Water-Supply and Irrigation Paper No. 90

Series { B, Descriptive Geology, 36
0, Underground Waters, 22

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND WATER RESOURCES

OF PART OF THE

LOWER JAMES RIVER VALLEY, SOUTH DAKOTA

BY

J. E. TODD and C. M. HALL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1904

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Bulletins, Professional Papers, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. The following Water-Supply Papers are out of stock, and can no longer be supplied: Nos. 1-14, 19, 20, 22, 29-33, 46, 57-64. Complete lists of papers relating to water supply and allied subjects follow. (B=Bulletin; PP=Professional Paper; WS=Water-Supply Paper.)

SERIES I—IRRIGATION.

WS 2. Irrigation near Phoenix, Ariz., by A. P. Davis. 1897. 98 pp., 31 pls. and maps.
WS 5. Irrigation practice on the Great Plains, by E. B. Cowgill. 1897. 39 pp., 11 pls.
WS 9. Irrigation near Greeley, Colo., by David Boyd. 1897. 90 pp., 21 pls.
WS 10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 51 pp., 11 pls.
WS 13. Irrigation systems in Texas, by W. F. Hutson. 1898. 68 pp., 10 pls.
WS 17. Irrigation near Bakersfield, Cal., by C. E. Grunsky. 1898. 96 pp., 16 pls.
WS 18. Irrigation near Fresno, Cal., by C. E. Grunsky. 1898. 94 pp., 14 pls.
WS 19. Irrigation near Merced, Cal., by C. E. Grunsky. 1899. 59 pp., 11 pls.
WS 23. Water-right problems of Bighorn Mountains, by Elwood Mead. 1899. 62 pp., 7 pls.
WS 32. Water resources of Porto Rico, by H. M. Wilson. 1899. 48 pp., 17 pls. and maps.
WS 43. Conveyance of water in irrigation canals, flumes, and pipes, by Samuel Fortier. 1901. 86 pp., 15 pls.
WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles, Wyoming, by G. I. Adams. 1902. 50 pp., 11 pls.
WS 71. Irrigation systems of Texas, by T. U. Taylor. 1902. 137 pp., 9 pls.
WS 74. Water resources of the State of Colorado, by A. L. Fellows. 1902. 151 pp., 14 pls.
WS 87 Irrigation in India (second edition), by H. M. Wilson. 1903. 238 pp., 27 pls.

The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Part II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Part III.

SERIES J—WATER STORAGE.

WS 33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls.
WS 40. The Austin dam, by Thomas U. Taylor. 1900. 51 pp., 16 pls.
WS 45. Water storage on Cache Creek, California, by A. E. Chandler. 1901. 48 pp., 10 pls.
WS 46. Physical characteristics of Kern River, California, by F. H. Olmsted, and Reconnaissance of Yuba River, California, by Marsden Manson. 1901. 57 pp., 8 pls.
WS 58. Storage of water on Kings River, California, by J. B. Lippincott. 1902. 100 pp., 32 pls.
WS 68. Water storage in Truckee Basin, California-Nevada, by L. H. Taylor. 1902. 90 pp., 8 pls.
WS 73. Water storage on Salt River, Arizona, by A. P. Davis. 1902. 54 pp., 25 pls.
WS 86. Storage reservoirs of Stony Creek, California, by Burt Cole. 1903. 62 pp., 16 pls.
WS 89. Water resources of Salinas Valley, California, by Homer Hamlin. 1904. — pp., 12 pls.

The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Part IV.

[Continued on third page of cover.]

Water-Supply and Irrigation Paper No. 90

Series { B, Descriptive Geology, 36
O, Underground Waters, 22

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND WATER RESOURCES

OF PART OF THE

LOWER JAMES RIVER VALLEY, SOUTH DAKOTA

BY

J. E. TODD and C. M. HALL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1904

CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., July 21, 1903.

SIR: I have the honor to transmit herewith, for publication in the Water-Supply and Irrigation series, a paper on the "Geology and Water Resources of a Portion of the Lower James River Valley, South Dakota," prepared by Messrs. J. E. Todd and the late C. M. Hall, acting under the direction of Mr. N. H. Darton.

The region is a portion of the territory of which Mr. Darton made a reconnaissance several years ago. Professors Todd and Hall have obtained a large amount of new data, and this is presented in maps and diagrams which, it is believed, will prove of interest and value to many persons.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

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

GEOLOGY AND WATER RESOURCES OF PART OF THE LOWER JAMES RIVER VALLEY, SOUTH DAKOTA.

By J. E. Todd and C. M. Hall.

LOCATION AND IMPORTANCE OF THE REGION.

The region treated in this paper includes the Alexandria, Mitchell, Huron, and De Smet quadrangles. It is bounded by parallels 43° 30′ and 44° 30′ north latitude and meridians 97° 30′ and 98° 30′ west longitude. It embraces the whole of Davison, Hanson, and Sanborn counties, the most of Beadle and Miner, and portions of Kingsbury, Jerauld, Aurora, and McCook counties, S. Dak. It is traversed from north to south by James River Valley, along which it extends for about 75 miles.

The peculiar geologic interest in this region arises from the presence in its southern portion of a low buried mountain range, carved out of pre-Cambrian rocks, over which Cretaceous strata were laid down until the whole became a plain. The way in which this was accomplished has been revealed clearly by the numerous borings made for artesian wells. The region also exhibits representative portions of the Gary and Antelope moraines of the Wisconsin age of the Glacial epoch.

The economic value of the investigation here presented is mainly connected with the underground water resources, for the greater part of the region lies in the artesian basin. The number of water-bearing strata, the pressure of the water, and various other questions connected with the development of this resource have been studied with care.

TOPOGRAPHY.

In general the surface is very even, none of it being too rough or too steep for plowing except in the immediate vicinity of the larger streams and in a few ravines which are cut in its steeper slopes. Much of the region is nearly level, but as a whole it presents considerable range of altitude. James River crosses it near the center in an almost direct south-southeast direction. Its northeast corner lies on the western rim of the Coteau des Prairies, at an altitude of over 1,800 feet above sea level, and its southwest corner rises on the opposite side of the valley to an altitude of nearly 1,700 feet, while the general level of the wide valley between averages about 1,300 feet.

The highest point is about the middle of the east line of sec. 12, T. 111 N., R. 57 W., where an elevation of about 1,850 feet above sea level is reached. Near the southwest corner the highest point is at an altitude of 1,690 feet, on the middle of the south line of sec. 9, T. 107 N., R. 63 W. The lowest points are along James River, the surface of which has an altitude of about 1,200 feet in the southern and 1,230 feet in the northern portion of the region.

GEOGRAPHY.

The whole surface was originally prairie with the exception of a few small groves along James River. One of these which attracted much attention in the early settlement of the country lies in a bend of James River near Forestburg. The whole surface is underlain by a clayey subsoil with the exception of some sandy areas in the vicinities of Letcher, Forestburg, and Huron. North and northwest of Forestburg the sand is so extensive that sand hills 15 to 30 feet in height have been formed. One of these opposite the mouth of Redstone Creek is known as Belchers Mound.

The area is drained mainly by James River and its tributaries. None of the tributaries contain flowing water throughout the year except Sand Creek for 7 or 8 miles above its mouth and Pearl Creek for half that distance. James River flows in a trough about half a mile wide and from 50 to 80 feet deep. It is a sluggish stream, having a width of 80 to 100 feet in ordinary stages and a depth of 3 to 10 feet. Its bottom land is fertile, but much of it is subject to occasional overflow.

The arrangement of the streams has been mainly determined by the movements of the ice sheet during the Glacial epoch, as will be explained in a subsequent section.

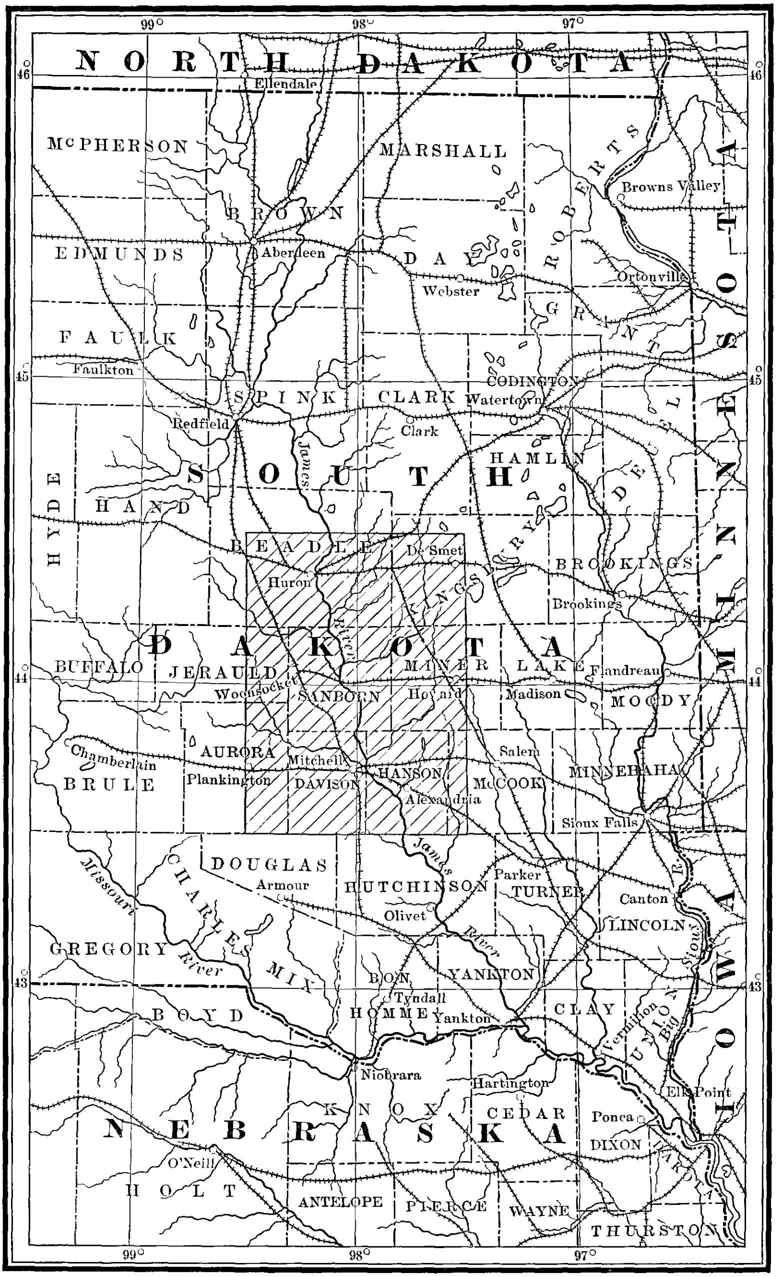
GEOLOGY.

The geology of this area is simple. Nearly the whole surface is covered with the glacial clays and stream deposits of the Quaternary. The rocks lie nearly horizontal and there are no traces of recent igneous action, exposures of older rocks occurring only in the southern quarter.

The following rocks occur in this area: The Algonkian, the Dakota, Benton, Niobrara, and Pierre formations, and the glacial deposits of the Quaternary. (See Pl. III.)

ALGONKIAN.

The crystalline rocks are represented by two formations, which were possibly formed at widely separated times. The first is the granite, which is nowhere exposed but has been struck in drilling wells at several points, and the other is the Sioux quartzite, which outcrops east of Mitchell and is often found in drilling. There are two theories concerning the relation of the granite to the quartzite. According to the first it is a much older formation, corresponding in age to the granite extensively exposed along Minnesota River below Bigstone Lake, which is believed to antedate the schists and quartzites of Minnesota and the Black Hills. According to the other view this granite



Scale

0 25 50 miles

INDEX MAP OF EASTERN SOUTH DAKOTA, SHOWING AREA UNDER CONSIDERATION.

is an eruptive rock, which has been intruded into the quartzite in the form of dikes or sheets. If this is the case, it corresponds to an igneous rock forming a dike in the quartzite north of Corson, S. Dak. In favor of the latter view may be urged the evident unevenness of its surface. For example, it has been struck at the depth of 500 feet, or 860 feet above the sea, in sec. 25, T. 103 N., R. 61 W., while at Mitchell, less than 5 miles away, at a depth of 710 feet, or 590 feet above the sea, the quartzite, which according to the first view must lie above it, had not been penetrated; or, in other words, the granite had not been reached.

Besides the instance already mentioned, the granite has been struck in two or three wells about 5 miles north of Farmer, and a little beyond the north line of this area near Hitchcock. In the latter case it seemed to be overlain by several feet of quartzite.

The granite from the Budlong and Motley wells north of Hitchcock and from wells north of Farmer, in Hanson County, is a fine-grained, light-gray rock abounding in transparent feldspar, while that from the wells southwest of Mitchell is darker and coarser.

From wells at Huron and near Esmond it appears that below the water-bearing rock there are several feet of secondary deposits from granite, such as arkose, impure kaolin strata, and the like, then weathered granite before the sound rock is reached.

The deepest well at Huron, city well No. 4, opposite the college, according to the report of Mr. F. H. Holton, who drilled it and submitted specimens of the lower strata, shows the following record:

Record of deep well at Huron, S. Dak.

	Thickness.	Depth.
	Feet.	*Feet.*
First strong flow, probably top of Dakota	-------	740
Unreported, but doubtless mostly shale	124	864
Hard rock	6	870
Sandstone and water flow	3	873
Unreported, but mostly shale	60	933
Sandstone and water flow	3	936
Black shale	125	1,061
Pebbly sand and water flow	9	1,070
Coarse sand with rounded grains about the size of No. 6 shot, largely reddish-brown concretionary grains with some white quartz-like material struck at corresponding levels in the Wilcox well and city well No. 3. The brown grains are apparently siderite, or carbonate of iron	30	1,100
Gray sandy rock with green and brown specks and whitish opaque grains, like weathered feldspar (arkose), and lumps of coarse red granite	36	1,136
Soft, fine-grained, kaolin-like clay	2	1,138
Hard rock, probably granite	1	1,139

The Sioux quartzite, which is exposed in the southeastern portion of the area under consideration, is commonly a dense and firmly silicified rock. It is usually fine grained and thick bedded, but in some cases a few feet of it contains numerous pebbles, while not infrequently the rock is so thin bedded as to be worthless for building purposes. Moreover, at some points it is so imperfectly consolidated that it may be dug with a pick. A case of this sort occurs southwest of Bridgewater, in the valley of Wolf Creek. This soft rock, however, is very limited in extent, the normal hard quartzite occurring within a few feet of it. Associated with the quartzite and interstratified with it are occasional thin beds of a red, hardened clay, called "pipestone." When this has been exposed to the weather it becomes chalk-white. Examples of the latter condition are found at the Wolf Creek locality.

The peculiar interest of the quartzite in connection with the subject under consideration is the fact that it is the bed rock over all the area. The water-bearing strata rest upon it and its presence marks the lowest horizon at which a flow may be obtained. Hence it is of importance to be able to recognize it and to have a general knowledge of its depth below the surface.

In drilling, the quartzite may be distinguished from pyrite, which is of about the same hardness, by its thickness, the latter being rarely more than a few inches thick. Greater thickness also serves to distinguish it from some of the hard layers of the Dakota formation, which are rarely over 4 or 5 feet thick. Moreover, the Dakota rocks are usually cemented by carbonate of lime, which effervesces with acids, or by iron oxide or carbonate of iron, which is of a dark or rusty color, while the quartzite is uniformly of a light pinkish shade. However, in some cases a compound microscope is necessary to detect the difference. When so examined quartzite is recognized by clusters of sand grains cemented together so firmly by glassy silica that usually the original grains divide along the fractures as easily as they separate where cemented. Similar examination suffices to show the presence of granite, which, as has already been stated, has been struck at several points in this area.

BED-ROCK CONTOUR.

In general the quartzite underlies the whole area under consideration and has the configuration shown by the contour lines in Pl. III. The most conspicuous feature of the bed-rock surface is a high ridge, having a breadth of about 12 miles, which enters the east side of the area, affording surface exposures in the vicinity of Spencer and Bridgewater. Its outcrop area narrows rapidly toward the west, so that the westernmost appearance of the rock on the surface is on Enemy Creek, in the western part of T. 102 N., R. 59 W. In the triangle between the limits indicated it lies next underneath the drift and shows frequently in the bottom of the valleys of the larger streams. It has an altitude of 1,380 feet at Spencer and about the same near Bridgewater. On Enemy Creek it rises to only about 1,200 feet. Its most extensive exposure is in the bottom of James River Valley at Rockport. It has been traced farther west at lower levels in a zone of considerable width, and about a mile southwest of Mitchell has been struck at a depth of nearly 258 feet, or about 1,087 feet above sea level. At Plankinton it was found at a depth of 800 feet, or 700 feet above sea level.

This ridge is not a smooth anticline, but is composed of strata dipping in different directions at from 2° to 5°. It seems to be much eroded in places, where portions of the original surface are left as peaks between the valleys. Differences of elevation of 300 feet or more have been found within the distance of a mile. The northern slopes of this ridge seem to be generally rougher than the southern, and the valleys are correspondingly deeper and narrower. Toward the north the general surface of bed rock drops 600 feet in 8 or 10 miles from the last-observed outcrops. Then by a gentler slope it reaches a depth of 1,000 feet, or 300 feet above sea level, and continues northward till it rises slightly near the northwestern part of this area. Southward the slope is more gentle and a depth of 600 feet is not reached within 20 miles of the last outcrop, which carries the observation much beyond the limit of this area. These general facts are derived from well records, as the wells strike the quartzite very frequently in the vicinity of the ridge, but rarely far from it. The various sections and maps published in this paper exhibit such details as are available concerning the relations and distribution of the quartzite.

PALEOZOIC GAP.

In this region there are no traces, even in the numerous borings which have reached the Algonkian, of any Paleozoic formations or of any Triassic or Jurassic strata. The nearest occurrences of Paleozoic rocks that have been discovered are in the borings at Ponca, Nebr., and Sioux City, Iowa. During Paleozoic times, when great masses of sediments were being deposited in many other regions, this area was probably an elevated land surface. It is possible that soils and vegetation may have extended over it, and possibly some thin deposits which were removed by the advance of the sea during Cretaceous and earlier times. At any rate no traces of such deposits have been found in this vicinity on the surface of the quartzite. Since several hundred feet of strata of marine origin representing all the ages of Paleozoic times are found in the Black Hills, the shore of the Paleozoic sea probably extended across South Dakota from north to south, west of the present course of Missouri River. Moreover, the deep erosion of the intensely hard Sioux quartzite indicates that it was subject to erosion for a great length of time.

CRETACEOUS.

Resting upon the Sioux quartzite are sands, sandstones, chalk, and clays belonging to the Cretaceous series, comprising the Dakota sandstone, Benton formation, Niobrara chalk, and Pierre shale. As these are intimately connected with the sinking of artesian wells, it is desirable to describe them at some length, although some of them are exposed only in very limited areas over a surface of perhaps 150 square miles, mainly west of James River and between Firesteel Creek and the southern limit of this area. These exposures are usually near the water level of the larger streams, but in some cases they rise 20 or 25 feet higher.

DAKOTA FORMATION.

This is the principal formation which supplies water to the important artesian wells of North and South Dakota. It nowhere comes nearer the surface than about 200 feet. Judging from well records, it consists of alternate beds of sand and sandstone, 50 to 100 feet in thickness, with masses of clay or shale interstratified between. It possibly includes in this part of the State, at least in its thickest developments, the formations which in the Black Hills were originally included in it, but which have more recently been separated under the names Fuson and Lakota, and are believed to represent the lower Cretaceous.

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. There it is rarely over 100 feet in thickness, according to Darton. It is of medium grain, though finer and coarser grained layers are found. From material thrown out of many wells in the eastern part of the State it may usually be described as a fine-grained gray sandstone.

It extends partly over the lower portion of the ridge of red quartzite above described to an old shore line which has been uplifted to about 1,100 feet above the sea a few miles southwest of Mitchell, but owing to flexure declines toward the east and north several hundred feet before it passes beyond the eastern margin of the area under consideration. The top of the Dakota sandstone drops in all directions from this old shore line with a slope which is steep near the quartzite ridge and gradually diminishes until the formation is nearly horizontal. North of the quartzite ridge it reaches an altitude of about 675 feet at Woonsocket and less than 600 at Huron. West of Huron it seems to rise again toward the northwest in the vicinity of Wolsey. Southward from the ridge the decline is more gentle and the Dakota probably does not fall below about 800 feet above the sea, even in the remote southwest corner of the region.

The shales of the Dakota resemble those of the formations higher up, and, like them, occasionally contain calcareous concretions which may be mistaken in drill holes for limestone strata. Sometimes, also, there are concretions of pyrites large enough to cause considerable

ARTESIAN WELL AT WOONSOCKET, S. DAK.

hindrance in 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 various sections exhibit the character and thickness of the Dakota sandstone and associated formations. In the discussion of the sources of artesian water further light will be given on the number, thickness, and subdivisions of the sand strata in these formations. The information is mainly derived from the reports of well drillers, who unfortunately do not all agree in their interpretation of facts. Most drillers use jet drills, which mingle the drillings in such a way that it is often difficult to determine the character of the formation worked upon, and frequently also the driller is not disposed to examine with much care the character of the deposits or to measure carefully the exact position or thickness of any of the strata, points which would be of special interest to geologists. The driller is interested chiefly in the water-bearing strata, and of these only in such as produce a flow sufficient for his purpose. When asked for the history of a particular well, he is apt to remember only the depths of the flows struck and of the levels where he found the most serious obstacles. Hence it may reasonably be supposed that the deeper sandstone strata are often thicker than is reported in the logs and that the upper water-bearing sands especially are probably more numerous than usually reported.

Thickness.—Before the thickness of the Dakota can be determined it must be decided what shall be assumed as the division between this formation and the overlying Colorado. If the second important sandstone below the chalk is taken as the top of the Dakota, the formation has been penetrated to a depth of 300 or more feet in the deepest borings. It is possible that 50 or even 100 feet may be added to this before the crystalline rock is reached in the region between Huron and Woonsocket, where the formation seems to reach its greatest depth. North of Mitchell a thin and comparatively unimportant sandstone bed intervenes between the upper sandstone stratum of the Benton and the top of the Dakota.

Two wells at Huron, Beadle County, have been bored through the Dakota sandstone into the underlying quartzite and granite, and the following is a combined record:

Section of Dakota formation in city wells Nos. 3 and 4, Huron, S. Dak.

	Feet.
Sandstone, strong flow (at depth of 740 feet)	5
Sandy shale	50
Hard sandstone	12
Sand rock (much water)	65
Gray limestone ? Shale Sandstone, thin Shale	58

Section of Dakota formation in city wells Nos. 3 and 4, Huron, S. Dak.—Cont'd.

	Feet.
Sandstone	8
Black shale	125
Pebbly sand and water	9
Coarse sandstone on quartz rock or granite	30

At De Smet, on the highlands 30 miles east of Huron, a deep boring passed through a thick series of sandstone with shale intercalations, probably comprising the greater part of the Dakota formation and possibly including in its upper beds the lower portion of the Benton formation.

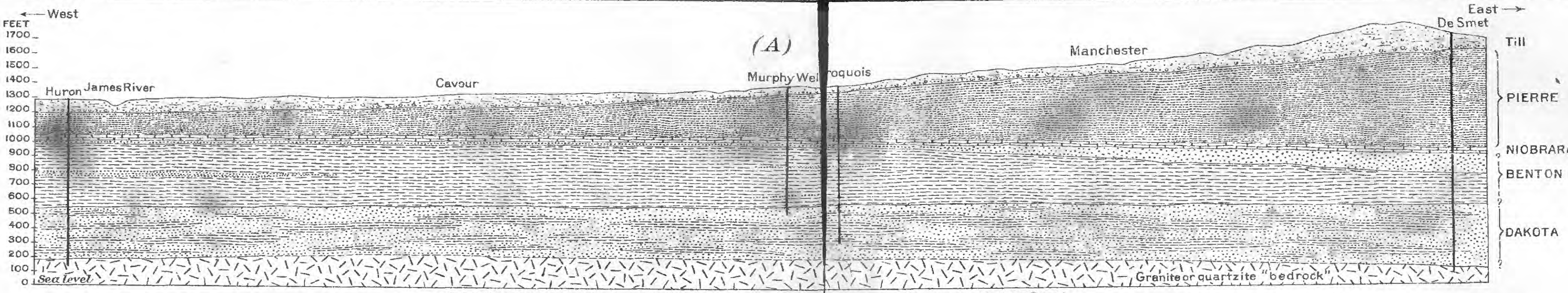
Section in lower part of boring at De Smet, S. Dak.

	Feet.
Benton?:	
Hard sandstone (at depth of 840 feet)	25
Sandstone	120
Shale	200
Dakota:	
Sandstone	271
Hard sandstone	14
Sandstone	140

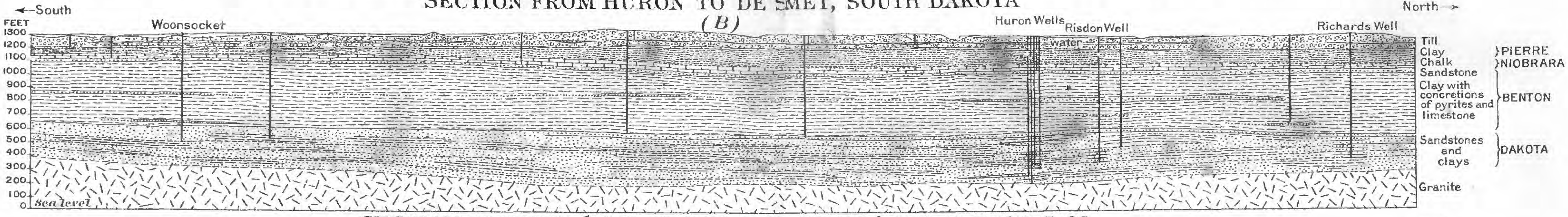
In a well 2 miles southwest of Letcher it is reported that Dakota beds have been penetrated from 500 to 683 feet without reaching their base. The material is mainly clay, including several sandstone layers with flowing water.

In the Ashmore well, southwest of Artesian, the Dakota sandstone appears to have been entered at a depth of 626 feet, and its upper members include 6 feet of sandstone and 67 feet of shale, lying on sandstone which was penetrated 2 feet.

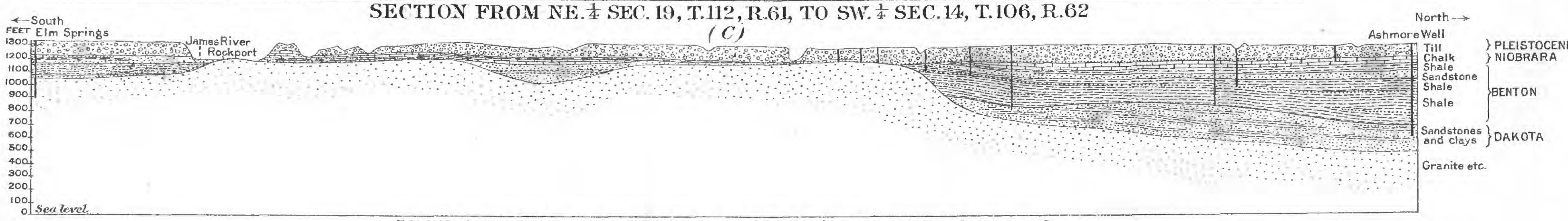
In Sanborn County many wells have reached the Dakota sandstone, and the well at the mill at Woonsocket penetrated a solid mass of it from 697 to 775 feet, but had no need to go to the base. In Davison County the thickness is variable, and the formation grows thinner and disappears entirely in an irregular area on the higher slopes of the underground ridge of quartzite south and southwest of Mitchell. At Mitchell it appears to extend from 440 feet to the quartzite at 540 feet, comprising 39 feet of sandstone above and 11 feet of sandstone at base, separated by 50 feet of shale. In the Smith & 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 of which the top is at a depth of 475 feet. At Ethan there are only 8 feet of sandstone on the quartzite, and this may belong to the Benton. In the Lowrie well, northwest of Ethan, the Dakota appears to be 92 feet thick. It lies on quartzite at a depth of 477 feet, and consists 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, and in the J. K. Johnson well, 3 miles due north of Mount Vernon, where the underlying bed rock was not reached, the section is as follows:



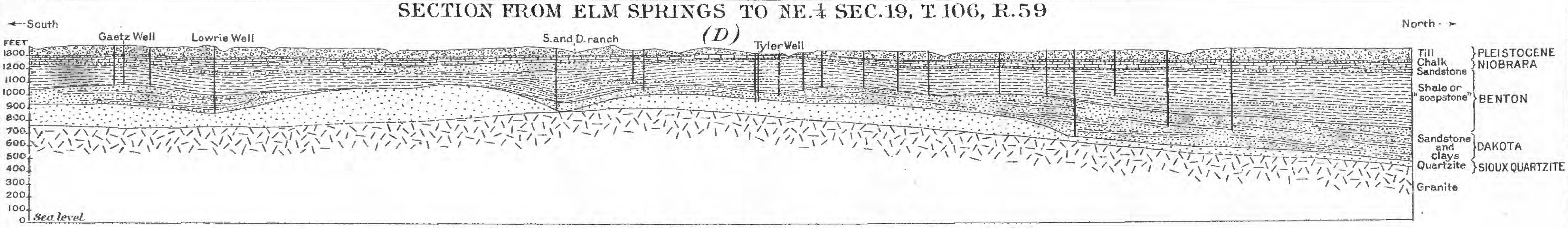
SECTION FROM HURON TO DE SMET, SOUTH DAKOTA



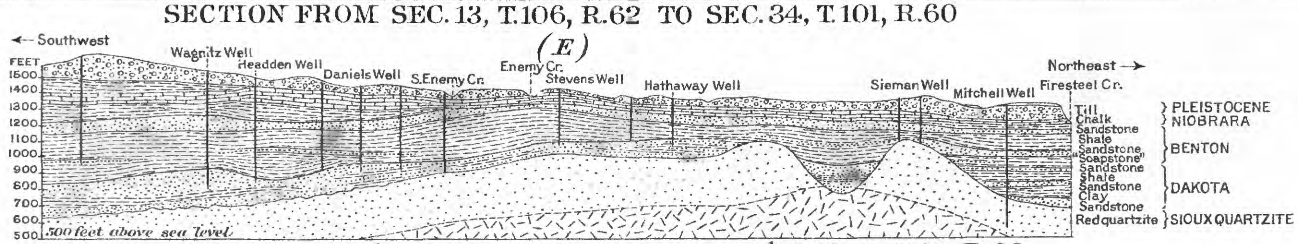
SECTION FROM NE. ¼ SEC. 19, T. 112, R. 61, TO SW. ¼ SEC. 14, T. 106, R. 62



SECTION FROM ELM SPRINGS TO NE. ¼ SEC. 19, T. 106, R. 59



SECTION FROM SEC. 13, T. 106, R. 62 TO SEC. 34, T. 101, R. 60



SECTION FROM SW. ¼ SEC. 33, T. 101, R. 62 TO NE. ¼ SEC. 14, T. 10, R. 60

JULIUS BIEN & CO. LITH. N.Y.

Section of Dakota formation north of Mount Vernon, S. Dak.

	Feet.
Sandstone (at depth of 350 feet)	70
Shale	50
Sandstone	36
Shale	90
Sandstone	44

In eastern Aurora County several wells penetrate the formation a hundred feet or more and find alternate beds of sandstone and shale. The well at Plankinton is reported to have reached granite at 756 feet, and the overlying Dakota appears to comprise 218 feet of beds (from a depth of 538 feet), reported to consist largely of shale, with several thin sandstone bodies.

From the Storla well, in the southwest corner of the county, are reported beds, apparently Dakota, from a depth of 457 to 760 feet, as follows:

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

	Feet.
Sandstone	13
Shale	60
Sandstone	5
Shale	30
Sandstone	10
Shale	45
Sandstone	10
Shale	110
Sandstone	20

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.

	Feet.
Sandstone (at depth of 455-516 feet)	61
Shale	104
Sandstone	Few
Shale, etc	133
Sandstone	2

In the Raesley well, 4 miles southeast of Plankinton, the section is as follows:

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

	Feet.
Sandstone (at depth of 477 feet)	12
Shale	116
Sandstone	5
(?)	24
Shale	45
Sandstone	39

The formation is absent in the central and southern portion of Hanson County, but in its northern and northeastern part it has been penetrated by several deep wells and found to consist of 20 to 53 feet of sandstone lying on granite or quartzite. Apparently it thickens rapidly northward under the western part of Miner County and in the southeastern part of Sanborn County.

Fossils.—The Dakota formation is considered to be a fresh-water deposit from the fact that fossils occur rarely and that a few distinctly fresh-water species have been found in it.

A species of *Goniobasis* was obtained in quantity from wells around Esmond at a depth of 785 feet, or about 30 feet above the main flow. Mr. T. W. Stanton, to whom the specimens were submitted, declares them identical with a species found in the Dakota of Jefferson County, Nebr.[a]

BENTON FORMATION.

The Benton formation consists mainly of dark shales, with thin beds of sandstone and limestone. In an area of considerable extent in Sanborn and adjoining counties the Niobrara chalkstone lies on a bed of sandstone 10 to 85 feet thick, sometimes with a thin intervening mass of shales. This was formerly supposed to be a portion of the Dakota sandstone, for it often contains considerable water, sometimes under pressure, but it has been found to be underlain by a thick mass of typical Benton clay containing marine fossils. This upper sandstone outcrops at several localities along Firesteel, Enemy, and Twelvemile creeks, and along James River at intervals from north of Mitchell to beyond Elmspring. The most northern point where it appears on the surface is in the bottom of the valley of James River, in sec. 22, T. 104 N., R. 60 W. A mile or two farther south it is exposed at several points along Firesteel Creek, particularly near the crossing of the railroad north of Mitchell, and at points as far west as sec. 36, T. 104 N., R. 62 W. The outcrops near the railroad rise about 20 feet above the stream, or to an altitude of 1,280 feet above sea level. It is exposed also along Enemy Creek south of Mitchell, and between that point and James River, and forms low cliffs along the river below Rockport, rising 30 to 50 feet above the stream. It is a rusty-brown sandstone, usually hard and of dark color on the surface, but softer below, varying much in character, sometimes being coarse and containing small pebbles and at other times extremely fine grained. It frequently shows oblique lamination in strata 3 or 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 is not merely due to erosion. It seems rather to have been

[a] Proc. U. S. Nat. Mus., vol. 17, 1894, p. 135, pl. viii, fig. 10.

RISDON ARTESIAN WELL, NEAR HURON, S. DAK., THROWING A 10-INCH STREAM TO A HEIGHT OF 12 FEET.

caused by unequal deposition, which may correspond to sand reefs, or possibly dune action, although there are no distinct traces of the latter.

The shale which overlies the upper sandstone of the Benton in part of the area attains a thickness of 50 feet in its greatest development. It appears not only in wells, but in a few exposures in secs. 25 and 26, T. 103 N., R. 60 W., near the railroad, on opposite sides of the ravine leading into James River.

Fossils characteristic of the Benton have been reported in wells on the east side of James River, near the south line of Hanson County, more than 100 feet below the surface, and in several wells in the northeastern part of Hanson County. In sec. 36, T. 104 N., R. 62 W., there are several feet of dark clay intervening between the chalkstone and the sandstone in an exposure on the south side of Firesteel Creek. Wells in that vicinity, also those near and south of Plankinton, disclose a dark clay next below the chalk, which is probably the same member.

Below the sandstone lie about 200 feet of gray and black shales indistinguishable from similar deposits in other formations of the Cretaceous. There occurs in this shale, in the vicinity of the quartzite ridge near Mitchell, another stratum of sandstone which seems to be thicker, more porous, and therefore more water bearing. North and west of Letcher it apparently becomes very thin and is often overlooked by drillers. Nevertheless, when carefully looked for it may usually be found, and will furnish a meager supply of water.

Thickness.—The upper surface of the Benton, as has already been stated, rises nearly 1,300 feet above sea level in the vicinity of Mitchell, and north and south of Plankinton it rises higher than 1,300 feet, judging from the reports of wells. It rarely falls below 1,000 feet in the region around Huron. Its thickness, therefore, may be estimated to be 350 to 400 feet, or nearly double the estimate given by Doctor Hayden from his observations along Missouri River.

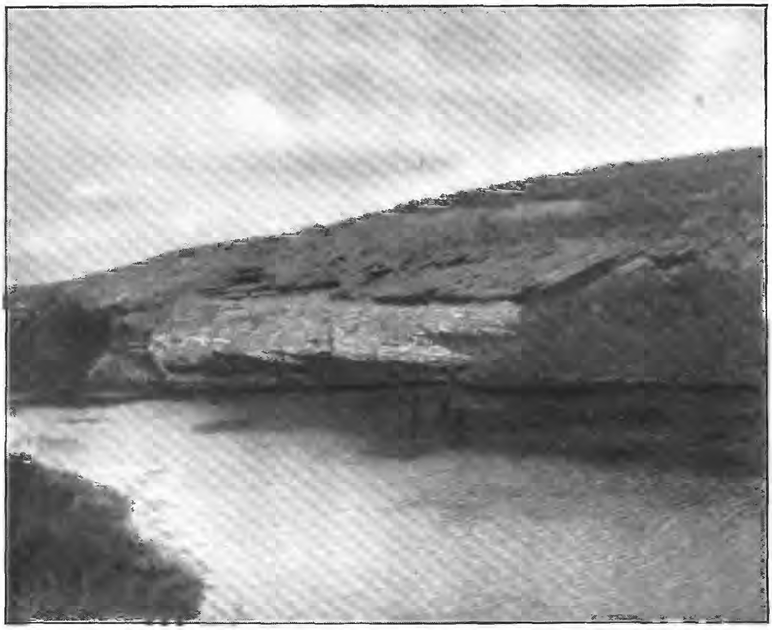
Fossils.—Besides the sharks' teeth and traces of vegetation already mentioned, special note should be made of a stratum of fossiliferous limestone discovered in several wells in the vicinity of Woonsocket. Though reported from several wells, our most definite knowledge comes from a well 2 miles north of Woonsocket. 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. These were submitted to Mr. T. W. Stanton, of the Survey, and he reports that at least three different kinds of fossils were represented, of which one was a small *Nucula* with striated surface that may be the young of *N. cancellata*, M. and H. Another is possibly a young *Mactra*, and the third, the most common form, was 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 main flow. These are distinctly marine in character, and hence form a strong reason for considering this stratum as part of the Benton. In the well at Farwell sharks' teeth were found in large number in the shales 400 feet below the surface. In the Ashmore well, southwest of Artesian, fossils were obtained a short distance above the top of the water-bearing Dakota sandstone, comprising a *Mactra* and a *Fasciolaria*.

From the black clay above the sandstone north of Mount Vernon a saurian vertebra about 4 inches in length was obtained.

NIOBRARA FORMATION.

The most characteristic feature of this formation is the chalkstone, which merges into calcareous clay and shale. It is of drab color, but on weathering becomes white, cream-colored, or often a light-straw color. As the formations both below and above are clay, it follows that the limitations of this formation can not be very sharply defined where the more impure deposits are dealt with. The recognition of this formation is especially difficult in wells, for where the chalk has not been exposed to atmospheric action it presents a leaden color, closely resembling the gray clays of the Pierre and Benton. Many well drillers do not recognize it north of the vicinity of Woonsocket.

The most definite distinction between the chalkstone and the clay is that when pulverized the chalkstone does not become plastic and sticky like the clay, but behaves more like a fine sandstone, from which, however, it is usually readily distinguished by its softness and lack of grit. From the evidence obtained it remains doubtful whether real chalkstone extends into the northern part of the area around Huron or into the western part about Plankinton, farther south. Perhaps the strongest evidence of its presence there is the fact that valuable pump wells are obtained at points where we should expect to find it. These wells are commonly said to derive their water from "soapstone," but it is difficult to see how that can be, for clay shales are commonly very impervious. It is well known that similar waters are obtained from chalkstone in the shallower soft-water wells west and southwest of Mitchell. Moreover, the wells said to be from the soapstone in the Huron quadrangle are soft-water wells like those from the chalk farther south. In the southern half of the area the chalk is often conspicuously developed and outcrops in many exposures. They appear at intervals of a mile or so along Firesteel Creek from its mouth to a point north of Mount Vernon. In some cases the chalkstone and sandstone of the uppermost Benton appear in the same vertical section. For 5 or 6 miles west of the railroad bridge over Firesteel Creek, sections of chalkstone and sandstone alternate at about the same level, indicating unconformity. Whether this is due to erosion or flexing or to some irregularity in deposition has not been surely determined, but it is probably the latter. Exposures of



A. UPPER BENTON SANDSTONE ON FIRESTEEL CREEK, IN T. 104 N., R. 61 W.

B. ARTESIAN SPRING IN T. 104 N., R. 60 W.

chalkstone appear along a channel of Enemy and Twelvemile Creek in T. 102 N., R. 61 W.; also on the lower portion of Twelvemile Creek east of Ethan. It is exposed also along James River near Rockport, at the mouth of Redstone Creek, and above the mouth of Firesteel Creek. In several places it lies only a few feet above the Algonkian. Many feet of it are found in wells 3 or 4 miles north of Alexandria, but, in general, the summit of the quartzite ridge from Alexandria eastward seems not to be overlain by it.

Thickness.—Over most of the area under consideration the Niobrara has been much thinned by erosion. In a strip running through the Alexandria quadrangle from Farmer northward wells fail to show the presence of chalkstone. Instead, there is a deposit of sand, presumably of Pleistocene age. The outlines of this have not been very clearly determined, but it seems to be several miles in width. East of this strip it would appear from the reports of some well drillers that the chalkstone comes in as if in the form of a buried escarpment. It seems not unlikely that the pre-Glacial course of James River may have been in that direction.

The thickest deposits of chalkstone yet reported are in the southwestern part of the Mitchell quadrangle, where a thickness of more than 200 feet is given. This may include some shale below. In some of the sections in the northern part of the Huron quadrangle what has been reported as gray shale has been indicated in the figures as chalkstone. It is not unlikely that, if carefully examined, the chalkstone of a bluish gray color might be found as thick in that portion as anywhere. At any rate, the beds including clay, which belong properly to the Niobrara, may be considered to be at least 200 feet in thickness.

Fossils.—The chalkstone frequently contains teeth and scales, mostly of bony fishes, although sharks' teeth are also found. Occasionally quite perfect specimens of bony fishes have been found.

The most common fossil is a small oyster about an inch in length, called *Ostrea congesta*, which is especially characteristic of the Niobrara formation. These fossils occur in thin layers of limestone and are frequently clustered on fragments of large shells, either *Pinna* or *Inoceramus*.

PIERRE SHALE.

This formation consists almost entirely of dark, plastic clay or soft shale, with occasional calcareous concretions. It is very uniform in character, but varies slightly in color. It underlies the drift in the northern half of the area to which this report relates, but has been eroded from the uplifted area about Mitchell. It dips northwestward and increases in thickness in that direction and in the northern portion of the area, especially in the highlands between Huron and De Smet, it is several hundred feet thick.

TERTIARY GAP.

No traces of the latest Cretaceous, or Laramie, nor of the Tertiary beds found farther west have been recognized in this area. It is not improbable that the thin edge of the Miocene may have extended over this region, but the Pliocene and early Pleistocene erosion which excavated the James River Valley before the advent of the ice must have removed them.

QUATERNARY.

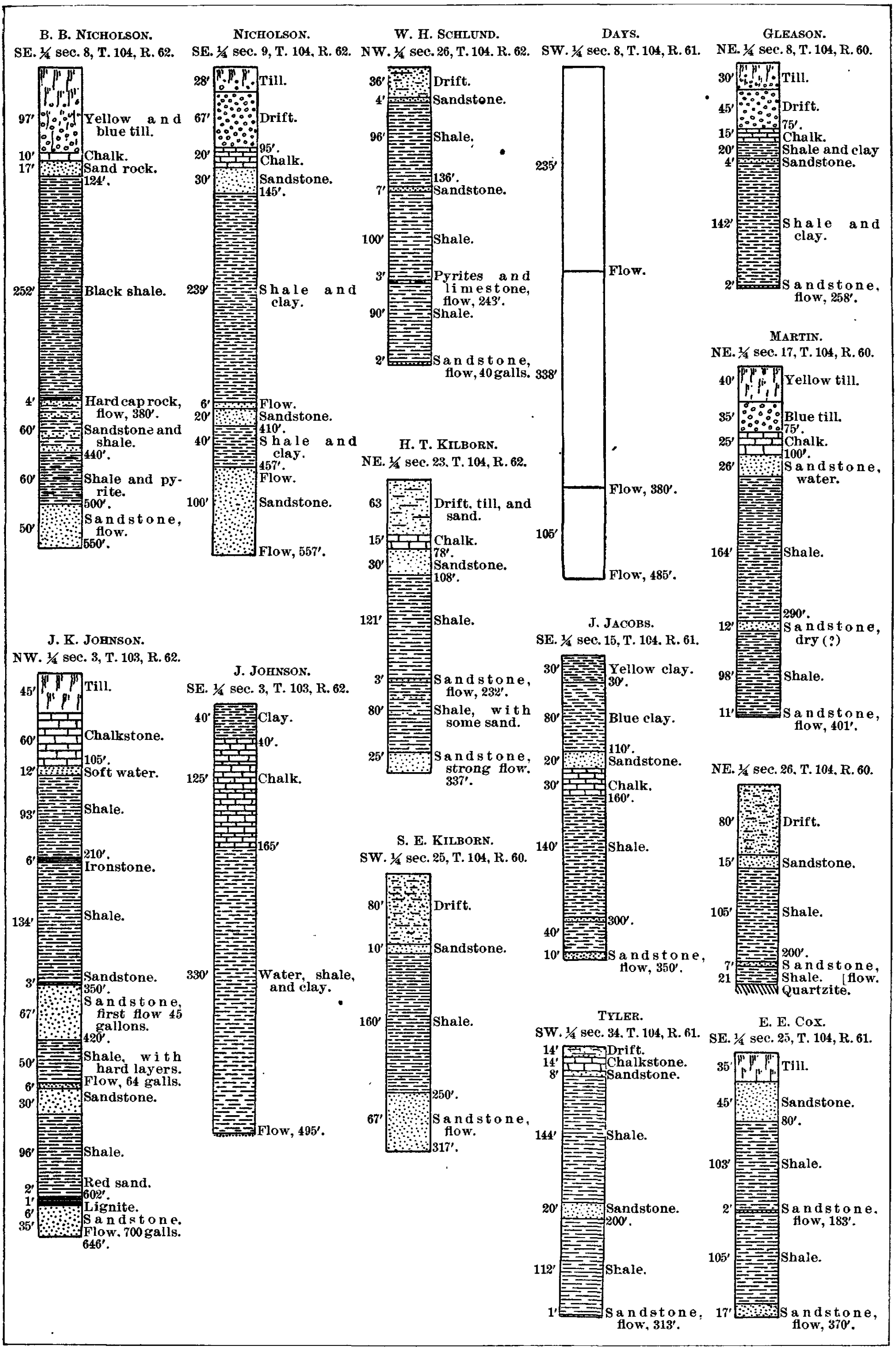
As already stated, the earlier Quaternary was an epoch of erosion. James River Valley at that time had attained approximately its present form and relative altitude, but the peculiar distribution of certain water-bearing strata below the till north of the quartzite ridge may have taken place in that period. The fact that from some wells in that region pieces of peat and numerous fresh-water shells have been thrown up strongly suggests that they came from a pre-Glacial marsh deposit which may have been connected with the flood plain of James River of that time.

With the exception of these beds most of the formations we have considered thus far have been of marine origin. In the remainder of the Quaternary deposits there is a marked contrast, not only in the cause and method of deposition, but also in the way in which they overlie all earlier formations without respect to altitude.

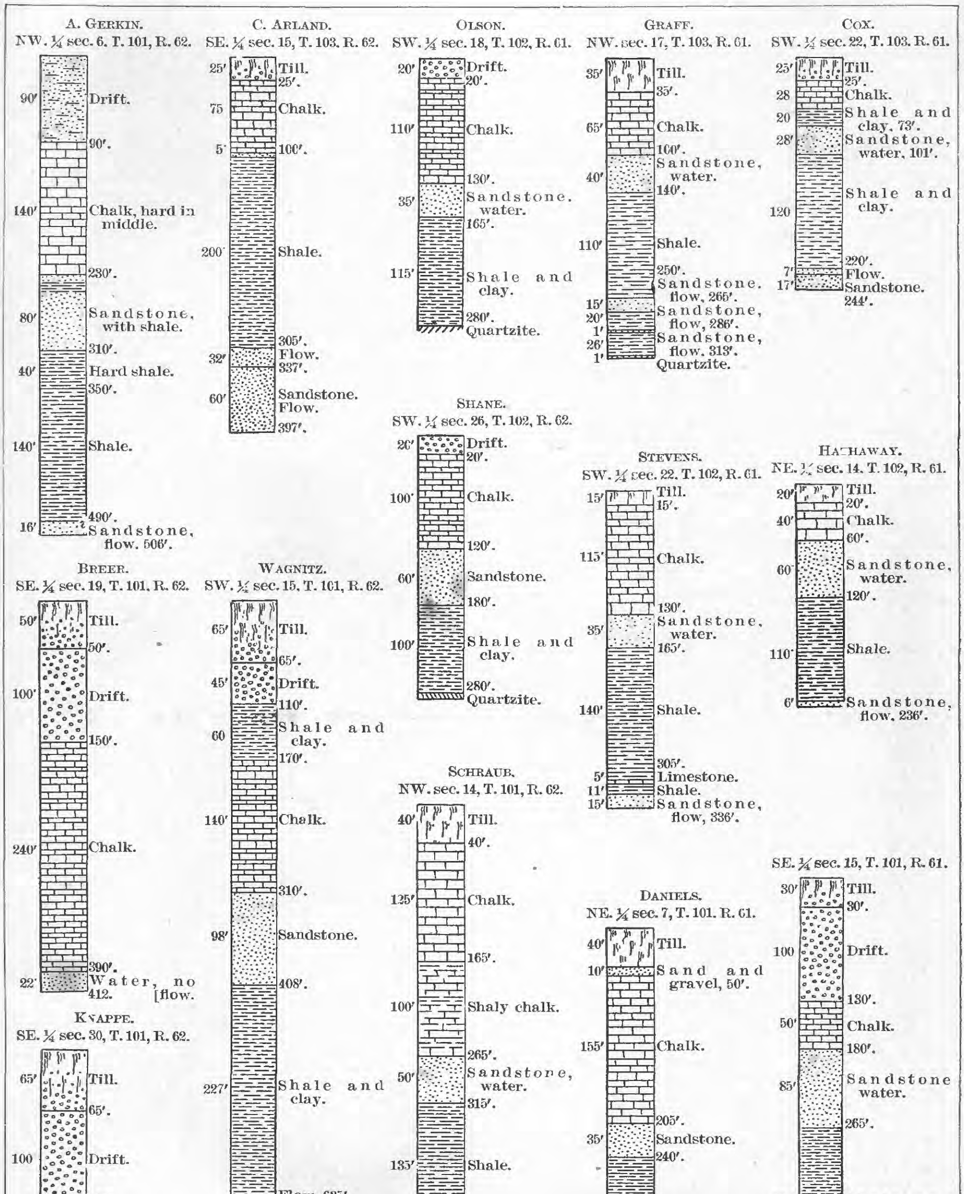
GENERAL DESCRIPTION OF GLACIAL ACTION.

To understand the conditions under which the Pleistocene deposits were laid down, it is necessary to know something about ice sheets, such as are now found in Greenland or Alaska. The beginning of a glacier is due to the accumulation of snow. As it accumulates from year to year, partial melting and the pressure of superincumbent material compresses it into ice and it commences a slow, flowing movement down a valley. The ice moves like the river, except that the motion is sometimes independent of local valleys or channels, and is very much slower. Its form is more lobate, with the breadth often nearly as great as the length, and the movement is everywhere toward the edge.

The limit of the ice is determined by the relation of the melting to the velocity. If these influences are just balanced—in other words, if the ice at any point melts as fast as it moves forward—the edge will remain constant, and as the ice transports much gravel and clay, a ridge or moraine will be formed at the edge. If the ice moves more rapidly because of rapid accumulation of snow at the fountain head, or if the melting diminishes, as in winter or in a succession of cool and cloudy seasons, the ice will advance, overriding the moraine, if such has been formed. If the converse in either of these cases is true, the edge of the ice will recede, and if continued sufficiently the



LOGS OF WELLS IN DAVISON COUNTY, S. DAK.



LOGS OF WELLS IN DAVISON COUNTY, S. DAK.

ice will gradually withdraw until it entirely disappears. Such has been the case with the vast ice sheets which comparatively recently covered this region.

As the ice proceeds the débris under the thicker central portions will be pushed along, producing scratches and grooves upon the underlying rocks, but toward the edge, where the ice sheet is thinner because of rapid melting above and below, the débris below, consisting of bowlders and clay, will cease to be moved, and, like the sediment of a river when the current slackens, will build up a bar. Moreover, the material carried in the lower part of the ice sheet will gradually be dropped and become more or less assorted by the waters which result from the melting of the ice. The resulting deposits will be of fluvial character where drainage is free, and lacustrine where escape is hindered. In the latter case especially portions of the ice mass will become detached and buried in the débris and their melting will be delayed until after the surrounding material has become permanently settled, so that eventually pond holes, and even lake beds of considerable size, will result.

From this sketch of the glacial action one can readily understand how the first advance of the ice is preceded by a flooded condition of all streams. In case they flow from the ice, their waters will be swollen by the melting ice and their sediment increased by the mud and sand contributed by the glacier. In case their course is toward the ice sheet or parallel with the edge, they will become dammed and changed temporarily into lakes in which the material from the ice will be deposited.

From this explanation also it may be seen that the pre-Glacial surface will be more or less covered with a layer of sand or gravel before the bowlder clay or regular glacial till is deposited upon it.

It is also seen how the pre-Glacial surface divides the course of the ice sheet and decides the character, in a measure, of the deposits laid down by it. The axis of the ice flow will coincide with the central portion of the pre-Glacial valley, and over it the ice will be thickest and its surface most elevated. The divides between the valleys and other elevated points will be the last to be covered by the ice and the first to be uncovered. From this fact it might be expected that the glacial deposits are thinner there, but such is not often the case, because of the tendency for the deposits to accumulate more rapidly under the thinner portions of the ice, as before explained. These facts are well illustrated in this area.

TILL OR BOWLDER CLAY.

This deposit is the accumulation formed underneath the ice, as has already been explained. It is generally of unstratified character, being a heterogeneous mixture of sands, clay, gravel, and occasional bowlders. It is usually distinguished from ordinary stream deposits by its unassorted character and the absence of stratification. It frequently contains pockets or lenses of sand of considerable extent, which is often stratified. In some cases these are portions of the accumulations of subglacial streams, which have become broken up and buried in the till. They sometimes contain abundant water, but are often dry and filled with air, which is sometimes under pressure. The ingredients of the till vary in different localities according to the rocks over which the glacier has passed. In this area the clay comprises perhaps 90 per cent of the whole.

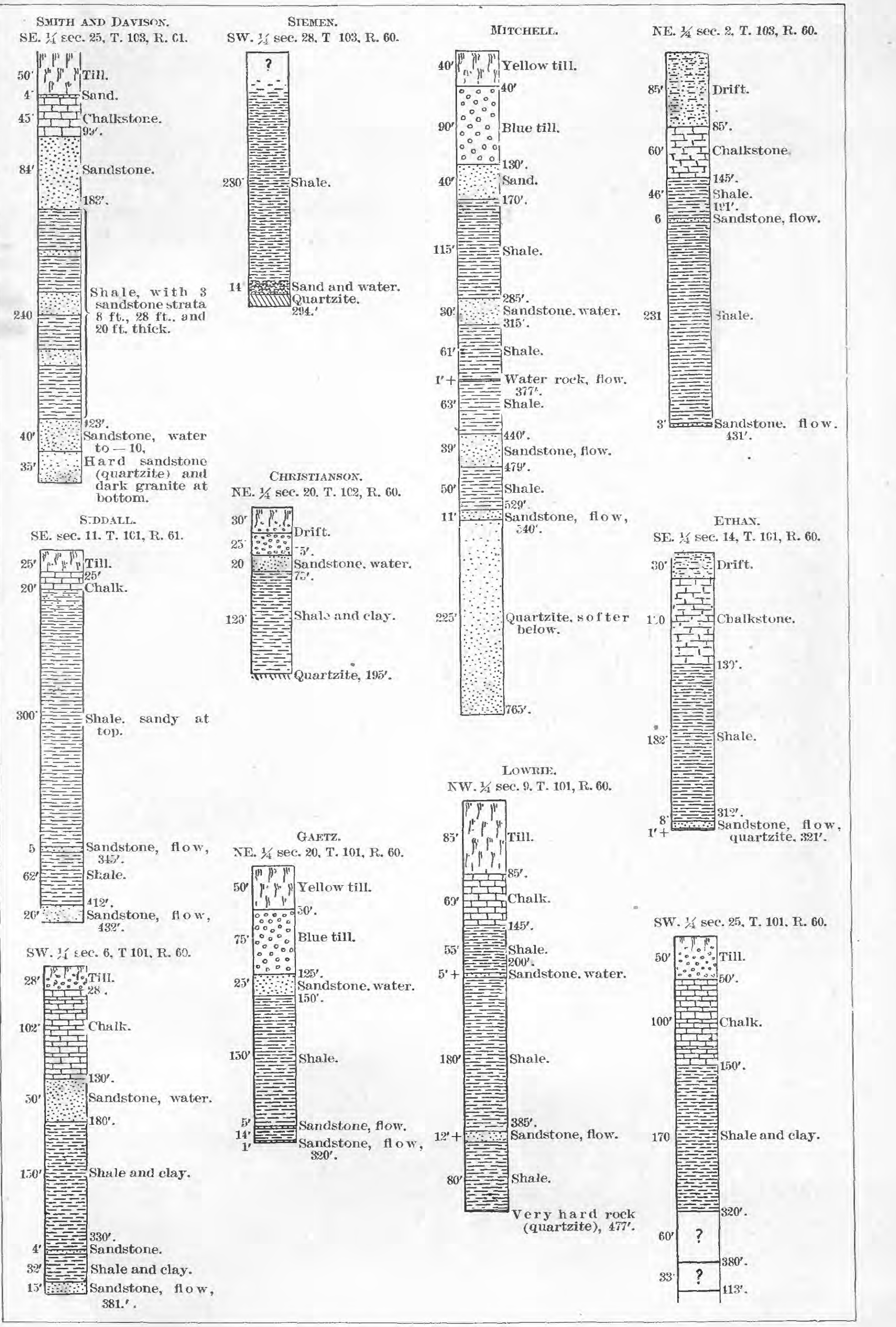
Surface of the till.—The surface of the till in lower places is more or less covered with silt, laid down by the waters escaping from the ice soon after its deposition, and also by the wash in more recent times, especially upon hillsides. In some localities, also, considerable silt has been deposited from the atmosphere; but both of these influences have not modified the till of this region to any great extent, except in the lower portions bordering James River, of which mention will be made in a later section. The surface of the till in general may be said to be much more even in this area than is frequently the case in other regions. This is mainly the result of its having been deposited far within the principal moraines upon a surface already smoothed by former and more vigorous ice sheets.

The till of this region exhibits the usual basin and swell surface, but in a very mild degree. Few of the basins are of sufficient extent to hold water through the summer time. As a whole, however, they have a most important influence in retaining the surface water. When snow melts, or after rains, they hold the water so that over much of the surface very little of the rainfall escapes into the streams.

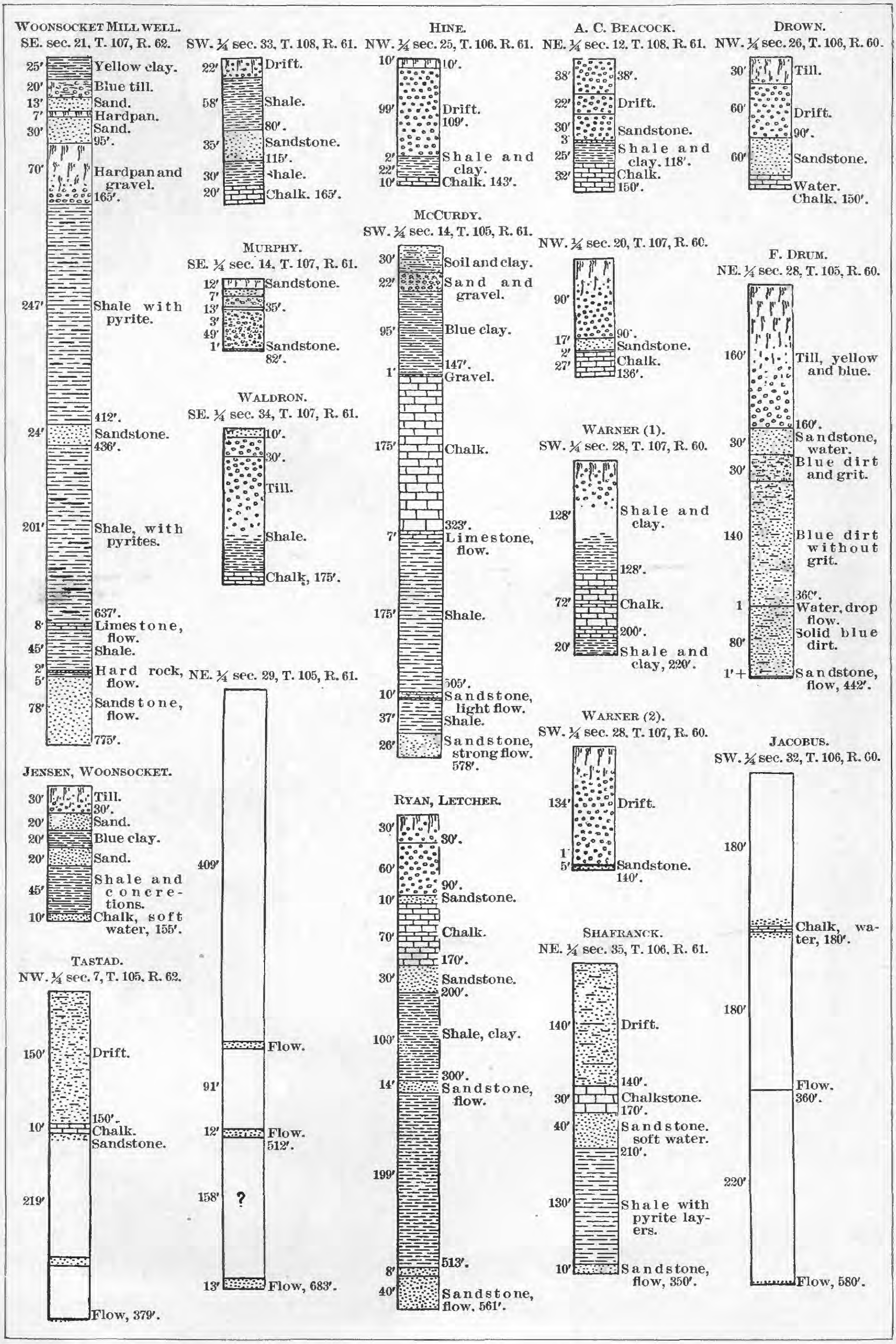
An area around Huron, covering perhaps 100 square miles or more, seems to have been, during the recession of the ice, a shallow lake. So, also, at an earlier stage there was an area of similar character and equal extent east of Woonsocket; and also another northeast of Mitchell. All of these will be discussed more in detail under the heading "Ancient channels."

Thickness of the till.—The average thickness of the till can be roughly estimated to be about 75 feet over the whole area. Southwest, west, and south of Mitchell, within a radius of 10 or 12 miles, the thickness is often less than 50 feet. This includes the region in which the Cretaceous strata outcrop. So, also, in the valleys of all the principal streams the thickness of the till is often less than 20 feet. On the contrary, in the elevated region about De Smet depths of 200 or 250 feet may occur, although but few drillings have been made to show this fact. Southward from that region the till gradually diminishes in thickness, until in the vicinity of Spencer it is generally less than 50 feet. In the region south of Plankinton, also, wells show a frequent thickness of 150 feet, while some attain over 200 feet.

In the flat lands east of Woonsocket the depth of the till is nearly



LOGS OF WELLS IN DAVISON COUNTY, S. DAK.



LOGS OF WELLS IN SANBORN COUNTY, S. DAK.

100 feet, and this thickness prevails generally under the morainic belt north of Sand Creek and Redstone Creek. Southeast of Wolsey, in the flat country, the till usually has a thickness of 60 or 70 feet; it probably has about the same thickness in the flat lands around and east of Huron.

In considering these statements it should be remembered that the separation of the till from the underlying clay of the Cretaceous is often very indistinct. Well drillers very frequently do not distinguish the two formations; hence the reports upon which the preceding statements have been made are few and far between. In the region near the Cretaceous outcrops no water is found between the till and the underlying chalkstone or sandstone. Hence in drilling wells the till is not looked for in such portions of the region. Elsewhere, also, in this area, more frequently than farther south, there seems to be an absence of the sand stratum which separates the till from the underlying clays, and even in some cases where sand is found it is so fine that it can not be utilized for water supply. It is nearly impossible to separate the fine sand from the water, even when the casing is covered with very fine-meshed screen.

Another consideration also tends to produce confusion, especially in the northern part of the area. There exist in the upper part of the Cretaceous one or two water strata, which join the bottom of the till at a very small angle. Hence, where the thickness of the till is estimated from the depth of wells, by an oversight the measurement may extend below the till to the Cretaceous clays. This danger is especially strong in the northern half of the area.

Another source of error, against which it is impossible to guard, is the irregular thickness of the till in some localities. Two wells sunk only a few rods apart are frequently reported to find the bottom of the till at very different depths. Sometimes such reports may arise from the sand pockets which we have already referred to as occurring in the till, but in some cases the statements refer to the striking of soapstone, or Cretaceous clay. In this case there could be little doubt that the bottom of the till had been reached. On the whole, therefore, the statements concerning the thickness of the till must be taken as only very general estimates.

MORAINES.

The till sheet already described is sometimes called the ground moraine, but the moraine spoken of here is always the system of hills believed to have been heaped up around the edge of the ice sheet. It is sometimes more definitely called a terminal moraine. Such hills are recognized more by their relative position than by any one characteristic which they bear individually. Each one is usually lengthened parallel with the course of the system, abounds in bowlders, and has somewhat abrupt sides, but all of these characteristics are not always found together.

As a system, the moraine usually presents these 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 trifling size or many rods in width, and cut down through the whole height of the moraine.

The height of the moraine at any one point is due to several conditions:

1. The relative height of the pre-Glacial surface.

2. The amount of material pushed forward by the ice at that point, which depends again on the transporting power of the glacier and the time its edge remained stationary.

3. The amount of material washed away.

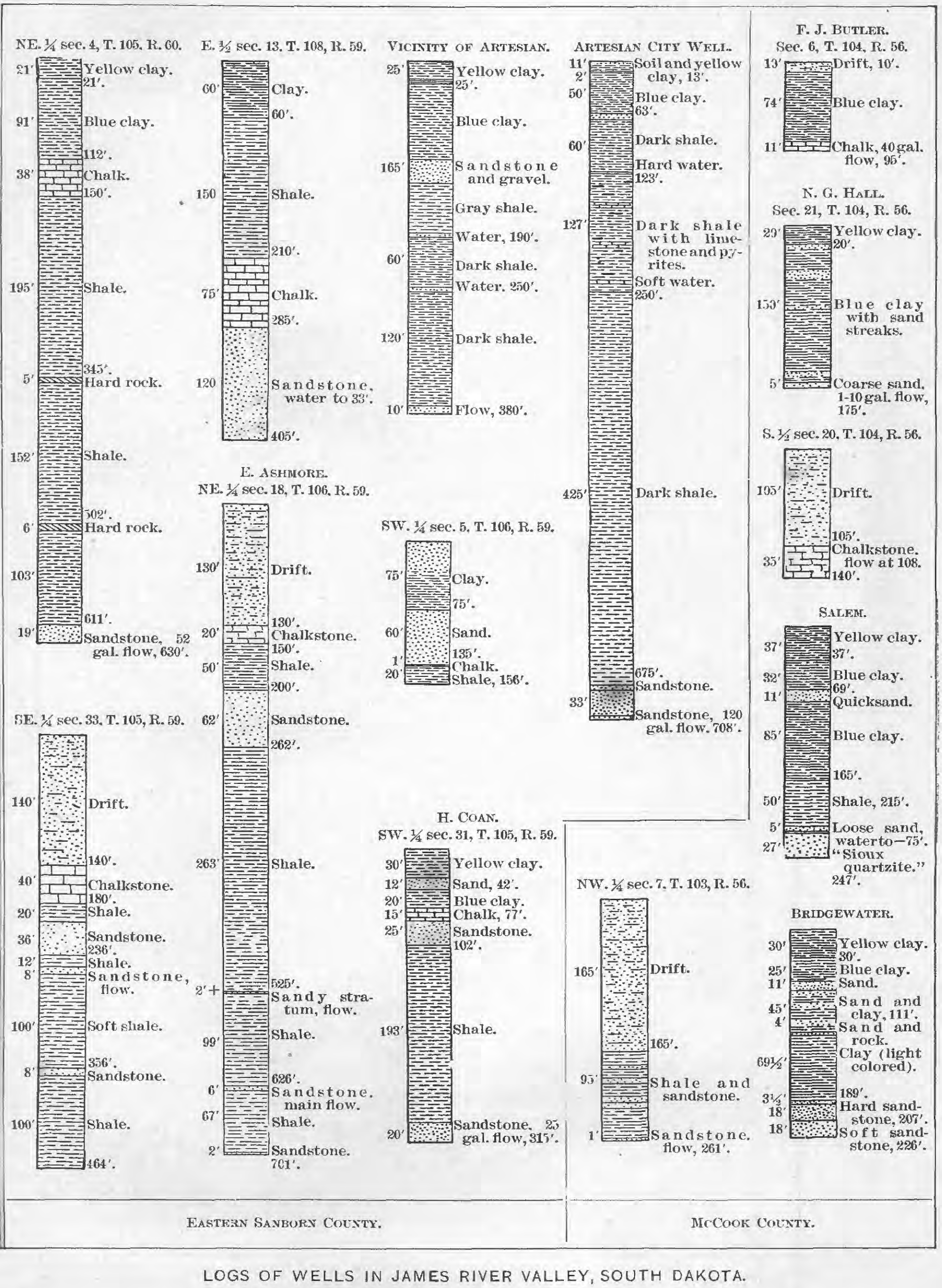
4. The consistency of the material—an excess of clay or sand tending to produce a low and even moraine, while excess of stony material is favorable to the formation of a high and rugged moraine.

The moraines of this area are mapped on Pl. III; consequently it will be unnecessary to speak definitely of their location. With few exceptions they are not conspicuous features. Generally they consist of low, broad swells, showing the usual surface of the till, except that occasional peaks which rise more or less abruptly 15 or 25 feet above the surrounding surface are scattered over the general level. The swell may have a height of 20 or 30 feet above the till, into which it insensibly merges. The intervening depressions and basins are also more numerous and larger than elsewhere. Moreover, the moraines usually present a large number of bowlders, beds of gravel, and other marks of abundant and free-flowing waters.

In the area under consideration are portions of two principal moraines, both of which present three or four minor subdivisions. The moraines belong to the Wisconsin stage of the Glacial epoch and are commonly known as the Second, or Gary moraine, and the Third, or Antelope. The former name is derived from the town of Gary, S. Dak., where it was first studied, and the second from a ridge in Minnesota Valley. In general it may be stated that these moraines were formed as portions of loops extending southward across the axis of James River Valley. Previous to their formation the ice had covered the whole area to a depth of several hundred feet, and pushed south and west to the vicinity of Missouri River, where it rested for a time and formed the First, or Altamont moraine. Hence the moraines in this area were formed on a fairly smooth and level surface. For the same reason, also, they are less irregular and prominent.

These loops show higher hills upon the southwest side, while upon the southeast and east they are sometimes not easily traced.

The Gary moraine enters the west boundary of the area north of Firesteel Creek, near the north boundary of Jerauld County. It is



LOGS OF WELLS IN JAMES RIVER VALLEY, SOUTH DAKOTA.

there usually developed in an irregular ridge, rising more than 100 feet above the valley of the stream outside, or west. It continues southward along the east side of Firesteel Creek, soon becoming a low swell, and so continues across the main channel of Firesteel Creek into Davison County. Here it follows a tributary from the south, which connects by a valley with the upper portion of Enemy Creek, and again with the upper part of Twelvemile Creek. The outer margin of this moraine still follows this channel in a southeasterly direction till it crosses the north line of Hutchinson County east of the ninety-eighth meridian. This outer member does not reappear in this area until it crosses the northeast corner in a north-northwest direction, west of De Smet. Branching from this, near the north line of Davison County, is the second member, which passes more to the east along the main channel of Firesteel Creek and James River, crossing the latter near the south boundary of the area. This does not appear again until it is found in connection with the first member near De Smet. A third member leaves the other two southwest of Woonsocket, and takes a course approximately parallel with the last, passing south and a little southeast of Mitchell, forming a short but high reentrant angle just east of James River, northwest of Bard, thence continuing along the east side of James River until it is lost in the plain east of Rockport. Its eastern limb reappears near Epiphany and continues north in a low ridge west of Wolf Creek and west of Howard, keeping the same direction till it joins the older members west of De Smet. A fourth member, rather more clearly defined in its western portion than the last, leaves the preceding member northwest of Woonsocket, and about 3 miles west of that place is developed into a high, narrow ridge, known as the "Pony Hills." It diverges still more from the former members so that it crosses the railroad in scattered knolls about 5 miles northwest of Letcher, and north of that place forms a rough strip about 2 miles in breadth nearly to James River. East of that stream and north of James Creek its main portion turns northeast. Its course northeast of Artesian is so faintly developed that it has not been traced. This member seems to have formed the main barrier which produced a shallow lake east of Woonsocket. From its southern side this lake had three or four outlets through the moraine: Long Lake, northwest of Letcher; a similar channel east of Letcher; and James River.

The Third or Antelope moraine lies along the west side of the area west of Wolsey in the form of a conspicuous ridge. It turns southeast and later to the east north of the main course of Sand Creek. It crosses James River on the north line of Sanborn County, becomes less prominent, and gradually curves in a northeast direction, becoming still less prominent, but is faintly developed west of Iroquois, where it has a north course, which continues beyond the limits of the area. This may be considered the first member of the Third moraine and the most conspicuous part of it.

Lying approximately parallel with the first member are two or three lines of scattered knolls, beginning near the northern boundary, west of Broadlands, and curving around south of Huron. One of these is developed into a ridge 30 or 40 feet in height south of Cavour. As these have much of their course in a plain which probably was at one time a shallow lake, they are very feebly developed.

Along the inner side of the first member of the moraine, on the west side of James River, lies Cain Creek and east of it Pearl Creek. The portion of the moraine lying between Cain Creek and Sand Creek is traversed by two or three well-defined channels, reaching through the moraine from the valley of one stream to the other.

ANCIENT CHANNELS AND TERRACES.

Under this head are included all water-laid deposits of any considerable thickness except such as are in the immediate flood plains of present streams. In some of the shallow channels the older deposits may not be clearly separable from those of recent origin. In such cases the later are included under this head. The geologic map shows the location of these channels. They correspond generally with the present waterways, for the latter are the puny successors of the former, and yet the direction of drainage has been so changed in a few cases that some of the present valleys are connected by a network of older channels.

General character.—These channels vary from broad, shallow depressions, approaching lakes in character, through which streams passed for a comparatively short time, with a sluggish current, to troughs 20 to 40 feet in depth, in which the abundance of coarse material shows that they were occupied by vigorous streams for some time. In both cases the coarser deposit is usually sufficiently covered with finer material to afford rich soil. Where the channel deposits have been cut through by the deeper trenching of the later streams similar differences in the character of the deposits also occur. In some cases the old channel deposit is at a height of 50 or 60 feet above the present stream. In many cases, however, the old deposits have been only slightly eroded, because the later drainage has passed off in another direction.

We find the older channels changed to terraces, particularly along James River, where sometimes two, at different altitudes, appear. East of Huron, for example, these are found at about 40 and 60 feet, and east of Mitchell at about 80 and over 100 feet above the stream. They are not always distinctly marked, but may merge one into the other. The usual indication of such a terrace is a sharp, stony edge capping the river bluff and a generally flat surface extending for many rods.

FRAZIER ARTESIAN WELL, 10 MILES NORTHEAST OF MITCHELL, S. DAK., 295 FEET DEEP.

Origin.—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 in its different stages. The arrangement of the channels is evidence of the former existence of an ice sheet over this region. The size, and particularly the course, of some of the channels and the amount of coarse material found in them can not well be explained in any other way.

The order in which these channels were occupied may be learned from the map, where they are numbered; but it should be remembered that it is impossible to represent the order of their occupation with minute accuracy. In some cases the same channel has been used in opposite directions, and this change has perhaps occurred more than once. It will be noticed that the numbers are generally wide apart, but are sometimes found near each other, especially along the course of James River. In such cases it is intended to indicate that the channel had been used at times corresponding to the occupation of channels bearing those numbers and that the altitude of the formation does not clearly distinguish the order of time. Usually the later terraces are lower than the older, but this is not always the case. During the rapid unloading of débris from the ice the streams might at one time erode and at another time fill, so that waters are conceived to have been at nearly the same level at widely different times.

To give an example of the way in which the channels record the presence and different stages of the ice sheet and at the same time the varying directions in which the water flowed, attention is called to the channels west and south of Mitchell. (See Pl. III.)

When the ice occupied and was building the outer member of the Gary moraine, the drainage about the western edge was discharged along a channel which follows the course of Firesteel Creek and a southern tributary, and which leads west of Mount Vernon; then through the main branch of Enemy Creek to the center of T. 102 N., R. 61 W., when it passed by another intermediate channel into the north branch of Twelvemile Creek, thence by another crosscut to the south branch of the same stream. Into this the water from the ice sheet discharged by several outlets through the moraine. Since the course of this stream was on a higher level than the land farther east a short distance within the edge of the ice sheet, as soon as the ice began to recede the waters at several points, particularly near the north line of Aurora County, turned eastward through the outlets and followed for a time the edge of the ice, while it formed the second member in a way analogous to that already sketched. When the ice receded to the third member a similar change took place by the main stream, following the present course of Firesteel Creek to a point northeast of Mount Vernon before turning south. The course of Firesteel Creek was not occupied as at present until the ice had withdrawn beyond the junction of this stream with James River.

ANCIENT LAKES.

In connection with the channels, certain extensive areas which may be called ancient lakes should be considered. The use of this term does not imply that they were occupied at one time by water, although this may have been the case. It is probable that as the ice receded over them from the south toward the north the southern portion was first occupied by more or less ponded water and filled by the accumulating sediment from the streams draining the adjacent ice sheet; as the ice uncovered one portion after another these areas were successively filled with sediment in the same way, until, on the recession of the ice, they became flat plains, covered with sand or clay, with points of the underlying till rising above it like islands, and shallow channels winding about irregularly upon it. In some cases shallow lakes may have continued for an indefinite period. The largest and best example of this sort lies between Woonsocket and Forestburg, and extends from the outer portion of the third moraine to the fourth member of the second moraine. It covers an area of perhaps 50 miles. Over this area the surface is poorly drained and covered either with fine clay, commonly called gumbo, or with sand which is sometimes gathered in dunes by the wind. The gumbo seems to have been formed by the settling of clay in comparatively quiet water. The sandy areas from their position overlying the gumbo and till seem to have been formed as deltas by Sand Creek and Redstone Creek.

A similar area, not so clearly defined, surrounds Huron, especially on the south and east. This does not present so much of the gumbo surface, and the sand is also less marked.

Between Letcher and Mitchell and extending eastward across James River is another flat area which presents more of the usual surface of the till and less of the sand and gumbo.

GEOLOGIC HISTORY.

The granite which underlies most of James River Valley is considered to be part of the very old surface which existed before life appeared upon the earth. Whether it may be, in some cases, part of the original substance of the globe or whether it was first laid down in an ocean and afterwards changed to a crystalline rock by heat and pressure has not been satisfactorily ascertained.

The Sioux quartzite, which is exposed in the region east of Mitchell, belongs to a later epoch, and certainly was deposited in the ocean, probably upon the margin of a land area which existed farther east in Minnesota and Wisconsin. From that land, the waves, ocean currents, and tides, which were probably more vigorous then than now, derived the sands and spread them out over the bottom, much as now takes place on the seashore. As the material accumulated there was a gradual sinking of the ocean bottom till a thickness of several hun-

ARTESIAN WELL ON SCHLUND FARM, DAVISON COUNTY, S. DAK., 390 FEET DEEP, 40-GALLON FLOW.

dred feet had been laid down. There is no clear evidence that there was any animal life in that ancient ocean.

In the succeeding age there was a disturbance which resulted in the eruption of molten rocks which may have reached the surface and penetrated the sand strata in both dikes and sheets. It was probably during this period that the sand became consolidated into the hard stone we find to-day. Some of the igneous rock which appeared at that time has been found at Hull, Iowa; near Corson, in Minnehaha County; in Hanson County, sec. 26, T. 104 N., R. 58 W., and at Yankton. Probably in early Cambrian time this region was above sea level, and then followed the long period of erosion which is mentioned above as the Paleozoic gap. It may have been that the first upheaval of this region was a few hundred or a few thousand feet, but more likely the rise was by several successive elevations. It is probable that during the erosion of Paleozoic time several hundred feet of rock were carried away, and that the buried ridge extending through the Mitchell region is but a small remnant of the original rock mass. The land surface at this time may have been clothed with vegetation and occupied by animals of various kinds. During the last of the Paleozoic and the early part of the Mesozoic the seashore must have been beyond Missouri River on the west.

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 the Cretaceous period had passed, for the first deposits appear to have been the sediments of Dakota time. These were mainly sands deposited on beaches and in estuaries, but in intervals of quieter and deeper waters clays were also laid down. It is likely that the sands were carried by vigorous tidal currents and probably came 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 which were being 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 fish, huge reptiles, and mollusks. Deep waters and clay deposition 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

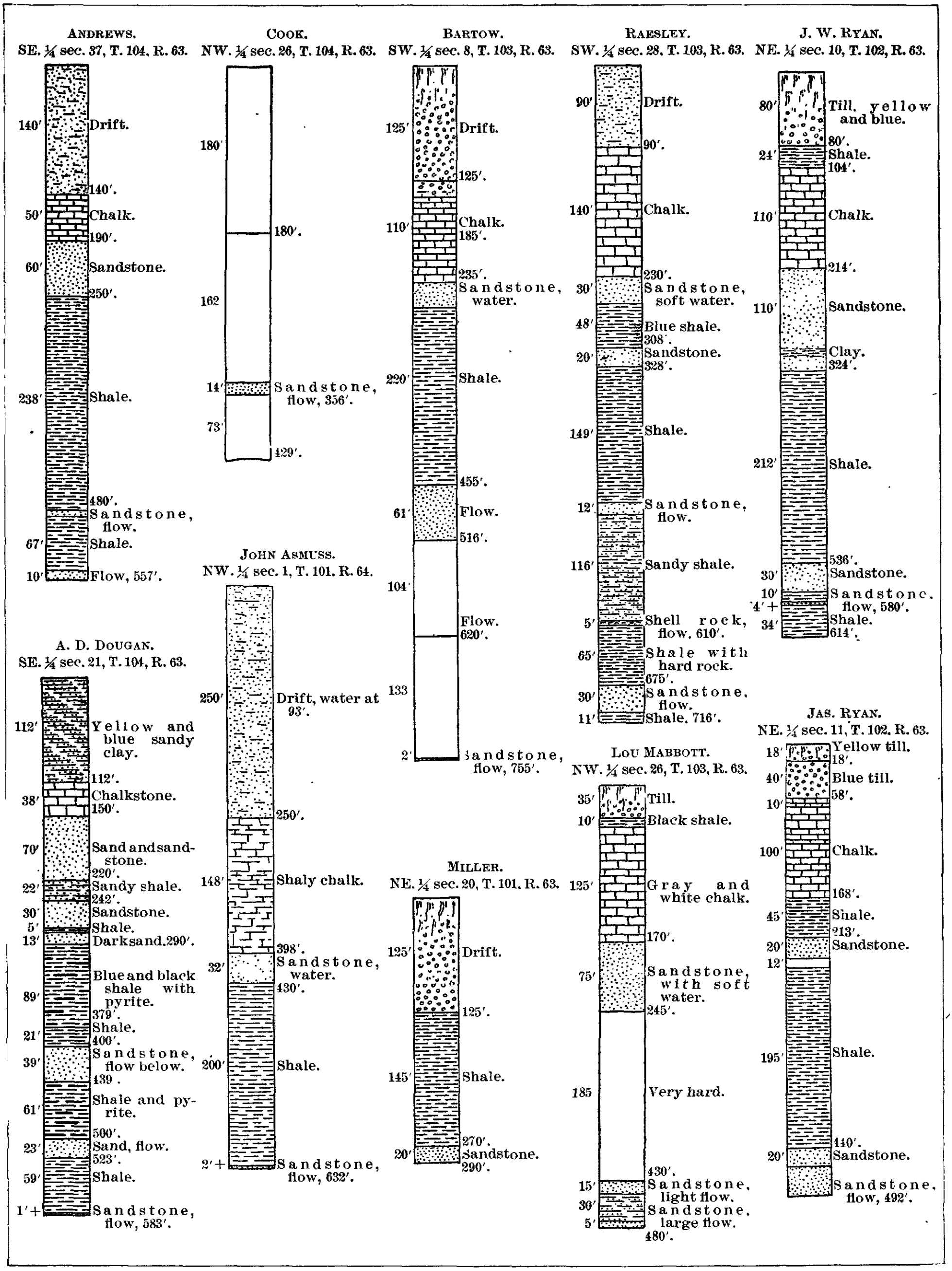
Laramie sandstones were laid down; but as these formations are absent to the southeast there is no evidence as to the conditions in southeastern South Dakota in this epoch, and presumably it was then a land surface. Probably the land surface continued during the Tertiary period, and some of the streams of later Tertiary time spread local deposits of sands in some portions of the region, but it is impossible to affirm what the conditions were in this area, because subsequent erosion has removed all such deposits. During the later part of the Tertiary period there was doubtless a large stream somewhere near the present position of James River, flowing toward the south.

The remarkable area furnishing artesian waters from underneath the till near Artesian may be considered as some evidence that the former course of James River lay along that line. The prominent range of knolls east of Mitchell suggests the presence underneath of a prominent point in the underlying rock which may have existed on the west side of the pre-Glacial James River. The lower land 3 or 4 miles east of the James, south of Alexandria, continuing to Hutchinson County toward the mouth of Wolf Creek, and the apparent recency of the trough of James River west of it below Rockport, as is indicated by the prominence of sandstone cliffs at several points, also the absence of chalk in a strip passing Farmer, Hanson County, combine to at least suggest that the pre-Glacial course of James River lay east of its present course through the southern part of this area. This suggestion has not, however, been tested by a comparison of significant well borings.

Into James River probably came White River, through the valley of Red Lake, White Lake, and Firesteel Creek. Those rivers doubtless had many small tributaries which had rapidly cut down the soft materials composing the surface. The elevated region in the southwestern part of Davison County may be considered a remnant of the old divide south of it.

Such were the drainage conditions until the Ice Age began, when it is supposed the climate became moister and colder. During the earlier stages of the Ice Age the ice had not broken over the divide between James River and Red River, and hence the streams, although swollen by rains, did not receive water directly from the ice. If the ice reached the boundaries of the State at any point, it probably did so in Minnehaha County, coming over from the Minnesota Valley, and Big Sioux and Vermilion rivers carried off the water.

During the Wisconsin stage the ice finally extended over the divide east of James River near the north boundary of the State, and steadily progressed down the valley until it had filled it to a depth in the center of 1,000 to 2,000 feet. At this time the ice extended as far west as Kimball, southwest of Lake Andes, south to Yankton, east to the East Vermilion, and southeast to Canton and Vermilion. During this stage the region was being ground down, chalkstone and softer



LOGS OF WELLS IN EASTERN AURORA COUNTY, S. DAK.

deposits were carried away, and the surface of the quartzite was planed and grooved as is found southwest of Bridgewater and at numerous other exposures.

This condition probably continued for hundreds of years, but in due time, possibly from a sinking of the northeastern part of the continent or from some general climatic change, the strength of the ice current was checked, and it gradually melted back, possibly until a portion of this region was uncovered. It is barely possible that the marsh deposits before referred to, found near the southwest angle of this area, were laid down at that time; but this does not seem likely, because they seem rather to be Cretaceous clays than till underneath them.

Again the ice sheet advanced and formed the first member of the Gary moraine. At that time the southwest angle of this area was uncovered, and also the northeast angle, and the drainage from the west side of the ice sheet passed through the valley west of Mount Vernon, and that from the east side through the valley east of De Smet. The southern point of the ice must have extended into the northeastern part of Yankton County. When the ice receded to form the fourth member of that moraine, the west branch of Sand Creek drained down the channel west of Pony Hills west of Woonsocket, while the drainage from the east side was largely by Rock Creek.

While the Third or Antelope moraine was forming, the North Fork of Sand Creek, fed by several streams from the ice sheet, washed much débris into the basin east of Woonsocket. At the same time Redstone Creek sustained a similar relation on the east side of the James.

The last appearance of the ice in this area was an almost stationary glacier. The ice probably lay in extensive blocks in the basins east of Huron, even after James River was running near its present course, a little northwest, perhaps with icy banks. A portion of the basin north of Huron seems to have been more open and to have received much sand and silt from the melting ice sheet farther north, not only through the James, but by a channel which led past the present location of Broadland.

Afterwards the streams assumed their present courses, and, though somewhat larger than at present, had little effect upon the surface of the country except to deepen the channels which were occupied by permanent water. It is believed that James River had cut nearly to its present depth before the ice had disappeared from the State. The main geologic development of the country since the disappearance of the ice has been in the formation of the soil, which has gone on by the accumulation of alluvium along the principal streams. To this may be added the deepening of fine material over the general surface by the burrowing of animals, the wash from the hillsides, the settling of dust from the atmosphere, and the accumulation of the remains of vegetation.

ECONOMIC GEOLOGY.

There are no deposits of mineral ores or of coal in this area. Fragments of coal are sometimes found in the drift, but they have been brought by the ice or by streams from the northern part of James River Valley.

Valuable quarries of red quartzite have been opened near Spencer and Alexandria and quarries might be operated at perhaps a dozen other points. Their location may be learned from the geologic map (Pl. III) by noticing the outcrops of Algonkian, or quartzite. Chalkstone and the upper Benton sandstone have also been used for the construction of buildings, but the material is not considered sufficiently durable. Much of the stone locally used for foundations and other rough buildings is derived from the drift. It consists of granite, limestone, and greenstone bowlders, which are very durable and with a little care may be neatly laid.

Deposits of clay of economic value are not certainly known to exist. A bed was opened southeast of Mitchell, from which brick were manufactured at that place, but the frequent occurrence of lime nodules in it rendered the preparation of it too expensive for practical purposes. It is not improbable that diligent search would find beds of silt near James River, or of gumbo in the lake basins, in sufficient quantity to be of some local value in making brick, but there is apt to be so much lime and coarse material mingled with it that brickmaking will not be extensively carried on in this region.

Sand and gravel deposits may be found very generally in the more important old channels.

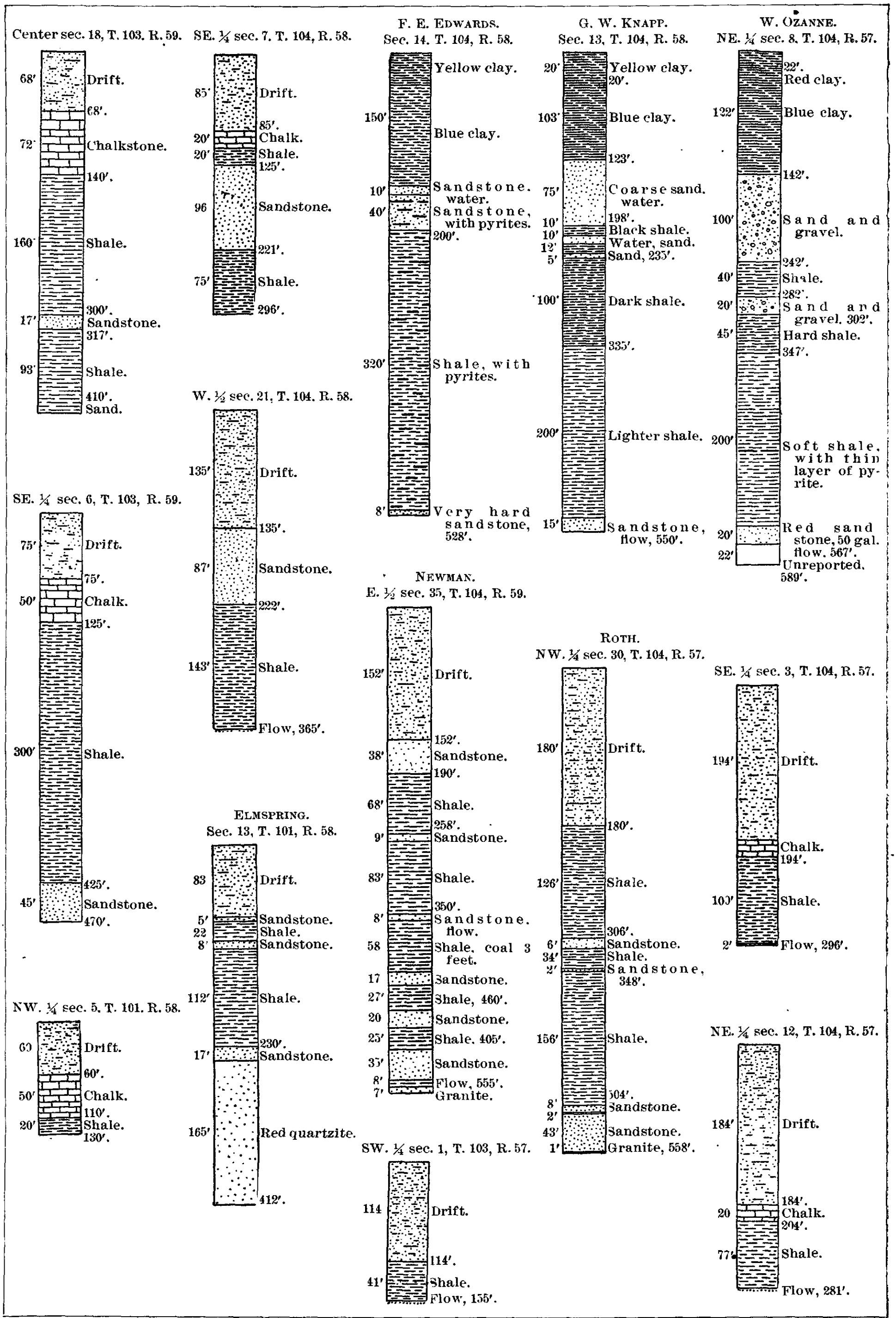
WATER SUPPLY.

This resource is not only of prime importance, but considerable knowledge of its distribution, character, and accessibility is directly obtained by geologic investigation. Its occurrence may be classified first into surface waters and subterranean waters. The former will include lakes, streams, and springs, and the latter wells—both pump wells and artesian wells.

Surface Waters.

LAKES.

The numerous basins found upon the surface of the till form important natural reservoirs for holding the rainfall, and doubtless assist much in diminishing the evil effects of droughts. Only the largest of them retain water from year to year. Only a few of those marked upon the map (Pl. III) have areas of open water. More frequently they are filled with grass or reeds. Some of them have become convenient reservoirs for the overflow of artesian wells.



LOGS OF WELLS IN HANSON COUNTY, S. DAK.

Some of the largest cover an area of 2 or 3 square miles, as a lake 5 or 6 miles northwest of De Smet.

STREAMS.

Mention of these has already been made under the heading "Geography." Attention is here called to an interesting feature which is usually manifest in the upper and middle courses of the smaller streams. Most of them show the occurrence at irregular intervals of deep pools, sometimes 5 or 6 feet deep and a rod wide, and extending in length for several rods. These are separated by deposits of sand and gravel, which, in the latter part of the season, are often dry and grassed over. These pools usually contain water, which is kept comparatively pure by a slow circulation which passes down from pond to pond through the gravel bars. In time of rain these bars are overflowed and the decomposing vegetation in the ponds is apt to be swept out.

SPRINGS.

The pond holes just mentioned might be named in this connection, as they are supplied from ground water which drains in below the surface. But there are also clearer examples of springs, and the springs of this region are supplied from three more or less distinct sources.

One source is the sand or gravel capping the terraces. Springs of this sort abound near James River in the ravines south of Rockport and for a few miles north and south of Forestburg and on the Firesteel north of Mitchell. Another source, scarcely separable from the first, is from sand strata considerably below the surface. Several fine springs of this class are found along the lower course of Pearl Creek and along the east side of James River, between Huron and the mouth of Shue Creek. These all furnish clear, cool, hard water, which deposits in some cases considerable travertine or limestone.

One spring, at least, is known to come from the Benton shale. It is found on the west side of Twelvemile Creek, about 2 miles north of Hutchinson County. It is known that the chalkstone is often saturated with water, but at no point in this area are circumstances such that it is brought to the surface in the form of springs.

A third source of springs, producing some of the finest to be found anywhere, is the Benton sandstone. All that are known from this source probably spring from the first sandstone below the chalk. It is possible, however, that near the quartzite leaks from deeper strata may reach the surface. One of the most notable of these springs is found about 3 miles east of Ethan. It has been impossible to measure the quantity of water escaping here because of its discharge through a mass of moss covering an acre or more; but some idea of the amount of water discharged may be obtained from the fact that after cold weather, with a temperature of 20° below zero, it kept open a pond several square rods in extent and sustained a stream a quarter of a mile long, free from ice in the middle. In the lower course of Enemy Creek, extending 2 or 3 miles above its mouth, are several large springs supposed to be fed from this source. It is possible, however, that some of them may be supplied from water high up in the same stream through crevices in the quartzite. Another fine spring, one of the best examples of this class, is found in the northeast corner of sec. 27, T. 104 N., R. 60 W., on the east side of James River. It is a circular basin about 30 feet across, in the flood plain of James River. Its depth has not been determined, but it keeps flowing a stream 4 or 5 feet wide and 3 to 6 inches deep.

Subterranean Waters.

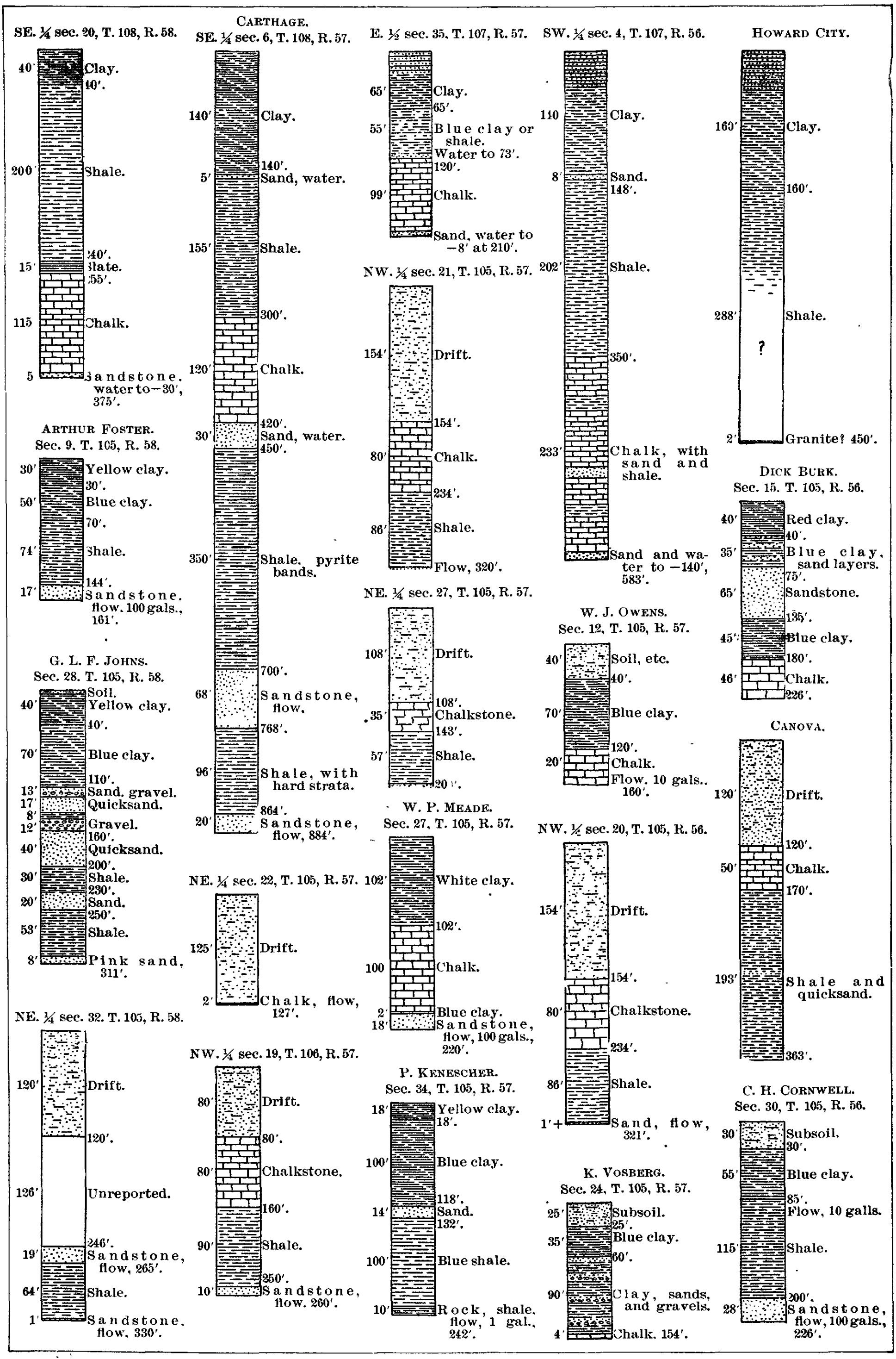
WELLS.

Reference has been made already in the discussion of surface waters to the close connection between water holes along watercourses and the motion of waters near the surface in old channels and in the upper part of the till. Thus far natural waters only have been discussed. We will now consider those obtained artificially. Wells may be conveniently classified into shallow wells, pump wells, and artesian wells.

SHALLOW WELLS.

This term includes wells supplied from waters which have recently fallen upon the surface and which can be obtained without penetrating any impervious layer. Such wells are easily obtained closely adjacent to any of the present watercourses, whether these contain any standing water upon the surface or not. They may be found also frequently in the vicinity of basins, especially after a wet season. Such wells in this area may obtain water at a depth of 10 to 30 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 the rainfall only and the region is subject to long-continued droughts. Of this class only those can be counted upon as a permanent supply which are so situated as to draw from a large catchment basin. In digging such wells, if no water is reached before the blue bowlder clay is struck, none will be found until the clay is passed through.

As regards the area under consideration, it may be suggested by what has already been stated that extensive areas where shallow wells are permanent may be found in connection with the flat areas about Huron and Woonsocket. In the sand of the Woonsocket basin copious wells are found in the eastern and southern part, west of Sand Creek, at a depth of 10 to 20 feet. So, also, north and northwest of



LOGS OF WELLS IN MINER COUNTY, S. DAK.

Huron, in the vicinity of the broad, meandering channels, abundant water is found, except in very dry seasons, by digging 10 or 15 feet.

In the area southwest of Huron, where the stratum of sand is found about 80 feet below the surface, permanent wells occur, which may be considered as belonging to this class. They are from 30 to 35 feet deep.

PUMP WELLS.

Under this head we include the deep wells in which a tubular or force pump is often necessary, or where the water supply is reached only after passing through an impervious layer. Three distinct geologic horizons supply such water in this area, particularly in the northern part—viz, (1) the sands below the till; (2) either a porous stratum or crevices, probably in the chalk, and (3), of most importance, the sandstone below the chalk, which is the first regular water-bearing stratum of the Benton-Dakota series.

As before explained, there is usually below the till a stratum of sand or gravel. This is also commonly filled with water. As soon, therefore, as the till has been drilled through at ordinary level, the water rises several feet, sometimes very nearly to the surface. The water from this source is heavily charged with lime, and sometimes with iron. It is commonly cool and wholesome. In some regions, however, either at first or soon after the well is dug, the water becomes so impregnated with the soluble salts which abound in the bowlder clay that it becomes offensive and sometimes injurious. This has been especially true of the wells in the plains west and north of Woonsocket. It has not been ascertained whether this is due to the abundance of mineral salts accumulated in this basin before the deposition of the till or to organic matter deposited there, or whether it is due to the water standing in the till after the well is dug. Similar cases are reported occasionally from other places.

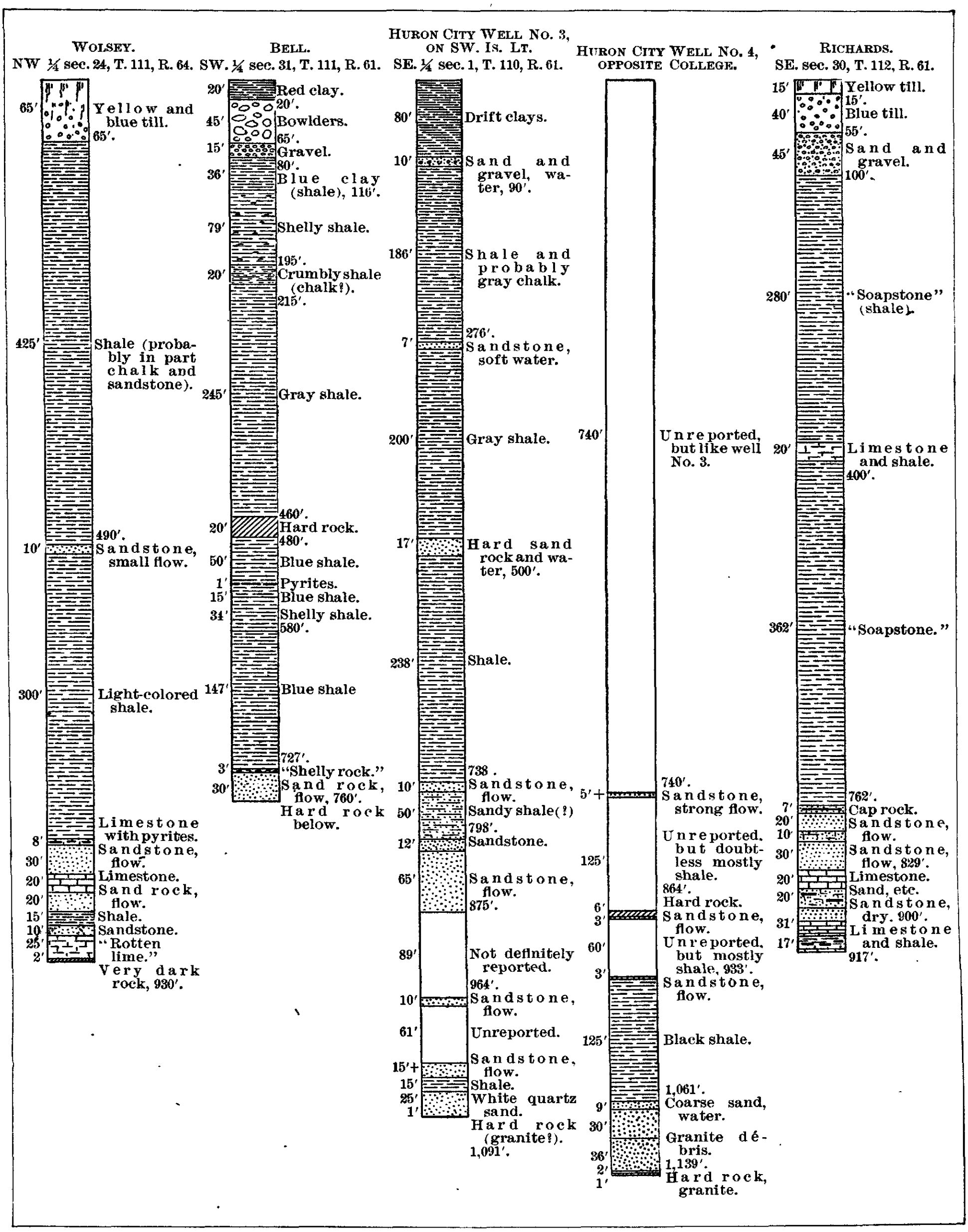
A few localities of limited area have failed to furnish water from this horizon. It may be supposed that they occur where the original surface of Pierre and Benton clay was so elevated that it was not submerged by the waters attending the advance of the ice sheet, so that the till was deposited in close contact with the Cretaceous clay. Such a locality as this is reported from sec. 24, T. 110 N., R. 64 W. Another is near the southwest corner of sec. 31, T. 112 N., R. 63 W., and doubtless others occur, but they are not so frequently reported since more desirable horizons have been discovered, and this one is less relied upon.

Similar failure to find water occurs over the chalkstone, where it lies so high that the water has drained away to the surface, as southwest and south of Mitchell. On the other hand, in certain areas the water in this horizon is under such pressure that it produces valuable flowing wells. Such an area begins in the southern part of Floyd Township (T. 108 N., R. 60 W.) and extends southeast past Artesian, which place derives its name from the early discovery of this fact. Here the flowing water is obtained by simply penetrating the till. In Plano Township (T. 104 N., R. 59 W.), also water is obtained from beneath the till, but it is probably derived from the upper Benton sandstone beneath.

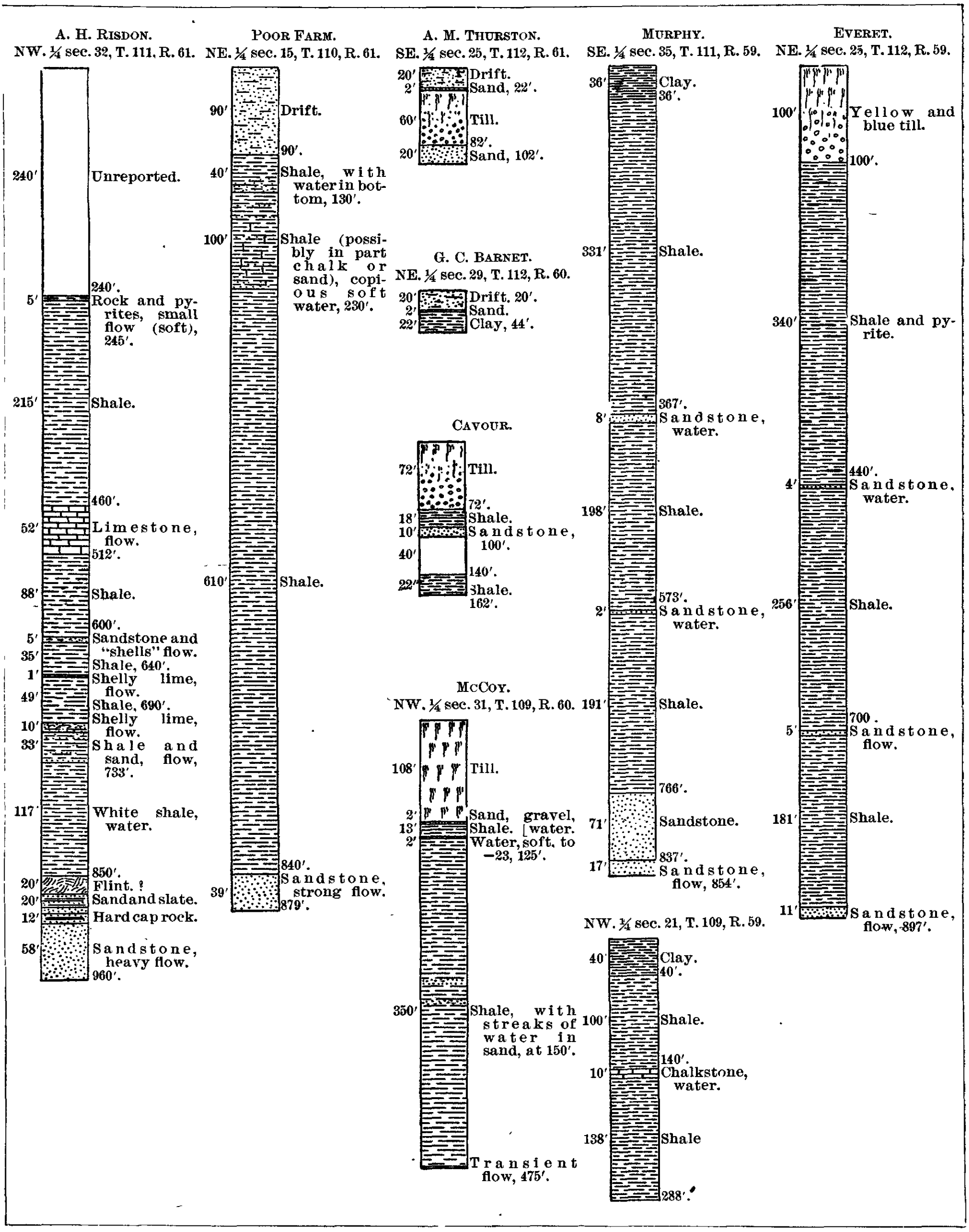
In the northern part of the area another horizon is much relied upon for furnishing pump wells. It seems to lie in the shales above or beyond the chalkstone, but this has not been clearly proved. East and southeast of Huron it lies at a depth of 115 to 175 feet, the depth increasing toward the north, but it seems to lack the regularity of most water strata. Some of the shallower soft-water wells about Plankinton are from this horizon rather than from the sandstone a little below. These wells may be due to crevices in the shale or chalkstone which supply water from more extensive horizons lower down. The water from this source is commonly spoken of as from the "soapstone," and is soft.

The third and most important pump-well horizon is in the widespread sandstone at or near the top of the Benton formation, which throughout this area seems to lie just below the chalk, but south of the latitude of Mitchell a mass of clay or shale is found between the chalk and the water stratum. In some localities this sandstone furnishes flowing wells, particularly in the trough of James River, and along the valley of Firesteel, Enemy, and possibly Twelvemile Creek, except where the altitude of the land is too high for the water to come to the surface. Here again there is an irregularity, especially in the northern part of Sanborn County, for the waters seem in some cases to have escaped upward into the chalkstone, so that in many localities water appears as soon as the chalkstone is reached. Some well drillers have the idea that the chalkstone alternates with the sandstone in the same horizon, and where the chalkstone is present the sandstone is either absent or reduced to an insignificant thickness. This opinion has gained some strength from the observed relation of the chalkstone to the sandstone where it is exposed along Firesteel Creek; but it is probable that the sandstone extends underneath the whole, but with unequal thickness, and that the chalkstone lies in the depressions of its upper surface, and wherever it is not too much permeated with clay it becomes a medium of water distribution from the sandstone, which is the main course of the water.

The waters from this horizon are universally, so far as known, soft—i. e., the mineral salts dissolved are those of soda, which do not interfere with the use of soap. The water is also more palatable than that from the lower horizons of the Benton or Dakota. It supplies what are known as "soft-water wells" throughout this area, except in the more elevated portions, where it lies so deep that few have sunk wells to it. Moreover, the pressure in it would only be sufficient to



LOGS OF WELLS IN WESTERN BEADLE COUNTY, S. DAK.



LOGS OF WELLS IN EASTERN BEADLE COUNTY, S. DAK.

raise the water to from 200 to 300 feet below the surface in the elevated region around De Smet. Furthermore, in the southeastern part of this area, which is underlain by quartzite near the surface, this water horizon has not been recognized, probably owing to the fact that the stratum is absent, or is so confused with the sand below the till that it is not distinguished from the higher horizons underneath the drift.

It has been already noted that the same horizon furnishes flowing wells in one locality and valuable pump wells in another. It follows from this that some of the horizons, which are discussed more fully under artesian wells, are really a source of pump wells in the more elevated portions of the area. For example, the main stratum furnishing artesian water in James River Valley may furnish an unfailing source for pumping beyond the limits of the artesian area indicated upon the map.

ARTESIAN WELLS.

There have been considered water horizons as deep as the first one below the chalkstone, which is referred to the top of the Benton formation. Attention has been called also to the fact that this and the higher strata furnish artesian wells in certain narrow limits. In the further discussion under this head mention is made particularly of water strata lower down having such pressure that they are the source of artesian wells over extensive portions of this area, in fact, over most of the area.

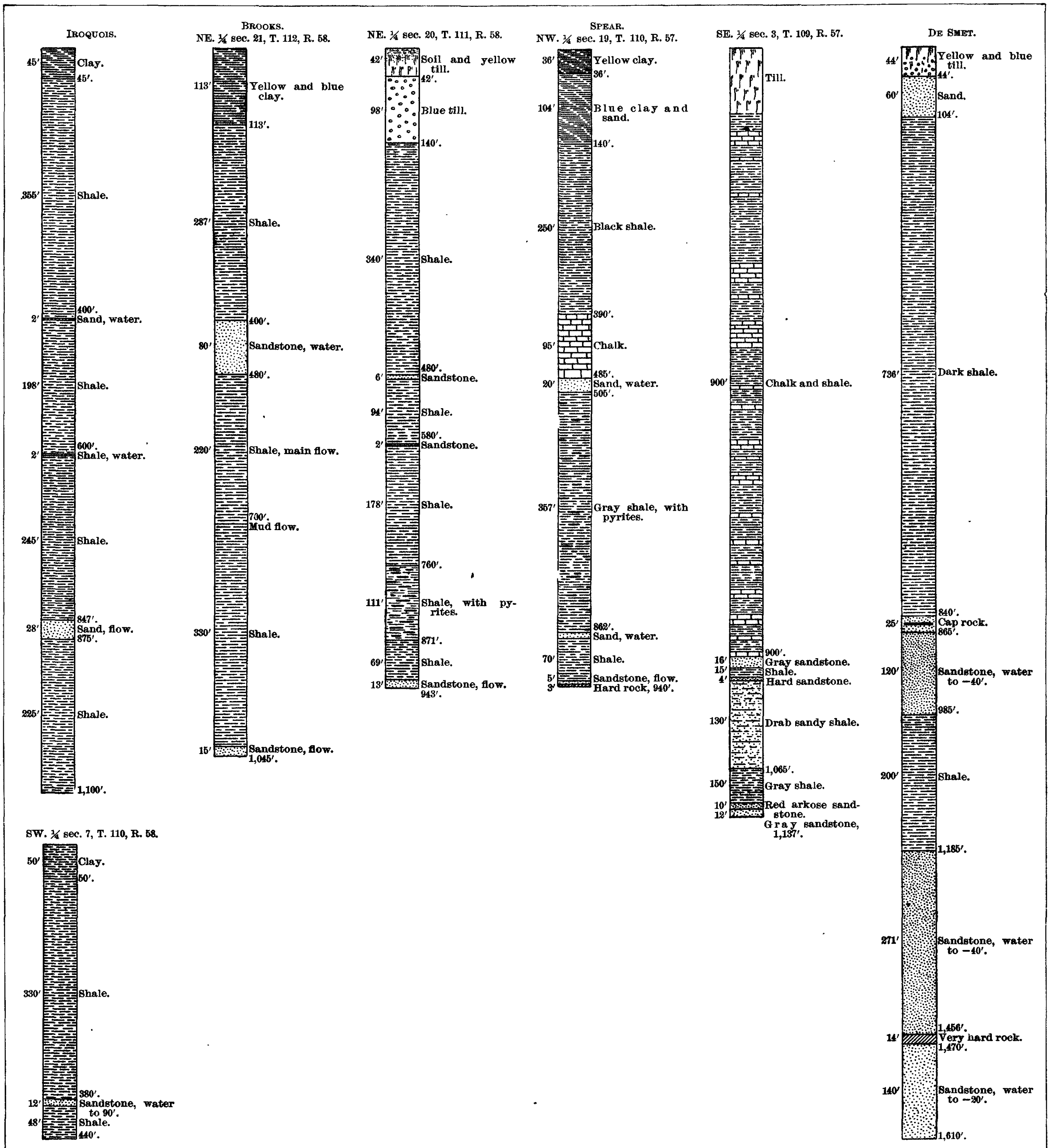
The character of the Dakota formation has been discussed already, but perhaps the fact has not been emphasized sufficiently that the different strata of sand often are independent of one another. This is mainly indicated by the usually well-marked difference in pressure. For example, in the same well, one stratum may sustain a closed pressure of 75 pounds to the inch and another below it, separated from it by 15 or 20 feet of shale, or sometimes even by a less thickness of hard rock, may furnish a pressure of more than 100 pounds. Moreover, there are differences in the character of the water of different strata.

The second sand stratum in the Benton formation furnishes numerous wells from 250 to 500 feet deep in western Hanson County and Davison County, and the same horizon may be traced throughout the northern portion of this area, but it becomes so thin and the water furnished so meager that it is usually overlooked or cased off. Its depth is about 500 feet at Huron, 600 near the southeast corner of Beadle County, about 350 feet in the region about T. 101 N., R. 64 W., although it is now usually neglected except in Davison and Hanson counties, where its supply is more copious. It nevertheless has good pressure, that may in years to come afford a supply when some of the strata which are now more drawn upon have become exhausted.

The next horizon is the Dakota sandstone, which is mainly relied upon for the more copious wells throughout the whole area. The larger wells are nearly all supplied from this horizon. In order to obtain the largest amount of water, it is customary to penetrate deep into this formation, so as to gain the combined flow from several sandstones. The water is usually hard, but suitable for all farm and household purposes. It is also used for supplying cities, not only for domestic purposes but for fire protection. In some cases the pressure is sufficient for fire protection, for instance, at Huron and Woonsocket. The depth at which this horizon is struck, of course, depends in part upon the altitude of the surface and in part on the depth of the beds. The stratum lies higher in the vicinity of the quartzite ridge and lower toward the north, so that it is reached at about 750 feet at Huron, at about 650 at Woonsocket, at about 850 at Iroquois, at about 600 at Artesian, at about 900 near Manchester, at about 450 at Mitchell, and 546 at Plankinton. The depths to the principal flow are shown on Pl. I.

Lower horizons of Dakota sandstone supply the Melville, Riverside, Wolsey, Plankinton, and T. O. Storla wells, and the lowest sandstones supply some wells in the vicinity of Huron, as the Risdon and the new city well, which reach a stratum lying immediately above the bed rock. The extent of the lowest stratum has not been widely explored. It is absent in the southeastern portion of the region, contiguous to the high underground ridge of quartzite.

Pressure.—In general the pressure increases downward in the different flows. This is what might be expected, mainly because of less chance for leakage from these beds along the eastern margin of the basin. The lower water-bearing strata may be supposed to reach to a higher altitude along the intake zone in the Rocky Mountains and Black Hills, which would give a higher initial head, but so slight a difference would be lost in the great general loss of head eastward. The lower beds also have the first chance to become filled by the surface waters, for they lie farthest back on the mountain slopes. The pressures of the wells over much of this area have not been satisfactorily obtained. The reasons for this are several. The first pressures, or those of the first wells opened, were much higher than any that can be obtained at present, at least without closing all other wells in the vicinity, which is impracticable. For example, at Huron the pressure first reported, and this is believed to have been from the first main flow, was 120 pounds, but at present from none of the wells of the city can a pressure of more than 70 pounds be obtained. Another difficulty is that many of the wells have been finished in such a way that it is impracticable to apply a gage at the present time. On account of corrosion of the pipes the older wells can not safely be closed to obtain pressure. Another source of error comes from imperfect casing in the well, so that it is impossible really to



LOGS OF DEEP WELLS IN KINGSBURY COUNTY, S. DAK.

close the well because of underground leakage. This applies either in taking the closed pressure with a gage or the pressure by allowing the water to rise in the standpipe. On the artesian map (Pl. I) the pressures, where determined, have been recorded by stating the number of feet above sea level to which the water would rise. There are also drawn upon the map contour lines which bring out graphically the slope of pressure or hydraulic gradient of the first main flow or the third water stratum below the chalk. This will be found not to agree with all of the closed pressures recorded, for some of them are from other horizons.

From a study of these contours it would be seen that the pressure diminishes toward the margin of the artesian area in all cases, but with a complexity which is difficult to express in language. For example, the slope of pressure in the southwestern part is toward the northeast. In the northern part of Hanson County it is toward the south. It will be noticed also that although the pressure diminishes mainly toward the east from Huron eastward there is a slight increase of pressure. This may at first be thought difficult of explanation, but when we remember that several large wells have been flowing in James River Valley, supplied from this source, for several years, we may explain the apparent anomaly by considering an extension of this local exhaustion so as to affect the area farther east. Moreover, since in the highlands, away from the larger streams, we may suppose the leakage from the different water-bearing strata is much less than in James River Valley, and that the region east of that stream may be supplied from the north, we have further light upon the subject.

Limits of the artesian area.—The limit of the artesian area, as drawn on the artesian map, is estimated from the closed pressure observed in the few wells near it, and as these are lacking toward the south the limit there is less reliable. Moreover, the pressure mapped by contours and used in making the estimate is that of the first main flow or the third water stratum below the chalk. It is probable that from lower strata, which very possibly underlie Miner County, a somewhat higher pressure may be obtained. If so, the limit will be correspondingly shifted toward the east. It is not probable, however, that the area will be much increased from this cause. The pressure of the Risdon well was 165 pounds when the city well of Huron was 120. That difference would be equivalent to an altitude of 104 feet, but the difference of pressure would doubtless be much less near the margin.

It should be remembered that the limit in this area from the north line to the south line of Miner County is due to lack of pressure, not to the absence underneath of the water-bearing strata. Hence, deep pump wells may draw from the artesian supply eastward to an indefinite distance. In the counties farther south, however, the water strata, excepting one or two of the upper ones, are lacking. Moreover, the latter merge into the sand under the till, so that the waters are quite different in character.

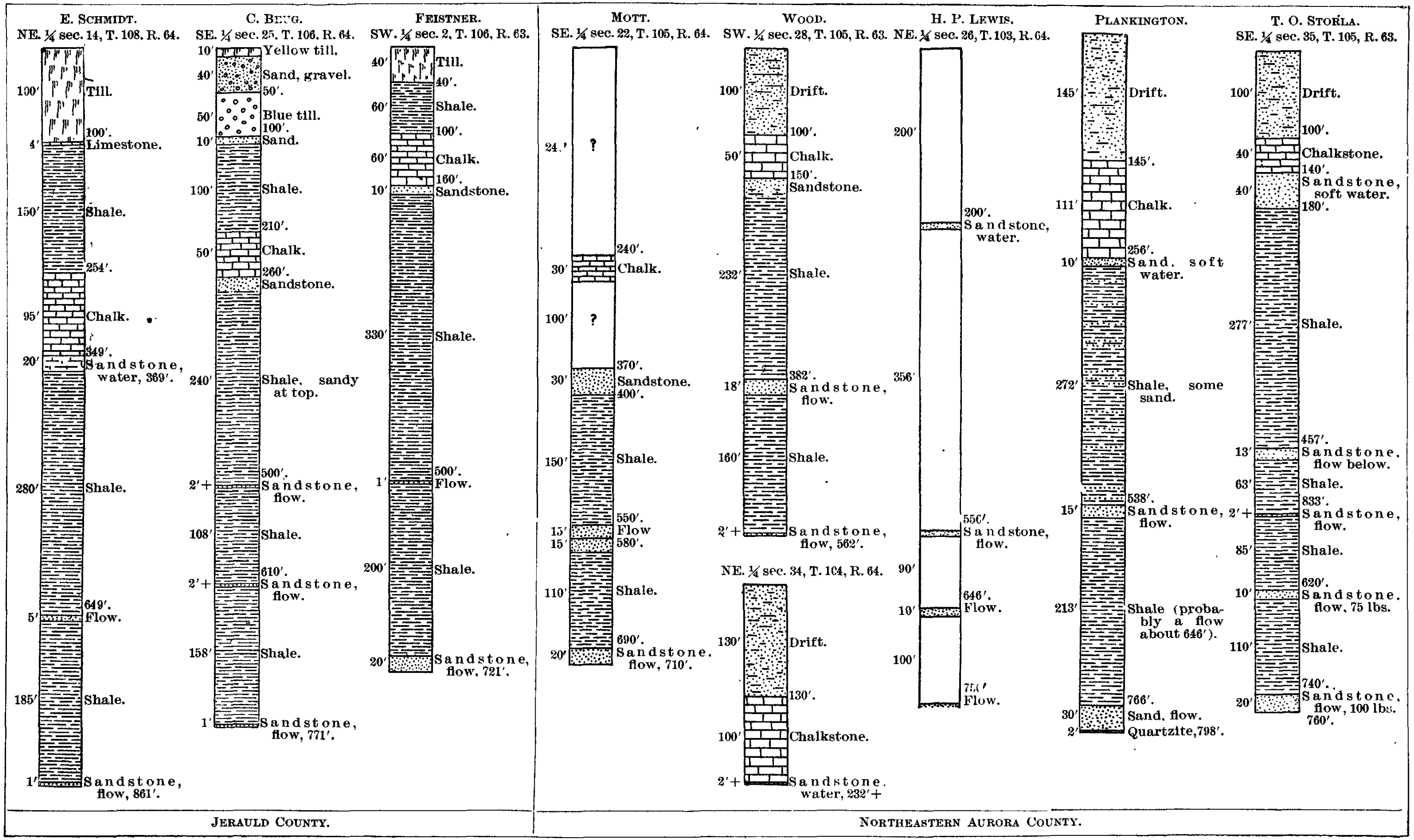
Causes of apparent decline in pressure.—It is now generally admitted not only that the copiousness of the flow of wells diminishes, but also that their closed pressure declines. This becomes evident without the use of instruments; first, the distance to which the water is thrown from a horizontal pipe grows shorter; then, after a time, the stream, which first filled the pipe, fails to completely fill it. In some cases a test with a gage shows merely a decline in copiousness without material decline in pressure. It may be accounted for by the deposition of mineral matter about the bottom of the pipe in such a way as to clog the pores of the sand through which the water comes, but more commonly the pressure has been found really to diminish. Thus in the wells at Huron some that once showed a pressure of 120 pounds when closed now fail to reach 80. Similar facts have been reported from Mitchell, Mount Vernon, and Plankinton.

The unwelcome conclusion impressed by these facts has led many to search for reasons other than the one first suggested, viz., the partial exhaustion of the artesian supply. It is claimed, and apparently substantiated by facts, that new wells frequently have a pressure equal to that of early wells supplied from the same source. 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 the strict truth of this statement.

The first cause of apparent decline is a less copious flow, occurring either, at first, when a new well taps the same water-bearing sandstone, or by the clogging of a well that once flowed freely. The former case may result from the fine character of material or the thinness of the water-bearing stratum where penetrated; but the more significant examples are those which may result from the clogging of the well. As wells are usually finished by extending the pipe into the water-bearing rock and perforating it as high up as that formation extends, it will be readily seen that the surface opened for the delivery of water to the well is equal to the whole perforated portion of the pipe. 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 terminates in the cap rock. As time passes, sand gradually works in from the sides, and portions of the cap rock are undermined and dropped down, so that in such cases the free access of the water is considerably checked.

Theoretically the closed pressure would 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 pressure would be that when a gage is attached it takes longer to reach a maximum point. As this rise may be very gradual, some errors of reading have doubtless resulted because the observers did not wait long enough.

Another cause of diminished pressure is leakage. This may be



LOGS OF WELLS IN JERAULD AND AURORA COUNTIES, SOUTH DAKOTA.

either visible from the imperfect closing of the pipe or it may be invisible below the surface of the ground. As is well known, pipes deteriorate rapidly under the influence of most artesian waters, and it becomes almost impossible to close the joints perfectly. Where there is a considerable extent of piping, as in the distributing pipes of a city, all joints are not certain to be stopped. Hence this may explain sometimes the apparently diminished pressure in older wells.

The diminished pressure in a particular well may sometimes result from the opening of another well not far away. The distance to which this influence may extend will, of course, be greater where the water-bearing stratum is of coarse texture, and therefore the usual supply of water more free.

In cases where water has been drawn freely from several wells, or even from one large well, there is no doubt a local depression in the head or lowering of pressure, which will take considerable time to restore. This might occur and yet cause no permanent decline of supply.

Notwithstanding all the considerations offered thus far, it seems not unlikely that the rapid multiplication of wells in a region may really reduce the pressure over the whole region to the amount of a few pounds. It is therefore important that facts should be collected and sifted to ascertain whether this is the case, and if so, 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 1,000-gallon a minute well would be sufficient to supply 450 wells furnishing 100 barrels a day, which would be an adequate supply for an ordinary farm.

Closing of wells.—Much damage is sometimes done by the free running of wells. In some cases large wells have been drilled with the intention of irrigating, and sufficient rainfall for a series of years has rendered that unnecessary. The water from such wells has been allowed to run to waste, thereby drawing unnecessarily upon the general supply. Moreover, it has often rendered considerable land in the vicinity unproductive. The practice, therefore, of closing wells when not needed should be recommended. The only objection to this is the possibility that wells when closed will become clogged. This danger may be avoided by the gradual closing of a well, even when it is known to carry some sediment. When the water runs clear, and especially where the well has never thrown sand, there is very little danger. Some large wells made to furnish power are habitually kept closed when not in use without serious injury. In case a well does become clogged by the settling of sand it may often be opened by letting down an iron rod and churning it up and down until the flow is started.

To avoid producing too sudden changes in the flow, which may produce injurious effects at the bottom of the well, the opening and closing should be done gradually.

INDEX.

O

[Mount each slip upon a separate card, placing the subject at the top of the second slip. The name of the series should not be repeated on the series card, but the additional numbers should be added, as received, to the first entry.]

Author.

Todd, J[ames] E[dward]

. . . Geology and water resources of part of the Lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. Washington, Gov't print. off., 1904.

47 p., 1 l. illus., 23 pl. (incl. maps in pocket). $23\frac{1}{2}^{cm}$. (U. S. Geological survey. Water-supply and irrigation paper no. 90.)

Subject series B, Descriptive geology, 36; O, Underground waters, 22.

Subject.

Todd, J[ames] E[dward]

. . . Geology and water resources of part of the Lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. Washington, Gov't print. off., 1904.

47 p., 1 l. illus., 23 pl. (incl. maps in pocket). $23\frac{1}{2}^{cm}$. (U. S. Geological survey. Water-supply and irrigation paper no. 90.)

Subject series B, Descriptive geology, 36; O, Underground waters, 22.

Series.

U. S. Geological survey.

Water-supply and irrigation papers.

no. 90. Todd, J. E., Geology and water resources of part of the Lower James River Valley, S. Dak., by J. E. Todd and C. M. Hall. 1904.

Reference.

U. S. Dept. of the Interior.

see also

U. S. Geological survey.

SERIES K—PUMPING WATER.

WS 1. Pumping water for irrigation, by Herbert M. Wilson. 1896. 57 pp., 9 pls.
WS 8. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls.
WS 14. New tests of certain pumps and water lifts used in irrigation, by O. P. Hood. 1898. 91 pp., 1 pl.
WS 20. Experiments with windmills, by T. O. Perry. 1899. 97 pp., 12 pls.
WS 29. Wells and windmills in Nebraska, by E. H. Barbour. 1899. 85 pp., 27 pls.
WS 41. The windmill; its efficiency and economic use, Part I, by E. C. Murphy. 1901. 72 pp., 14 pls.
WS 42. The windmill, Part II (continuation of No. 41). 1901. 73-147 pp., 15-16 pls.

SERIES L—QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls.
WS 22. Sewage irrigation, Part II, by G. W. Rafter. 1899. 100 pp., 7 pls.
WS 72. Sewage pollution in the metropolitan area near New York City and its effect on inland water resources, by M. O. Leighton. 1902. 75 pp., 8 pls.
WS 76. Observations on the flow of rivers in the vicinity of New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.
WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp.

SERIES M—GENERAL HYDROGRAPHIC INVESTIGATIONS.

WS 56. Methods of stream measurement. 1901. 51 pp., 12 pls.
WS 64. Accuracy of stream measurements, by E. C. Murphy. 1902. 99 pp., 4 pls.
WS 76. Observations on the flow of rivers in the vicinity of New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.
WS 80. The relation of rainfall to run-off, by G. W. Rafter. 1903. 104 pp.
WS 81. California hydrography, by J. B. Lippincott. 1903, 488 pp., 1 pl.
WS 88. The Passaic flood of 1902, by G. B. Hollister and M. O. Leighton. 1903. 56 pp., 15 pls.

SERIES N—WATER POWER.

WS 24. Water resources of State of New York, Part I, by G. W. Rafter. 1899. 92 pp., 13 pls.
WS 25. Water resources of State of New York, Part II, by G. W. Rafter. 1899. 100-200 pp., 12 pls.
WS 44. Profiles of rivers, by Henry Gannett. 1901. 100 pp., 11 pls.
WS 62. Hydrography of the Southern Appalachian Mountain region, Part I, by H. A. Pressey. 1902. 95 pp., 25 pls.
WS 63. Hydrography of the Southern Appalachian Mountain region, Part II, by H. A. Pressey. 1902. 96-190 pp., 26-44 pls.
WS 69. Water powers of the State of Maine, by H. A. Pressey. 1902. 124 pp., 14 pls.

[Continued on fourth page of cover.]

SERIES O—UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by Israel C. Russell. 1897. 96 pp [illegible]
WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp. [illegible]
WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897 50 pp., 3 pls.
WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 18[illegible] 56 pp., [illegible] pls.
WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls.
WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp.
WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.
WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., [illegible] pls.
WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
WS 53. Geology and water resources of Nez Perces County, Idaho, Part I, by I. C. Russell. 1901. 8[illegible] pp., 10 pls.
WS 54. Geology and water resources of Nez Perces County, Idaho, Part II, by I. C. Russell. 1901. 87-141 pp.
WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls.
WS 57. Preliminary list of deep borings in the United States, Part I, by N. H. Darton. 1902. 60 pp.
WS 59. Development and application of water in southern California, Part I, by J. B. Lippincott. 1902. 95 pp., 11 pls.
WS 60. Development and application of water in southern California, Part II, by J. B. Lippincott. 1902. 96-140 pp.
WS 61. Preliminary list of deep borings in the United States, Part II, by N. H. Darton. 1902. 67 pp.
WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls.
B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.
WS 77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. [illegible] 4 pls.
WS 78. Preliminary report on artesian basins in southwestern Idaho and southeastern [illegible] by I. C. Russell. 1903. 53 pp., 2 pls.
PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.
WS 90. Geology and water resources of part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. — pp., 23 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Part II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Part II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Part II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Part IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Part IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Part IV; Artesian well prospects in the Atlantic Coastal Plain region, by N. H. Darton, Bulletin No. 138.

SERIES P—HYDROGRAPHIC PROGRESS REPORTS.

Progress reports may be found in the following publications: For 1888-89, Tenth Annual, Part II; for 1889-90, Eleventh Annual, Part II; for 1890-91, Twelfth Annual, Part II; for 1891-92, Thirteenth Annual, Part III; for 1893-94, B 131; for 1895, B 140; for 1896, Eighteenth Annual, Part IV, WS 11; for 1897, Nineteenth Annual, Part IV, WS 15, 16; for 1898, Twentieth Annual, Part IV, WS 27, 28; for 1899, Twenty-first Annual, Part IV, WS 35-39; for 1900, Twenty-second Annual, Part IV, WS 47-52; for 1901, WS 65, 66, 75; for 1902, WS 82-85.

Correspondence should be addressed to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.