DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 34

GEOLOGY AND WATER RESOURCES OF A PORTION OF SOUTHEASTERN SOUTH DAKOTA.—TODD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1900

IRRIGATION REPORTS.

The following list contains titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888–89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889–90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890–91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, in two parts; Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; and "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND WATER RESOURCES

OF A PORTION OF

SOUTHEASTERN SOUTH DAKOTA

BY

JAMES EDWARD TODD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1900

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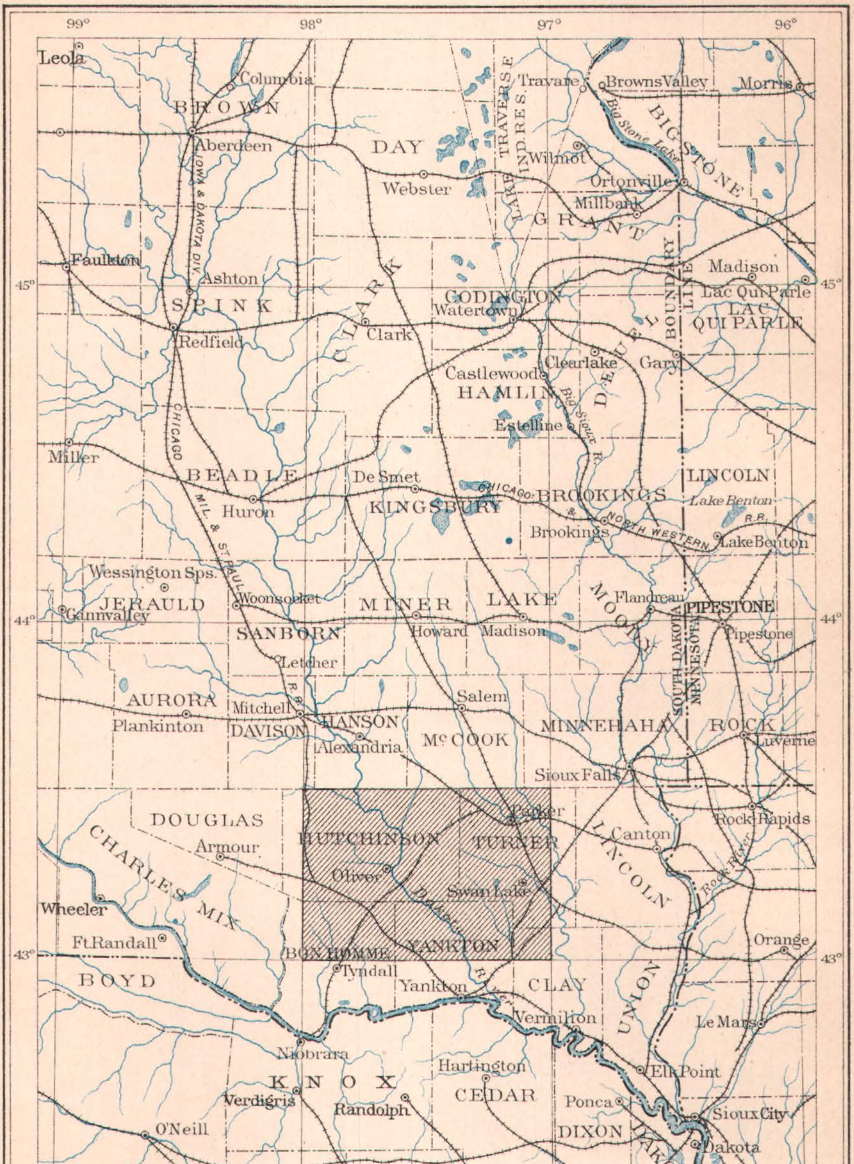
DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, February 15, 1900.

SIR: I have the honor to transmit herewith a manuscript giving the results of investigations of underground waters of a portion of southeastern South Dakota, prepared by Prof. James E. Todd, and to recommend that it be printed in the series of Water-Supply and Irrigation Papers.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



INDEX MAP OF EASTERN SOUTH DAKOTA

Showing area under consideration

BY J. E. TODD 1899.

Scale

25 0 25 50 MILES

JULIUS BIEN & CO. N.Y.

GEOLOGY AND WATER RESOURCES OF A PORTION OF SOUTHEASTERN SOUTH DAKOTA.

By JAMES E. TODD.

LOCATION OF REGION.

The area to which this paper relates is represented on the Olivet and Parker sheets of the Topographic Atlas of the United States, published by the United States Geological Survey.[1] It occupies large portions of Turner and Hutchinson counties, and small portions of Bonhomme, Yankton, and Clay counties, South Dakota. It is especially instructive from the fact that it includes typical areas of the valleys of James and Vermilion rivers, and Turkey Ridge, which forms a portion of the divide between the two streams. Moreover, it exhibits characteristic features of two kinds of artesian supply, viz, that from the Dakota sandstone, and that from the sands underlying the drift. It also exhibits plainly the typical conditions of most forms of shallow wells, as well as the tubular wells common to the eastern portion of South Dakota. The region for the greater part is prairie and rarely so rough as to be unfavorable for ordinary agriculture. It includes wider ranges of altitude than most areas of similar extent in the Mississippi Valley; in the immediate valleys of Vermilion River, Clay Creek, and James River the surface is not over 1,180 feet above the sea, while in the northern culmination of Turkey Ridge it reaches 1,750 feet, and in the southwestern portion of the region it attains an altitude of 1,650 feet, which is considerably below the higher points of the Choteau Creek Hills a little farther west.

GENERAL GEOLOGY.

Nearly the whole surface of the area is covered with glacial drift. The exceptions are the alluvial flats in the larger valleys, and scattered exposures of older rocks occurring mainly along the sides of the canyons in the southern part of Turkey Ridge and in the bottoms of the

[1] These sheets may be procured at 5 cents each by addressing The Director, United States Geological Survey, Washington, D. C.

river channels. The strata lie nearly horizontal everywhere. No folds, faults, or igneous outflows have been discovered. Frequent borings have been made to a depth of 200 or 300 feet in obtaining wells, and a few have been sunk to 600 or 700 feet. These have furnished important facts concerning the position of strata below the surface.

ALGONKIAN.

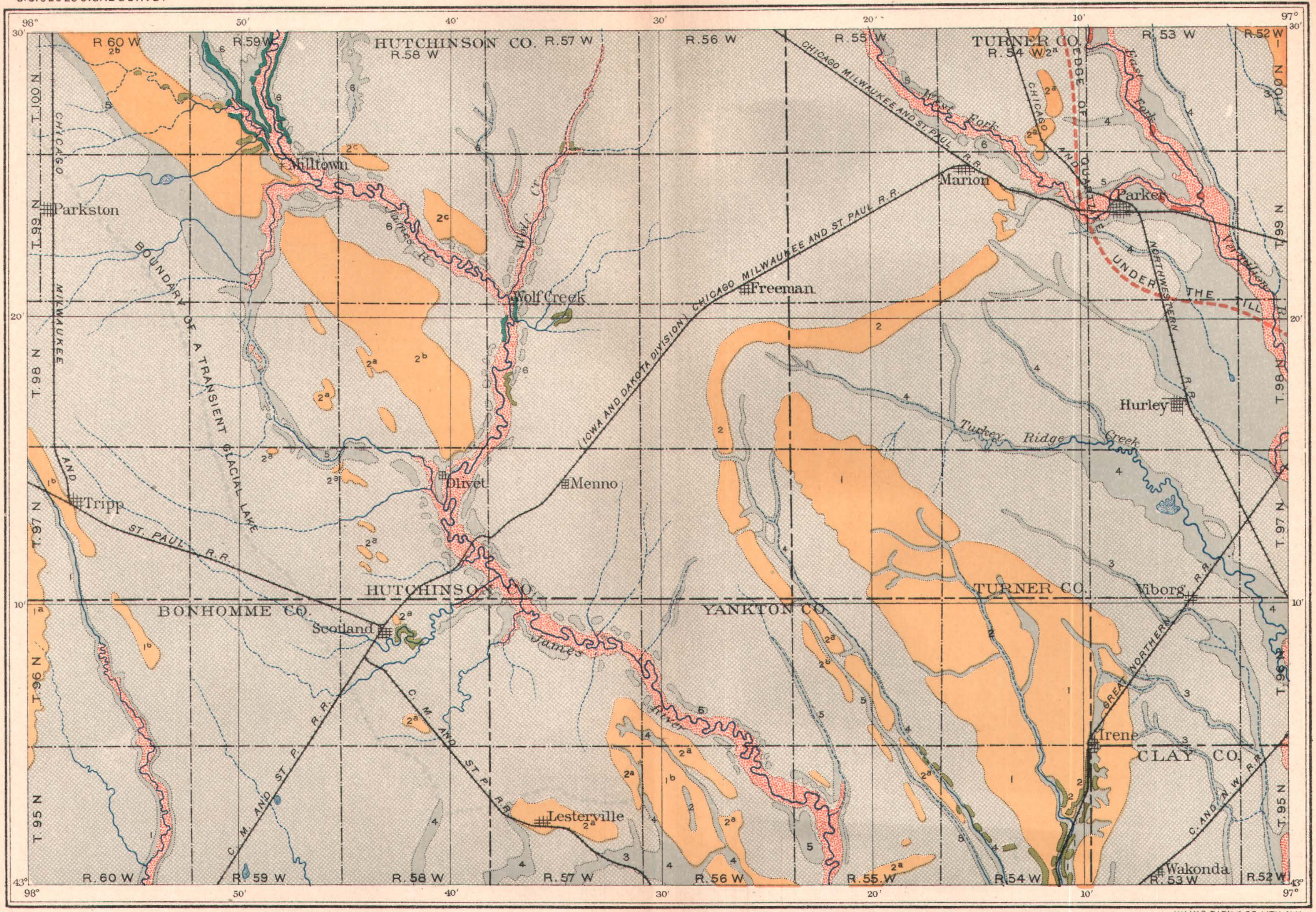
SIOUX QUARTZITE.

The oldest rock exposed in natural outcrops or by borings is the Sioux quartzite, a name given by Dr. C. A. White, when State geologist of Iowa. Exposures are found at a number of points along the East Fork of Vermilion River from the north line of Turner County to the vicinity of Parker, their location being indicated on Pl. III. Borings some distance from these exposures have shown that this formation is "bed rock," and the depth to its surface is indicated upon the map (Pl. IV). The rock is frequently called Sioux Falls "granite," from the extensive exposures and numerous quarries in the vicinity of Sioux Falls. It is for the most part a red or purplish quartzite of intensely compact and durable character, and is susceptible of a fine polish. It lies in strata which dip generally to the north at an angle of 3° to 5°. In sec. 8, T. 100 N., R. 53 W., it is in layers which are generally not more than 6 inches in thickness. East of Parker it is more massive, and the layers are 2 or 3 feet in thickness. No trace of slate or pipestone has been found in any of these exposures. No fossils have been noted in the formation anywhere, except some small lingulæ found by Prof. N. H. Winchell near Pipestone, Minnesota.[1] This formation is generally referred to the Algonkian. Its thickness has not been determined. At Sioux Falls a boring 500 feet deep revealed no important difference in the character of the rock.

THE PALEOZOIC GAP.

In this region there are no traces of Paleozoic formations nor of the Triassic and Jurassic of Mesozoic time. The surface of the Sioux quartzite shows marks of long erosion at an elevation of several hundred feet above sea level. The nearest occurrence of Paleozoic rock that has been discovered is in the borings at Ponca, Nebraska, and Sioux City, Iowa. While the mountain masses of the Appalachian region and the extensive coal fields of the eastern part of the Mississippi Valley were forming this area was probably a barren mountainous region. It is possible that soils and vegetations which may have extended over it were removed by the advance of the sea during Cretaceous time. At any rate, no traces of soil are now found upon

[1] Sixteenth Ann. Rept. Geol. Nat. Hist. Survey Minnesota.



GEOLOGICAL MAP OF A PORTION OF EASTERN SOUTH DAKOTA

BY J. E. TODD 1899

Scale

5 0 5 10 15 MILES

LEGEND

ALGONKIAN	CRETACEOUS		PLEISTOCENE			
SIOUX QUARTZITE	DAKOTA FORMATION	COLORADO FORMATION	MORAINES (Numbered in order of occupation)	TILL	ANCIENT CHANNELS (Numbered in order of occupation)	ALLUVIUM

the surface of the quartzite. Since several hundred feet of strata of marine origin, representing all the ages of Paleozoic time, are found in the Black Hills, the shore of the Paleozoic sea must have extended across South Dakota somewhere west of the present course of the Missouri River. Moreover, as the Triassic formations of the Black Hills testify to an inclosed sea, barren of life, we must believe that during that epoch this inland sea was detached from the ocean.

CRETACEOUS.

Resting upon the Sioux quartzite, as revealed by borings, there are sands, chalk, and clays belonging to the Cretaceous. We have no trace of the earlier beds which represent this age elsewhere, but several hundred feet of the later Cretaceous deposits underlie much of the area.

DAKOTA SANDSTONE.

Resting upon the quartzite, as shown by many borings, there is a series of sandstone and shale which Dr. F. V. Hayden, the first United States geologist who examined this region, named the Dakota formation, from extensive outcrops near the town of Dakota, in Nebraska. This formation is only exposed in this area along James River and Twelvemile Creek above Milltown, and about the junction of Wolf Creek and James River. Its general distribution underground is, however, well shown by the borings of the deeper artesian wells. From these data the formation is known to underlie the area, except in the region about Parker and northeastward. As the surface of the quartzite is uneven and the upper portion of the Dakota sandstone is more or less eroded, the margin is quite ragged and uneven. In the southern part of the area, the Dakota deposits probably have a thickness of 300 or 400 feet, but as deep borings in that region are few, and none are known to have penetrated to bed rock, this is only an estimate. From borings in this area and from exposures elsewhere, it is known that the formation is composed of sheets of sand or sandstone more or less completely separated by thick beds of clay and shale. The sandstone strata are usually of fine-grained, well-washed materials, and vary in thickness from 10 to 100 feet. The clay deposits are in general thick, and very often form a hard shale; locally they include compact limestone, plastic clay, and iron pyrites. The last is very hard and forms a serious obstacle in drilling. The number of sand strata which are water bearing increases toward the south, where the formation thickens.

In eastern South Dakota the upper part of the sandstone is a stratum generally presenting harder layers often spoken of as "cap rock." They are sometimes so hard as to give the impression that the red quartzite has been struck, but in all cases, so far as known, the cement is calcareous or ferruginous rather than siliceous, as in the quartzite. Its calcareous character is revealed by use of an acid, which causes effervescence; the ferruginous cement is shown by its dark color.

The Dakota sandstone underlies all the area except a small district near Parker. It is exposed extensively along the James River and Twelvemile Creek above Milltown, and also near the mouth of Wolf Creek. At the latter place it seems to be in a low arch or anticline lifted to a height of 25 or 30 feet above the level of the James River. The principal exposures are upon the west side of the river, in sec. 6, T. 98 N., R. 57 W. The material here is a soft, irregularly stratified sandstone scarcely hard enough for building purposes. Exposures on the James River above Milltown begin about a mile above that point in the form of low barren slopes on both sides of the river, which gradually rise until south of Elmspring the upper portion of the formation is about 60 feet above the level of the James River. Here it exhibits a few castellated cliffs. About 1½ miles south of Elmspring, upon the east side of the valley, the following section is exposd:

Section 1½ miles south of Elmspring, South Dakota.

	Feet.
Slope of till	50
Soft brown sandstone, some pebbles above; irregularly stratified, springs below	35
Slope mostly clay, evidently Dakota, to the level of the James River	20

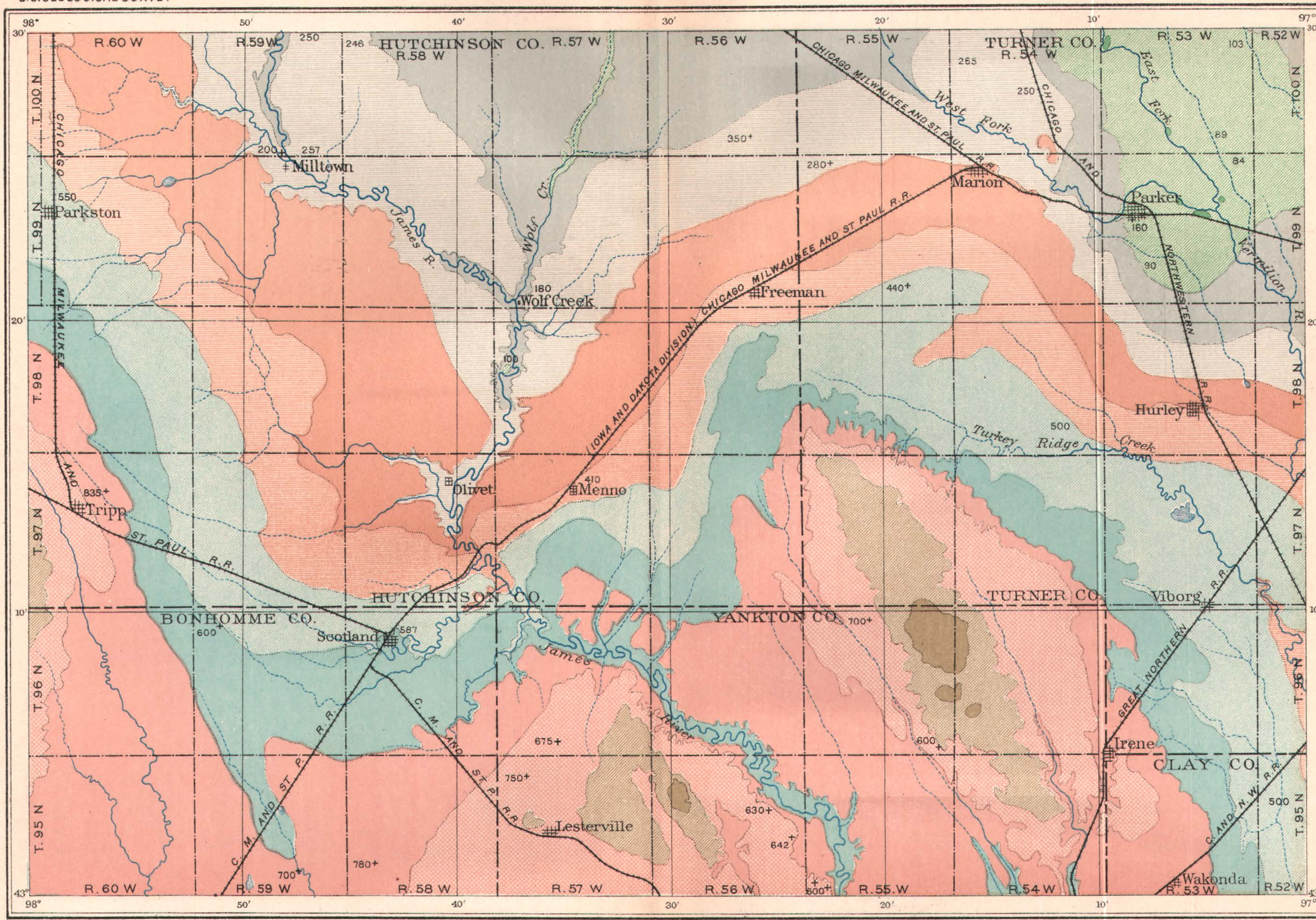
Farther south, about a mile above Milltown, the sandstone is more perfectly consolidated and shows much oblique lamination, and it has been quarried to some extent for building purposes. The sandstone appears on both sides of Twelvemile Creek, following the main stream for 3 or 4 miles. North of the northeast corner of sec. 34, T. 100 N., R. 59 W., it has been quarried considerably. The following section of a well near Elmspring exhibits this formation more completely:

Section in well at Elmspring, South Dakota.

	Feet.
(1) Yellow and blue clay (till) with water at 60 feet	83
(2) Sandstone	8
(3) Sand	20
(4) Sandstone and clay, irregularly stratified	20
(5) "Blue clay" (shale), with one or two strata of sandstone	116
(6) Red quartzite	70

All except No. 1 and No. 6 belong to the Dakota formation.

The formation thickens by the intercalation of other strata, both toward the west and south. Near the James River, at the southern portion of the area, wells indicate that the Dakota formation may be from 300 to 400 feet in thickness. A characteristic view of the upper portion of the formation, as shown on the Firesteel northwest of Mitchell, is given on Pl. IX, *A*.



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Note: Figures denote depths of borings
If without + sign quartzite was met with at that depth
All depth areas estimated averages
The quartzite surface has many local irregularities

MAP OF A PORTION OF EASTERN SOUTH DAKOTA

Showing depths to bed rock

BY J. E. TODD 1899

Scale

5 0 5 10 15 MILES

0' | 0'-100' | 100'-200' | 200'-300' | 300'-400' | 400'-500' | 500'-600' | 600'-700' | 700'-800' | 800'-900' | 900'-1000' | 1000'-1100'

COLORADO FORMATION.

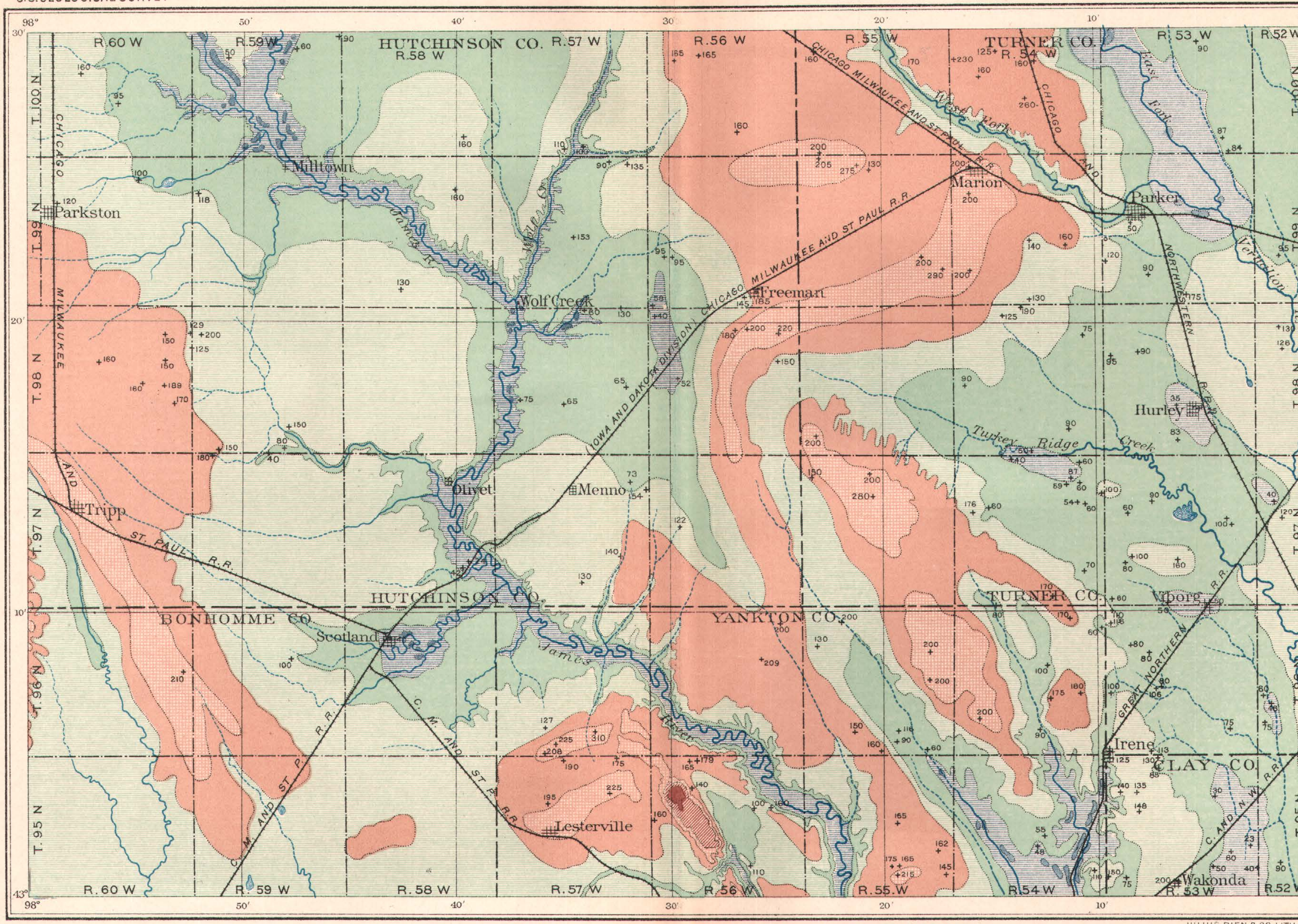
This includes two series of deposits, which were first separated by Dr. F. V. Hayden. The lower series, composed mostly of shale and clay, was named Benton, from its great development near Fort Benton, Montana, and the upper series, composed largely of chalkstone, was called Niobrara. These two subdivisions, though usually differing considerably in lithologic character, are often grouped together because of the similarity of the fossils which appear in them. Moreover, the line between them is not easily established, because in many places the chalk grades into the clay and shale; and even when fairly pure, enough protoxide of iron is present to give it a bluish tint resembling the shale. It has been found very difficult to separate them in this area by means of the reports of well-borers. One well-borer will say that within a given region he has struck no chalk, but has struck shale and clay. Another will distinguish between the chalk and the clay, recognizing the fact that the former differs from blue shale or "soapstone," while a third may speak of the chalk as a fine sand. Practically, the distinction which is most obvious to the well-borer is that chalk does not become plastic by becoming wet, but acts more like fine sand. On the other hand, the shale, or "soapstone," as it is frequently called, becomes plastic and sticky, and not easily distinguished from the clay except by its hardness.

The Colorado formation is exposed in this region only at a few localities, which are indicated upon the map, viz: Along the South Fork of Twelvemile Creek; on Wolf Creek, about 6 miles above its mouth; 2 or 3 miles south and east of the latter point, and still more prominently in the vicinity of Scotland. It also appears conspicuously along Turkey Creek between Irene and Volin, and also along Clay Creek north of the latter place. From a study of the formations along the Missouri River it is inferred that the Niobrara chalkstone is quite evenly stratified, compact, with some of its layers forming a hard limestone, but more frequently the clayey material is more prominent. From the exposures along the river it would seem that it has a thickness of 150 to 200 feet. Its original thickness was probably not uniform, but it was accumulated in large lenticular masses.

At Scotland and near Milltown the stone has been quarried and used for building. When first taken out it is easily cut with a knife and shaped to any form desired. When thoroughly seasoned it resists the weather so that buildings formed of it have stood for twenty-five or thirty years. When exposed upon a slope it crumbles under the action of frost and becomes a white earthy mass. The protoxide of iron, which colors it blue or light gray when exposed to the weather, becomes a yellow oxide or a carbonate, so that where it is near the surface the chalk soon becomes a light yellow or pure white color. It contains fossils that characterize it elsewhere in the Missouri River Valley, including *Ostrea congesta*, different species of *Inoceramus*, some of them of large size, but usually much broken; a large shell apparently a *Pinna*, and numerous scales and teeth of fishes, both of sharks and common bony fishes. Elsewhere the bones of large reptiles have been found in this formation, but as yet none have been found in it in this area. The chalk rarely shows noticeable shells of Foraminifera, but the mass of the deposit is found by microscopic examination to be composed of coccoliths and other minute organisms found in the chalk elsewhere. At some points the chalk is found to pass laterally into a light-gray clay, and it would seem that chalk and clay might have been formed contemporaneously in neighboring parts of the sea bottom. The difficulty of determining the real thickness of the chalk in this region arises from the fact that well-borers do not readily distinguish between it and the overlying and underlying clays and shales. In no case has it been reported thicker than 100 feet except at Tripp, where it is stated to be nearly 300 feet thick. It is probable that it varies greatly in different localities, though in general it appears to thicken toward the southwest, like the other formations which we have considered. It has not been so much removed by erosion in that direction.

The Benton shale is not clearly exposed at any point in this area. From the study of it along the Missouri River it is found usually to be composed of a dark clay, easily absorbing water and quickly becoming very plastic. At a locality southwest of Mitchell it is excavated for making brick, and one quite striking feature is that the sides of the pit are constantly sliding in, and even in the adjoining prairie the slope is marked with crevasses or cracks, indicating its creeping nature. Similar features have been noted in sec. 33, T. 100 N., R. 59 W., on a slope above the Dakota sandstone and below the level of the chalkstone. It is impossible to estimate the thickness of the formation with any accuracy, but there is clear evidence that the clayey member corresponding to the Benton is found here in considerable quantity. It is probably 50 feet thick. Elsewhere it has been reported in borings as underlying the chalkstone and lying on the sandstones of the Dakota.

Before the deposition of the Colorado formation the Dakota sandstone seems to have been somewhat eroded, especially in the highest portions adjoining the quartzite. Possibly this was due to "contemporaneous erosion" rather than to true unconformity; that is, it was due to the action of tidal currents or waves cutting out channels without any exposure to the action of streams upon a land surface. Moreover, the Colorado overlaps considerably beyond the edge of the Dakota sandstone.



+210 (etc.)
Representative wells and their depth in feet which obtain pump water at base of till

MAP OF A PORTION OF EASTERN SOUTH DAKOTA

Showing depths to waters at base of the till

BY J.E. TODD 1899

Scale

5 0 5 10 15 MILES

0′ | 0′-50′ | 50′-100′ | 100′-150′ | 150′-200′ | 200′-250′ | 250′-300′ | 300′-350′

PIERRE SHALE.

Pierre shale follows next in succession to the Colorado formation, and is very thickly developed along the Missouri River above the Niobrara chalk. It undoubtedly overlies that formation also in the Choteau Creek Hills, though it has not been distinctly recognized there in exposures or in wells. Upon Turkey Creek, on the east side of sec. 11, T. 95 N., R. 54 W., a few feet of dark, plastic clay overlies the chalkstone, which doubtless is Pierre. Careful examination will probably reveal other similar exposures. It is a formation which often contains remains of marine reptiles and many cephalopod shells. The shales are quite calcareous and their fossils are frequently embedded in large concretions of limestone.

TERTIARY DEPOSITS.

The only natural exposures in the area under consideration which may possibly belong to the Tertiary are beds of a yellow loam resembling loess, which occur overlying the Cretaceous at several points on Turkey Creek, also southeast of the mouth of Wolf Creek. These are underneath the glacial drift and may possibly belong to the Pliocene. Borings in the higher portions of Turkey Ridge and the Choteau Creek Hills reveal thick deposits of sand underneath the till. These also may belong to the Tertiary, and may be even as old as the Loup Fork. On the other hand, it is possible that they are accumulations preceding the deposition of the drift during the Pleistocene. No fossils have been discovered, so no conclusion can be confidently expressed as to their age.

PLEISTOCENE DEPOSITS.

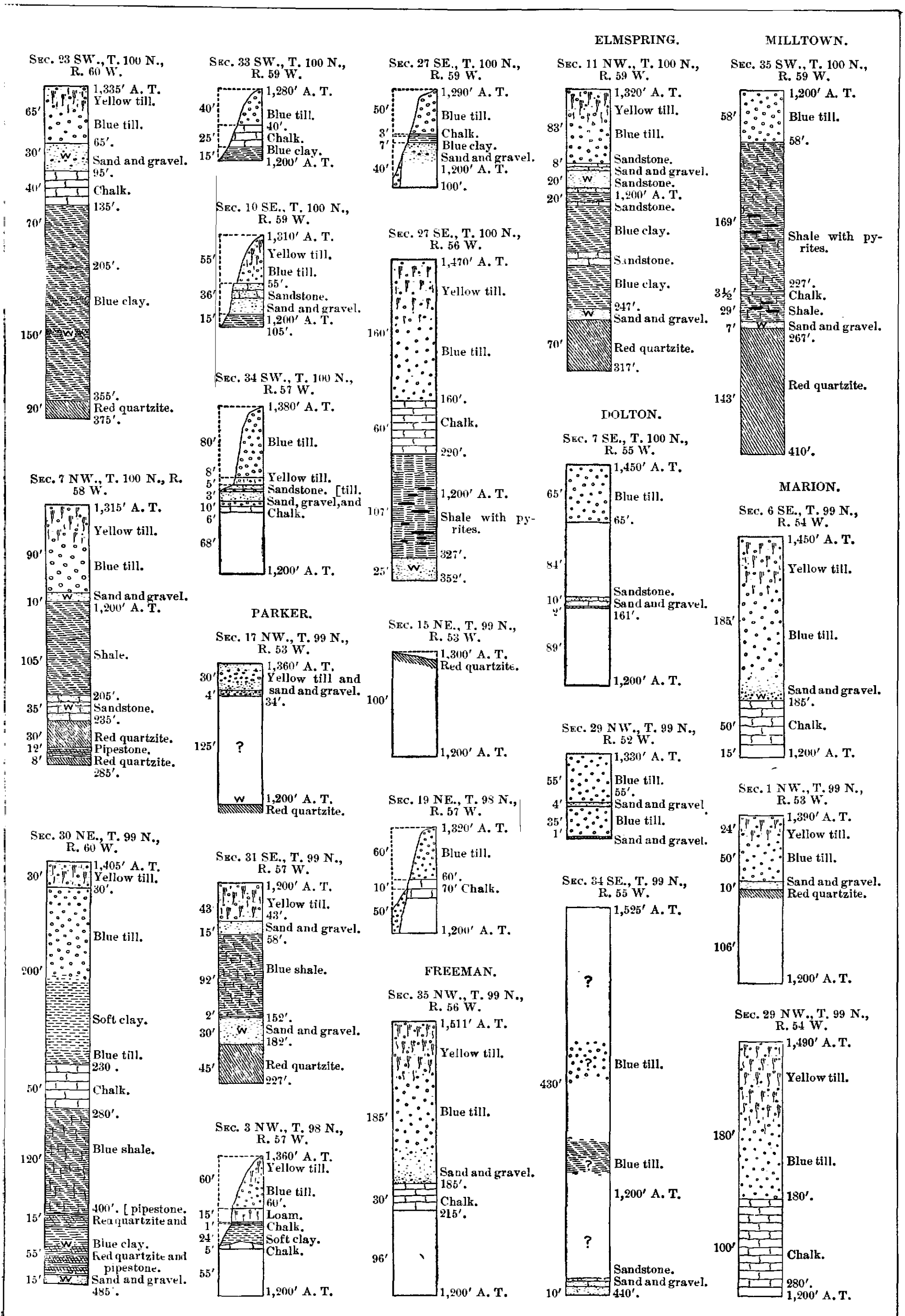
In this region the Pleistocene deposits are very prominent and cover very nearly the entire surface. All the exposures of older rock do not occupy more than 4 or 5 square miles. The deposits of this epoch may be enumerated in chronological order, as follows: (1) The preglacial or circumglacial sands and gravels; (2) the glacial till or bowlder clay, separable into the upper or yellow bowlder clay and the lower or blue bowlder clay; (3) the moraines, which include those of two distinct epochs, with minor subdivisions; (4) terraces and ancient channels, which may be referred to three or four different stages of the glacial occupation of the country; (5) alluvium.

PREGLACIAL OR CIRCUMGLACIAL DEPOSITS.

The preglacial surface was probably covered with silt and clays resembling those of the region now found west of the Missouri. The surface there, however, is probably now eroding faster than at that time, for the base-level of drainage was probably much higher relatively and of gentler grade. The hillside wash and alluvium was perhaps more marked than is now found in the trans-Missouri region, but as the ice sheet, which resembled that of Greenland at the present time, slowly advanced from the north there was spread before it almost everywhere a fringe or apron of torrential deposits. Heavy sand and gravel bars accumulated along the channels of the principal streams leading from the ice sheet. A less amount of similar deposit was accumulated in all water courses as their upper portions began to be supplied from the melting ice. Hence, most of the surface became covered with a nearly continuous but uneven layer of sand and gravel, and as the result of the process we find to-day nearly everywhere below the till, or blue clay, of this region a stratum of sand and gravel, containing in most cases abundant water. The finer portions of preglacial soil and surficial deposits of that time seem to have been washed away, leaving the sand clean and porous. This deposit of sand, which may be compared to a blanket, lies over the uneven surface of the Cretaceous clays, mantling the upland as well as the lowland. It appears to be generally thicker upon the higher points, where its accumulation may have been due in part to the action of winds. It is needless, perhaps, to remark that the sands of this deposit, like the bowlder clay above, contain pebbles of granite, greenstone, and limestone. This deposit is rarely exposed, but there are a few places along the base of the bluffs of the James River where it appears. The more notable ones are about a mile below Milltown, and at intervals for 2 or 3 miles above the mouth of Wolf Creek. It may be recognized at other points by the appearance of springs near the level of the stratum. It appears, usually with less thickness, above the older rocks wherever they are exposed. There, however, it is less frequently the source of springs, because such points are more elevated, and because the bowlder clay has crept down and covered it more often than where it has been more recently exposed by the action of the streams. Sometimes this deposit attains a thickness of 100 feet, but generally it is very much thinner. In some cases it may be entirely wanting, so that the well-borer passes from the bowlder clay into the Cretaceous beds without noticing the transition. This formation plays an important part in the water supply of the region and will be further described under that head.

TILL OR BOWLDER CLAY.

This formation presents the same features that are found in corresponding regions elsewhere, as in central Minnesota, Iowa, and Illinois. It is an unstratified mixture of clay, sand, and worn pebbles and bowlders, the last mentioned sometimes attaining a diameter of several feet. In this formation are found local developments of stratified sand, commonly spoken of as pockets, though they are



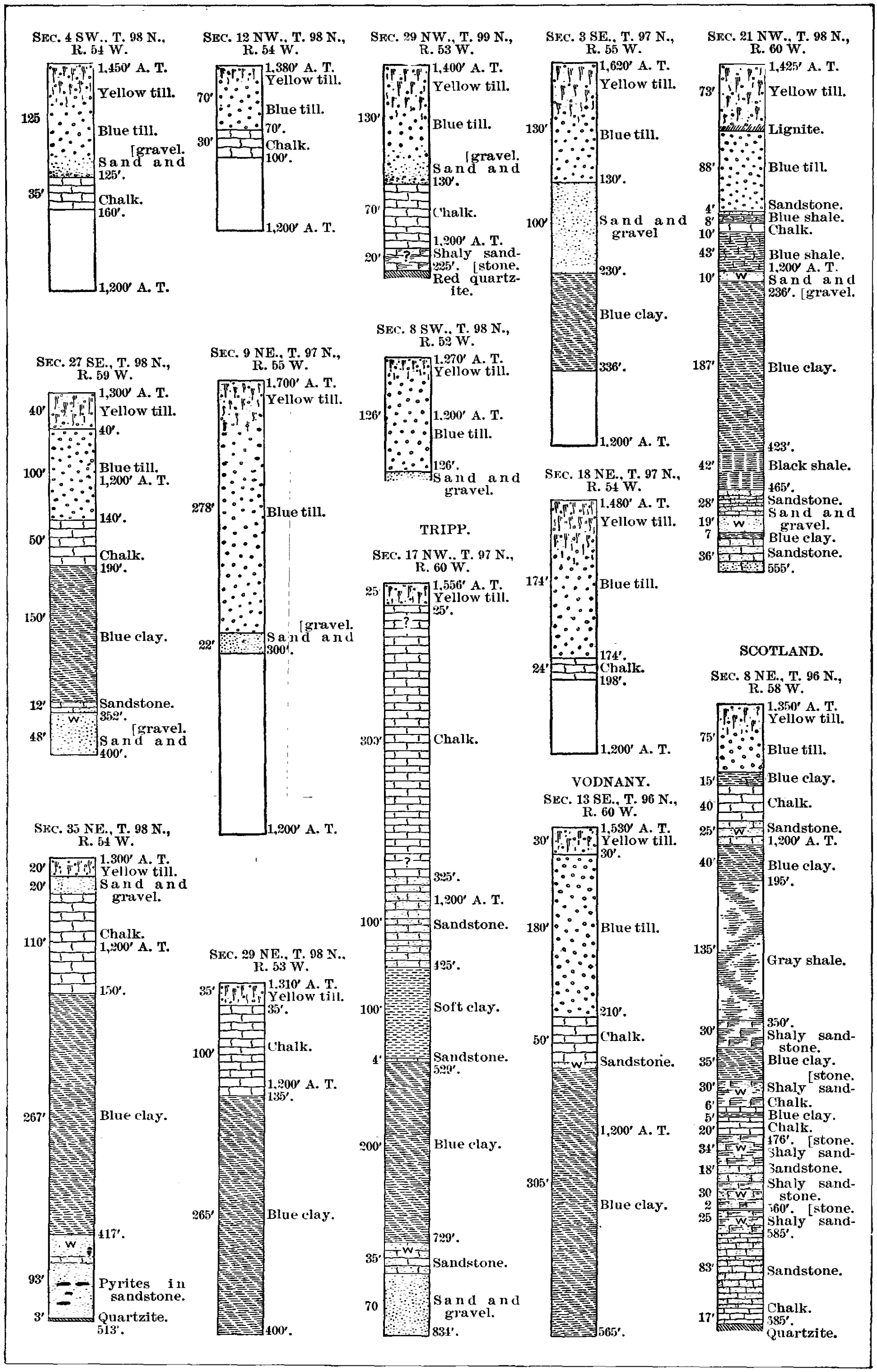
LOGS OF WELLS IN HUTCHINSON COUNTY, SOUTH DAKOTA.

sometimes known to be portions of channels of considerable length, and also of sheets that may locally separate the bowlder clay into two or more members. The till of this region is much more clayey than at points farther east because for some distance the ice had 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 bowlders most widely distributed are gray and reddish granites, and peculiarly compact and fine-grained limestones of a straw color or clear white. The latter contain *Favosites* and cup-corals, with occasional Brachiopods, indicating their Paleozoic origin. Next in prominence are bowlders of a fine-grained trap or greenstone. Besides these, in some portions of the area, a large percentage of the erratics, usually those of smaller size, came from a red quartzite ridge lying to the north. The distribution of these is so remarkable about Turkey Ridge as to attract popular attention. In the main part of this ridge they form about 90 per cent of all bowlders, but outside of or across the valleys of Clay and Turkey Ridge creeks they are very rare. The till varies in thickness from 80 to 250 feet. In general it is thickest upon the higher elevations—as, for example, the Choteau Creek Hills and James Ridge. Near the exposures of the older rocks, which we may suppose to represent points that have resisted preglacial erosion so that they are relatively more elevated, a thickness of less than 50 feet is found, as in the vicinity of Scotland and Elmspring, but over the even surface between Parkston and Olivet it amounts to 125 or 150 feet. Between the Choteau Creek Hills and James Ridge the thickness is frequently 300 feet. It is probable that the thickness is not very uniform and may vary greatly within short intervals. Apparently the surest evidence of reaching the bottom of the till is that the water when struck rises promptly and to a considerable height. This is a fact which well-borers remember and recognize more distinctly than any discrimination of material, for pebbles and bowlders are found in both the till and the sand below. It is not uncommon for two neighbors to sink wells, one having to go to a depth of 250 or 300 feet, while the other may obtain water within 150 or 200 feet. This evidence is not always decisive, for there are sometimes within the till local developments of sand which yield abundant water. However, in many cases the wells have gone farther and demonstrated that in such cases, no till is found below the sand.

It has been noted in other regions that the till consists of two or more numbers belonging to different epochs, and it would seem not improbable that such occurrences may be discovered in this area, but thus far we have been unable to ascertain that this is the case. This is the more remarkable when we consider the number of borings which have extended not only through the till, but to the Dakota sandstone below. However, since well-borers are not discriminating in this matter, more careful observations may eventually reveal the fact that such a division of the till really exists, at least in the vicinity of moraines. We may mention in this connection a singular phenomenon which occurs about 6 miles east of Wolf Creek colony. In the extreme northeastern corner of T. 98 N., R. 57 W., and in the sections adjoining, are three or four flowing wells obtaining water from a depth of from 55 to 65 feet, while 1½ miles farther west no water is obtained until a depth of about 150 feet is reached, and then it has not sufficient head to flow. This would suggest a division of the till into two members, separated by a sand deposit which does not extend to the second locality mentioned above. This may prove to be a separation of the earlier and older deposit of till, and may extend farther east, and may be caused by the recession and readvance of the ice, corresponding to the interval between the Altamont and Gary moraines. Another explanation may be equally satisfactory, viz, that at one time there existed in the region of flowing wells a subglacial channel which deposited a sheet of sand, which would be strictly subglacial, upon the formation of till already laid down by the glaciers while the till above was of englacial origin and was deposited above the sand deposits of said stream during the final melting of the ice sheet. Similar suppositions may explain similar flowing wells both north and south of the area named and also east of Parkston.

As elsewhere, the upper part of the till has, when weathered, a light buff or yellowish color. This is so prevalent that it is only at unusually recent natural exposures, or in the digging of deep wells, that the blue character of the unweathered till appears. An impression prevails that it differs materially in character from the yellow till, since the yellow till contains water, often in considerable quantity, which supplies the shallow or surface wells of the country. It is a general rule that if sufficient water is not struck before the blue clay is reached, no more can be expected until that formation is completely penetrated. The blue clay is frequently spoken of as joint clay, from the fact that it is usually divided into polygonal masses by irregular joints crossing one another. These allow slight motion whenever the formation lies upon a slope, so that in the vicinity of streams, though less plastic than the Cretaceous clays, it is subject to landslides, which cause it to cover the underlying sands.

The surface of the till, as elsewhere, abounds more or less in shallow basins or lake beds, which may be filled with water in the wet season. In some localities these are so deep that they retain water several feet in depth year after year, but more frequently they are dried up by the advancing summer and are capable of tillage. Since none of them are supplied except by rainfall, even the deepest are apt to become empty after a succession of dry years.



LOGS OF WELLS IN HUTCHINSON COUNTY AND IN NORTHEASTERN PORTION OF BONHOMME COUNTY, SOUTH DAKOTA.

MORAINES.

These are local developments of the till in the form of elevated ridges, usually with the surface rougher than elsewhere. In other words, the surface rises into abrupt ridges or knolls perhaps to the height of 25 or 30 feet, though we do not find the best examples of such topography in this area. The intervening depressions and basins are also more numerous than elsewhere. Moreover, the moraines usually present a larger number of bowlders and beds of gravel, and bear other marks of abundant and free-flowing water. They are generally looked upon as marking the line where the edge of the ice sheet remained stationary for a considerable length of time. While the ice gradually brought materials to that point, the process of melting prevented its farther advance, and as the ice melted the clay and gravel contained in it were dropped along its edge. With this explanation we can easily understand how some areas would be much more abundantly supplied with materials than others, because of differences in velocity and load of the ice and in its relation to the attending waters. We rarely find the edge of the ice sheet clearly marked for any great distance by morainal deposits. The moraines are usually best developed at higher levels. Where the edge of the ice sheet rested in still water, whether in a lake or a sluggish stream, the material brought up by the ice would be widely distributed by the water and a comparatively level surface would be formed. Where the edge of the ice was washed by the stream for some distance, the material contributed by the ice would be carried away and hence not deposited as an accumulation.

In the area under consideration we have portions of two systems of moraines, with minor subdivisions. These are believed to belong to the Wisconsin stage of the Glacial epoch, and are known as the first, or Altamont moraine, and the second, or Gary moraine. The first moraine includes the hills in the northeastern corner of the Parker quadrangle, and the main portions of Turkey Ridge and James Ridge, and the whole of the Choteau Creek Hills. The surface in all these areas is more elevated than the region within the moraine, and is usually marked with stony hills, with more numerous and deeper basins between.

The second, or Gary moraine, is represented by the ridge beginning east of the West Fork of the Vermilion and forming the divide between it and the East Fork of the Vermilion. It passes south and southeast around the head of Turkey Ridge, then south along the east side of the same to the southern line of the area, where it turns west and skirts the eastern slope and around the northern end of James Ridge; thence, for several miles, it is imperfectly represented by the ridges near Lesterville and the gravelly hills at Scotland. These seem to mark the earlier stage of its deposition. North of Olivet it again appears more continuous, but of subdued form, and extends northwest along the divide south of Twelvemile Creek to the northwest corner of the area. In general, this moraine is of lower elevation than the first, and has its knolls less prominent. Its highest portion is southeast of Freeman, where it attains an altitude of more than 1,600 feet.

ANCIENT DRAINAGE SYSTEMS.

Connected with these moraines are ancient systems of drainage, quite distinct at several points from those of the present time. We will not dwell upon them further than to call attention to some of the more notable cases. During the occupation of the first moraine the drainage from between the lobes of ice occupying the Vermilion Valley and the James was by means of Turkey Creek and its branches. Similarly, upon James Ridge, between the James River lobe of ice and the one to the west, are imperfect traces of a similar system. During the occupation of the second moraine the drainage was largely down the present course of the West Fork of the Vermilion River, Turkey Ridge Creek, Clay Creek, and Beaver Creek, and at that time a lake of considerable extent occupied the Vermilion Valley, east of Hurley. A much more transient one also occupied the region west of the ice sheet northwest of Scotland, which, for a time, drained toward the south into the upper part of Beaver Creek, but soon found its outlet down the James River Valley. The latter stage of this lake seems to have persisted along the valley of Dry Creek, east of Parkston, until the formation of the later part of the Gary moraine.

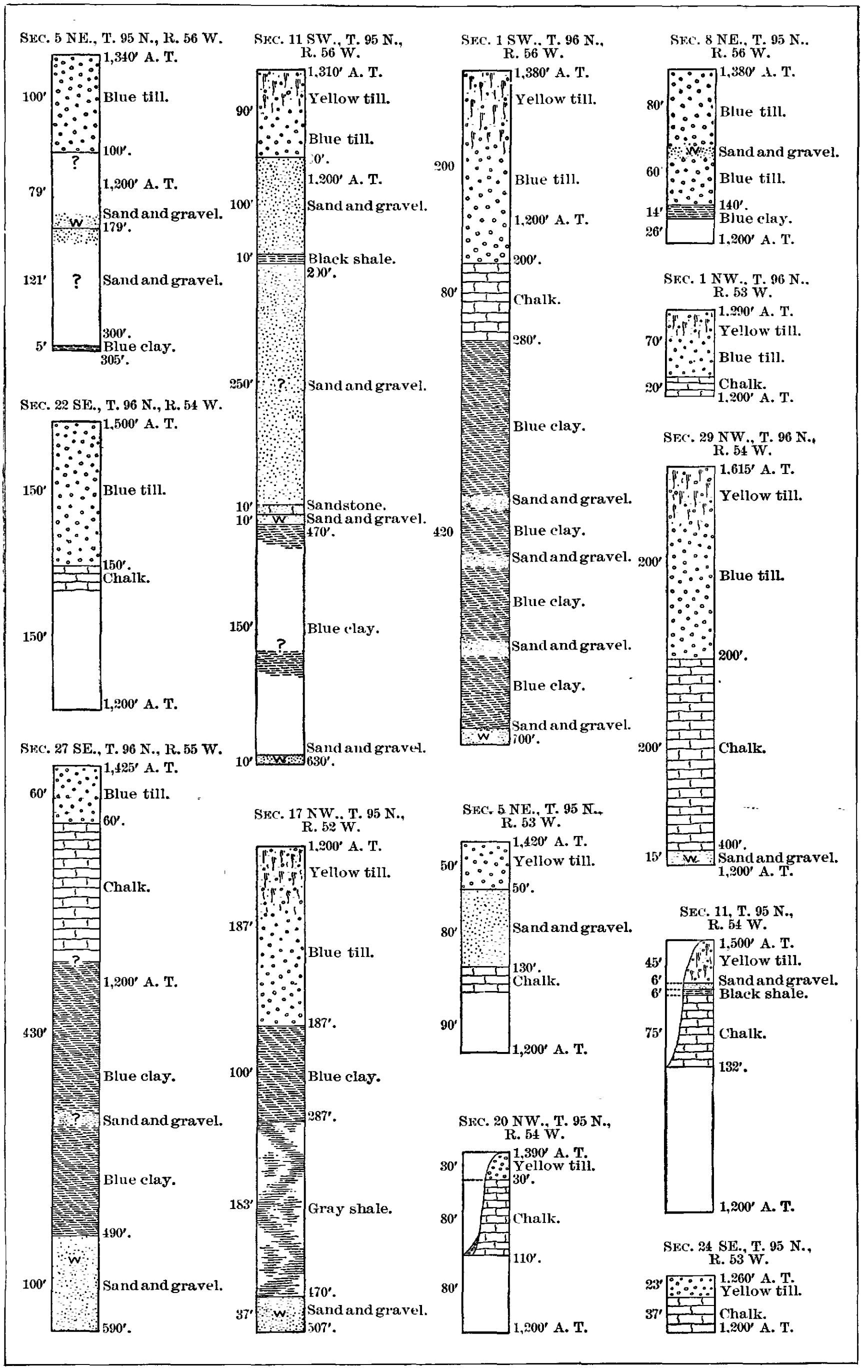
WATER SUPPLY.

Under this head are included the most important economic results of the study of the geology of this area. The subject of water supply is divided into surface waters and underground waters. Under the former are included lakes, springs, and streams, and under the latter are included the supplies which furnish shallow wells, artesian wells, and tubular or pump wells.

SURFACE WATERS.

LAKES.

These receive their waters directly from the rainfall and endure according to the extent of their drainage basin, the depth of their reservoir, and the dryness of successive years. The rainfall of the region varies greatly during different seasons. Its average is about 25 inches. After a succession of wet years, the lake beds over the whole region are filled with water, and in the spring also, if there has been much snow, the same is true. However, in the latter part



LOGS OF WELLS IN YANKTON AND CLAY COUNTIES, SOUTH DAKOTA.

of summer nearly all of them become dry. Some of the more important are marked upon the map as regular lakes. Within the last twenty-five years some lakes have passed through a summer with 10 or 15 feet of water, and a few years later have become dry enough for tillage.

SPRINGS.

Permanent springs are rarely found, but a few occur along the James River and its principal tributaries. They receive their waters from the various formations which are treated more fully under the head of underground waters.

One class of springs which, perhaps, are not often recognized as such derive their waters from the rainfall seeping through the upper part of the drift into the water courses. Since the water from them is contained in isolated basins or waterholes in the water courses, many may not recognize the fact that the water supplied comes from below the surface, but this is doubtless the fact. To the constant movement of the water, more fully described under the head of underground waters, is to be traced the purity of the water in the ponds and their freedom from stagnant properties.

Other springs are derived from the gravel and clay deposits capping the ancient terraces or lining the old water courses of the Glacial epoch. As an example of this may be mentioned a spring in the southwest corner of sec. 34, T. 100 N., R. 59 W., which is supplied from the gravel deposits in an old channel of the James River about 100 feet above the present stream. Another less copious spring appears on sec. 3 of the same township, where the same channel meets the deeper valley of Dry Creek. Another spring from these same deposits appears on or near sec. 15 of the township to the south. It is probable that careful examination would reveal several more of similar origin.

Still other springs derive their waters from the sands below the bowlder clay. These fail to bring water to the surface except where it rests upon underlying clays, probably Cretaceous, although this can not always be easily demonstrated. Springs of this sort have been noted at the base of the bluffs on the right bank of the James River at a number of points between the mouth of Dry Creek and Wolf Creek. It is probable that a further search would discover many more.

A few springs are known to come from joints or porous strata in the chalkstone. Such are found near Scotland and along Turkey Creek. Their waters are frequently unpalatable from impregnation with alum salts.

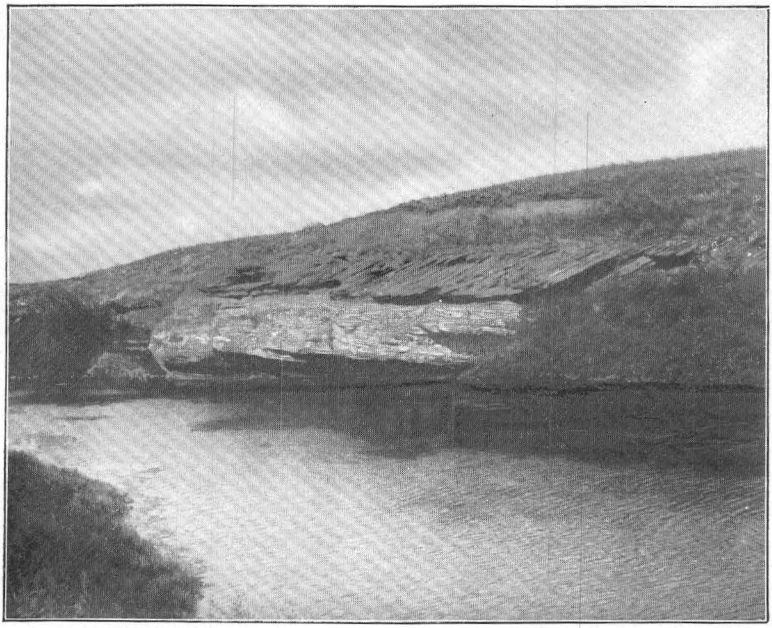
Other springs seem to be supplied from the sandstone of the Dakota formation. Cases of this kind have been noted a mile or two south of Elmspring, where the water escapes from the base of the sandstone as it rests upon the shaly clay below. Other springs which we believe are supplied from the same geological stratum are found near Olivet. They are two in number, the smaller appearing 10 or 12 rods southeast of the bridge crossing the James River east of Olivet; the other about a quarter of a mile farther north, within a few rods of the edge of the bottom adjoining the river. Both of these springs or ponds, as they may be called, are surrounded with bulrushes and are of circular form. The water rises nearly to the level of the bottom land, which is 10 feet higher than the ordinary stage of the James River nearby. Since they are more than a half mile from the base of the bluffs on the east, and the water is higher than can be found at ordinary stages in the James River within 2 or 3 miles farther upstream, it seems clear that the supply is derived from a stratum of the Dakota sandstone, and that we have here, as it were, natural artesian wells. The large spring has a diameter of about 150 feet of open area besides that occupied by bulrushes. Quite similar to the Olivet springs is the one 5 miles north of Mitchell, shown on Pl. IX, *B*. It differs only in having higher banks. Pl. X, *A* shows another type, escaping close to Sioux quarzite ledges on Enemy Creek, southeast of Mitchell. It is probable that similar leaks from the artesian stratum escape into the trough of the James River below the water, or at least below the surface. Some of the small marshes which are found upon the flood plain may be supplied from this source, although probably most are supplied from the waters escaping from the sand sheet below the till.

STREAMS.

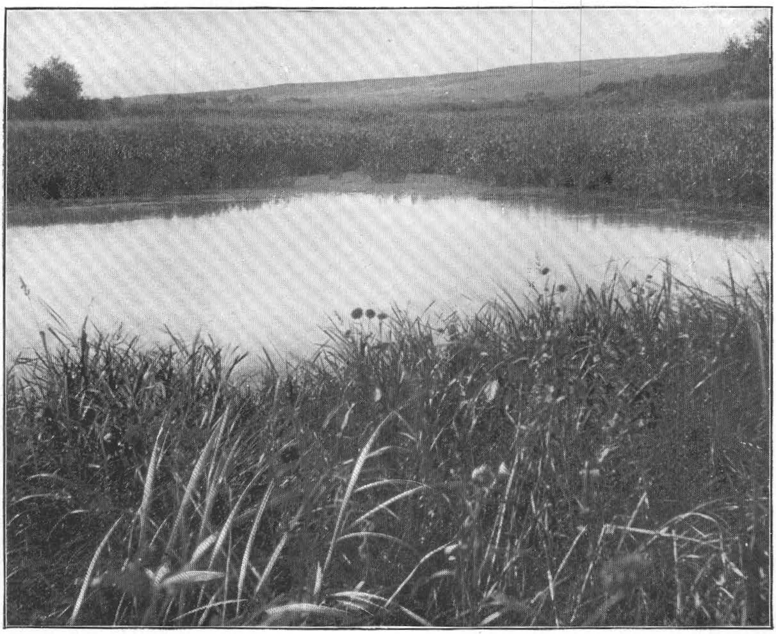
The James River is the only stream in this area which may be depended upon to contain running water at all times. The lower portions of Wolf Creek, Twelvemile Creek, and Lonetree Creek are rarely entirely dry, but above the last mile or two of their course the water in the latter part of summer rarely flows upon the surface.

UNDERGROUND WATERS.

The most accessible underground waters are those flowing near the surface of the ground or seeping through the upper portion of the till toward a water course, where there are shallow accumulations of sand, which form conduits for it. It flows slowly through the lower portions of these sand accumulations and appears at intervals in waterholes along the upper portions of the more prominent streams. In these it rarely comes forth in sufficient strength to attract attention. Where the slope of the surface is toward an undrained basin, the water, flowing on yellow till, contributes to the level of the water in an open lake until the water level sinks below the surface, as it soon does in the great majority



A. DAKOTA SANDSTONE ON FIRESTEEL CREEK, IN TOWNSHIP 104 NORTH, RANGE 61 WEST.



B. ARTESIAN SPRING, IN TOWNSHIP 104 NORTH, RANGE 60 WEST.

of cases. It may then be drawn upon by shallow wells which for a number of years may be entirely adequate for the demands of neighboring farms, but in time of drought gradually become exhausted. Where the surfaces slope toward a water course, the water accumulates in larger supply, but it also flows away sooner. Shallow wells, therefore, along the ancient water courses which were occupied by streams of considerable size during the presence of glaciers in the vicinity, afford some of the most copious wells in the region, some of them being quite shallow. These shallow wells were the main dependence of the farmers of the region in the early settlement of it. In 1881 and a few years subsequent, water was abundant in these surface wells, but after a series of dry years this supply became exhausted and farmers were forced to go deeper for their water supply.

The next supply was that derived from the sand and gravel at the base of the drift. These are reached by penetrating the till, which is done by boring, often to 300 feet below the surface. This depth would be a serious disadvantage were it not in a measure compensated for by the rise of the water, so that in many such wells the water stands within 5 to 25 feet of the surface; some, in fact, became flowing wells. There are wells of this class in the area which have been flowing for over twenty years. The depth to these subtill waters is shown on Pl. V. As we have elsewhere stated, the thickness of the till varies considerably within short distances. Hence, the depth indicated on the map sometimes may not be within 25 to 50 feet of the point where water will be reached, although in the majority of cases it is believed that it will be much nearer. Moreover, as will be readily understood, the subtill sand sheet is not everywhere filled with water, especially in higher regions. Therefore the sand may be reached and passed through to the Cretaceous shale below without yielding water. This seems to have been true in some cases in the Choteau Creek Hills. On the other hand, flowing wells are frequently found at lower levels. Such areas, however, are of comparatively slight extent, and the pressure head is not level, but slopes irregularly with the surface. This is doubtless due to the slow motion of the water below. The areas where flowing wells from this source have been obtained are indicated on Pl. II. Probably others may be found by boring, especially at intermediate altitudes remote from important streams. In some cases the erosion of the ravine or watercourse is that which renders the flowing wells possible, because it decreases the altitude of the surface while the head remains constant. As we have already stated under General geology, cases are not infrequent where deposits of sand and gravel are locally developed in the till itself. These frequently furnish a copious supply of water, and in such cases wells yield water without entirely penetrating the till. On the other hand, sands below the till are absent at some points. In such cases no water is likely to be reached short of the main artesian supply. The deep wells supplied from this source are commonly known as tubular wells, though that term strictly indicates the construction of the pumps used. Hence, we may conveniently speak of the Pleistocene subtill sands as the "tubular-well supply."

It seems evident that the original source of this supply is the rainfall, the same as in the case of shallow wells, but it is a more constant supply, because the water enters it more gradually. It is more continuous, and does not waste in evaporation as in shallow wells. It should not, however, be considered inexhaustible, because if a tubular well is drawn upon too freely it may be expected to gradually fail, especially if it is in an elevated region.

The way in which the water enters this stratum is not well understood. In general, the till seems to be so perfectly impervious that, especially at lower levels, it prevents the escape of the water below quite completely. We have before called attention to the joints in the clay, which, at certain times, especially in more abrupt portions of the surface, and after drought, are probably opened sufficiently to allow water to enter from the surface. Besides, it is not improbable that the bottom of the ancient channels may at some points cut through the till to the lower Pleistocene sands in such a way as to add materially to this supply.

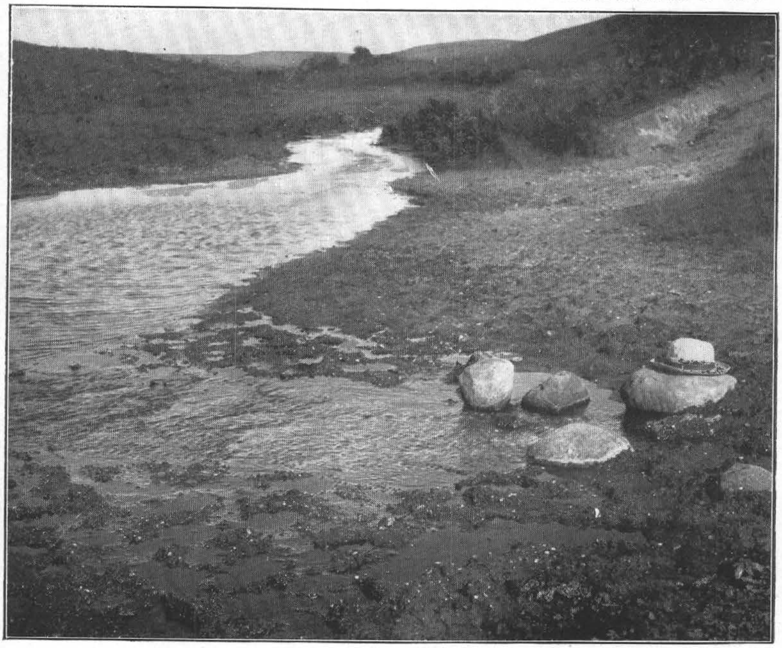
WATER FROM THE OLDER STRATA.

In case sands belonging to the Tertiary should be discovered in the region it is likely that they will be closely connected with the lower Pleistocene sands, and hence we need not discuss them separately. The chalkstone of the Colorado formation is porous and water bearing; in fact, springs are occasionally found flowing from it. We have already spoken of springs from it at Scotland. It exists in such detached masses, and wherever it affects wells is so closely underneath the drift that it need not be treated at any length separate from the tubular-well supply.

It has been found convenient in some places to use chalk as a filter to keep out the sand from the bottom of the well. Moreover, there appears in some places, although not certainly in this area, a stratum of sandstone in the chalk which affords water more copiously and may sometimes have a relation similar to that of the Dakota sandstone underneath.

MAIN ARTESIAN SUPPLY.

Those who have studied the matter universally agree that the main artesian supply is from the sandstone and sand beds of the Dakota formation. This remarkable formation is the source of water in Texas and Colorado, as well as in this region. It owes its efficiency to four



A. SHERRILL SPRING, ON LOWER ENEMY CREEK.

B. KILBURN RUN, FED BY KILBURN WELL, NORTH OF MOUNT VERNON, SOUTH DAKOTA.

conditions: (1) Its great extent, underlying most of the Great Plains from the Rocky Mountains to about the ninety-fifth meridian. (2) Its highly elevated western border, located in the moist region of the mountains and crossed by numerous mountain streams. (3) The fact that it is extensively sealed on its eastern margin by the overlapping clays of the Colorado formation, and where that is not the case, by the till sheet of the Glacial epoch. (4) The excavation of wide areas, especially in Dakota, by older streams, so as to bring the land surface below the pressure height or "head" generated by the elevated western border of the formation. From this source also are derived the copious pumping supplies of water over wide areas, where the pressure is not sufficient to produce flowing wells.

Pl. X, *B* gives a vivid impression of the possibilities of such wells. The flow is through a 3-inch pipe and from a depth of only 337 feet. The stream rivals the Firesteel nearby in the amount of flowing water. It is estimated to furnish over 1,000 gallons a minute. Most of the wells in the area are much smaller and are much more convenient for ordinary farm use, besides being more enduring.

The Dakota deposits underlie nearly the entire area treated in this report, but from the relation of pressure to surface the true artesian area is limited approximately as represented upon the map (Pl. II).

In boring wells the term "flow" is used by some persons to indicate that the water has sufficient pressure to rise some distance in the well, but it is more customary to limit the term to those cases in which there is sufficient force for the water to rise to or over the top of the well. From a comparison of the sections of different wells it appears that the sheets of sand are more or less separated by intercalated sheets of clay, the permeable sandy deposits extending out into thin, wing-like sheets. In this way there are in this area at least three horizons with well-marked flows. The first or uppermost of these probably corresponds to the stratum which is exposed above Milltown. This bed, of course, can not hold water under pressure sufficient to produce flowing wells in the vicinity of its exposure where the head is lost by leakage. The second flow is that which supplies most of the wells northeast of the town of Tripp. The third is that probably reached in the deep well at Tripp. Probably others occur still deeper in the southeast portion of the Olivet quadrangle.

From a study of the sections of the wells it is evident that the successive flows rise somewhat toward the exposures of quartzite, but that the higher water-bearing strata considerably overlap those below. In other words, the lowest sandstone stratum of the Dakota does not extend as far northeast by several miles as those higher up. There has been no effort to express on the map the extent of the different water-bearing strata, but they may be inferred from the irregularities in the depths given.

PRESSURE.

From a superficial study of artesian wells it might be thought that the water, especially in particular artesian basins, has the same head or would everywhere rise to the same plane. Such, however, is far from the fact in the wells of South Dakota. In general, the pressure declines toward the margin of the water-bearing strata. This is readily explained, as noted above, in the shallow basins by supposing that the water is moving as a slow current toward leaks along the margin of the formation where it joins the older rocks or where fissures may connect it with the bottom of streams. Each flow, in general, shows this same decline in pressure toward the northeast.

Moreover, from what we have said about the relation of the Dakota sandstone to the Sioux quartzite and Colorado clays, one can easily understand how the lower flows are found to have higher pressure. Their leakage is much less free. Upon the map (Pl. II) there are contours representing the altitude of "head," which in its downward slope east may be regarded as a "hydraulic gradient." From the nature of the case, it would be impossible to represent the pressure for each water-bearing stratum, and we have therefore taken the data from the more important wells; or, in other words, the lines of altitude of "head" may be taken as representing the relative pressure in the more available and accessible stratum. It is not unlikely that the sinking of wells 300 to 500 feet in depth, to the third or fourth flow, may show considerably increased pressures. It will be observed that the lines have a distinct curve toward the south and east. This may be ascribed, especially in the case of the 1,400-foot line, to the fact of locally increased leakage along the James River Valley, together with the general diminution of supply to the south and east in eastern South Dakota.

The pressure in the wells of this area has not been very generally noted. Many of the wells are small and intended simply for farm supply, so that the pressure has not been an important consideration. At Tripp the pressure was 10 pounds and at Scotland perhaps 4 or 5 pounds, soon after the wells were finished, but at present they barely flow. The wells southeast of Parkston are reported to have a pressure of 40 pounds, and at that place 55 pounds has been recorded recently.

VARIATION OF PRESSURE.

This brings us to a consideration of certain influences that affect pressure. Under this head we shall consider, briefly, a variety of influences that have been found to affect pressure, and will give others the cause of which has not been discovered.

(1) Variation in adjacent wells. Places are not infrequent, although not notable in this area, where wells at nearly the same point have

widely different pressure. In some cases it is evident that the wells are supplied from different sources or flows. This conceivably may be true, even when the water is from the same depth; for, as before stated, the water-bearing strata branch, and do not always extend upon the same level. More frequently, however, these wide local variations are due to the pressure from the stronger flow expending itself along the outside of the pipe into an upper stratum of less pressure.

(2) Variation in the same well at different depths. This need not be dwelt upon, for we have already explained how lower strata are more perfectly sealed on their eastward margin and therefore display higher pressure.

(3) Variations in the same well because of wells in the vicinity. The distance to which the influence of the escape of water from a well extends may reasonably be supposed to be directly proportional to the amount of water discharged. We may conceive that the flow of the well produces a depression in the surface, or "head," so to speak, proportional to the amount of water discharged, somewhat as in the case of an opening in the bottom of a reservoir. If the flow is rapid the depression may be great, so that if the well is closed its pressure will be at first, perhaps, several pounds below the original pressure, but as the water flows in from adjacent areas the pressure in the well will gradually regain its former amount. So, if two wells are near each other, we can not expect that the closed pressure of one will approach very closely to the original figure if the other is left open.

(4) Effect from varying barometer. As the pressure taken is with a gage affected by the pressure of the air, it follows that when the barometer is high the pressure of the fluid within will be correspondingly diminished. The influence is, of course, slight, and will be overlooked unless the pressure in the well is very weak. Under such circumstances, however, an increase of the pressure of the air may sometimes be sufficient to stop the flow and, conversely, a low barometer may increase the flow.

(5) Periodic variations. In a number of the weaker wells there has not only been a decline of pressure, but from time to time an increase. This increase has been in some cases related to the time of year, the spring being sometimes marked by a stronger flow. This again varies according to years, and it is believed to be most satisfactorily explained by supposing that the water is obtained from the melting of snows or from streams subject to floods.

(6) Effect of varying leakage in the vicinity. This has been observed in wells near the Missouri River. When the river is high the pressure in the wells increases. It is easily explained by supposing that there are points of leakage underneath the surface of the river, and that the increase of hydrostatic pressure from the stream checks the leakage to such an extent that it increases the pressure in adjacent wells. While

this has not been noted in the area, it is not improbable that examples occur near the James River. This variation, of course, is slight, and would be unnoticed except in very weak wells.

Upon the map (Pl. II) approximate depth to the surface of the Dakota sandstone is represented. As was stated in the discussion of that formation, this does not always directly mark the upper limits, but more definitely the level from which flowing wells may be obtained. In cases where water is not found at the depth indicated the boring may be hopefully carried through lower horizons to bed rock, the depth of which is shown on Pl. IV. In the southeastern corner of the area and along its western side the Dakota sandstone is thicker and probably carries more water-bearing strata.

HINTS ON THE CONSTRUCTION OF WELLS.

Although the practical application of the following hints belongs to the work of the well-borer, and may be discussed more efficiently from the standpoint of an engineer, yet they may be advantageously noted here in connection with the geological facts.

(1) Since the pressure in the upper flows is less than in the lower by many pounds to the inch, it is very important that the communication between the lower flows and the higher should be entirely cut off. Otherwise the full pressure from the lower stratum will not be observed at the mouth of the well, but will expend itself by leaking into the strata below the surface. The desire of the well-digger to keep his pipe loose may tempt him to leave the bore too large—hence the danger we speak of.

(2) It is very desirable that the larger pipe lining the bore be firmly fixed in the hard stratum above the water-bearing rock. This may be done in most localities, as a compact stone is found just above the porous sands which bring the water. Much depends upon this, for if a pipe be left loose, and the opening in the rock left incompletely stopped, water is likely to escape around the pipe and, if not checked, may eventually destroy the well.

(3) A well should be sunk as rapidly as consistent with good work, especially after water has been reached. Otherwise, the great pressure of the water may cause it to erode an irregular opening and prevent the accomplishment of the two points already given.

PERMANENCE OF ARTESIAN SUPPLY.

All natural products are liable to exhaustion. With gold, coal, and other metallic products no general rules can be laid down by which we may foretell how soon the supply may fail. With water it is otherwise. As we have already said, multiplication of wells must tend to exhaustion. If, however, the loss by wells and leakage does not exceed the annual supply which enters the formation on the west, an equilibrium may be gained which will be as constant as in a river. It may be expected to have similar fluctuations. At present the pressure in wells in the area discussed is generally slightly declining. Some wells of original low pressure have ceased to flow, as at Scotland, Tripp, in sec. 12, T. 95 N., R. 56 W., and in other places, but the great majority have failed but little. There is no apprehension of early failure.

From the sheet-like form of the water strata and their nearly horizontal position, the decline of pressure will necessarily be very regular and gradual. If, to illustrate, a well having a pressure of 50 pounds should show a decline of 2 pounds a year, under similar conditions it would last twenty-five years with gradually decreasing flow. Moreover, it is possible, if not probable, from the wide extent of the Dakota sandstone at high altitudes toward the west, that there is a reserve supply which may become more available as the head declines.

Many of the reported cases of failure from other portions of the artesian area have been shown to be due to stoppage by sand or to subterranean leakage resulting from the rusting of the pipe or imperfect construction, and sometimes from the breaking of the pipe by caving.

Until more is known of the circumstances controlling the supply little more can be said upon this point.

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1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Bighorn Range and Bighorn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett; and "Preliminary report on the artesian waters of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the calendar year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton; and "Reservoirs for irrigation," by J. D. Schuyler.

1899.

Nineteenth Annual Report of the United States Geological Survey, 1897–98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton; and "A preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

1900.

Twentieth Annual Report of the United States Geological Survey, 1898–99, Part IV, Hydrography, 1900; octavo, 660 pp.

Contains a "Report of progress of stream measurements for the calendar year 1898," by F. H. Newell, and "Hydrography of Nicaragua," by A. P. Davis.

WATER-SUPPLY AND IRRIGATION PAPERS, 1896–1900.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost, as noted above. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Postage stamps, checks, and drafts can not be accepted. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Underground waters of southeastern Nebraska, by N. H. Darton, 1898.
13. Irrigation systems in Texas, by William Ferguson Hutson, 1898.
14. New tests of pumps and water lifts used in irrigation, by O. P. Hood, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.
17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
20. Experiments with windmills, by Thomas O. Perry, 1899.
21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems in the Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.
25. Water resources of the State of New York, Part II, by George W. Rafter, 1899.
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett, 1899.
27. Operations at river stations, 1898, Part I, 1899.
28. Operations at river stations, 1898, Part II, 1899.
29. Wells and windmills in Nebraska, by Erwin Hinckley Barbour, 1899.
30. Water resources of the Lower Peninsula of Michigan, by Alfred C. Lane, 1899.
31. Lower Michigan mineral waters, by Alfred C. Lane, 1899.
32. Water resources of Puerto Rico, by H. M. Wilson, 1900.
33. Storage of water on Gila River, Arizona, by J. B. Lippincott, 1900.
34. Geology and water resources of southeastern S. Dak., by J. E. Todd, 1900.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gaging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. [Approved June 11, 1896; Stat. L., vol. 29, p. 453.]

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