fox Hills and Laramie formations once extended east of Missouri River, but they also have suffered widespread erosion and only a few traces now remain in the extreme northern portion of the State. Tertiary deposits also appear to have been laid down over part of the region, and are represented by small remnants in the Bijou Hills and other higher ridges.

The surface of the Mitchell quadrangle is covered with drift deposits except in the vicinity of streams, where the older rocks appear much more frequently than is common elsewhere in James River Valley. The general position of the older rocks is nearly horizontal. They are all sedimentary, no metamorphic or igneous rocks being found on the surface except in the form of bowlders in the drift.

ALGONKIAN SYSTEM.

Granite.—The oldest formation known in the quadrangle is a dark-gray granite, which was struck at a depth of 500 feet in a well in the SW. ¼ of sec. 25, T. 103, R. 61. It probably underlies the Sioux quartzite in other portions of the region, which would indicate Archean age, but it may possibly be an eruptive rock, similar in relation to that which has been exposed near Corson, S. Dak. In the well at Mitchell no granite was struck, although the quartzite was penetrated more than 300 feet.

Sioux quartzite.—Next to the deeply buried granite, the oldest formation known in the region is a very hard, dark-purple or red quartzite, popularly known as the "Sioux Falls granite" or "jasper." It is an extremely compact stone, composed almost wholly of quartz grains, originally fragmental, but now entirely cemented by the deposition of silica between the grains and the secondary growth of the crystalline fragments. The rock is nowhere exposed within the quadrangle, but has been struck in wells at several points, and outcrops a short distance to the east. In these exposures it shows well-pronounced joints running northwest. Along James River the rock dips about 4° to the southeast.

The Sioux quartzite has an important relation to the formations outcropping within the quadrangle, for it is the rock on which they rest. It is also of considerable importance in connection with the water supply, since it is the lower limiting horizon of the deep waters of the region.

The configuration of the surface of this rock within the quadrangle is represented by contours on the Artesian Water sheet. From these contours it will be seen that its surface is irregular, presenting knobs or hills with sharp valleys between. The localities at which it has been struck are comparatively few, and for the greater part of the area the contours are hypothetical, but in drawing them due consideration has been given to the thickness of the overlying strata as shown in wells. These strata abut against the quartzite to a considerable extent, but in places they rise and overlap it, as has been definitely observed in exposures in adjacent areas. Further deep drilling may show that some of the contours are not properly placed, but it is believed that the larger outlines are correctly represented. Some uncertainty as to the details of the contours is due to difficulty in distinguishing the quartzite from concretions of iron pyrites, which have a similar hardness and are sometimes found in masses which similarly resist the drill. These masses are not infrequent in the shales that are penetrated in drilling wells, and in some places efforts to obtain water have been abandoned when these concretions were encountered, on the supposition that the quartzite had been reached. Near such wells other borings have penetrated to greater depths without meeting the hard bed, which would indicate the absence of the quartzite in the first instance and the existence of a local mass of pyrites, for these concretions do not have any considerable horizontal extent. Ordinarily samples of the boring clearly indicate the nature of the rock, and true quartzite has been obtained in several places near Mitchell. In the northern portion of the quadrangle no data showing the position of the quartzite have been obtained, and the contours are here drawn hypothetically. Determination of the areal extent of the quartzite is also rendered difficult by the fact that in some localities the rock, which is generally extremely hard quartzite, appears to give place to sandstone; hence it is possible that in a few of the deeper wells the horizon of quartzite has been reached without being recognized.

The quartzite rises in a ridge of considerable prominence, buried under later sediments, beneath the level surface of James River Valley. This old ridge presents many irregularities of form, but their details can be ascertained only in the most general way, so that it is impossible to foretell with much definiteness the depth to this rock at any particular spot. The map gives only the general outlines, and local variations of 100 feet, either more or less, are probable. The deep valley represented in the quartzite south and east of Mitchell is indicated by numerous observations. There is little doubt that this valley was eroded by a stream in pre-Cretaceous time. On its northwest side, near Mitchell, the rock is struck at a depth of about 250 feet, and different borings outline the general position of the valley to the east. A well at the Mitchell waterworks went down about 560 feet before striking quartzite, and another, 4 miles southwest, went 500 feet, as is indicated on the map; hence the bottom of the ancient valley must be at least about 600 feet below the present surface, and it is so represented on the map. Doubt as to this interpretation arises from the possibility that the deeper borings mentioned may have penetrated a soft place in the quartzite. If such is the case the valley may not be so deep as is represented by 100 or 200 feet.

The quartzite in this general region appears to have been a land surface during all of Paleozoic time and much of Mesozoic time. It was subjected to erosion for a very long period, and in the eastern portion of South Dakota there is no trace of the Cambrian, Silurian, Devonian, or Carboniferous.

CRETACEOUS SYSTEM.

Eastern South Dakota is underlain by several formations of Cretaceous age, including the Dakota, Benton, Niobrara, and Pierre. Of these, only the Benton and Niobrara (Colorado group) are exposed at the surface in this quadrangle, though the Dakota is well known by means of well records. It is possible that the Lakota sandstone and Fuson shale, of the Lower Cretaceous, occur in connection with the Dakota of this area, but they have not so far been discriminated in the well records, and all the beds have been classified as Upper Cretaceous.

DAKOTA FORMATION.

The Dakota formation is the principal water-yielding horizon of the region, and supplies all of the more important artesian wells of North and South Dakota. Within this quadrangle it nowhere comes nearer the surface than about 200 feet. The sandstones outcropping at several points in the quadrangle and mapped as Dakota on the Areal Geology sheet have, since the completion of the map, been determined to be Benton, and hence belong to the Colorado group. Judging from well records, the Dakota consists of sand and sandstone ranging from 50 to 100 feet in thickness, interstratified with masses of clay or shale. Its water-bearing portions, as shown by records of wells bored throughout the eastern part of the State, is mostly a fine-grained gray sandstone.

The Dakota formation as exhibited in the rim of the Black Hills is usually a brown sandstone, hard and massive below, but thinner bedded above, having an average thickness of 100 feet. It varies from fine grained to coarse grained and usually is only moderately compact. In eastern South Dakota the formation lies on the quartzite, but in the Mitchell region it abuts against the higher portions of the quartzite ridge, on which the Benton shales and sandstones overlap. The Dakota terminates at this overlap in an old shore line, which presents considerable irregularity of outline and altitude, the latter due to local variations in amount of later uplift. From this old shore line along the quartzite ridge the Dakota sandstone slopes away in all directions. It is believed that this shore line is nearly intact, for probably there was but little erosion before the deposition of the Benton. The dip of the sandstone is more rapid near the quartzite ridge, and gradually diminishes away from it until the rock lies nearly horizontal. North of the quartzite ridge, on the north line of the quadrangle, it descends to an altitude of about 625 feet. South of the ridge the decline is more gentle, and the sandstone probably does not go below 800 feet above sea even in the southwest corner of the quadrangle. These relations are shown in the cross sections of figs. 1 and 2.

The shales of the Dakota resemble those of the overlying formations, and, like them, contain calcareous concretions which may be mistaken for limestone strata. Sometimes, also, there occur concretions of pyrites large enough to hinder the drilling. The different layers of sandstone are often harder near the top, and this has given rise to the expression "cap rock." Frequently the drill has to penetrate several feet of hard rock before the water-bearing strata are reached.

The Dakota sandstone is variable in thickness, but, as few borings have gone to its bottom, precise figures are available only for some limited areas. On the higher slopes of the underground quartzite ridge south of Mitchell it thins out entirely and the Benton beds overlap it. In the western portion of the quadrangle several borings penetrated the sandstone for 300 feet without reaching its bottom, but probably 350 feet is its maximum thickness. A well 2 miles southwest of Letcher penetrated Dakota beds from 400 to 863 feet beneath the surface without reaching their base. The material is mainly clay, but includes several sandstone layers with flowing water.

In Sanborn County many wells have reached the Dakota sandstone. The well at the mill at Woonsocket penetrated a solid sandstone mass belonging to this formation extending from 697 to 775 feet beneath the surface, without reaching the base of the formation. In Davison County the thicknesses are variable and diminish rapidly to nothing in an irregular area on the higher slopes of the underground ridge of Sioux quartzite lying south and southwest of Mitchell. In Mitchell Township the Dakota appears to extend from a depth of 445 feet to the quartzite at 540 feet, comprising 39 feet of sandstone at the top and 11 feet of sandstone at the base, separated by 45 feet of shale. In the Smith and Davison well, 4 miles southwest of Mitchell, in a valley in the buried quartzite ridge, the formation is represented by 40 feet of sandstone and 10 feet of shale lying on quartzite, the top of which is at a depth of 475 feet. At Ethan there are only 8 feet of sandstone on the quartzite, and this may be Benton. In the Lowrie well, northeast of Ethan, the formation appears to be 92 feet thick, lying on quartzite at a depth of 477 feet and consisting of a top member of sandstone about 30 feet thick and a lower series of shales. The formation thickens rapidly to the west and south. In the J. K. Johnson well, 3 miles due north of Mount Vernon, the section is as follows, the underlying "bed rock" not having been reached:

Partial section of Dakota formation north of Mount Vernon, S. Dak.

	Thickness in feet.	Depth in feet.
Sandstone	70	350
Shale	50	400
Sandstone	36	436
Shale	90	526
Sandstone	44	570

In eastern Aurora County several wells penetrate the formation 100 feet or more and find alternations of sandstone and shale. It is claimed that the well at Plankinton reached granite at 756 feet, and the overlying Dakota appears to comprise 218 feet of beds (538–756 feet), reported to consist largely of shale with several thin beds of sandstone.

In the Storla well, in the northeast corner of the county, beds apparently Dakota were struck at a depth of 457 to 760 feet, as follows:

Partial section of Dakota formation in Storla well, Aurora County, S. Dak.

	Thickness in feet.	Depth in feet.
Sandstone	13	470
Shale	63	533
Sandstone	2	535
Shale	30	565
Sandstone	10	575
Shale	45	620
Sandstone	10	630
Shale	110	740
Sandstone	20	760

In the Dougan well, 4 miles northeast of the Storla well, there were 23 feet of sandstone on 60 feet of shale lying on sandstone.

In the Bartow well, 3 miles northeast of Plankinton, the following beds are reported:

Partial section of Dakota formation in Bartow well, near Plankinton, S. Dak.

	Thickness in feet.	Depth in feet.
Sandstone	61	455–516
Shale	104	516–620
Sandstone	few	
Shale, etc.	133	
Sandstone	2	

In the Resley well, 4 miles southeast of Plankinton, the section is as given in the next table.

The Dakota formation is regarded as a fresh-water deposit for the reason that fossils rarely occur in it, and those that have been found are of fresh-water species. These abound near Sioux City, Iowa, and in Kansas and Nebraska. Fossil leaves

Partial section of Dakota formation in Resley well, near Plankinton, S. Dak.

	Thickness in feet.	Depth in feet.
Sandstone	5	610
?	20	630
Shale	45	675
Sandstone	30	705
Shale	11	716

of deciduous trees are reported from several wells not very remote from this region, and such leaves have been found in the sandstone near Sioux City.

COLORADO GROUP.

The Colorado group exhibits two quite distinct formations. The first or lower is called the Benton shale, so named because of its prominent development near Fort Benton, on the upper Missouri. In the southeast corner of the State it consists of lead-colored or dark-gray shale containing calcareous and ferruginous concretions. Where it is exposed along Missouri River it is estimated to have a thickness of about 200 feet, but it thins eastward. In the vicinity of the Black Hills the Benton is much thicker, and is divided into several different formations. It consists there largely of dark shale, but exhibits also layers of sandstone, sometimes of considerable thickness, and also a persistent layer of shaly limestone abounding in *Inoceramus labiatus*—features also prominent in the southeastern South Dakota region.

The second or upper member of the Colorado group is the Niobrara chalkstone, named from its prominence near the mouth of Niobrara River. It is usually of a drab color except where it has been weathered. It may then be snow-white, but is more commonly of a light straw color. It varies considerably in composition, often carrying a large proportion of clay. It is not always clearly distinguishable from the Benton shale below, owing to its variable composition. The purer chalk seems to be limited to lenses of large extent, merging into clay. In some exposures chalk may be found at one point and a few rods away its place may be taken by gray clay.

Benton formation.—In the area under consideration the Benton formation is somewhat unusual in character, since it includes a relatively larger amount of sandstone than is common to it elsewhere. The general section includes an upper and a lower shale bed, with thick sandstone between. The upper shale bed is occasionally absent, particularly in the northern portion of the quadrangle, and in the lower shale there is a second, thinner sandstone under at least a portion of the area.

The basal member of the Benton consists of 100 feet or more of gray and black shale, indistinguishable from similar deposits in other formations of the Cretaceous. The sandstone interbedded with it varies in thickness, becoming thicker in the vicinity of the quartzite ridge, against which it abuts near Mitchell. North and west of Letcher it apparently becomes very thin and is often overlooked by drillers. Nevertheless, when carefully looked for it can usually be found.

Above the basal shale comes a sandstone which for some time has been considered the top of the Dakota formation and is so indicated on the Areal Geology sheet. This appears at several points in rather prominent exposures. The most northern point where it appears on the surface is in the bottom of the trough of James River, in sec. 22, T. 104, R. 60. A mile or two farther south it is exposed at several points along Firesteel Creek, particularly near the point where the creek is crossed by the railroad north of Mitchell, and at another point as far west as sec. 36, T. 104, R. 62.

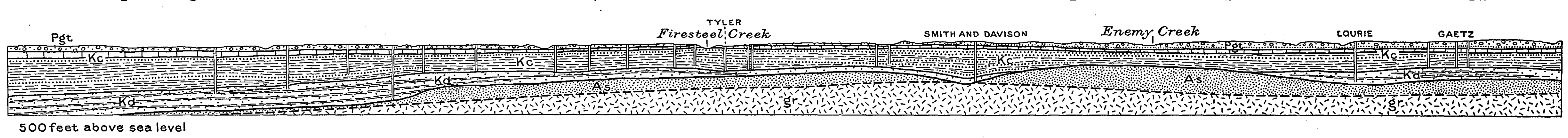

FIG. 1.—Sketch section across the Mitchell quadrangle along the line A–A on the Artesian Water sheet, showing the artesian wells in that vicinity extending to the Dakota water-bearing sandstone. gr, granite; As, Sioux quartzite; Kd, Dakota formation; Kc, Colorado group; Pgt, glacial till.
Horizontal scale: 1 inch=3 miles. Vertical scale: 1 inch=1500 feet.

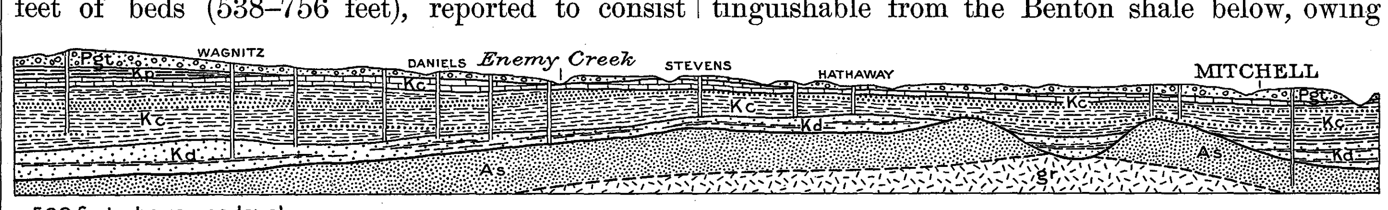

FIG. 2.—Sketch section across the Mitchell quadrangle along the line B–B on the Artesian Water sheet, showing the artesian wells in that vicinity extending to the Dakota water-bearing sandstone. gr, granite; As, Sioux quartzite; Kd, Dakota formation; Kc, Colorado group; Pgt, glacial till.
Horizontal scale: 1 inch=3 miles. Vertical scale: 1 inch=1500 feet.

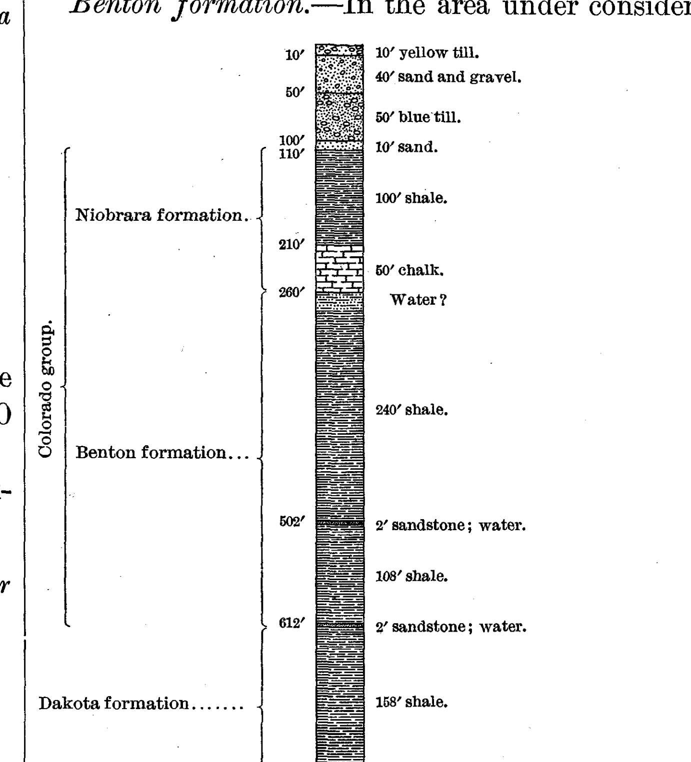

FIG. 3.—Section of Beug well, 1 mile north of Parsons, sec 25, T. 106, R. 64.

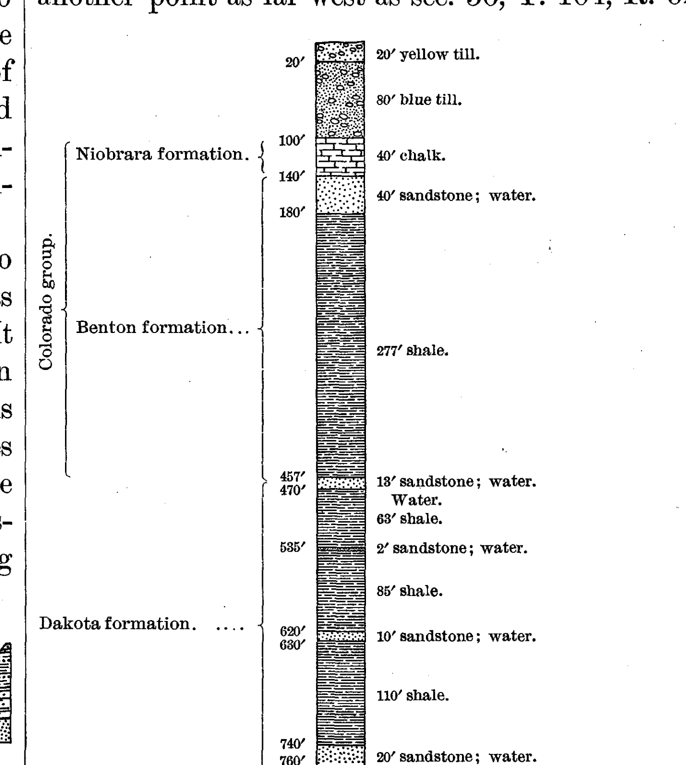

FIG. 4.—Section of well 2 miles southeast of Storla, sec. 35, T. 105, R. 63.

The outcrops near the railroad lie about 20 feet above the stream, or at an altitude of 1280 feet above sea level. The sandstone is exposed also along Enemy Creek south of Mitchell, and between that point and James River. It also forms low cliffs along James River below Rockport, rising 30 to 50 feet above the stream. This sandstone varies in thickness from 20 to 50 feet or more. It is a rusty-brown stone, usually hard and dark colored on the surface, but softer below. It varies much in character, in places being coarse and containing small pebbles, and at others being extremely fine grained. It frequently shows oblique lamination in strata 3 to 4 feet in thickness.

No fossils have been found in these outcrops except sharks' teeth, which in some places are very numerous. Traces of wood and leaves have also been found at a few points. Its upper surface is uneven, but this unevenness is not due merely to erosion; it seems rather to be caused by unequal deposition, and may indicate the occurrence of sand reefs. In the northern portion of the quadrangle this sandstone lies immediately beneath the chalk of the Niobrara, but toward the south an upper, clayey member appears between them and attains a thickness of 50 feet or more. This clay appears in several wells, but its only outcrop in the quadrangle is in sec. 36, T. 104, R. 62, where several feet of dark clay intervene between the chalkstone and the sandstone in an exposure on the south side of Firesteel Creek. Wells in that vicinity, and also those near and south of Plankinton, report a blackish clay which seems likely to correspond with the deposit.

The upper surface of the Benton rises to nearly 1300 feet in the vicinity of Mitchell, and north and south of Plankinton it rises higher than 1300 feet, judging from the reports of well drillers. Its thickness may be estimated to be 200 to 350 feet, an average being about 250 feet. Near and on the underground quartzite ridge north of Mitchell it thins somewhat, 150 feet being its average thickness across the crest of the ridge.

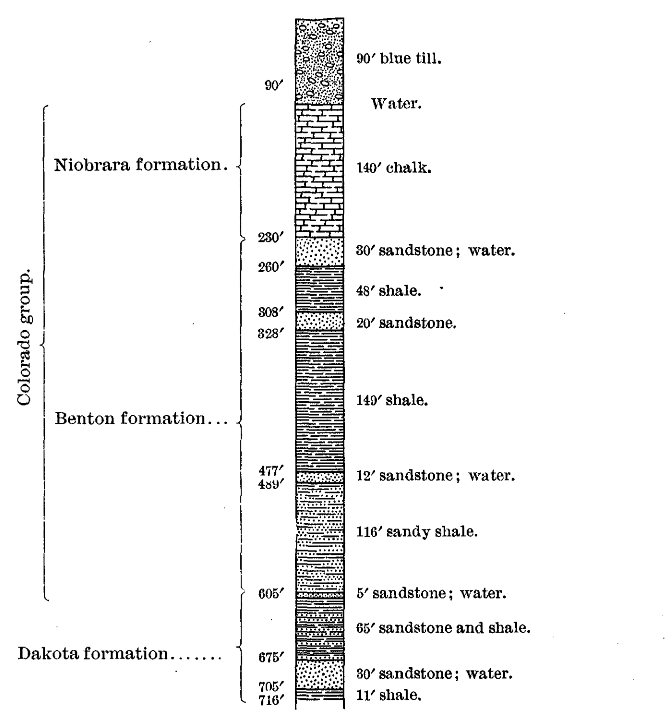

FIG. 5.—Section of Resley well, 4 miles south-of-east of Plankinton, sec. 28, T. 103, R. 63.

Besides the sharks' teeth and the traces of vegetation found in the sandstone, a stratum of fossiliferous limestone was discovered in a number of wells in the vicinity of Woonsocket. Though reported from several wells, our most definite knowledge comes from a well 2 miles north of that town. From a break in the pipe, which was afterwards proved to be 580 feet below the surface, fragments of a fossiliferous limestone were frequently thrown out from time to time. Some of these were submitted for examination to Dr. T. W. Stanton, of the United States Geological Survey, and he reports that at least three different species are represented, one of which is a small *Nucula* with striated surface, that may be the young of *N. cancellata* M. & H.; another is possibly a young *Mactra;* and the third, the most common form, is probably a *Lucina*. The specimens were too imperfect to permit more definite determination. They were found 250 feet below the chalkstone and about 100 feet above the the main water flow. These fossils are distinctly marine in character and indicate that this stratum is a part of the Benton. Other Benton fossils were found in the Ashmore and Farwell wells, in the Alexandria quadrangle.

From the black clay above the sandstone, north of Mount Vernon, a saurian vertebra about 4 inches long was obtained. A large characteristic fragment of *Prinotropis* is said to have been taken from a depth of several feet on the east side of James River 1½ miles north of Elmspring.

Niobrara formation. — As already stated, the most characteristic feature of this formation is the chalkstone, but no doubt considerable deposits of clay should be considered as included in it. As

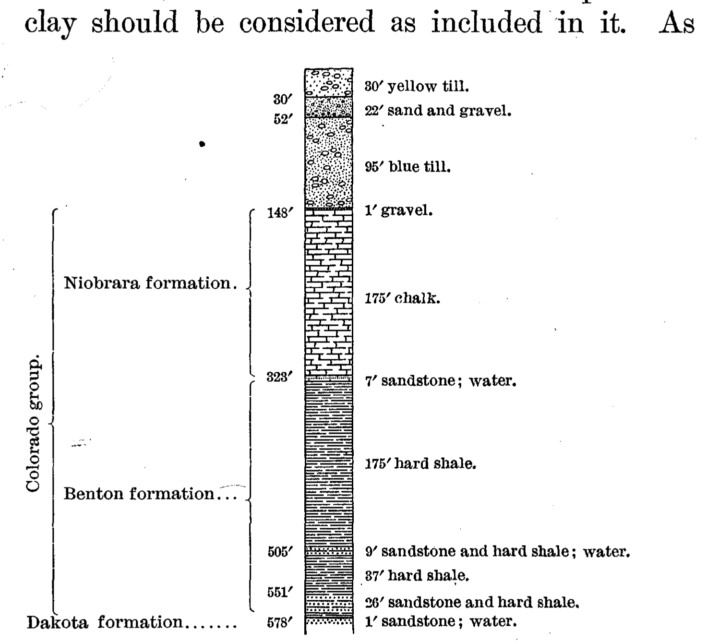

FIG. 6.—Section of McCurdy well, near Letcher.

the formations both below and above are clay, the areal distribution of the Niobrara can not be very sharply defined in this drift-covered region. It is especially difficult to recognize the different beds in wells, for there the chalk has not been exposed to atmospheric action, and has a leaden color, closely resembling the gray clays of the Benton. The chalkstone is exposed at many points along James River and its western tributaries, as may be seen on the geologic map. It often rises in cliffs 15 to 20 feet above the adjacent stream, but as it is quickly disintegrated when moist and exposed to freezing, it more frequently appears as a steep slope marked by a whitish soil and stunted vegetation. In the central, eastern, and southeastern portions of the quadrangle the chalk is often conspicuously developed and appears in many exposures that occur at intervals of a mile or so along Firesteel Creek, from its mouth to a point north of Mount Vernon. In some places the chalkstone and sandstone of the upper Benton appear in the same vertical section. For 5 or 6 miles west of the railroad crossing of Firesteel Creek, sections of chalk and sandstone alternate at about the same level, suggesting an unconformity. Whether this is due to erosion, to landslips, or to some irregularity in deposition has not been surely determined, but landslip is the most probable cause. Exposures of chalkstone appear in a cut between the channels of Enemy and Twelvemile creeks, in T. 102, R. 61. Near the northeast corner of sec. 29, T. 101, R. 59 (Worthen Township), the chalk appears in a steep bank facing northeast, where the lower portion shows beds of unusual hardness. Its texture here

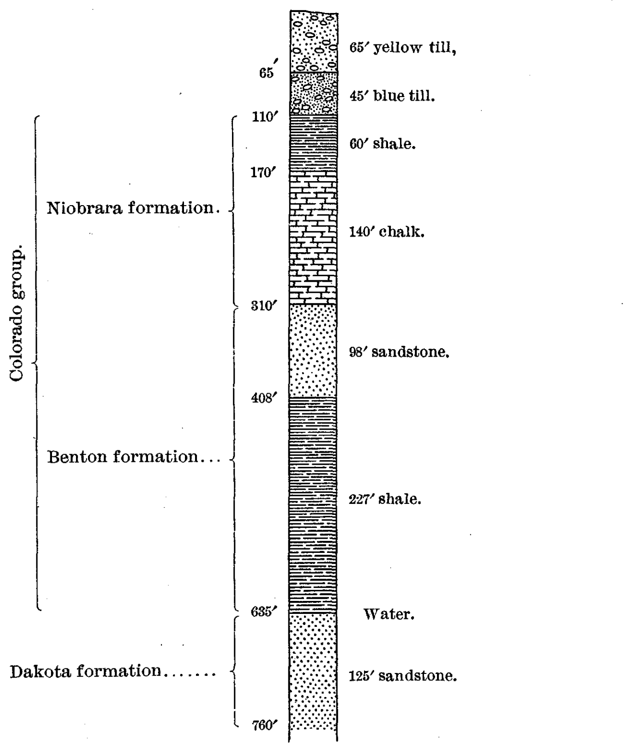

FIG. 7.—Section of well at Stover.

approaches that of limestone and it shows a pseudo-slaty cleavage. Its color is light drab. The most northern exposure is in sec. 26, T. 104, R. 60 (Perry Township). The disappearance of the rock north of that point is due partly to its decline in altitude, but mainly to its removal by glacial erosion. The highest occurrences of the chalk in this quadrangle are near the southwest corner, in sec. 36, T. 102, R. 60 (Prosper Township), and on the south line of sec. 18, Worthen Township, where its altitude is 1320 feet above sea level.

Over most of the quadrangle the chalkstone has been much thinned by erosion. Probably no locality in the quadrangle shows the summit of the uppermost portion of the formation. The greatest thickness is in the southwestern part of the quadrangle, where over 200 feet is occasionally reported. Possibly this includes some of the hard shale beds associated with the chalkstone. The formation rises on the slopes of the underground quartzite ridge. Over its crest the upper members were removed by erosion before the ridge was covered by glacial deposits.

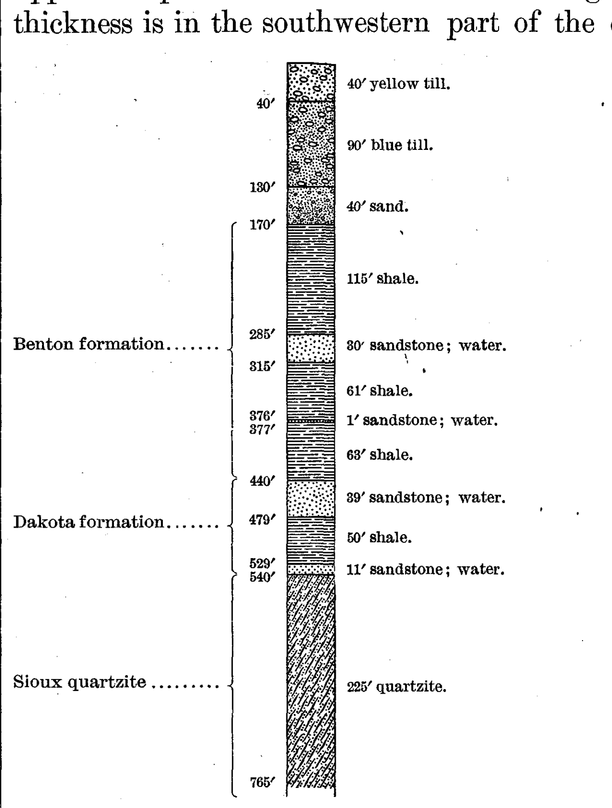

FIG. 8.—Section of well at Mitchell.

The chalkstone frequently contains fish teeth and scales, mostly of bony fishes, although sharks' teeth are also found. Occasionally nearly perfect specimens of bony fishes have been found. The most common fossil is the small oyster, about an inch in length, called *Ostrea congesta*. These shells are frequently clustered on fragments of larger bivalve shells, either of *Pinna* or *Inoceramus*, which are rarely found in small fragments, even where there are good exposures.

Well sections showing the character and relations of the Cretaceous formations in different portions of the quadrangle are given in figs. 3 to 8.

PIERRE SHALE.

This formation consists almost entirely of dark plastic clays partially hardened into shale, with occasional calcareous concretions. It overlies the chalkstone in the western part of this quadrangle, and is thicker under the more elevated portions of the region westward. It is everywhere heavily covered by drift. Doubtless it originally covered the whole area, but was eroded from the ridge near James River before and during the Glacial epoch. No fossils have been obtained from this formation in the Mitchell quadrangle, and little is known of it except that it is a dark-blue or black shaly clay.

PLEISTOCENE SYSTEM.

The formations so far described are sedimentary, and with the possible exception of the Dakota are of marine origin. To these the Pleistocene deposits present a marked contrast, not only in their origin but in their mode of occurrence. They are the products of glacial action and overlie all earlier formations without respect to altitude, forming a blanket over the whole surface with the exception of a few square miles that are covered by alluvium or occupied by outcrops of the older rocks. The deposits include till or bowlder clay, morainic material, and certain stratified or partially stratified clays, sands, and gravels formed along abandoned river channels and terraces. The bowlder clay forms a great sheet, spreading over nearly the whole of the area. The morainic material occurs in a series of rough, knobby hills and ridges that cross the quadrangle from northwest to southeast and occupy its northeastern half. The channel and terrace deposits fill valleys and cover flat areas, lying mainly in close proximity to the morainic ridges.

Till or bowlder clay.—The till presents the features of a deposit that is found in similar regions elsewhere, as in central Minnesota, Iowa, and Illinois. It is an unstratified mixture of clay, sand, and worn pebbles and bowlders, the latter sometimes attaining a diameter of several feet. In it are local developments of stratified sand, sometimes mere pockets, sometimes portions of channels of considerable length, and sometimes sheets that locally separate the bowlder clay into two or more members. The till of this region is much more clayey than that found at points farther east, because for a long distance the ice moved over and deeply eroded the dark-colored clays of the Cretaceous. For this reason the erratics are perhaps less frequently striated and planed.

The till here, as elsewhere, exhibits an upper, yellowish division, known as yellow clay, and a lower, blue portion. The upper clay is simply the oxidized or weathered form of the lower, and the separation between the two is not very clearly defined. In the sections they are sometimes distinguished, but not always. The blue clay, moreover, is apt to be confused by well drillers with the underlying Cretaceous clay of similar color, so that in their reports part of this clay may in some cases be included with the Pleistocene formations. This is very likely true of the section in T. 101, R. 64.

No distinct traces have been found of a subdivision of the till into different members, such as occurs in some other localities, and the whole is believed to have been formed by the Wisconsin ice sheet. It should be noted, however, that even if there be a division there is little likelihood that it would be reported by well borers, for the Pleistocene is not frequently the source of water supply, and hence the drillers are less critical in their observations of it than of the underlying rocks. Occasional fragments of wood have been reported from it, but in every case, when inquired into, they proved to be isolated pieces and not parts of a "forest bed."

The surface of the till shows the characteristic irregularity common to it elsewhere. There are many small, irregularly placed hills or knolls and minor basins without outlet. These features are fainter than usual, and the general surface is much more nearly that of an even plain than is common in drift-covered regions. The reason for this seems to be that the pre-Glacial surface was acted upon by the ice for a long period, and, the underlying rocks being soft and somewhat uniform in character, the surface was planed down rather evenly. There has also been a considerable amount of filling of the minor basins with silt, laid down by waters escaping from the ice soon after the deposition of the till, and also, in more recent times, with wash, resulting from rain and the melting of snow. In some localities considerable silt has been deposited by the wind, but this influence has not modified the till of this region much, so that its surface is now nearly as it was left by the ice sheet.

Southwest of the morainic area there is a strip, 3 or 4 miles wide, which is nearly level, especially toward the southeast, where it also broadens. This belt shows but few bowlders on the surface, and may be considered as the flood plain of the ancient drainage channel around the edge of the ice. From this strip there is a gradually increasing rise to the southwest, which is especially pronounced in the southeastern part of the quadrangle, where a rise of 100 feet in less than 3 miles occurs. Viewed from a distance this rise suggests the presence of a moraine, and the number of erratics on the surface strengthens the impression, but further investigation shows that the region lacks the characteristic knoll-like features of a moraine, and it can not be correlated with any similar areas in a linear system. It seems to be due to a pre-Glacial elevation culminating in Aurora Township (T. 101, R. 63). Over this elevation the ice was thin and the till accumulated more thickly. The waters from the melting of the ice seem to have eroded the surface more than usual, especially along the southern side, because of its elevated position and its earlier uncovering and the freer escape of the water. The whole of this portion of the till is more or less furrowed by watercourses, first occupied as the ice withdrew and considerably deepened during the centuries since.

The surface of the till northeast of the moraine is more nearly level, and northeast of Morris Run it is as level as an ordinary alluvial plain, with the exception of some knolls, few of which rise more than 5 feet above the general level. This surface is, of course, more recent than the one just described, is at considerably lower level, and, especially in the flat portion, is more modified by the deposition of silt.

The exposures of older rocks are more frequent and more widely distributed in this quadrangle than is usual in this region, and over nearly a third of the quadrangle the till is less than 50 feet in thickness, averaging for the whole perhaps less than 25 feet. From the southeast the till thickens rapidly toward the southwest, attaining a depth of over 200 feet on the high land in Aurora and Truro townships. To the north and northwest it thickens less rapidly and rarely attains a thickness of 150 feet.

Moraines.—The quadrangle is crossed from northwest to southeast by one of the great moraines which mark a pause in the movement of the ice sheet. Northeast of the main moraine, as indicated on the Areal Geology sheet, there are various areas that mark minor stages in the retreat of the ice. The various morainal ridges may, however, be considered as parts of a single moraine or system of moraines, and this is the usual method of treating them.

The material composing the moraine is similar to that of the till already described, but the ridges are considerably more stony. Numerous bowlders are found upon them and they comprise considerable masses of gravel. In the sharp ridges south of Enemy Creek large quantities of crushed sandstone appear on the northern slope, which give the impression that the Dakota sandstone rises high in their interior, but from a deep cut made on the east line of sec. 16, T. 102, R. 60, and one on the railroad just east, it is found that the sandstone is mainly on the surface, the interior being composed of ordinary till. Evidently the sharpness of the ridge is partly due to the amount of rock which the ice brought from the brown sandstone ledges of the Dakota formation, exposed just north.

As a system the moraine usually consists of stony, knobby hills mingled confusedly with circular and winding basins which often contain water, but sometimes both basins and hills are very faintly developed, so that the whole constitutes a broad swell. The moraine is traversed here and there by valleys through which water escaped from the ice sheet. These may be of very small size or many rods in width, and may cut down through the whole height of the moraine.

The topography of the moraine in this quadrangle is mostly of subdued type. During its formation the ice sheet was comparatively thin; the débris consisted largely of clay, and the discharge of water was not free. At a few points, especially toward the northern part of the quadrangle, the moraine presents a high, evenly formed swell-ridge. In the southern part, about the headwaters of Twelvemile Creek, small ridges rising 15 or 20 feet above the intervening valleys are common. South of Mitchell, on Enemy Creek, there are very abrupt stony ridges rising 50 or 60 feet above the general level.

The outer boundary of the moraine on the west is the well-defined channel running from the upper part of Firesteel Creek southeastward to the southeastern corner of the quadrangle. Its eastern boundary is very indistinct. This is partly due to the fact that the moraine is irregularly subdivided into three or four members. The first or oldest member lies immediately east of the channel already mentioned. The second is joined to the first toward the north, lies east of a second channel which leaves Firesteel Creek in the west side of T. 104, R. 62, and runs at a high level southeastward across the valley of Enemy Creek immediately south of the conspicuous hills 5 miles south of Mitchell. Both of these members of the moraine are much traversed by channels, which are usually broad, from 25 to 50 feet deep, with abrupt sides, and which often show considerable gravel in their bottoms. The third member enters the quadrangle on the west side of Twin Lake Township (T. 106, R. 62) and runs southeastward nearly to Firesteel Creek, then reappears 2 or 3 miles south of that stream and continues in an east-southeast course, passing immediately south of Mitchell. This member is the least defined of the three. A short, sharp ridge in the eastern part of Twin Lake Township may be considered a fourth member, which may be correlated with a rough belt, rising not much above the level of the plain south, which turns east through the northeast corner of Letcher Township, where it is about 2 miles wide, and continues with even smoother surface across James River. It abounds in small basins. It forms the southern boundary of a sandier area, which will be further treated under the heading "Ancient channels and terraces."

Scattered over the till between these more distinct members are occasional knolls of morainic origin.

These different members, which, as has been already indicated, may be regarded as separate moraines, are more conveniently spoken of as different members of one. This has been named the Second or Gary moraine, the latter name being given to it on account of its development near the town of Gary, in the eastern part of the State. It has been traced in a more or less continuous line on both sides of James River Valley around the "Head of the Coteau," near the north line of the State, into the Minnesota Valley, and, in fact, with more or less confidence across the United States to the Atlantic Ocean.

Ancient channels and terraces.—Scattered throughout the quadrangle there are numerous abandoned channels and old terraces, usually, though not always, clearly separable from the present drainage lines and evidently much older. In some of the shallower channels the older deposits may not easily be distinguished from those of recent origin. In such cases the latter have been included under this head. The Areal Geology sheet shows the location of these channels. They correspond generally with the present waterways, for the latter are the puny successors of the former, though the direction of drainage has been so changed in several cases that the course of the water has been actually reversed.

These channels vary from mere flat-bottomed depressions, through which streams passed for a comparatively short time, to those having troughs a hundred feet deep, in which the abundance of coarse material shows that they were long occupied by vigorous streams. In both cases the coarser deposit is usually largely covered with finer material. Where the old channel deposit has been cut through by the deeper trenching of a later stream, the differences in the character of the deposits made by the ice and by the water become very evident. In some cases the surface of the old channel deposit lies at a height of 80 to 100 feet above the present stream. In many cases, however, the old deposits have been only slightly trenched, the later drainage having been in some other direction.

These ancient channels were developed during the presence of the glacier and served to carry off the water from the front of the ice sheet. The arrangement of these channels forms one of the strongest evidences of the former presence of a glacier in the region. The size and course of some of the channels and the amount of coarse material found in them could be explained in no other way.

The order in which these channels were occupied may be readily made out from the Areal Geology sheet, on which they are numbered. It should be remembered, however, that it is impossible to represent them with minute accuracy. For example, the whole of channel No. 3 may not have been occupied during exactly the same time. In general the lower portions of a channel bearing a particular number was probably occupied considerably earlier than the upper portion, though this was not always the case.

The channels in the southwestern part of the quadrangle began to be occupied as soon as the ice had retreated from that region, but the principal channel, No. 2, was the first to mark distinctly the location of the edge of the glacier. It carried away not only the water produced by the melting of the ice immediately within this quadrangle, but also that drained from a region extending for an indefinite distance to the north. In the basin now occupied by White Lake there was probably at one time a large, shallow lake which drained partly by Platte Creek into the Missouri, but about the time of the formation of channel No. 2 it probably discharged by this line into James River. The western side of this channel has an even top and the adjoining land is level, especially toward the south. It is probable that at different seasons this surface was covered by flood waters from this channel.

When the ice receded from the outer ridge of the moraine in this area to the second position marked on the map, the water beneath the ice which discharged into channel No. 2 flowed northwest because of the lower level of the land in that direction. It is supposed this first became true of the channels now occupied by the upper branches of Twelvemile Creek and Enemy Creek, but not long after by those in Palatine Township (T. 104, R. 63), and a little later by the one farther north. In this second stage, therefore, though still occupying the upper part of channel No. 2, the water through the lower portion of its course followed that marked No. 3, along the outside of the second member of the moraine, to James River.

When the ice occupied the third member of the moraine the water followed it again from the southern portion of the quadrangle and occupied channel No. 4. As the moraine of the upper margin of the quadrangle was more compact and had fewer drainage channels crossing it, and the channel on the west had probably worn deeper, the water did not break through to the edge of the ice sheet north of the channel of Firesteel Creek; at least if any water was discharged in this direction it was through a very shallow channel, which has not left its imprint upon the topography. As the ice retired from member No. 3, the water followed it along the line of Firesteel Creek and of the creek south of Mitchell, at which time the descent was so rapid and the flow so vigorous that the erosion was more rapid; at the same time the volume seems not to have been so great as during the stage next preceding. The next channel, marked No. 5, was not occupied for a very long time, especially in its upper course, but the channel from the basin in the northeast corner of the quadrangle, which joins the main channel west of Letcher, was occupied much longer; in fact, the lake in Logan Township was probably filled with water until the ice had receded many miles north of the quadrangle. In this way Dry Run was excavated much deeper than most of the channels. At about the same time a well-defined channel crossing Butler Township (T. 105, R. 60) was occupied, and doubtless a terrace occurring below its mouth along James River was formed at this time. The trough of the James was, however, excavated mostly at a subsequent time, when it was the main drainage channel for all the water shed by the glacier while it receded in and from the upper part of its valley. The flat plain east of Letcher, as already hinted, may owe its level character in part to the deposition of silt during a flooded stage, and hence might be considered a very transiently occupied terrace of James River.

In Logan and Union townships (T. 106 N., Rs. 60 and 61 W.) there is an extensive level plain covered in part with sand and containing small shallow lakes which mark the position of one of the ancient bodies of water.

Osars.—In the northern portion of Lisbon Township (T. 102 N., R. 61 W.) there are a few elongated, winding, stony ridges that are not improbably deposits of this class, which are considered to have been formed by subglacial streams. They are, however, so intimately related to the moraine that it is difficult to say, without considerable excavation, whether they are osars or not. They may be best seen on the north line of section 11.

Alluvium.—All the streams that traverse the region are subject to sudden floods, caused not only by occasional excessive rainfall but by the rapid melting of abundant snows during certain seasons. The gravels of these ancient channels and lake basins, already referred to, are thickly covered with fine silt, which is in part dust deposited from the air. The alluvial plain of James River is about half a mile wide. Some portions of it are dry and well adapted to cultivation; other parts are marshy, and all are more or less subject to occasional floods. The alluvial deposits are from 10 to 20 feet thick, the upper 3 to 5 feet being usually a fine black loam and the lower portion sand.

GEOLOGIC HISTORY.

The earliest phases of the history of the region of which this quadrangle is a part may be stated very briefly. At some stage preceding the formation of the Sioux quartzite a land surface composed of granite and schist occupied central Minnesota, and possibly covered the area lying north and east of this quadrangle. From that land area material was derived, both by the action of streams and by wave erosion along the shore, which was laid down over the region now occupied by the Sioux quartzite. The deposits consisted mainly of stratified sands, but occasionally comprised thin beds of clay. The deposits were thicker toward the center of the broad area that now extends southwestward from the vicinity of Pipestone, Minn., and Sioux Falls, S. Dak. After this period of deposition there seems to have been an epoch of slight volcanic disturbance and igneous outflow, as indicated by the occurrence of a dike of olivine-diabase near Corson, S. Dak., and in borings at Yankton and Alexandria, S. Dak., and by a dike of quartz-porphyry near Hull, Iowa.

Through silicification the sandstone thus deposited was changed into intensely hard and vitreous quartzite, and the clay beds were transformed into pipestone and more siliceous red slate, as at Palisade. Microscopic examination shows that the silicification was effected by the crystallization of quartz around the separate grains of sand until the intervening spaces were entirely filled. The material of the quartzite as originally laid down in the sea may have included scores, or even hundreds, of feet of material above that which is now found. In time the region was lifted above the sea, and during some part or all of the long era of the Paleozoic it was a peninsula. It may at times have been submerged and have received other deposits, but if so they have been eroded. That it was not far from the ocean, at least during a portion of the time, is attested by the occurrence of Carboniferous rocks under Ponca, Nebr.

At the beginning of Jurassic time the land began to subside and the sea gradually advanced in central South Dakota, but apparently in this region a land surface continued until much of Cretaceous time had passed, for the first deposits appear to have been sediments of Dakota time. These were mainly sands deposited on beaches and in estuaries, but, in intervals of quieter and deeper waters, clays also were laid down. The sands, which were doubtless carried to and fro by vigorous tidal currents, were probably derived in part from the disintegration of the quartzite along the adjacent shore. The clay may be traced with considerable confidence to the soil and fine material that were washed from the land as the waters continued to advance toward the east.

At the end of the Dakota epoch the ocean waters overspread the region as far as southeastern Minnesota, and the deposition of the Benton shales began. There were some short periods of shallow waters with strong currents which deposited local layers of sand, but clays were the predominant sediments. In Niobrara time the waters were deep and clear in the greater part of the area and great deposits of carbonate of lime accumulated, now represented by the chalkstone. At this time there was abundant life in the waters, including fishes, huge reptiles, and mollusks. Deep waters and clay deposits continued during Pierre time, and probably several hundred feet of Pierre sediments extended across southeastern South Dakota. In the latter part of the Cretaceous there were at first shallow ocean waters, of Fox Hills time, and then brackish and fresh waters in which the Laramie sandstones were laid down; but as these formations are absent in the region lying to the southeast, there is no evidence as to the conditions existing in southeastern South Dakota during this epoch. Presumably this region was then a land surface, which probably continued during Tertiary time, when some of the streams of the late Tertiary spread local deposits of sands in portions of the region. If, however, these sands covered any part of this quadrangle they have been removed by erosion.

During the latter part of the Tertiary period there was doubtless a large stream flowing southward somewhere near the present position of James River. Into this stream White River probably emptied, through the valley of White Lake and Firesteel Creek. Those rivers doubtless had many small tributaries, which rapidly cut down the soft material composing the surface. The elevated region in Baker Township (T. 101, R. 62) may be considered as a remnant of the old divide south of the old White River.

Such was the condition that existed until the Ice Age began, when the climate became more moist and cold. During the earlier stages of the Ice Age, before and during the Kansan stage, the ice had not broken over the divide between James River and Red River, and hence the streams, though swollen by rains, did not receive water from the ice. If the ice reached the boundaries of this State it did so probably in Minnehaha County, coming over from the Minnesota Valley, and Big Sioux and Vermilion rivers carried off the products of melting.

During the Wisconsin stage the ice finally passed over the divide, entered James River Valley, and steadily progressed down that valley until it had filled it to a depth, in the center, of 1000 or 2000 feet. At that time the ice extended as far westward as Kimball, southwest of Lake Andes, southward to Yankton, and eastward to Lake Madison. During this stage the region was being ground down and the chalkstone carried away, to be mingled with the débris of the ice sheet.

This condition continued probably for hundreds of years, but in due time, for some reason, the strength of the ice current was checked, and it gradually melted back until the southwestern part of this quadrangle became uncovered; nor did the retreat cease until the edge of the ice had receded beyond the line of Firesteel Creek, and possibly farther, for there are no means of determining how much of the surface was then uncovered.

Following this the ice advanced until it reached the line of the outer member of the moraine crossing the quadrangle. It may have at that time advanced farther southwest, but did not rest at any one point long enough to deposit a moraine. It rested along the line of the first member until that moraine had been accumulated and the drainage channel numbered 2 on the map had been formed. The ice then receded, as has already been sketched under the heading "Ancient channels and terraces."

Subsequently the ice paused in its retreat, and then, after forming a slight moraine south of Huron and another near the north line of the State, receded so far that it no longer influenced this area. The streams by this time had become fixed in their present courses, and though probably somewhat larger than at present, had little effect on the surface of the country except to deepen the channels that were permanently occupied by water. It is believed that James River had cut nearly to its present depth before the ice disappeared from the State.

The principal geologic event since the disappearance of the ice sheet has been the deposition of the thin mantle constituting soil. This has gone on by the formation of alluvium along the principal streams, by the wash from hillsides, and by the settling of dust from the atmosphere. To these soil-making agencies may be added the burrowing of animals, by which the soil is loosened, and the deposition of vegetable remains.

ECONOMIC GEOLOGY.

In this area there are no deposits of mineral ores or of coal. The few samples of mineral that are sometimes submitted to geologists for examination are invariably iron pyrites, which have no value unless found in very large quantities. Fragments of coal are sometimes found in the drift, but these were brought by the ice or by streams from the lignite beds of the northern part of James River Valley, in North Dakota.

BUILDING STONE.

Most of the stone that has been used for foundations and other rough building has been derived from the drift. It consists of bowlders of granite, limestone, and greenstone.

Sandstone.—The brown sandstone of the upper Benton has been locally used for rough work. It has been quarried on Firesteel Creek near the railroad crossing. At that point the stone is durable and blocks of considerable size may be cut, although the stone is not of fine enough texture for good work. It is very ferruginous. Stone of equal excellence is found in exposures in secs. 34 and 35, T. 104, R. 61, and also in sec. 22, T. 104, R. 60. At the other points marked on the map it seems to be too soft for use in permanent buildings.

Chalkstone.—There are no ledges of limestone in the region, but chalkstone has been used for the walls of buildings, especially in early years, and several buildings in Mitchell show its pleasing appearance and durability. The stone, when carefully chosen and seasoned, seems to be easily worked. It may be cut with a common saw, but stands the effects of weather well. The main drawbacks are the difficulty of finding blocks of sufficient size and the danger of injury in quarrying. It has a dull white or yellowish cream color. When the stone is left moist, as on the ordinary surface of a hillside, it is broken and disintegrated by frost, so that not many blocks of considerable size remain after a few seasons; but on an abrupt slope, or in a cliff where drainage is good, it stands for years. Quarries have been opened northeast of Mitchell on Firesteel Creek, and also on Dry Run. At perhaps a score of other points the exposures offer equal encouragement to quarrying. The localities may be readily ascertained from the Areal Geology sheet.

CLAY.

Deposits of valuable clay within the quadrangle are rare. The brickyard at Mitchell is supplied from a pit about 2 miles southeast of that place, where the clay is obtained from a Benton horizon found beneath the chalkstone. This clay is not very well suited for brick-making, because it contains small calcareous nodules. An exposure of clay shale was observed on the east side of sec. 16, T. 102, R. 62 (Union Township). At first appearance it seems suitable for ordinary brick-making, but no tests have been made. It is possible that diligent search may discover in some of the old channels, or in the flood plains of the recent streams, accumulations of silt of sufficient depth and of suitable quality for brick-making, but none have yet been found.

SAND AND GRAVEL.

Along channels occupied during the Glacial epoch deposits of sand and gravel abound at several points, so far as can be judged from outward appearance. Pits have been opened on the edge of a high terrace northeast of Mitchell, adjoining the town, also along the old channel north of Mount Vernon, and in the bottom of the channel near the southeast corner of sec. 30, T. 103, R. 62 (Mount Vernon Township).

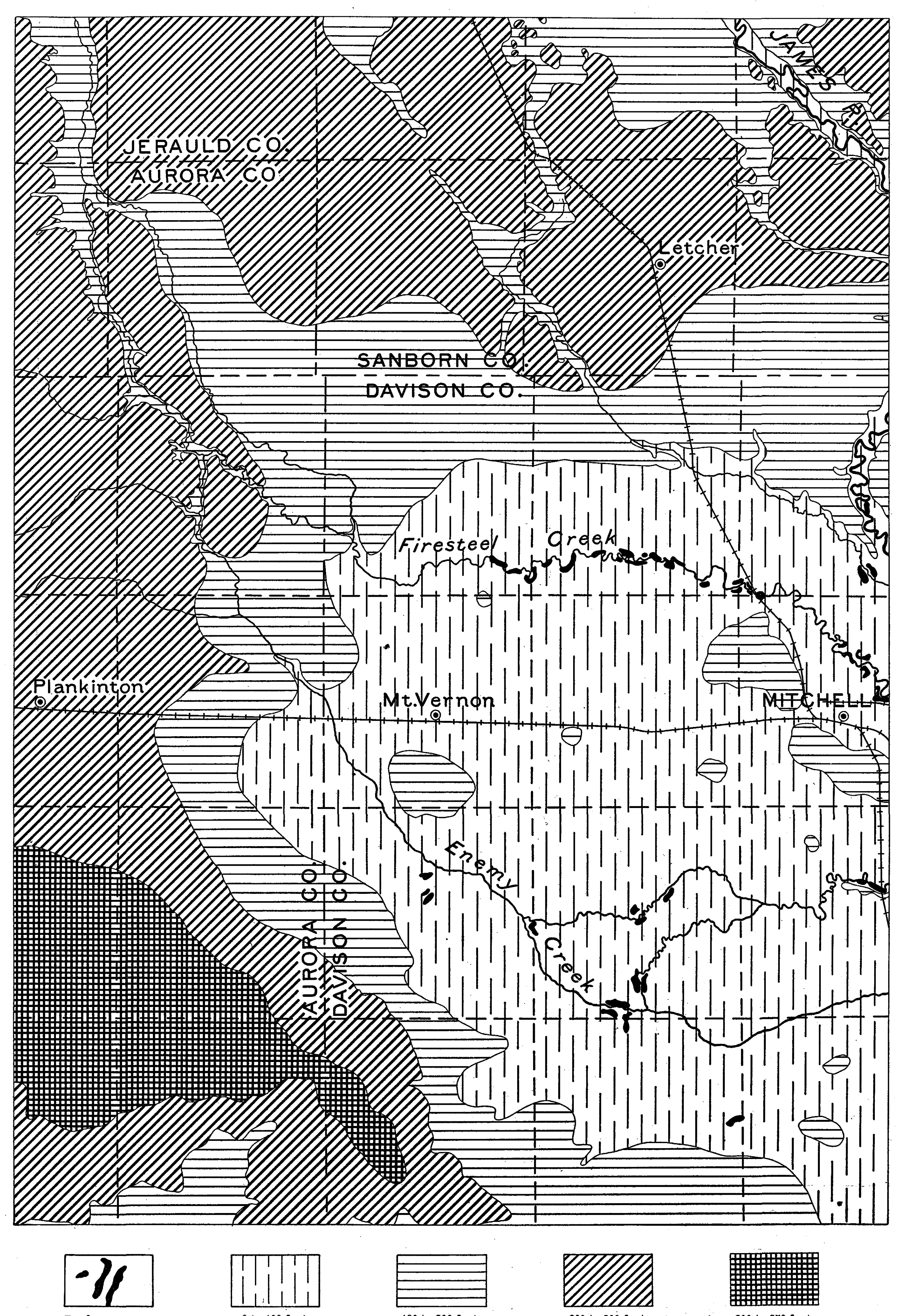

Fig. 9.—Sketch map of Mitchell quadrangle showing approximate depths to the bottom of the drift. Water can usually be obtained from sands and gravel at the base of the drift, and generally rises many feet in wells.

WATER.

This resource is of prime importance. Perhaps the greatest of the benefits resulting from the geologic investigation of the region will be the determination of the distribution, character, and accessibility of its waters. They may be classified into surface waters and subterranean waters. The surface waters include springs, streams, and lakes; the subterranean waters are reached by wells, both pump and artesian.

SURFACE WATERS.

Streams.—James River and Firesteel Creek along a few miles of its lower course are the only streams in which there is running water the year round. James River is a sluggish stream, several yards wide and from 3 to 10 feet deep. Because of its steep banks and muddy bottom it can rarely be crossed except by bridges. The water is more or less hard and presents the qualities common to surface streams.

Firesteel Creek shows running water for about 8 miles above its mouth, but in the latter part of summer, in its narrower portions, the stream is not more than a yard wide and 3 or 4 inches deep. This does not, however, represent the full amount of water carried by the stream, for most of its course is occupied by deep ponds, nearly a rod in width and 3 or 4 feet deep, and these extend up the valley at least to the northern line of Palatine Township (T. 104, R. 63). A large portion of the water carried by the stream flows underneath the surface, through the surrounding gravel. In this way the water in the pond holes is kept pure; in fact, they have the general characteristics of springs. It is probable that much of the water in this stream is derived from the upper stratum of the Dakota or the Benton sandstone, which also supplies the soft-water pump wells of the region.

Enemy Creek presents features similar to those of Firesteel Creek except that it has no running water in this quadrangle. It probably receives water from the sandstone in the same way at a point near the eastern margin of the quadrangle, and the stream is more permanent below that point.

Similar statements may be made of Twelvemile Creek. The upper portions of the streams already mentioned, and of the watercourses in this quadrangle generally, carry off much water in the spring and after a rain, when they are subject to flood. Water holes are apt to be found at distances which increase more and more toward the source, and these water holes have characteristics similar to those lower down. As the season advances the holes dry up one after another, the larger ones being most persistent. They usually show connection with subterranean drainage and if kept free from contamination afford good water. The exceptions to this statement are shallow holes which are separated from the subterranean flow by an impervious layer of sand.

Springs.—The pond holes just mentioned are really springs, but of these there are better examples. The springs of the region are supplied from at least three different horizons, and, as in other regions, their positions are near the larger streams.

The Pleistocene deposits are commonly the source of springs in this area. The water comes from layers of sand and gravel above, within, or underneath the bowlder clay, more commonly from the coarse material deposited in old channels or on terraces. Frequently where a recent stream has cut across an older channel a springy slope appears. Such springs are often copious and constant, and may usually be recognized by their high altitude. They are sometimes 50 feet above the present streams. Most of the springs are of this class.

In no case can it be said with certainty that a spring derives its waters from layers of sand within the till, nor can it be said positively that any springs come from underneath the till. At a few points along the southwest side of the moraine there are springs which may have this source, more particularly in sec. 25, T. 102, R. 62 (Union Township), and in sec. 15 of the same township. One reason for the rarity of springs of this class is the porous character of the upper part of the chalkstone, which is the prevalent underlying rock.

A few springs may possibly belong to the Niobrara formation. It is known that in adjacent territory water is found following crevices in the chalkstone and underlying shale. There are only a few points where impervious layers of clay between the chalkstone and the sandstone appear at the surface, and hence the water is not apt to be brought out in the form of a spring. In sec. 6, T. 104, R. 62 (Blendon Township), there are a few weak springs which seem to come from this horizon. It should be remarked that the chalkstone does not readily absorb and distribute water unless it has been weathered.

A few springs derive their water from the upper Benton sandstone. These are the most copious springs in the region. The best example of this class is found near the northeast quarter of sec. 27, T. 104, R. 60 (Perry Township). This spring is situated upon the bottom land of the James, several rods north of the river, into which it pours a constant stream measuring perhaps a yard in width and 2 or 3 inches in depth, but much choked by vegetation. It occupies a circular, steep-sided depression, in which it forms a pool about 30 feet across and of considerable depth. It is a little over half a mile southeast of an exposure of upper Benton sandstone. Another spring, less confidently referred to this source, is in sec. 36, T. 104, R. 62 (Blendon Township). It lies in a vacated bend of Firesteel Creek, a little above the present level of the stream, on the north side. The abundance of water constantly issuing from the spring is convincing evidence that it has some other supply than the old channel. Another is near the southwest corner of sec. 31, Perry Township. This is not sufficiently separated from Firesteel Creek to show how much water flows from it, but it is a large circular pool of unknown depth on one side of the main channel. It is just west of extensive exposures of upper Benton sandstone. The popular impression, which is probably correct, is that a number of such streams discharge into Firesteel Creek between the two last mentioned, and that possibly there are others farther west.

Lakes.—The map sufficiently indicates the lakes; none are very large or very prominent.

SUBTERRANEAN WATERS.

In the discussion of surface waters reference was made to the close connection between water holes along watercourses and the motion of waters near the surface in the upper part of the till. Mention has been made also of the connection between springs and the water in the drift, as well as the waters in the Niobrara chalk and the upper Benton sandstone. Thus far surface waters only have been treated. Those obtained from below the surface by artificial means will now be discussed.

These may be studied under the headings shallow wells, tubular wells, and artesian wells.

SHALLOW WELLS.

By shallow wells is meant those supplied from waters that have recently fallen on the surface and that can be obtained without penetrating an impervious layer. Wells of this class can easily obtain water close to any of the present watercourses, whether these contain standing water on the surface or not, or in the vicinity of basins. Such wells may obtain water at a depth of from 10 to 50 feet, but do not afford a copious or permanent supply except when located near the bottom of a large depression or near a channel draining a considerable area. The reason for this is obvious, since the water comes from precipitation only and the region is subject to continuous droughts. Only those wells of this class that are so situated as to draw from a large catchment basin can be depended upon for a permanent supply. In digging such wells, if no water is reached before the blue bowlder clay is struck, none will be found until the clay has been passed through.

TUBULAR WELLS.

Under this head will be included simply the deeper wells in which a tubular or force pump is usually necessary. Frequently the water rises nearly to the surface, and occasionally it flows. These wells are from 100 to 300 feet deep. In this region the deep tubular wells usually derive their waters from the upper sandstone of the Benton formation, but a few obtain water from the sands underneath the till, and some from the chalk just beneath. Others possibly procure water from the lower part of the chalk formation, although this case is not well proved.

The wells supplied from the sands below the till are mainly in the southeast corner of this quadrangle, although there are a few in the northwest and in the north which possibly may be supplied from this source. The depths to the base of the till are shown in fig. 9. The reason water is not commonly found at this horizon, as in other regions, is seen in the prominence of the underlying chalk and the deep channels which traverse it. As a result of these, not only are sands below the till less general, but their waters when present leak out at the surface. A few wells in the vicinity of Plankinton, in a district extending in a strip north and south, appear to be supplied from the lower part of the chalk. They are reported to furnish hard water, and some of them give forth a disagreeable odor. That water is sometimes derived from the chalkstone is indicated by the fact that some of these wells are shallower than those which supply soft water from the sandstone in the same localities, as well as by the fact that water is found in the lower portion of the chalkstone in the quadrangle next east. It is not known, however, whether this water has found its way down from the surface or whether it has passed upward from the underlying sandstone and become contaminated with lime or sulphureted hydrogen from the chalkstone and shale.

A very important and valuable supply of water is derived from the first sandstone below the chalk, which has been erroneously called the first sandstone of the Dakota, and is so shown on the Areal Geology sheet. Throughout the whole quadrangle this water is soft and is frequently spoken of as "soft as rain water." It is not pure, but carries considerable quantities of soluble alkali, which, however, does not impair its taste. Unlike the waters from lower levels, it does not rust iron and tin, and it may be used for washing without the use of any alkali to "break" it. It is the favorite supply of pump wells, and many draw from this source who have a copious supply of artesian water. The water from this sandstone may be obtained on the highest lands of the southeastern part of the quadrangle at a depth of less than 300 feet—near Plankinton, 250 feet; north of Plankinton, 200 feet; and north of Mitchell, 150 feet—and in the central and southeastern portions of the quadrangle at a much less depth. In all these cases the water rises many feet, and at several places affords surface flows. Such is the case near Firesteel Creek at the west side of Blendon Township. It is also true for a small area in the bottom of an old channel southwest of Mount Vernon. As before stated, this horizon discharges by springs into Firesteel Creek and James River, hence the head in wells can not rise above the level of the lower lands near those outlets.

ARTESIAN WELLS.

With the exception of a few wells, already mentioned, that furnish flows from the upper sandstone of the Benton, the numerous artesian wells of the quadrangle are supplied from lower horizons in the Dakota sandstone. Fig. 10 shows the depths to "bed rock"—mainly quartzite—the lower limit of water-bearing strata. Perhaps no quadrangle has a larger number of artesian wells than this one. Their locations and depths to flow or flows are given on the Artesian Water sheet, which also shows the depths to the top of the Dakota sandstone throughout the quadrangle. There are several of the deeper seated water horizons, but most of the wells are supplied from the "first" and "second" flows, as they are popularly called, while the stronger and larger wells are supplied from the "third" and "fourth" flows. As it is improbable that these water-bearing horizons preserve their continuity throughout the artesian basin, these terms are relative only. The sandstones are in widely extended sheets, with intervening deposits of shale or clay, and doubtless vary greatly in continuity, porosity, and relative position; hence a sandstone that affords a flow in one locality may thin out and yield no flow in another locality. Moreover, any estimate which comes from a comparison of simple depth may be misleading, because of the very gradual slope of the surface, which, although it appears to be a level plain, in fact often slopes 20 feet or more to the mile.

The extent, thickness, and variable character of the sandstone strata of the Benton and Dakota have been already described. One of these strata may constitute a single water-bearing horizon; or two, if connected either by porous beds or by breaks in the intervening shale, may be considered as forming a single horizon; although, if the water is in motion its flow may be irregular in volume and its pressure and rate of movement may vary greatly from place to place. Whether the supply in different wells or from different depths in the same well is from the same sandstone or not, will be most clearly determined by the pressure. In other words, the pressure should be the same from the same sandstone bed in the same locality. In some cases the evidence of pressure is not trustworthy, for some wells, which have imperfect casing or connections, allow water to escape beneath the surface, so that the full force is not shown at the mouth of the well. From the different pressures in different wells and of waters from different depths in the same well it is evident that there are, as before stated, several water-bearing beds in the Dakota formation underlying portions of this quadrangle. The lower ones appear to exist only in the northern and western portions, but the upper ones are of wide extent.

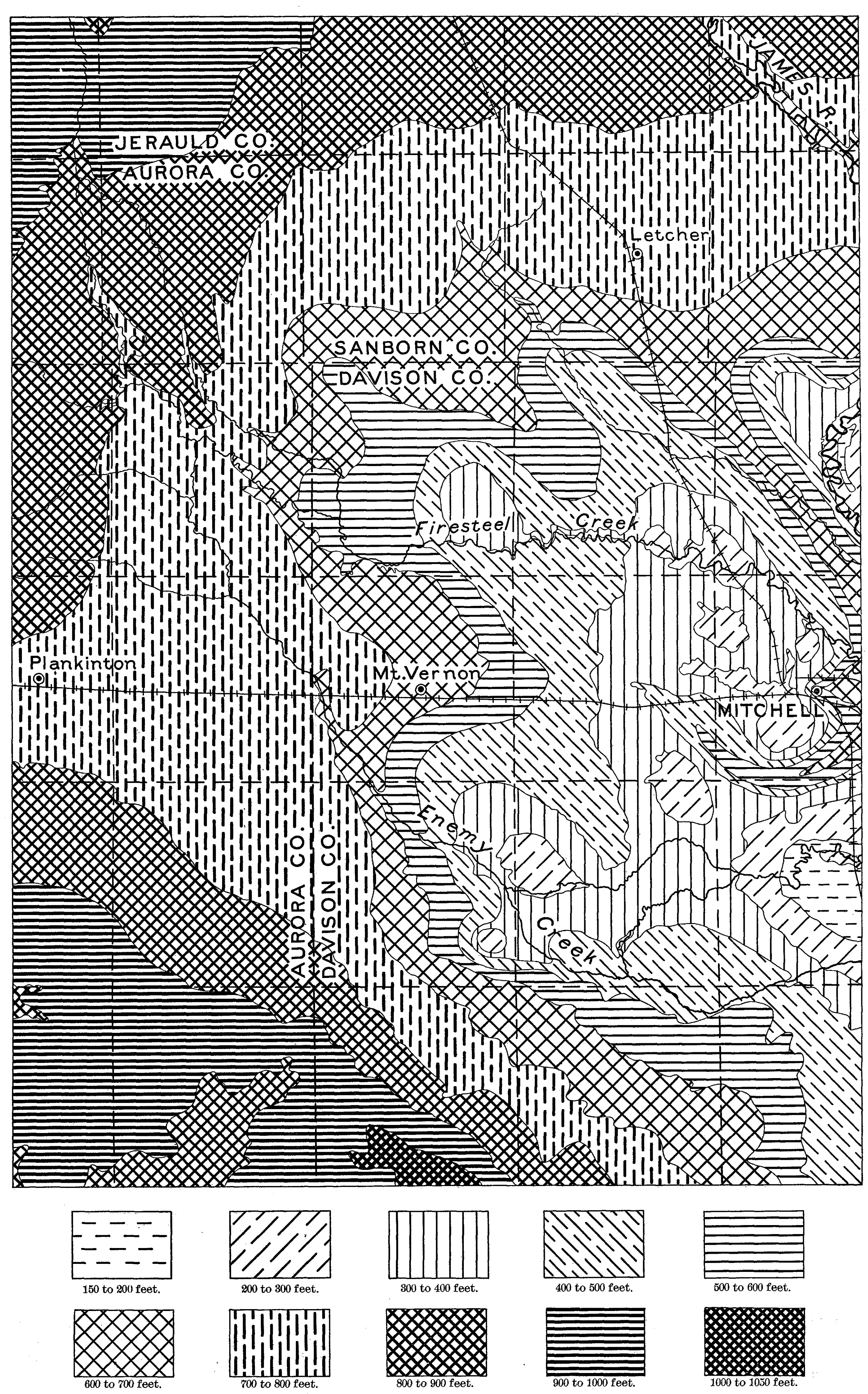

FIG. 10.—Sketch map of Mitchell quadrangle showing approximate depths to the Sioux quartzite, "bed rock" of well drillers, which is the lower limit of water-bearing strata.

From a comparison of depths, pressures, and amount of flow, it may be inferred that not only are the water-bearing beds mainly in sheet form but these sheets rise as they approach elevated portions of the underlying quartzite and overlap, yet each sandstone probably ends at a certain level which originally corresponded to that of the seashore at the time the sand was deposited; hence the lower beds do not extend so far as the upper, and are more closely sealed along their eastern margin. It is not impossible that, by the interpretation of carefully taken pressures, evidence may be found showing that different water-bearing sandstones communicate imperfectly with one another along the surface contact of the quartzite.

Following this interpretation, it is concluded, taking the Storla well in sec. 35, T. 105, R. 63 (Belford Township) as a standard, that there are represented, first, the top sandstone of the Benton formation, with its soft water, at a depth of 130 feet, which is called water-bearing horizon No. 1; another at 470 feet, which is commonly called the first flow, here called water-bearing horizon No. 2; one at 535 feet, which is No. 3; at 620 feet No. 4; at 740 feet No. 5. Probably some of these are local and not continuous to other wells. No. 2 supplies the soft-water artesian wells north of Firesteel Creek, except those already mentioned as belonging to No. 1; also the so-called first flow in Badger Township, and most of those around Mount Vernon.

Water-bearing horizon No. 3 corresponds to what has usually been called the second flow, and is that which has here been taken as the general flow, whose pressure is indicated on the Artesian Water sheet. This horizon, it is believed, supplies the flow of the Kilborn well, in sec. 23, T. 104, R. 62; the Schlund well, in the next section south; the second flow in the J. K. Johnson well and the Arland well, both in Mount Vernon Township; and the Cook, Dougan, and Andrews wells of Palatine Township (T. 104, R. 63). A number of deeper wells farther south derive water from the same horizon. Water-bearing horizon No. 4, it is believed, is represented in the Woodward well, in sec. 29, Letcher Township, in the J. K. Johnson well, and in the Bartow, Plankinton, and other wells in that vicinity. The apparent discrepancy in depth to flows in several of these wells is explained by the fact that the second and third water-bearing horizons are allowed to flow together in the wells. It is stated that the pressure in water-bearing horizon No. 4 was about 80 pounds at first, and the water from horizon No. 3 has a pressure of 55 pounds. The fifth water-bearing horizon of the Storla well and the Beug well, in sec. 25, T. 106, R. 64 (Viola Township), is probably represented by the fourth in some of the other deep wells, and this fifth water-bearing horizon does not extend nearly to the quartzite ridge. It may possibly be found underlying the southwest corner of the quadrangle, coming in on the south side of this ridge.

It has been remarked that water-bearing sandstone No. 2 includes soft water nearly to Firesteel Creek on the north. Water-bearing sandstone No. 3 supplies soft water in the Rarick and Jacobus wells, northwest and northeast of Letcher. This peculiar distribution of soft water toward the north and hard water toward the south is rather difficult to explain. Doubtless it is accounted for by the water partaking of the character of the deposit in which it stands, but on the supposition commonly entertained, that there is a slow movement of the water southward and eastward in this region, it is difficult to see how this can be. Another explanation for the difference in composition in the inclosing formation of the water-bearing bed may possibly be found in the larger deposition of lime and iron salts near the shore, while more soluble compounds accumulated in the deeper portions of the sea.

Amount of flow.—Artesian wells vary much in the relative copiousness of their supply. Compared with the larger wells those of small diameter afford a much smaller supply than the difference in the squares of their diameters would imply, because of the greater friction in the smaller pipe. It may be thought that the primary difference in the copiousness of the supply is due to differences of pressure, but that is not the case. For example, some wells in the vicinity of Letcher deriving water from the second water-bearing sandstone afford only a flow from a 2-inch pipe, and yet the pressures run up to 50 or even 70 pounds, while others in the vicinity deriving their supply from the third water-bearing sandstone afford several hundred barrels a day with less than half the pressure. The primary cause, therefore, of the amount of the discharge must be found in the porosity of the water-bearing stratum and the perfection with which the well is kept in communication with the stratum. From this it may be understood why wells from the same bed differ greatly in the freedom of their discharge. The amount of flow is dependent not only on the factors already mentioned, but also on the amount of surface of the water-bearing rock in the cavity communicating with the bottom of the well; hence a well that strikes the thin portion of the water-bearing bed can not obtain so great a flow as one penetrating a thicker portion, other things being equal.

Wells in this quadrangle that are 2 inches in diameter, which is a very common size, vary in the amount of their flow from less than a gallon a minute to more than 200 gallons. Wells extending to the deeper water-bearing sandstones usually have large diameters, and for that reason and because of the higher pressure of the water in the lower flows, as well as the greater thickness of the lower strata, their discharge is much greater. One of the largest flows is from a well north of Mount Vernon belonging to J. K. Johnson. It is estimated to furnish 700 gallons a minute from a pipe having a diameter of 4½ inches. Another is the Plankinton well, with a flow of 250 gallons and a diameter at the bottom of 3 inches. Without doubt, however, the largest flow is from the Kilborn well. With a diameter at the bottom of 3 inches, it is sufficient to keep two horizontal discharge pipes, one 4½ and the other 3 inches in diameter, constantly full. No careful estimate has been made of the amount discharged, but it must approach if not surpass 1000 gallons a minute. This is from a depth of only 300 feet, but it is believed to belong to the third water-bearing bed.

Quality of water.—Allusion has already been made to the softness of the water in the upper Benton sandstone and in the lower sandstones toward the north. In all these cases the water has a pleasant taste, many having the impression that it is quite pure, but evaporation shows that it is impregnated with some white mineral, probably carbonate of soda. It may be used with soap as easily as rain water. It does not rust iron and does not show the iron deposit about the well that is common to other artesian waters.

The waters from the second and third water-bearing sandstones toward the south and from the fourth and fifth horizons throughout the quadrangle are hard, often intensely so. They deposit a coating of rust on all objects with which they come in contact; moreover, they rapidly corrode the iron pipes used in the wells. This latter difficulty is obviated somewhat by the use of galvanized pipe, but even that in time yields at the joints, where the zinc is removed. It is the common impression that ordinary iron pipes are destroyed in less than ten years.

Varying pressure.—In general the pressure increases with the depth in different sandstones. This is true mainly because there is less chance for leakage along their eastern margin, but possibly also because of the higher altitude of the lower beds along their western margin in the Black Hills and Rocky Mountains, where the water enters. While the above rule holds in a great majority of cases, there are some marked exceptions. Perhaps the most notable is that already alluded to west and south of Letcher, where the second water-bearing bed has a considerably higher pressure and a much more rapid slope of pressure toward the southeast than are found in the next water-bearing bed below.

It seems probable, from some facts noticed in wells in the southern part of the quadrangle, that the lowest water-bearing bed has not the pressure of some higher up. This may be connected with the fact that several deep wells have been sunk in Douglas County, which perhaps have locally diminished the water from this stratum more than from those higher up.

Cause of apparent decline in pressure.—It is a fact now generally admitted that not only does the flow of wells decrease, but their first pressure declines. This becomes evident without direct measurements, first by a shortening of the distance to which the water is thrown from a horizontal pipe, and later by the fact that a stream which at first filled a pipe gradually fails to do so. In some cases a test with the gage shows that this is merely a decline in the amount of flow, without material decline in pressure, but in many cases the pressure is also found to be markedly diminished. For example, at Mitchell the water at first rose 13 feet above the surface, and it now barely reaches the surface. At Mount Vernon, where a pressure of 30 pounds was first reported, only 12 pounds is now obtained. At Plankinton the city well, which once had 55 pounds from the third sandstone, now gives only 45. The well at Letcher, which at first was reported to have 90 pounds, now shows little over 40. It seems probable, however, that in this case, as in the Plankinton well, the highest pressure first reported came from a lower stratum, which, because of imperfect packing, now communicates with one above, of lower pressure.

These facts suggest the partial exhaustion of the artesian supply, but it is claimed—and the claim is partially substantiated by facts—that new wells frequently have a pressure equal to that of the early wells supplied from the same water-bearing bed. Since the closed pressures, however, are less frequently taken than formerly, and from the nature of the case liberal margins are sometimes made for leakage, it is difficult to prove this.

In many cases diminution of flow results from the clogging of the well. As the wells are usually finished by resting the pipe on a firm stratum at the bottom of the well and perforating a portion corresponding to the thickness of the water-bearing stratum above, it will readily be seen that the surface open for the delivery of water to the well extends through the whole thickness of that stratum. As the water continues to flow, sand will gradually accumulate on the inside of the pipe and so gradually diminish the surface supplying water to the well. Something of the same sort may less frequently occur even when the pipe is fastened in the cap rock above the water rock and a cavity is made in the water rock. As time passes, sand gradually works in from the side, and possibly portions of the cap rock are undermined and drop down, so that even in such cases the freedom of the flow of the water is considerably checked.

Theoretically, the closed pressure should be the same whether the well is flowing freely or not, so long as the head of the water is the same. If the well becomes clogged, as suggested above, the only difference in the pressure should be that when a gage is attached it takes longer to reach the maximum point. As this rise may be very gradual, some errors of reading are likely to result because the observers have not waited long enough.

Another cause of decline of flow is leakage. This either may take place by imperfect closing of the pipe or may occur below the surface of the ground. As is well known, pipes deteriorate materially under the influence of most artesian waters, and it becomes almost impossible to close the joints perfectly. Where any considerable extent of piping, as in the case of the distributing pipes of a city, is included in the circuit, one can never be sure that all leaks are stopped. Doubtless the apparently diminished pressure in many older wells is due to leakage.

The diminished pressure in a particular well may sometimes be apparent only and may result from the opening of another well not far away. In such case no real closed pressure can be obtained unless both wells are closed at the same time. The distance to which this influence may extend will of course be greater where the water-bearing stratum is of coarser texture and the usual supply of water is, therefore, more free. For example, at Letcher there are two wells not far apart which are of the same depth. The pressure of either taken alone is about 40 pounds, while about a mile away another well supplied from the same water-bearing bed showed a pressure of 55 pounds, and 2 miles away one showed 65 pounds. The diminished pressures reported from Mitchell, Mount Vernon, and Plankinton are probably due to this cause. Moreover, in cases where water has been drawn freely from several wells there is, no doubt, a local depression of head which it would take considerable time to restore, possibly several days, with all the wells closed. Such a local depression of head might occur and yet no permanent diminution of supply exist.

Notwithstanding all the considerations offered thus far, it seems not unlikely that the rapid multiplication of wells in this quadrangle has really reduced the pressure a few pounds over the whole region. It is therefore important that facts should be collected and sifted to ascertain whether this is the case, and, if so, to determine the amount of diminution.

In view of such a possibility of overtaxing the supply, it would seem desirable to limit in some way the number of large wells allowed to flow freely. A single thousand-gallon-a-minute well would be sufficient to supply 144 wells, one to each quarter section in a township, each furnishing 285 barrels a day, or 7 gallons per minute, which would be an abundant supply for any ordinary farm. As it is, some large wells have been drilled with the intention of irrigating from them, and sufficient rainfall during recent years has rendered them worse than useless, for by their overflow considerable areas have been reduced to unproductive marshes.

SOILS.

No careful analysis of the soils of the region has been made and only some of the more obvious characteristics can be noted here. The soils may be broadly divided into three classes—stony, sandy, and clayey.

Stony soils are represented only in limited areas found mainly on the more abrupt slope of the highland in the southwestern portion of the quadrangle. There, as elsewhere in till-covered areas, large bowlders are found mainly on the surface. Along the moraine there are ridges that are stony and gravelly. Along the streams, especially on the abrupt edges of the higher terraces, and sometimes capping them for several rods back, bowlders, especially of smaller size, usually abound. They are portions of a horizontal stratum originally laid down in the bottom of an ancient channel. This coarse material seldom extends very far back from the edge or very far up and down the stream. It represents bowlder bars that accumulated at particular points. On some of the terraces this coarse material underlies the surface at so shallow a depth that it becomes a serious injury to the soil, because it produces too rapid underdrainage.

Sandy and loamy soils are found in the northeastern corner of the quadrangle, over both the old lake bed and the pitted plain adjoining. So, also, sand and gravel abound north and east of Mitchell, where the accumulation seems to have been on top of an old terrace and has possibly been increased in quantity by wind action, the sands being derived from the adjacent valley of Firesteel Creek.

While the soil of this quadrangle resembles that in other drift-covered regions, there are some peculiarities that need further explanation. In the morainic areas the soil varies considerably within short distances. The basins are usually covered with clayey soil, which is more pronouncedly clayey toward the center, being loamy near the margin. The loams of these areas are not only stony, as already described, but contain a great quantity of sand and gravel. The differences are not sufficient to require special treatment. Ordinary tillage so mingles the different soils that they are mutually beneficial.

A very different condition is found on the till-covered surface outside the moraine, especially where the land is unusually level. On the ordinary loamy surface of the till patches of clay are spread irregularly. These differ much in size and in depth. In wet weather these areas are very soft and miry, and in dry weather very hard and frequently seamed with mud cracks. They are usually covered with what is commonly called alkali grass, which in the latter part of the summer is dead, while the blue joint and other grasses on the loamy surfaces about them are still green. Sometimes the alkali in these spots is so abundant that they become barren. Frequently they are depressed below the level of the ground about them. This may be due partly to the wind blowing away the bare ground and partly to the buffalo in previous times licking the alkali at one time and wallowing in the mud at others. In a few shallow cuts near Plankinton it was noticed that the clay extended horizontally and that it and the loam were somewhat interstratified. It is possible that this peculiar feature of the country is due to bowlders or masses of Cretaceous clay that were brought by the ice and deposited without mingling with the other ingredients of the till. Another and more probable explanation is that alkaline water, gathering in depressions on the surface, dissolved out the silica, or fine quartz sand, in the till, leaving only the clay. These spots, though producing a marked impression on the vegetation of the natural surface, are not found to seriously interfere with cultivation. The alkali, if not too concentrated, is probably a help rather than a hindrance. Where it is collected in a large basin, so as to be persistent at one point in spite of cultivation, drainage and the addition of arenaceous material are the only remedies applicable.

Inside of the moraine, especially in the flat country east of Morris Run, irregularities of a different character are found. In that region there are over the surface low knolls and ridges, rarely more than a foot in height, on which buffalo grass grows, while the intervening surface is covered with blue joint. A section shows that the general surface is sandy, while the ridges are clayey. Apparently the knolls are projections of the till, while the sandy loam was deposited in the depressions by water or wind. In some places a fine, loess-like silt several inches deep is found covering the till subsoil. Possibly the thick growth of buffalo grass holds the fine dust better than the surrounding grass, and so causes it to accumulate. This spotted surface is not due to the presence of alkali, and it yields more readily to tillage than those already described.

July, 1903.