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THE UNDERGROUND WATERS OF SOUTHWESTERN OHIO

BY

M. L. FULLER AND F. G. CLAPP

WITH A DISCUSSION OF

THE CHEMICAL CHARACTER OF THE WATERS

BY

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THE UNDERGROUND WATERS OF SOUTHWESTERN OHIO.

By Myron L. Fuller and Frederick G. Clapp.

INTRODUCTION.

LOCATION AND AREA.

The district covered by this report is an area in southwestern Ohio extending from Ohio River on the south to the southern portions of

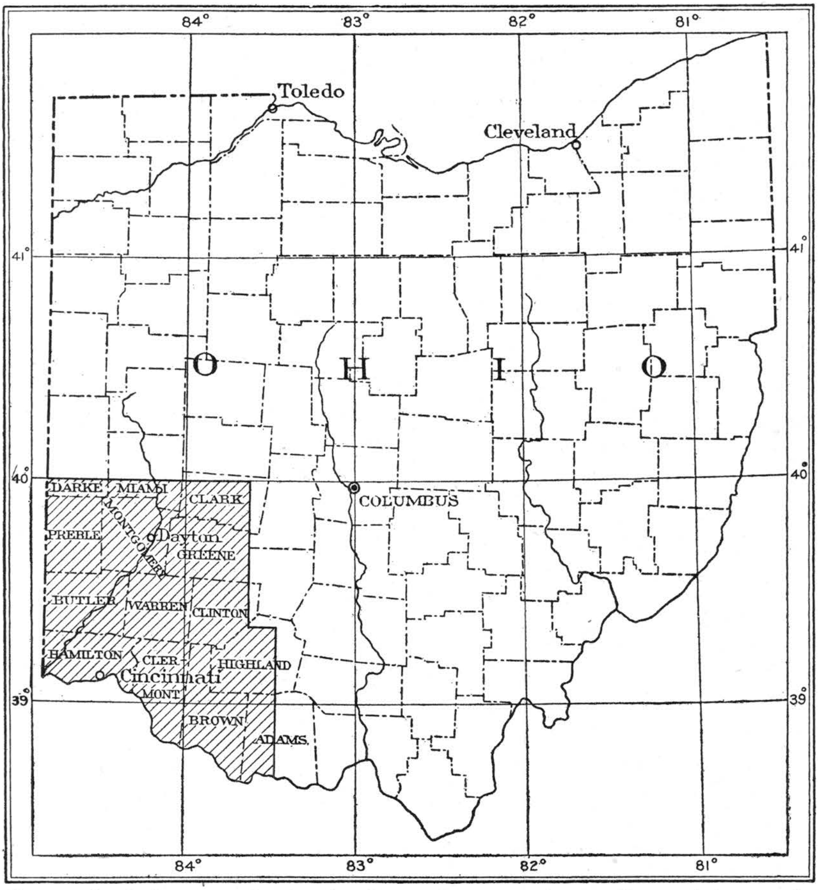

Figure 1.—Index map showing location and extent of area discussed in report.

Darke and Miami counties on the north, and from the Indiana State line on the west to central Adams and Highland counties on the east (fig. 1). The area averages approximately 80 miles from north to south and 70 miles from east to west and contains about 5,600 square miles, or about one-seventh of the total area of the State.

The district includes the following counties: Adams (western half), Brown, Butler, Clark, Clermont, Clinton, Darke (southern part), Greene, Hamilton, Highland (western half), Miami (southern part), Montgomery, Preble, Warren. The principal cities are Cincinnati, Dayton, Hamilton, and Springfield.

OBJECT OF INVESTIGATION.

The region under discussion receives abundant rainfall, the precipitation averaging over 40 inches a year. The streams, however, are rather far apart and springs are few and of small volume. Moreover, as the region is densely populated, the inhabitants averaging about 150 to the square mile in the area as a whole and 50 in the rural districts, and as it contains many paper mills, distilleries, powder mills, and other manufacturing establishments, the surface waters are in many localities badly polluted by sewage and industrial wastes and are entirely unfit for drinking. For these reasons carefully protected ground-water supplies are highly desirable for domestic uses, especially in cities and crowded villages, where the nearness of the houses and the proximity of barns, privies, and cesspools may make wells unsafe sources of supply.

The value of pure water for public supplies can not be overestimated, the industrial loss resulting from a serious typhoid or other epidemic due to impure water often being of such magnitude as to seriously interfere with the prosperity of a town. People who a few years ago regarded any clear and cool water as satisfactory are now demanding that its absolute safety be established by proper examination and inspection, and although in some localities a doubtful water may occasionally be accepted, condemnation of the supply and of those responsible for its installation is certain to follow its continued use.

Not only is the problem of procuring pure water for drinking and for other domestic uses recognized as urgent in the cities and villages, where it is not unusual to find practically every well more or less polluted, but it is of great importance in the country. Many farm wells are located in or near barnyards or hogpens and are contaminated by refuse blown into them by the winds, as well as by the bodies of snakes, mice, rabbits, and other animals that may fall into them in their search for water in dry seasons. Many wells that furnish drinking water are situated on low ground and receive the drainage from houses and yards, being thus sources of grave danger. To the farmer, therefore, information both as to the proper construction of wells and as to the best sources of water will be of great value.

One of the most important uses of water in many regions is for locomotive boilers. For the economical running of trains, especially freight trains, water must be provided every few miles. Where permanent streams are available and are not too muddy they generally furnish satisfactory supplies; but over many areas the streams are few, are far apart, and many of them go dry in times of drought. In such places wells must be the sources of supply.

In southwestern Ohio immense quantities of water are required in industrial processes. In the manufacture of paper, especially, a single mill may use several hundred thousand gallons of water daily, and as the water of the streams is generally too muddy and the quantity too uncertain for this purpose, wells are largely used. Many other industries, especially those located in cities where the rates charged for the public service practically prohibit its use, have urgent need of ground-water supplies.

The people of the vicinity generally know when a well has succeeded in obtaining a satisfactory supply, but knowledge of the conditions that determine the success of the well or of the limits to which the favorable conditions extend is as a rule scanty, and many thousands of dollars have been wasted in southwestern Ohio and elsewhere in well drilling in places where a geologist would have pronounced the attempt hopeless. Information regarding the proper construction of wells is also urgently needed in order that the largest possible supplies and the best and purest water which a well is capable of affording may be obtained.[1]

SOURCES OF INFORMATION.

EARLY STUDIES.

Previous to the investigations for the present report no specific study of underground waters had been conducted in the region, although some attention had been paid to the water resources by the parties investigating the geology of a number of counties for the State Survey, under Edward Orton, and by Frank Leverett in his studies of the drift of the region. The results of the former have appeared in the county reports of the State Survey and in a paper on the rock waters published by the United States Geological Survey.[2] The results of Leverett's work have appeared in several reports of the National Survey.[3]

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[1] See Bowman, Isaiah, Well-drilling methods: Water-Supply Paper U. S. Geol. Survey No. 257, 1911.

[2] Orton, Edward, The rock waters of Ohio: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1898, pp. 633–717.

[3] Leverett, Frank, The water resources of Indiana and Ohio: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, pp. 419–559. Also, Underground waters of eastern United States: Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 265–270.

BIBLIOGRAPHY.

The more important publications which relate in part to the underground waters of Ohio are listed in the following bibliography. Many of these reports are, however, out of print and inaccessible.

FULLER, MYRON L., LINES, E. F., and VEATCH, A. C., Record of deep-well drilling for 1904: Bull. U. S. Geol. Survey No. 264, 1905, 106 pp.

Lists a number of new wells in Montgomery County.

FULLER, MYRON L., and SANFORD, SAMUEL, Record of deep-well drilling for 1905: Bull. U. S. Geol. Survey No. 298, 1906, 299 pp.

Lists new wells in Brown, Darke, and Greene Counties.

FLYNN, BENJAMIN H., and FLYNN, MARGARET S., The natural features and economic development of the Sandusky, Maumee, Muskingum, and Miami drainage areas in Ohio; Water-Supply Paper U. S. Geol. Survey No. 91, 1904, 130 pp.

Includes a discussion of many of the public water supplies of southwestern Ohio, including those from springs, wells, and collecting galleries.

HUSSEY, JOHN, Report of the geology of Miami County: Rept. Geol. Survey Ohio, vol. 3, pt. 1, 1878, pp. 468–481.

Notes the abundance of springs at the horizon of the "Clinton" limestone, some of which are large enough for power development. Describes the large spring at West Milton and discusses the conditions of the underground collection of water. The wells of the drift and the evidence which they afford of buried channels are also considered (pp. 469–470).

LEVERETT, FRANK, The water resources of Indiana and Ohio: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, pp. 419–559.

After considering the physical features, drainage, lakes, etc., of the region (pp. 426–474), discusses underground waters, including wells of the drift, shallow and deep rock wells, subterranean drainage lines, springs, analyses of the waters, etc. (pp. 474–501), and gives extended descriptions of the water supplies of cities and villages (pp. 502–559).

——— Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, 802 pp.

No special discussion of the waters of the drift, but refers incidentally to wells and records, especially to the flowing wells of Ohio (see index of monograph).

LINDENMUTH, A. C., Report of the geology of Darke County: Rept. Geol. Survey Ohio, vol. 3, pt. 1, 1878, pp. 496–518.

Describes the lime, magnesia, and sulphur springs of various beds (pp. 496, 509, 517), and notes the abundance of good water in both drift and rocks (p. 517).

ORTON, EDWARD, Report on geology of Montgomery County: Geol. Survey Ohio, Rept. of Progress in 1869, pt. 3, pp. 143–171.

Describes the association of springs with the "Clinton" limestone (pp. 162–163).

——— The geology of Highland County: Geol. Survey Ohio, Rept. of Progress in 1870, pp. 255–294.

Notes prevalence of springs at shale layers in "Niagara" limestone (p. 275).

ORTON, EDWARD, The cliff limestone of Highland and Adams counties: Geol. Survey Ohio, Rept. of Progress in 1870, pp. 295–308.

Describes springs at top of the shale layers in the "Niagara" limestone (pp. 302, 304).

——— Geology of Hamilton County: Rept. Geol. Survey Ohio, vol. 1, pt. 1, 1873, pp. 419–434.

Gives sections and notes on wells near Cincinnati.

——— Geology of Clermont County: Rept. Geol. Survey Ohio, vol. 1, pt. 1, 1873, pp. 435–449.

Notes scarcity of springs and considers use of cisterns and wells in both rock and drift deposits (pp. 439–440, 446).

——— Geology of Clark County: Rept. Geol. Survey Ohio, vol. 1, pt. 1, 1873, pp. 450–480.

Describes springs of the "Niagara" limestone (pp. 465–466, 469).

——— Report on the geology of Greene County: Rept. Geol. Survey Ohio, vol. 2, pt. 1, 1874, pp. 659–696.

Discusses in detail the water-supply conditions of the county (pp. 690–696), including the "Clinton" and "Niagara" spring horizons, and horizons affording water to wells, the conditions leading to the contamination of ground waters, etc., and gives a full description of Yellow Springs and their surroundings.

——— Report on the geology of Warren County: Rept. Geol. Survey Ohio, vol. 3, pt. 1, 1878, pp. 381–391.

Discusses the wells and springs of the drift and the "Clinton" and "Niagara" limestones, and points out the need of cisterns in the blue limestone (Richmond and Maysville) districts. A large spring used for power development near Springboro is mentioned (pp. 388–389).

——— Report on the geology of Butler County: Rept. Geol. Survey Ohio, vol. 3, pt. 1, 1878, pp. 392–403.

Notes deficiency of ground water in the blue limestone (Richmond and Maysville) and in regions of thin drift. Cisterns are recommended (p. 403).

——— Report on the geology of Preble County: Rept. Geol. Survey Ohio, vol. 3, pt. 1, 1878, pp. 404–419.

Notes prevalence of springs, sometimes marked by petroleum shows, at horizon of "Clinton" limestone (pp. 406–408).

——— The Trenton limestone as a source of oil and gas in Ohio: Rept. Geol. Survey Ohio, vol. 6, 1888, pp. 101–310.

Contains notes on wells drilled for oil and gas in the several counties of southwestern Ohio, numerous detailed records, and notes on waters encountered or on casing used.

——— The rock waters of Ohio: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1898, pp. 633–717.

Discusses the geology (pp. 638–650) and considers the waters of various formations from Carboniferous to Ordovician, inclusive (pp. 651–696). Flowing rock wells and artesian wells of buried glacial channels are described (pp. 697–717).

PEALE, A. C., Lists and analyses of the mineral springs of the United States: Bull. U. S. Geol. Survey No. 32, 1886, 235 pp.

Gives list of mineral springs of Ohio, including those of the southwestern counties; contains analyses of artesian well water from Cincinnati; of salt well at Ludlow Grove, Hamilton County, Yellow and Bellbrook Magnetic Springs in Greene County, and Cedar Spring, Preble County.

FIELD AND OFFICE WORK.

The field work on which this report is based was begun August 1, 1906, by M. L. Fuller, assisted by S. R. Capps, with J. R. Evans serving as chemist until about September 1, from which date to the close of the work late in September the chemical work was performed by H. N. Parker. From September 1 to 20 F. G. Clapp, acting under M. L. Fuller, had charge of the party. The complete analyses in connection with the work were made by R. B. Dole, assisted by M. G. Roberts, and the discussion of the chemical character of the waters has also been prepared by R. B. Dole.

The work included the geologic tracing and correlation of the rock formations, a study of the water-bearing capacity of each formation outcropping at the surface or encountered by wells, the determination of the depth and yield of the waters, the study of the mineral springs, and the investigation of the public water supplies. Records of deep wells were procured, drillers were interviewed as to methods employed and general water conditions, and statistics were gathered in regard to the shallow wells in rock or unconsolidated material. The chemical work included field examinations of waters from each of the several classes of drift and rock formations and determinations of the carbonates, sulphates, chlorides, and iron. Complete analyses of samples of about 35 waters were made at the Washington laboratory, and analyses were obtained from owners of many wells. In the study of public supplies special attention was given to the sanitary quality of the water, with a view to determining sources of pollution and to making recommendations as to their removal.

The text relating to Preble, Butler, and Hamilton counties was prepared by F. G. Clapp, and the general discussion and the text relating to the other 10 counties was prepared by M. L. Fuller. Frank Leverett supplied the details of the distribution of the drift for Plate II, and M. L. Fuller and E. O. Ulrich most of the geology for Plate I. E. O. Ulrich and J. M. Nickles also assisted very materially in the preparation of the geologic discussions. Many drillers and well owners have also heartily cooperated in the work, and to them grateful acknowledgment is hereby made.

TOPOGRAPHY.

RELIEF.

Southwestern Ohio is in the main a plateau that stands between 800 and 1,100 feet above sea level; but the continuity of its surface is broken (1) by the deep valleys of the Ohio, Miami, Little Miami, and minor rivers and their tributaries, with bottoms extending from 100 feet or more below the crests of the adjoining uplands in the northern part of the area to over 400 feet below it in the vicinity of the Ohio; and (2) by the irregular morainal and less numerous rock hills rising above it. Of the subordinate features of the valleys the bluffs, terraces, and alluvial plains are the most interesting.

UPLANDS.

Nearly the entire surface area of the district under discussion belongs to the broad plateau that extends throughout Ohio and covers the greater portions of most of the adjoining States. Although marked by numerous deep valleys, some of them so close to one another that they are separated only by narrow ridges, the intervening crests generally stand very near the level of the plateau of which they are the remnants. The plateau, however, is not absolutely flat, but rises gradually from a general level of about 900 feet near the Ohio to about 1,100 feet in the northeastern and eastern portions of the area.

Near the Ohio, and for 10 or in some place 15 miles or more north of its valley, the plateau is broken by numerous deep valleys and ravines, the more important of which are those of Miami and Little Miami rivers and Mill and Whiteoak creeks. Farther back the crests begin to widen and the flat remnants of the general surface are easily recognized. These gradually become broader to the north until flat surfaces many miles in extent are found.

VALLEYS.

Under the head of valleys are included all the depressions below the plateau except a few sags, so shallow as to be hardly noticeable, which here and there indent the surface. All of the valleys have been cut by streams that flow across the plateau, although several, such as that along the western border of Hamilton County, that leading from Hamilton to St. Bernard and thence to the Little Miami near Madisonville, that extending from near Middletown to South Lebanon, that cutting across a bend of the Little Miami near Lebanon, that connecting Mad River with the Little Miami Valley south of Osborn, and that extending from the Miami near Tippecanoe to the Mad River Valley near Osborn, are no longer occupied by streams, having been produced by waters flowing from the ice sheet which once occupied the region (Pl. II) or by the present streams when flowing in channels since abandoned.

The larger valleys are those of the Ohio, Miami, and Little Miami or of former channels of these streams. Of these, the Miami Valley has the broadest bottom, its width being 1 to 3 miles or more; the Ohio Valley is in few places more than a mile in width in this region.

In general the valleys become shallower to the north, where they have a depth of only 100 or 200 feet below the adjoining upland, as compared to 400 feet or more near the Ohio. Near the Ohio the ravines formed by the small tributaries are a striking feature, cutting the surface into a complex series of sharp-crested ridges and V-shaped ravines, many of which, although very narrow, are hundreds of feet deep.

Of the minor features of the valleys the terraces are of most interest. They occur mainly along the Ohio and lower courses of Miami and Little Miami rivers and Mill Creek and consist of flat-topped remnants of deposits that once filled a portion of the valleys to about 600 feet above sea level.

MORAINES.

The moraines are highly irregular topographic features, ranging from low rounded knolls to high hills and ridges characterized by sharp knolls and basins. In general they have no great height in southwestern Ohio, although a few rise 100 feet above the surrounding surface. Neither do they form high or continuous ridges in this region.

DRAINAGE.

The drainage of southwestern Ohio is here described because the considerable development of the underground waters is a direct result of the inferiority of the surface waters for many uses.

Ohio River, the main stream of the region, rises in the mountains of Pennsylvania and West Virginia in regions where the rocks are prevailingly sandstone and shale with but little limestone and where there is either no drift at all or only drift composed of non-lime-bearing material. As a result the Ohio water is low in lime and magnesia and gives but little trouble in boilers. Unfortunately, however, it is very muddy and is undesirable for many industrial uses. It is also badly polluted by sewage from Pittsburgh and many small cities and towns, which makes it very dangerous for domestic use.

Of the tributaries of the Ohio, Miami and Little Miami rivers and Mill and Whiteoak creeks are the most important. Unlike the Ohio, all of them have their sources either in limestone regions or in areas covered by highly calcareous drift from which the waters dissolve large quantities of lime and magnesia. These waters are, therefore, unfit for boiler use without treatment, and because of their muddiness are likewise unsuitable for many industrial uses. Their muddiness and the shortness of supply in times of drought has led to the sinking of numerous wells to supply the paper and other mills along the Miami.

CLIMATE.

Southwestern Ohio has a warm, moist climate in summer and a moderately cold but humid climate in winter. The rainfall is very equally distributed through the four seasons, from which it follows that somewhat over three-fourths of the precipitation occurs when the surface is unfrozen and when the water can penetrate the ground and join the underground supply. The evaporation is moderate, little ground water being lost in this way. In fact, the climatic conditions are favorable for the storage of large supplies in the ground, and the absence of these, except in the valleys, is due to the imperviousness and small porosity of the soils and rocks.

Some of the statistics of climate and rainfall having a bearing on underground waters are given in the following table:[1]

Climate and rainfall statistics at stations in southwestern Ohio.

	Cincinnati.	Dayton.	Portsmouth.
Precipitation (inches):			
Spring	9.9	9.8	10.4
Summer	10.9	9.9	11.5
Autumn	7.9	8.0	8.5
Winter	9.7	8.9	10.0
Annual	38.4	36.6	40.4
Temperature (°F.):			
Maximum	105	108	106
Mean maximum	64	65	67
Minimum	−17	−28	−18
Mean minimum	47	42	45
Mean annual	55	53	56
Average days over 90°	25	36	37
Average days under 32°	80	102	89
Frost:			
Latest killing frost in spring	Apr. 24	May 5	May 30
Earliest killing frost in autumn	Sept. 30	Sept. 19	Sept. 3

GEOLOGY.

STRATIGRAPHY.

GENERAL SUCCESSION OF STRATA.

The rocks of southwestern Ohio, restricting the term "rocks" to the hard consolidated beds commonly so called, are predominately limestone, every formation exposed at the surface being chiefly of this character, except the Eden and Utica shales, and even in the Eden many thin layers of limestone are interspersed with the shale at intervals of a few feet. Beneath the surface the known rocks with one exception—the St. Peter sandstone—are of similar charac-

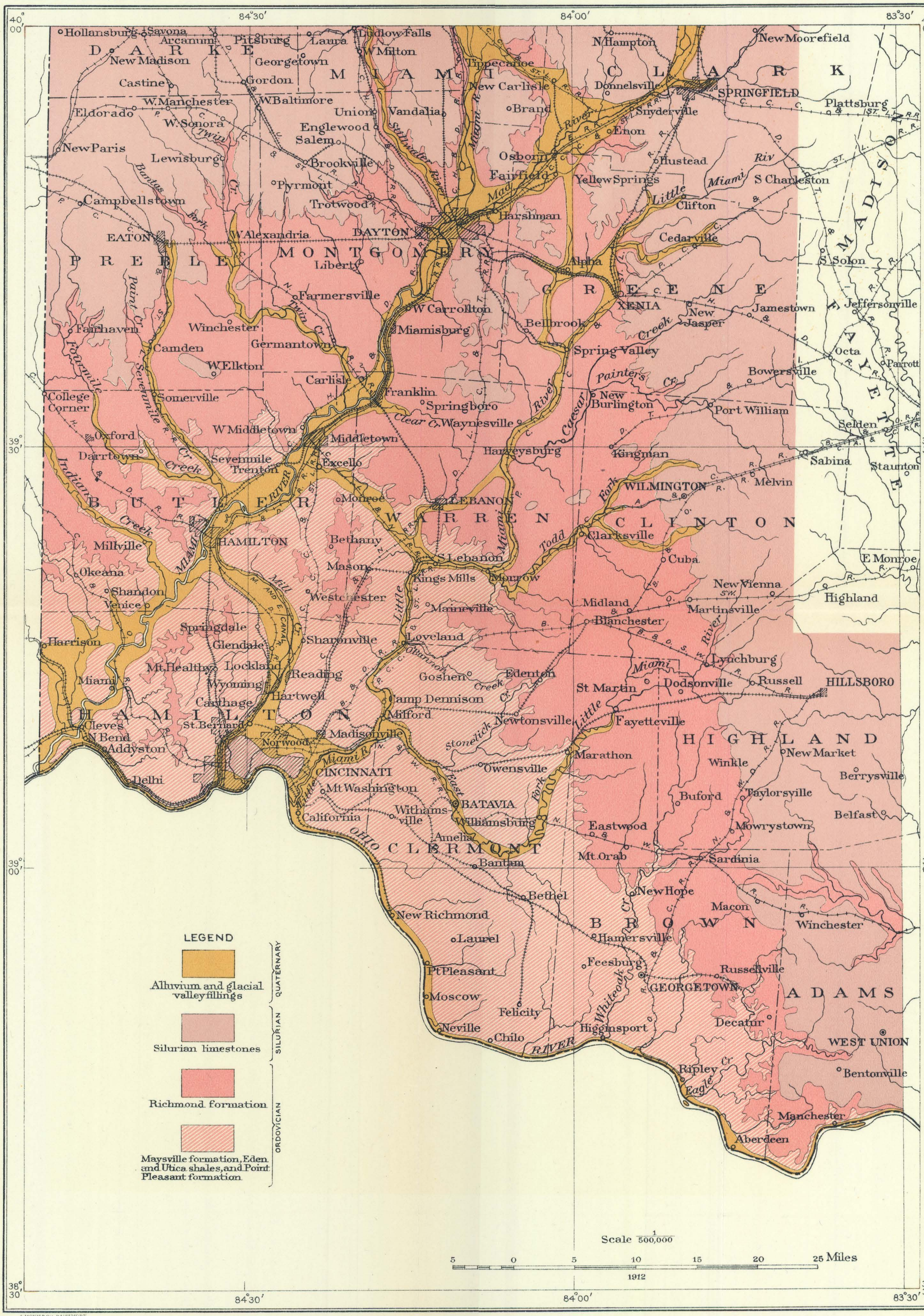
[1] Compiled from the climatologic report of A. J. Henry: Bull. U. S. Weather Bureau No. Q, 1906, p. 714.

ter. This succession of hundreds of feet of limestone with almost no sandy water-bearing beds, makes the problem of water supply especially difficult. Fortunately, however, the surface is covered by a sheet of unconsolidated pebbly clay underlain locally by some sand and gravel, and nearly all the larger valleys are deeply filled with sand, gravel, or unconsolidated glacial material. The age, thickness, character, and water supply of the rocks are shown in the table given below. The distribution of the hard rocks is shown by the geologic map (Pl. I) and that of the unconsolidated material by the map of the Quaternary deposits (Pl. II).

Geologic formations in southwestern Ohio and their water supplies.

System.	Formation.	Character and thickness.	Water supply.	
			Weathered outcrops.	Deeper drilled wells.
Quaternary.	Alluvium. Terrace gravels. Loess. Wisconsin drift. Illinoian drift. Old gravels.			
Carboniferous.	Mississippian sandstone.			
Devonian.	Ohio shale.			
Silurian.	"Helderberg" limestone.			
	"Niagara" limestone.[a]	Bedded or massive gray to buff limestone, varying from granular to compact and commonly characterized by small openings lined with minute crystals. Thickness, 250 feet.	Considerable water yielded to shallow wells.	Moderate amounts usually found in basal layers just above contact with underlying "Clinton" limestone or above particular included layers of shale. Less amounts in joints or solution passages in other portions.
	"Clinton" limestone.[a]	Massive buff to pinkish horizontal or cross-bedded limestone, composed largely of minute shell fragments. Few joints or bedding partings Thickness, 50 feet.	Amounts generally small, but some shallow wells obtain supplies. Usually acts as impervious bed and gives rise to springs along upper contact.	Moderate amounts in joints, bedding planes, and solution passages; springs numerous at top and bottom.

[a] Niagara as used by the Survey includes all of the limestone described in this report as "Niagara" and "Clinton," but in order to avoid confusion to the reader accustomed to the old nomenclature, and because of the lack of established names for the subdivisions here recognized, the use of the old names is continued in this report.



GEOLOGIC MAP OF SOUTHWESTERN OHIO

Compiled by Myron L. Fuller from field observations, maps of the Geological Survey of Ohio, and memoranda by E. O. Ulrich and A. F. Foerste

Geologic formations in southwestern Ohio and their water supplies—Continued.

System.	Formation.	Character and thickness.	Water supply.	
			Weathered outcrops.	Deeper drilled wells.
Ordovician.	Richmond and Maysville formations.	Gray to blue limestone layers 2 to 10 inches thick, alternating with shales. Prevailingly calcareous throughout most of thickness, which is 550 feet.	Yields moderate supplies to shallow wells.	Amount of water very variable, the majority of deep wells obtaining very small supplies or none at all. Water in some wells brackish and in a few slightly sulphurous.
	Eden and Utica shales.	Gray shales, weathering brownish. Thickness, 250 feet.	Furnishes small supplies to shallow wells.	Rarely water bearing. No successful deep wells known.
	Point Pleasant formation (contains true Trenton fossils).	Dark, hard, compact shale; layers 2 to 10 inches or more thick, alternating with beds of impure gray limestones of similar thickness. Formation, 150 feet thick.	Outcrop is below level of Ohio flood plain. Not utilized by shallow wells.	Carries water locally, but success of drilling is uncertain. Some of the water is salty or sulphurous.
	"Birdseye" limestone (so-called "Trenton" limestone of drillers).	Massive compact grayish limestone, breaking with conchoidal fracture. Thickness, 600 feet.	Does not outcrop in southwestern Ohio.	More or less water generally present but commonly salty. Not to be depended on for supplies of fresh water.
	St. Peter sandstone.	Porous calcareous sandstone. Thickness, 400 feet.	Does not outcrop in southwestern Ohio.	Yields abundant supplies of "Blue Lick" sulpho-saline water, which rises 175 feet above low water of Ohio.
Cambrian and Ordovician.		Varicolored dolomitic limestones and marbles with possibly shale in some places. Thickness, 3,000 feet, more or less.	Does not outcrop in southwestern Ohio.	Carries little or no water at depths at which it occurs in southwestern Ohio.
Cambrian.		Probably prevailingly sandy (not penetrated).	Does not outcrop in southwestern Ohio.	Never penetrated in southwestern Ohio. Waters likely to be strongly mineralized and unusable.

UNCONSOLIDATED DEPOSITS.

ALLUVIUM AND GLACIAL VALLEY FILLING.

Alluvium comprises stream deposits such as the gravel, sand, or clay fillings of the valleys. In southwestern Ohio it is present in greater or less amounts in all valleys, except a few sharp ravines near the Ohio and other large streams, where the small tributaries may flow on the bare rock. Naturally, the alluvium is considerably developed along Ohio River, where it has a depth of 100 to 168 feet, as shown by the bridge, waterworks, and well borings at or near Cincinnati. Its width in places may be 2 miles or more. Similar deposits occur along the Miami, Little Miami, Mill Creek, and numerous other rivers and large creeks, some of them reaching a width of 1 to 1½ miles, as on the Little Miami near Cincinnati. Few borings have been sunk through the alluvium in these valleys, but the depths in their lower portions are probably very similar to those in the Ohio. The thickness of the deposits doubtless decreases gradually upstream to the north, although wells as much as 70 feet deep failed to reach rock in the valley of Miami River at Dayton.

Superficially the alluvium generally consists of a sandy silt, but sand or gravel is usually found not far from the surface and continues to the bottom, except for a few more clayey beds at intervals. According to the statements of drillers, sand predominates in most wells, the gravels usually being rather fine and in beds of no great thickness. Probably, however, the tendency is to underestimate the amount of gravel, as usually only the sand is brought to the surface from the well. In fact, most of the wells, being of the driven type, give little evidence of the materials penetrated.

The pebbles in the gravel include many granitic fragments, presumably from the Canadian highlands, and have evidently been derived from the glacial drift of the region. Not all of the alluvium is of recent origin, however. In fact, except within 15 or 20 miles of the Ohio the greater portion is older than the last ice advance and is overlain in places by distinct morainal deposits of that stage. In general, however, the drift does not appear at the surface, apparently being covered by a relatively thin coating of glacial outwash or recent alluvium. It is probable that many of the reported clay layers are really beds of till. The drift layers are not clearly recognized in wells and are doubtless generally of no great thickness.

The surface elevation of the alluvium ranges from 450 or 500 feet near the Ohio to about 900 feet in the northern part of the area.

TERRACE GRAVELS.

Terrace gravels differ from alluvium in being the result of past rather than present stream action, for they stand distinctly above the level of existing flood plains. In general, the terrace materials are somewhat coarser than the alluvium, gravels as a rule largely predominating. Sand and clayey sand layers are not uncommon, however, and serve to collect the waters, which not infrequently deposit enough iron along the upper contacts to bind the sand or gravel into a hard stony mass, known locally as "cement rock." One of

MAP OF SOUTHWESTERN OHIO, SHOWING QUATERNARY DEPOSITS

By Frank Leverett, with modifications by Myron L. Fuller these layers (Pl. VI, *B*, p. 44) is very near the surface, but others occur at greater depths and have an important influence on ground-water supplies. Many of the pebbles are granitic, having been derived from drift materials brought down by the ice from the Canadian highlands.

The terraces are found mainly along the valley of the Ohio and not more than 15 or 20 miles up the valleys of its tributaries. In the immediate vicinity of the Ohio they reach a maximum elevation of 600 feet and are covered with several feet of the fine yellowish clayey silt known to geologists as loess. The best example of this high terrace is in the broad gravel-filled depression, supposed to be an old channel of the Ohio, connecting the present valleys of Little Miami River and Mill Creek northeast of Cincinnati. Madisonville, Oakley, and Norwood are upon its crest, and St. Bernard and Bond Hill rest upon an extension which runs up Mill Creek valley east of Carthage, Hartwell, and Wyoming to Reading. Along the Ohio few terrace remnants are left, but in protected spots a few benches may be seen. North of Cincinnati the materials are mainly gravels, but some old till beds of considerable thickness may be included. In many places the gravel layers have been cemented by iron and break away in big conglomerate bowlders where the deposits are cut by streams.

From the level of the higher terrace down to a few feet above the present flood plains of the streams are a number of intermediate gravel terraces. Of these the 550-foot terrace near the Cincinnati pumping station at California, the 550-foot terraces on both sides of the Ohio near Home City, the 570 and 600 foot terraces at Terrace Park and Milford on the Little Miami, the 550 to 600 foot terraces at many points along the Miami south of Hamilton, as well as the less extensive benches along many of the smaller tributaries, should be mentioned.

Along the tributaries of the Ohio the alluvium gradually rises upstream, approaching ever nearer to the altitude of the benches, which are more nearly flat, until at 15 to 20 miles from the Ohio it reaches the level of the highest loess-covered terrace and merges with it. Farther up the alluvium everywhere covers the terrace, reaching in the northern part of the area altitudes of over 900 feet, or 300 feet higher than its level near Cincinnati.

LOESS.

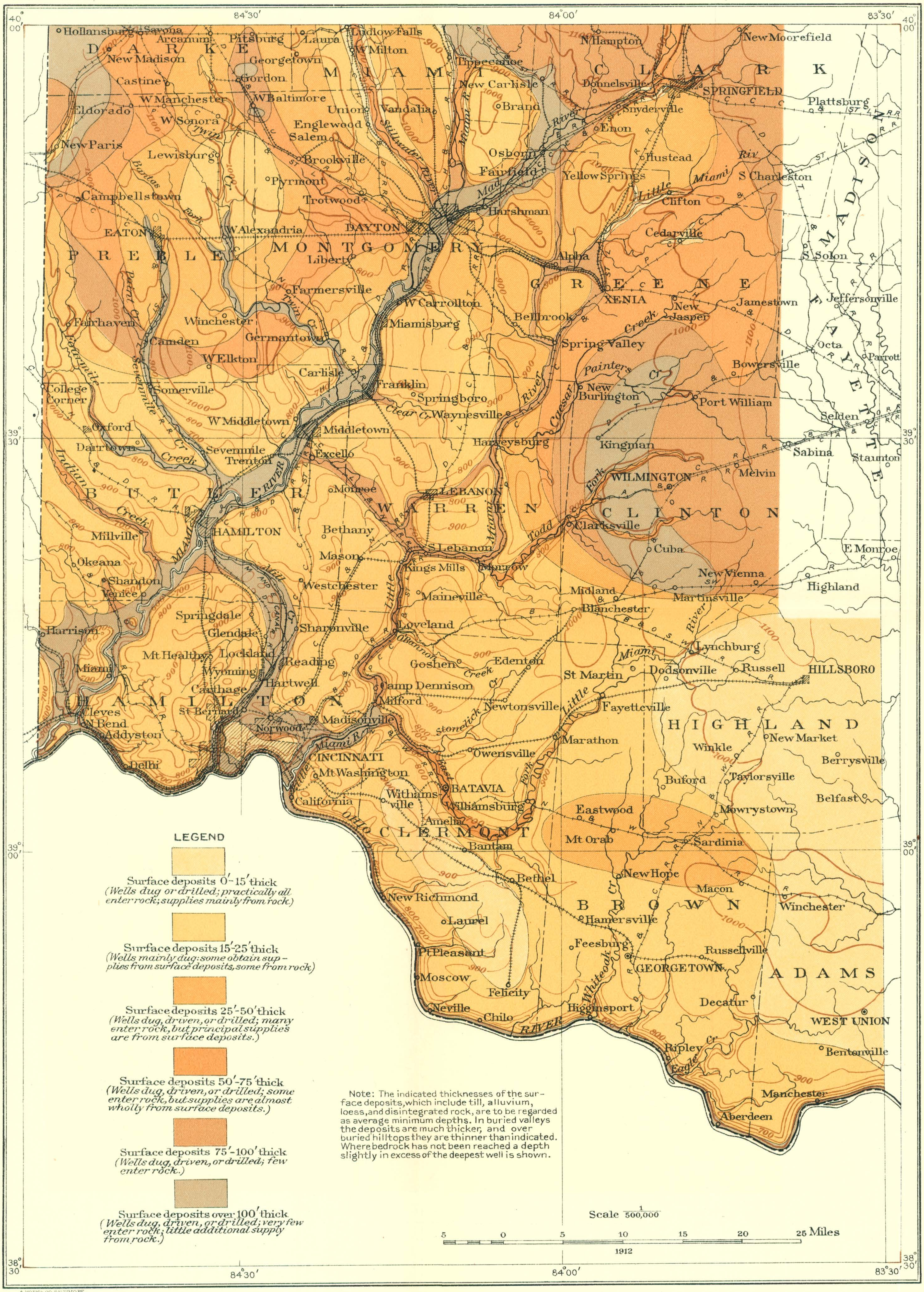
The loess, locally known as yellow loam, yellow clay, etc., is a fine, nearly structureless silt, with practically no coarse grains of any kind. It is yellowish buff in color, and although somewhat plastic when wet, is not a true clay. It contains few if any pebbles, and in this region is rarely if ever distinctly banded. It occurs at all elevations from that of the 600-foot terrace described in the preceding section up to the highest crests near the Ohio at something over 900 feet. It is not found in place below the 600-foot level, nor does it occur north of the southern limits of the last or Wisconsin ice advance. (See Pl. II.) In southwestern Ohio the upland loess seems to be mainly if not altogether the result of wind deposition, but it is possible that the loess of the valley terraces is water deposited and may have been, in fact, the original source of the upland material.

MORAINAL DRIFT.

Morainal drift is the term applied to the ridges of gravel or pebbly clay formed at the margins of the ice sheets that invaded the region in the geologic epoch immediately preceding the present. They are not true connected ridges, but are rather hills irregularly grouped together into more or less well-defined belts. (See Pl. II.) The older drift sheet thins out gradually to a mere fringe of pebbles, with no noticeable ridge at its edge; but the later or Wisconsin drift is marked by a number of ridges both at its southern limit and at several points where it halted temporarily during its retreat. Being formed mainly at the ice margins where considerable water resulted from melting, morainal deposits are generally gravelly and lack the compactness characteristic of drift which has been overridden by the heavy ice sheet; in some places, however, they contain considerable amounts of subglacial till. The gravel is commonly stratified, but generally the layers are very irregular and slope at high angles, owing to their deposition by tumultuous waters. In general they rest on till surfaces, which form impervious bottom layers. The ridges are not commonly very high, 20 to 30 feet being a common maximum on the upland, though exceeded in some places; in the valleys, especially on the sides, the ridges are much more conspicuous.

TILL.

The till is a heterogeneous mixture of clay and pebbles, with sporadic bowlders. In southwestern Ohio there are at least two tills representing differing glacial stages, the older being known as Illinoian and the younger as Wisconsin. The Illinoian, in its upper weathered portion, is yellowish or reddish, but below a depth of 10 or 15 feet it is an unoxidized grayish mass. In it clay predominates, making a firm, compact, impervious mass, in which pebbles are relatively few and of small size. The Wisconsin commonly contains less clay and more numerous and larger bowlders, consisting largely of limestone, shale, or other local rocks, though including many of granite from Canada. The mass is generally structureless, but in places an indistinct banding



MAP OF SOUTHWESTERN OHIO, SHOWING THICKNESS OF WATER-BEARING SURFACE DEPOSITS

By Myron L. Fuller

Surveyed in 1907

may be noted, and more rarely a thin band of stratified gravel is seen. The distribution of the till is shown by Plate II. It will be noted that with the exception of the valleys and the southern portions of Brown and Adams counties the whole of the region is covered with the till mantle. The map also brings out the limits of the late drift sheet and the extension beyond it of the earlier glacial drift. Near Ohio River and along the eastern margin of the outer drift the deposits are very thin, but the thickness increases to the northwest until in the northern part of the area the true drifts have a local united thickness of 100 to 150 feet or more. The variations in the thicknesses are shown on Plate III.

The till mantles the entire uplands and in places extends beneath the valleys (Pl. II), although it is not usually seen because of the covering of later alluvium. In the Ohio Valley most of the till has been removed by erosion since its deposition and it is now only found on the uplands.

The till represents accumulations of glacial materials dragged along and deposited beneath the ice sheets which covered the region in the geologic epoch immediately preceding the present. The layers of gravel and sand represent the work of streams or other bodies of water occurring beneath the ice. The lower and older drift is made up mainly of materials derived from the weathered rock surface over which the ice moved, the major part being from local rocks and a smaller proportion from Canadian rocks. The later or upper drift has less material derived directly from the local rocks, the larger proportion coming from the earlier drift or loess over which the ice moved, but with a considerable admixture of rock fragments from Canada.

OLD GRAVELS.

On the uplands southeast of Mount Washington, a few miles east of the mouth of Little Miami River, a small area of sand and gravel, apparently underlying loess and old till, appears to be of very early origin, its accumulation probably having taken place either in the latter part of the Tertiary period or in the early part of the Pleistocene or "glacial" epoch. This is borne out by the finding of mastodon teeth in a well sunk at Mount Washington. The gravel in which the fossils were found lies only 15 feet below the surface and consists of large flat pebbles standing partly on end, as in many of the present streams of the region, indicating that the stream was a rapid one. The entire deposit is very thin, shale being entered at 20 feet. The gravels have an altitude of 700 to 750 feet and are limited to a square mile or two southeast of Mount Washington, known locally as the American Flats, and to a much smaller area at the northern edge of the town.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.[1]

Character.—The "Niagara" limestone of southwestern Ohio is about 250 feet thick. In color it varies from very light gray through darker and bluish gray to buff. In general it is rather massive, presenting relatively few bedding planes. In fact, in the large quarry north of Mad River west of Springfield the writer did not see a single parting in a quarry face 50 feet in height, and even on blasting the rock broke into irregular fragments without reference to any structural planes. Elsewhere, however, the bedding is very marked, though in some places it is inconspicuous until brought out by weathering (Pl. VII, *A*, p. 45). The difference in the spacing of the parting planes in the lower unweathered and in the upper weathered portions is very noticeable. The texture varies from compact to granular, the former prevailing in the grayish types, and the latter being more common in the more open and therefore more weathered buff varieties. Many small openings varying in width from a fraction of an inch upward occur and are generally lined with coatings of minute crystals. In a very few places these openings are so numerous as to give the rock a superficial resemblance to the calcareous tufa deposited by limestone springs. Fossils are present, but are not nearly so numerous as in many other formations. They indicate a marine origin for the limestone.

The "Niagara" limestone outcrops around the borders of the region but dips gently away at the rate of 5 to 10 feet a mile both to the north and east. (See Pl. I.) It is the highest rock in the area, being overlain only by the glacial drift. The elevation of its outcrop commonly ranges from 900 to 1,000 feet.

"CLINTON" LIMESTONE.[1]

The "Clinton" limestone of southwestern Ohio, a relatively thin bed nowhere more than 50 feet thick, occurs at the base of the "Niagara" limestone and is shown on the geologic map (Pl. I) as a narrow band just south and west of the outcrop of the "Niagara." It is predominantly of a buff color but is nearly always characterized by a pinkish tinge or by streaks of red which suggest the iron-bearing layers of other regions and assist greatly in its identification. It seems to be composed largely of minute fragments of marine fossils which were rolled about by the sea and finally deposited in horizontal

[1] Niagara as used by the Survey includes all the limestones described in this report as "Niagara" and "Clinton," but in order to avoid confusion to the reader accustomed to the old nomenclature and because of the lack of established names for the subdivisions here recognized the use of the old names is continued in this report.

and cross-bedded layers. Bedding planes are more numerous than in the massive portions of the "Niagara," but the rock is denser and more insoluble and the bedding planes are less commonly developed as water passages, except near the base. Joints are very few in number. Altogether, the "Clinton" is a rather resistant rock and makes numerous abrupt scarps along the sides of many bluffs. (See Pl. VII, *B*, p. 45.)

RICHMOND AND MAYSVILLE FORMATIONS.

Taken together the beds of the Richmond and Maysville formations are about 550 feet thick and consist mainly of thin layers, 1 to 10 inches thick, of gray or bluish limestone, alternating with similar or somewhat greater thickness of soft bluish shales (Pl. VIII, *B*, p. 46). Both shales and limestones become yellow or brown by weathering. Outcrops near Cincinnati show a considerable thickness of rather fine shales at the top of the Maysville and at the base of the Richmond, but other parts of the formations are predominantly of limestone. Geologically the Richmond and Maysville can be divided, but considered as water bearers they are essentially a unit and are therefore generally treated together in this report. The distinction between them is seldom recognized in wells and they appear to carry water of the same general quality. The limestone layers abound in fossils that indicate the marine origin of the beds.

The Richmond and Maysville formations are far more extensive areally than any other formation in southwestern Ohio (see Pl. I), extending from the "Clinton" outcrop in Preble and Montgomery counties to Ohio River, and from central Greene, Clinton, and Highland counties to the Indiana line, thus constituting the surface rocks over the greater part of the region. They reach their highest elevation near their northern limit, where they stand as much as 975 feet above sea level. From this elevation they descend to less than 500 feet along the line where they cross the Ohio, in southeastern Clermont County. At Cincinnati their top is about 550 feet above sea level or 430 feet above the river.

EDEN AND UTICA SHALES.

The Eden shale consists of soft light and dark gray shales that weather yellow or brown on exposure. At the base of the Eden shale there are a few feet of drab shale representing the Utica shale. These two formations have a combined thickness of about 250 feet, nearly all of which belongs to the Eden shale. They are free from limestone, except for local layers in the Eden most of which are 1 to 4 inches thick and are separated by several feet of shale. They contain salt-water fossils, which indicate their marine origin. As the

Eden shale is among the lower formations, it outcrops only in the deep valley of the Ohio and in the lower portions of its tributaries (Pl. I). The upper part of the Eden surface near Cincinnati is about 720 feet above sea level and its bottom is 470 feet above sea level or 50 feet above lower water of the Ohio.

POINT PLEASANT FORMATION.

The term "Point Pleasant" is applied to the series of thin beds of alternating limestones and shales carrying true Trenton fossils and occurring immediately below the Utica shale in the vicinity of Cincinnati and along Ohio River both to the east and the west. At Cincinnati the Point Pleasant has a thickness of about 150 feet, but only 30 or 40 feet of this is above low-water mark, the top being considerably below the Ohio flood plain. The shales are dark-gray, hard, compact layers, 2 inches to a foot or more thick, and the limestones are impure grayish beds of about the same thickness. The heavier bedding and the more massive or compact character of the rock distinguish it from higher beds. It carries numerous marine fossils.

"BIRDSEYE" LIMESTONE.

The "Birdseye" limestone,[1] the so-called "Trenton" limestone of well drillers, is generally a massive, compact, grayish limestone, breaking with curved fractures, but at some points, as in the oil regions, it appears to be dolomitic and more or less porous in its upper part. In southwestern Ohio its total thickness is about 600 feet, but it does not outcrop, its upper part, or contact with the Point Pleasant formation, being about 100 feet below the level of Ohio River at Cincinnati.

During the oil and gas boom of 25 to 30 years ago many wells were sunk to the "Birdseye." From the data thus obtained the depth to the formation throughout the area became known and it was possible to construct a map (Pl. IV) showing by contours the elevation of its surface above sea level. Comparison with the elevation of the surface of the ground (see Pl. IV) gives the depth to the "Birdseye" at any particular point. The surface of the "Birds-

[1] Detailed investigations by E. O. Ulrich and others, made since the field work for the present report was completed, show that the geology beneath Cincinnati is far more complicated than has hitherto been supposed and that the elevation of the "Birdseye" limestone is considerably greater in the vicinity of the city, at least locally, than appears to be indicated by the structure contours of Plate IV. It is possible, if not probable, however, that the so-called "Trenton," upon which the structure contours are actually based, is not the top, but rather a lower and harder bed within the "Birdseye." If this is so, it will account in large measure for the discrepancies between the contours of the map and the elevations of the "Birdseye," as given in the text.

A. HOEN & CO. BALTIMORE

MAP OF SOUTHWESTERN OHIO, SHOWING ARTESIAN CONDITIONS

By Myron L. Fuller

eye" serves as a convenient reference horizon for other formations, notably for the water-bearing bed in the St. Peter sandstone below.

ST. PETER SANDSTONE.

The St. Peter sandstone in southwestern Ohio appears to be a shaly and calcareous, but more or less open, sandstone about 400 feet thick. It lies about 850 feet below the surface at Cincinnati, from which elevation it descends northward and eastward to a still greater depth before rising again. Its nearest outcrop is in southeastern Wisconsin, about 350 miles from Cincinnati. Eastward and southward it seems to thin out and disappear. Its porosity probably is due largely to the removal of the lime that originally filled the spaces between the sand grains.

CAMBRIAN AND ORDOVICIAN DOLOMITE.

The Cambrian and Ordovician dolomite lies, according to well records, about 1,225 feet below the surface at Cincinnati, its nearest outcrop being in the Appalachian region 200 miles southeast. It appears to be a buff, brownish, pink, or reddish dolomitic limestone or marble, possibly with a sporadic bed or two of shale. It was penetrated to a depth of about 1,000 feet by the well at the Moerlein brewery, but its bottom has never been reached. Observations in Tennessee lead to the belief that it is at least 3,000 feet thick.

STRUCTURE.

The part of southwestern Ohio herein discussed lies on the crest and flanks of what is known to geologists as the Cincinnati anticline. It is a broad rock arch or dome, the center of which is near Cincinnati. From it the rocks dip gently away to the east, north, and west, but rise to a still higher point in central Kentucky to the south. Nothing in the surface relief indicates the presence of this anticline, and it is recognized only by geologic studies. On Plate IV contour lines, or lines drawn through points of equal elevation, on the "Birdseye" limestone, as determined by well borings, are shown. Parallel to these contour lines the rock is horizontal, whereas at right angles it dips away at a rate indicated by the distance to the next contour, which is just 50 feet lower than the first. The rate varies from a little more than 10 feet to the mile near Miamisburg to about 3 feet to the mile in western Hamilton County and near Dayton. The contours also bring out the fact that the dome is not entirely regular but is marked by a crease of steeper dips along a line from Dayton to Hamilton.

UNDERGROUND WATERS.

RELATION TO SURFACE FEATURES.

So intimate is the relation of underground water to surface features that in many places the former may be said to be largely controlled by the latter. Thus, the amount of water absorbed depends to a large extent on the slope of the catchment surface; the direction and rate of movement of underground waters, especially of the shallower waters, depend largely on the direction and slope of the surface; the shape of the water table conforms in general to the surface configuration; the leakage from water-bearing beds as a rule depends on the cutting of the beds by depressions of the surface; and the depth, head, volume, and many other factors are materially affected or controlled by the character of the land surface. The study of surface features is therefore of great importance in all underground water investigation.

In southwestern Ohio, where the plateau constitutes the greater part of the surface, it is naturally an important source of ground water, the occurrence of which is intimately related to the nature of the surface formation, whether this be drift or rock, to the width of the plateau remnants where cut by valleys and ravines, and to the nearness of the bluffs at its edges.

On the sharp and narrow crests between the ravines the rainfall is quickly shed to each side, very little soaking into the ground; and even the small amount absorbed drains rapidly from the narrow ridges, leaving them little or no ground water above the level of the valley bottoms.

For similar reasons the amount of ground water decreases toward the edges of the valleys. A few miles back from these borders, especially in the flatter portions, ground water usually lies very near the surface, often rising in wet seasons within 5 feet of the top; but as the valley is approached the water level becomes much lower, until near the edge no water whatever may be found within reach of ordinary wells, both soils and rocks being completely drained.

Though the above generalizations are true throughout the area, whatever the nature of the deposits, the shortage of water is much more marked in certain types of materials. Where the surface materials are loose and porous sands and gravels the loss of the water is much more rapid than where they are pebbly clays and other relatively impervious materials. Likewise the loss is greatest in porous rocks and in those which, like the limestones, have numerous bedding planes and small solution passages that permit the ready escape of the water, and is least in impervious shales.

Although on account of their small area the valleys are not the most common source of ground water in southwestern Ohio, they are in many ways the most important, as they furnish supplies not only for three-fourths of the waterworks in the region, but for most of the manufacturing plants as well. The abundance of water is due to several causes. As the valleys are much lower than the surrounding hills they form natural lines of drainage, toward which the water in the rocks, as well as that upon the surface, moves. The water falling on the hillsides likewise finds its way to the valleys and is added to the supply. The main reason for the importance of the valleys as a source of water, however, arises from the gravel and sand with which the larger ones are filled to considerable depths; these materials, which have porosities of 25 to 40 per cent, hold immense quantities of water, which is readily given up to wells.

SOURCE.

POPULAR CONCEPTIONS.

In view of the number of different popular conceptions as to the source of the underground waters in southwestern Ohio a few words on the subject may not be out of place. In this, as in other regions in Ohio and in the upper Mississippi Valley, it is a common belief that the waters are derived through subterranean passages from the Great Lakes. The level of Lake Michigan is 581 feet, which is only 75 feet above Cincinnati, and with the exception of a few of the valleys is several hundred feet below the general level of this part of Ohio. The elevation alone, therefore, precludes such a source for the waters.

Along the Ohio another view, namely, that the ground water is derived from the river, is widely held by the people, who have long noted that in many places only the wells at or near river level procure water. Careful studies of the ground waters, however, have shown that they move in a manner similar to surface waters; that is, from the hills toward the valleys, and join the streams or underground flows in the latter just as surely as the tributary joins the master surface stream. When the river rises it backs up both the surface streams and the ground waters, which explains the fluctuations in ground-water level. Only when sudden floods lift the river faster than the ground water can come in do movements away from the river take place. Even then the water does not penetrate far inland.

LOCAL SOURCES.

The independence of the ground waters, even when near the river, is indicated by their composition, which is almost always quite different from that of the surface waters, the ground waters usually carrying very much larger quantities of mineral matter than the river water. Wells only 20 feet from the bank, if lightly pumped, will ordinarily draw from the ground water rather than the river, and wells sunk considerably below the river bed are even less likely to draw from the stream. If the wells are heavily pumped, however, river water may be drawn in. The nature of the ground-water movements and the reason why wells adjacent to rivers seldom get river waters is shown by figure 2.

Most of the ground water in valleys percolates from the surrounding hills, working its way downward through joints or fissures and

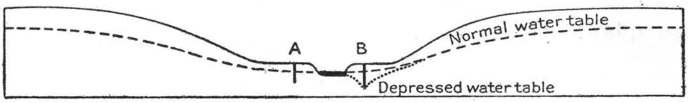


FIGURE 2.—Cross-section showing ground-water conditions in valleys. A, lightly pumped well not getting any of its water from the river; B, heavily pumped well securing more or less river water.

outward along bedding planes or other partings. That coming from below is relatively small in amount. On the hilltops the water is mainly derived directly from the rainfall and represents the portion not yet absorbed by the deeper rocks.

GENERAL SOURCES.

The water of the deeper rocks in southwestern Ohio is derived mainly in one or the other of two ways: (1) By absorption at their outcrops, and (2) by penetration downward through joints.

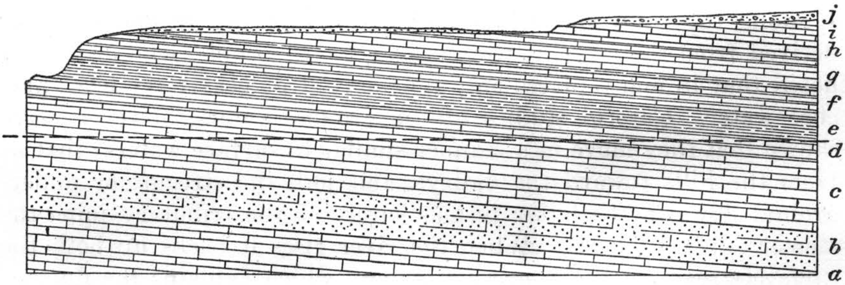


FIGURE 3.—Geologic cross-section of southwestern Ohio. *a*, Cambrian and Ordovician dolomite; *b*, St. Peter sandstone; *c*, "Birdseye" limestone (so-called "Trenton" of well drillers); *d*, Point Pleasant formation (Trenton fossils); *e*, Eden shale (including at base a small thickness of Utica shale); *f*, Maysville formation; *g*, Richmond formation; *h*, "Clinton" limestone; *i*, "Niagara" limestone; *j*, till. Dotted line indicates sea level.

From the geologic cross section (fig. 3) it is seen that the conditions of outcrop vary considerably. The "Niagara" limestone, which is the best water-bearing formation in the area, has a broad flat outcrop presenting abundant opportunity for the absorption of water from the overlying coating of drift materials, which serves as an admirable feeder. The "Clinton," because of its hardness, not uncommonly forms steep slopes or scarps (Pl. VII, *B*, p. 45) at its outcrop, making the absorption of water from the outcrop very difficult, especially as the drift "feeder" is in many places thin or absent. The limestones and shales of the Richmond and Maysville formations have very favorable catchment conditions, the outcrop being both level and covered for the most part by a drift "feeder," but unfortunately these formations contain enough shale to greatly hinder the circulation of water. Moreover, the lower part of the Maysville formation outcrops mainly on the steep bluffs of the Ohio and of its larger tributaries and thus has little chance to absorb water. The Eden shale likewise outcrops mainly in steep cliffs, which fact, taken in connection with the prevailing shaly character, effectually keeps out the water, making the formation the poorest water bearer in the district. Only the upper part of the Point Pleasant formation outcrops in the region, but, owing to the solubility of the limstone layers, it absorbs considerable water locally. These rocks outcrop farther south in Kentucky, but it is doubtful whether any of the water which

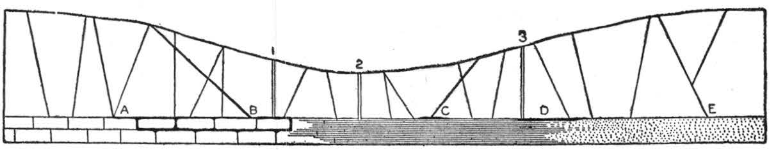


FIGURE 4.—Section illustrating the feeding of water beds through joints (water-bearing joints indicated by the heavier lines). A, B, Water horizon between limestone and compact, jointed rock fed by joints at A and B; C, water horizon between shale and compact jointed rocks with local circulation only; D, water horizon fed from sandstone bed; E, sandstone bed fed by joints; 1, flowing well from bedding plane between limestone and compact jointed rocks; 2, dry hole (no circulation along bedding plane); 3, flowing well from bedding plane fed from sandstone.

they contain in southwestern Ohio comes from this source. The "Birdseye" limestone does not outcrop in Ohio, but does outcrop over an extensive area in central Kentucky. Being locally rather soluble it is possible that some of the water may penetrate from the outcrop. The St. Peter sandstone does not appear at the surface anywhere to the south or east, apparently thinning out in these directions. To the north it comes to the surface in southern Wisconsin, about 350 miles from Cincinnati, where it has an elevation of about 800 or 900 feet. In view of the large volume of water which it contains, and of the thick covering of overlying beds, it seems likely that much of its supply is derived from the distant outcrop.

Besides the water which enters at the outcrop, much undoubtedly penetrates to the underlying beds through joints, as is shown diagrammatically in figure 4, in which A and B represent joints feeding a limestone furnishing water to well 1; C, a joint feeding a local bedding plane; D, a bedding plane connecting with sandstone fed by joint E and furnishing water to well 3.

It is probable that the water which so abounds at the top of the "Clinton" limestone reaches it in part through joints in the "Niagara" beds, as at A and B in the figure. Some water may reach the top of the Eden shale through joints in the Richmond and Maysville formations, but because of the insoluble character of the rocks the circulation is very slight, as at C in the figure. It is also barely possible that some of the water of the St. Peter may reach it through joints, but the amount so derived is probably very small.

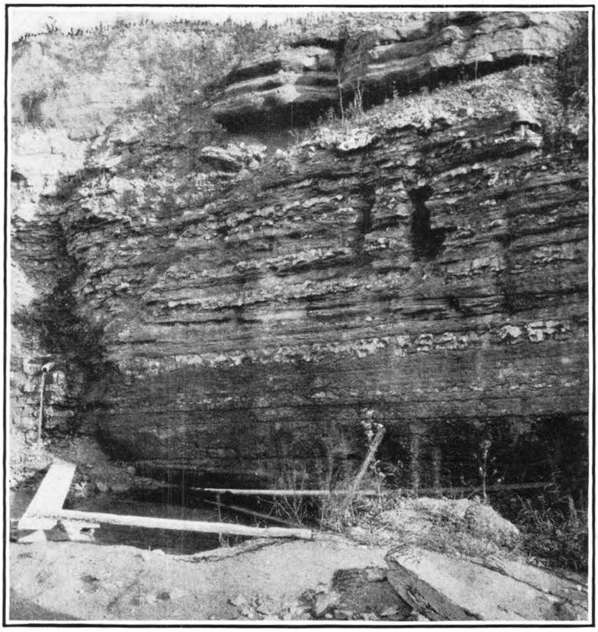
OCCURRENCE.

Waters in rock.—The underground waters derived in the several ways outlined above occur in the rocks under many conditions. In absolute amount that in the pores or spaces between the particles which make up the rock is probably greatest, but unfortunately in many of the finer-grained rocks the water in the pores, though abundant, is so firmly held that little or none of it is yielded to wells. In southwestern Ohio the St. Peter sandstone is the only formation that yields large amounts of water from the pores of the rock itself, the other formations giving it up only when it occurs along joints, bedding planes, solution passages, or similar openings.

Joints are smooth fracture planes cutting the rock in different directions. In limestone the joint openings are at first hardly appreciable, but as the waters work their way downward they gradually dissolve mineral matter from the walls, widening the joints until the water moves freely. Such a joint in the "Niagara" limestone is shown in Plate V, *A*. So universal is circulation of this type that a joint is rarely found which does not possess solution features or iron-stained walls that give evidence of the passage of water.

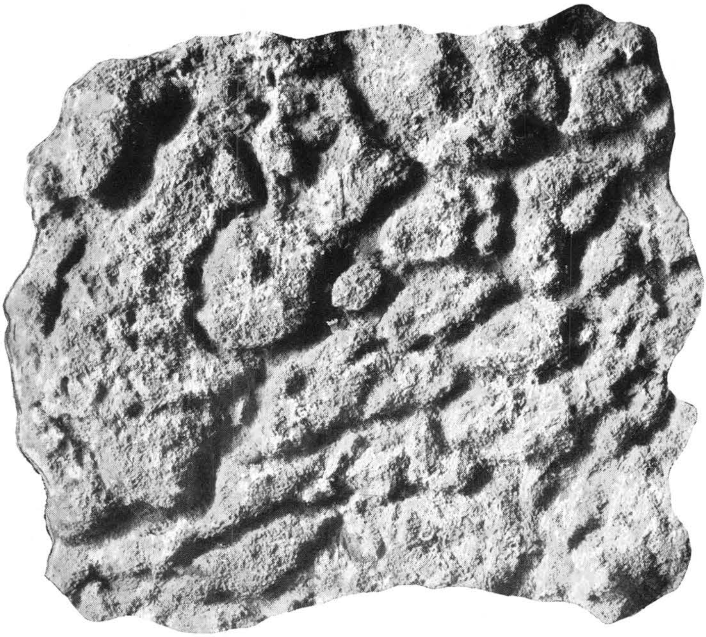
Bedding planes are even more important as water bearers than are the joints, for the water seeps along them at many points. The bedding planes, like the joints, are at first not generally actual openings; they simply represent lines along which the water percolates by reason of imperfect adhesion between layers of different texture or different materials. Under the action of the waters, however, they rapidly widen and afford passage for large amounts of water. The openings differ, however, from those of the joints. Instead of forming an open crack the waters dissolve a complicated system of meandering passages, such as those shown in Plate V, *B*, which represents a bedding plane in the Maysville formation.

As the joints and bedding planes become wider the water tends to concentrate along certain lines, forming solution passages, many of which are of considerable size. Plate V, *A*, shows a spring issuing from such a passage, which was uncovered and traced for a long distance during the process of quarrying. Plate VI, *A* (p. 44), shows another solution opening in the same quarry.



A. LARGE SOLUTION CHANNELS IN NIAGARA LIMESTONE.

Due to enlargement of vertical joints. Spring issues from bedding plane on left.



B. RAMIFYING SOLUTION CHANNELS ALONG BEDDING PLANE IN MAYSVILLE FORMATION.

Showing circulation of rock waters. About one-fourth natural size.

Waters in drift.—The drift includes the local irregular gravelly heaps and ridges and the pebbly clay or till which overlie the rocks of most of the area (Pl. II). The clay is not the ordinary compact, impervious, water-laid clay, but carries in places more or less sand and pebbles, which are either irregularly distributed through the mass, converting it into a heterogeneous mixture, or form more or less well-defined sandy or gravelly layers. Nearly everywhere it contains considerable water, even in its more clayey portions, in much of which the water gathers into little tubular channels, as well as saturating the more porous sandy or gravelly portions. The drift not only directly supplies important amounts of water, but also serves as a feeder to the underlying rocks, which will absorb more water from it than if they were exposed directly to the rain.

The more gravelly drift in the ridges contains little water, except in the very lowest parts, because of the ease with which it drains out from the open porous material.

Waters in alluvium, etc.—All the larger stream valleys and many of the smaller ones contain considerable depths of clays, alternating with more open sands and gravels that hold great quantities of water and afford excellent supplies to many towns and to numerous

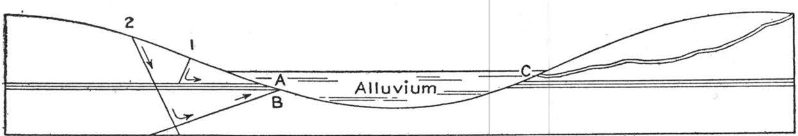


FIGURE 5.—Section showing valley alluvium fed from bedding planes and solution passages. A, Bedding plane, feeding alluvium with water derived from joint 1; B, joint feeding alluvium with water from joint 2; C, solution passage feeding alluvium.

manufacturing establishments. Nearly all of this water enters from the higher lands bordering the valleys and joins the underflow by seepages from bedding planes and by flows from joint planes and solution passages (see fig. 5). Analogous conditions probably exist at hundreds of points along nearly every stream in the region.

HEAD.

Many of the wells on low ground, both those in rock and those in the alluvial fillings of the valleys, yield flowing water, and nearly everywhere the water is under artesian pressure, rising very materially when encountered. The pressure, though depending on certain general principles, differs considerably with the different materials in which the water is contained and with the different degrees of confinement to which it is subjected.

Waters in rock.—Water contained in rocks may be either unconfined, in the upper weathered portion of the rock masses, or it may lie deep and be confined under pressure in pores, joints, bedding planes, or solution passages.

In deep confined waters the head is dependent on the factors that control the entrance of the water. Entering at the outcrop of sloping rocks, such as those of southwestern Ohio (fig. 3, p. 34) the water passes gradually downward under the action of gravity, is prevented from escape by overlying more or less impervious beds, and fills all the openings and pores which it can reach. As the beds are filled the water in their lower part is subjected to the pressure of the overlying water, and, when reached by a well, will rise in proportion to the height of the water level in the higher portion of the bed, giving, if the surface is low enough, an artesian flow.

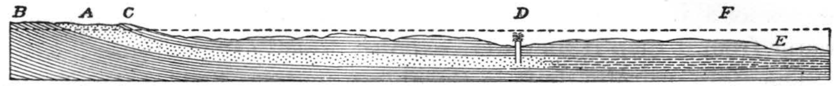


FIGURE 6.—Section showing conditions of flow in inclined porous bed, becoming thinner. *A*, Porous bed between impervious beds *B* and *C*, thinning out at *E*, thus furnishing conditions for flow at *D*, but not at *F*. Applied to the St. Peter sandstone, *A* would represent its Wisconsin outcrop, *D* the flowing wells at Cincinnati, and *E* its termination somewhere to the south or east.

The underground conditions controlling such flows differ considerably, some of the simplest being shown by figures 6 and 7, in which the water is represented as occurring in porous beds. In reality none of the beds in southwestern Ohio except the St. Peter sandstone is porous in the ordinary sense of the word, and the water really occurs in joints, solution passages, and bedding planes, in which the head depends on the source of the water and the conditions of retention. Where the opening drains freely into some valley or other depression the water may flow through the subterranean passages as does the

FIGURE 7.—Section showing conditions of flow in inclined porous bed, becoming impervious. *A*, Porous bed between impervious beds *B* and *C*, grading into nonporous bed at *E*, the confinement giving rise to a flow at *D* but not at *F*.

water of a surface stream over its bed, but where no ready escape offers the water accumulates, as in the porous beds previously described, subjecting the lower part to considerable pressure, whose degree varies with the level of the surface of the confined water.

Waters in drift.—In general the drift surface has a considerable slope from north to south, its elevation declining from 1,100 feet near its northern limit to about 800 feet at its southern border. As already explained it is characterized by numerous passages or porous layers, many of which appear to slope in the same direction as the surface. It therefore occasionally happens that the pressure transmitted in such passages from some higher point farther north is sufficient to lift the water to the surface even on the flat plains, and flowing wells result, as near Brookville in Montgomery County. The conditions are still more favorable in valleys or other depressions in the drift, in which flows are even more numerous.

Waters in alluvium, etc.—The head of the waters in the valleys is due to at least two different causes, one of which is the pressure transmitted from higher points farther upstream, and the other the pressure derived from the passages and lamination planes where the valley bottom is in drift or from joints, bedding planes, and solution passages where it is in rock. In order to obtain a flow from upstream pressure the water must have free entrance upstream, and must be prevented from rising downstream by some clayey or other more or less impervious layer. A similar cover must be present to give a flow when the alluvium is fed from the rocks. Unfortunately such a cover is lacking in many localities or is too imperfect to confine the water, which escapes upward and joins the streams. It is because of this fact that flows are not more common in valleys.

SUPPLY.

By available water is meant that portion of the ground water which can be economically obtained by man. It does not include the amount held in the microscopic pores of the compact rocks and never yielded to wells in appreciable quantities, even though it may be present in amounts greater than the free water.

Of the different materials in the region the drift and alluvium hold the largest percentages of available water. In the drift the amount probably varies from about 5 per cent in the clayey portions to 30 per cent or more in the more sandy or gravelly portions, the average probably being fully 15 per cent of the volume of the drift; that is, a saturated layer 100 feet thick contains the equivalent of a 15-foot layer of water. In alluvium sandy materials generally predominate, the average porosity being probably at least 20 or 25 per cent.

In the solid rocks the percentage of water is generally less. Of the limestones the "Niagara" and "Clinton" carry the most water, but even in these it is doubtful if the free water in a bed 100 feet thick would make a layer more than a foot deep. In the shaly limestones the amount is still less, there probably being not more than one-eighth or one-fourth as much as in the "Niagara," and in the shales the amount of free water is so small as to be practically negligible. In the deeper limestones, such as the "Birdseye," the aggregate amount is considerable, but probably would not aggregate more than a few inches to each hundred feet, and in the still deeper Cambro and Ordovician dolomite the amount is very small indeed. The St. Peter sandstone is an exception among the rocks of the region, for it probably carries at least 10 to 15 per cent of water, containing in its thickness of approximately 400 feet the equivalent of a 40 to 60 foot layer of water.

Exclusive of the water of the St. Peter sandstone, which is too high in sulphur for ordinary use, and the water of the "Birdseye" limestone, which is very generally salty, by far the greater part of the water occurs either in the drift and alluvium or in the "Niagara" and "Clinton" limestones, both of which are at or near the surface in this area are easily reached in shallow wells. Rock wells that go below the level of the "Clinton" limestone have rather small chances of success, although a few obtain satisfactory supplies; the majority either fail entirely or get supplies too small for ordinary uses. Deep wells give no promise, for though in most places they can obtain water, it will generally be either salty or highly charged with sulphur.

WATER-BEARING FORMATIONS.

Practically all rocks contain more or less water, and differ only in the degree of their saturation. Those containing water in only small amounts may play an important part as confining beds and must be considered in any discussion of the water. The several formations recognized in southwestern Ohio and their water-bearing capacities are considered below.

UNCONSOLIDATED DEPOSITS.

ALLUVIUM AND GLACIAL VALLEY FILLING.

Most of the water of the alluvium and of the interbedded glacial deposits works its way downward from the surrounding highlands by seepage from bedding planes, along solution passages or through joints in the rocks in which the valley is cut. Occasionally, as during floods, when the water in the stream rises faster than that in the ground, the flow may be reversed and river water may penetrate the alluvium on each side or may even force its way downward. As a rule, however, as is shown by the greater hardness of the water in the alluvium as compared with the river water, the alluvium contains chiefly the more mineralized waters from the rock hills. It also derives water directly from the rain that falls on its surface.

Ordinarily the alluvium is sufficiently permeable to permit water to percolate through its entire body, which, in fact, is always saturated below the water level of the stream. In severe droughts the water level in the smaller and more steeply sloping valleys sinks below the level of the stream bed, and the channels, except perhaps for a pool here and there, become dry. In most valleys, however, the water level is not far below the surface and there is considerable underflow. All the water occurs in the pores or openings between the grains, the amount so held usually varying from 25 to 35 per cent of the bulk, according to the nature of the material.

Although the alluvium is generally saturated with water below the level of the stream, all of this is not available for wells. Clayey materials, although perhaps containing 40 per cent of their bulk of water, hold it so firmly that little or none is given up to wells, and even sands do not yield all that they hold. In general, however, the sands and gravels yield their water freely, and in order to procure an abundant supply a well need only find a bed of material thick enough to permit the insertion of a sufficient length of strainer that is coarse enough to prevent the grains from passing through the screen. In most valleys such beds can be easily found, especially in the center, but in some the requisite sands or gravels are absent near the margins and the wells are failures.

TERRACE GRAVELS.

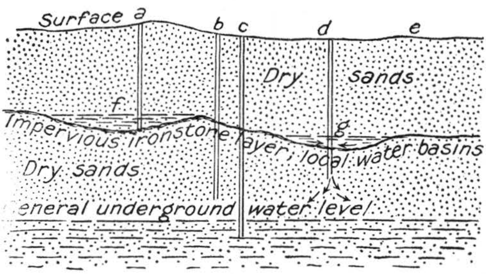


FIGURE 8.—Diagram showing occurrence of water in terrace sands and gravels. *a*, Well obtaining water from local water-bearing basin at *f*; *b*, well missing local basin and stopping short of general water level; *c*, well missing local basin, but obtaining water from general supply; *d*, well reaching local basin *g*, but penetrating its impervious underlying layer and permitting the water to escape.

The water in the terrace gravels, like that in the alluvium, is derived from the rocks forming the valley walls, from rainfall on the terrace surfaces, and occasionally from back-water of the flooded streams, seepage from the valley walls being the principal source of the water in both the gravels and the alluvium. Waters derived directly from the rainfall are collected by the layers of cemented rock and do not immediately join the ground-water body; hence they are less important as a source of supply in the terrace gravels than in the alluvium.

As already indicated, the terrace materials are generally open and porous, permitting the water, especially in the smaller terraces, to drain rapidly away, leaving only small supplies above the general ground-water level of the valley. In the broader terraces, such as those north of Cincinnati, the water may be held back by the friction of the sand and gravel and may stand considerably higher than it does near the stream. Where cemented layers (Pl. VI, *B*) have been found local water pockets commonly occur in depressions in the upper surface (fig. 8), a fact also true to a less extent of the clay layers.

Because of the ease with which the water drains from the gravels wells must generally be sunk to the level of the stream in the adjacent valleys before they reach supplies (fig. 8, *c*). A few wells draw supplies from pockets in the surface of the cement or ironstone layers (fig. 8, *a*), but many fail to strike such pockets (fig. 8, *b*), and others penetrate too far and lose all supplies (fig. 8, *d*). Clay or till layers collect the water in a similar way and some of them afford supplies to wells.

LOESS.

The principal source of the water of the loess is rainfall, and the water of the loess of the flat upland crests is derived solely from this source. On the hillsides and benches, however, especially where the loess rests directly on the rock, some water doubtless percolates laterally into it from the rocks against which it rests.

The water occupies the pores of the silt itself, there being no joints or other openings. Owing to the fineness of the silt the water ordinarily does not readily drain away, but is held in the material, especially where it rests on rock or other relatively impervious substance. Where the loess is thin and is underlain by porous beds it generally contains no water. Where it is thick it commonly yields moderate supplies of water to shallow wells, especially where it rests on an impervious substratum of rock or clay, but, except near the Ohio, it is generally only a few feet thick and wells go through it into the underlying materials. It is not a satisfactory source of water in southwestern Ohio, but in a few places it furnishes enough for stock.

MORAINAL DRIFT.

The moraines are commonly the highest deposits in the region and hence are fed almost entirely by rainfall. Where they are banked against the valley sides, however, considerable water may enter them from the rock or drift in which the valley is cut.

The moraines are commonly open and porous and the water drains out from them very readily, little usually remaining above the impervious till sheet or rock on which they rest. Where till is present, however, in the body of the moraine, the water may be held in local layers or pockets considerably above the base and in a few places may be confined under artesian pressure.

Because of the free drainage few shallow wells obtain water from the moraines, although some find a little on top of or within the clay or till layers or at the contact of the main till sheet below. Commonly, however, the wells have to penetrate the underlying till to a considerable depth before getting adequate supplies.

TILL.

As the till for the most part occupies the highest levels, it derives most of its water directly from rainfall, few rocks being in a position to yield water to it, but some of the till that lies in old buried valleys doubtless derives water from the rocks. The contact of the "Niagara" and underlying "Clinton" limestone is everywhere a strong spring horizon and considerable water must pass into the drift where it covers the contact.

The clayey portion of the till, like practically all other fine material, undoubtedly contains considerable water in its pores. In fact, the larger part of its water is so held. It includes, however, many gravel or sand layers, due either to water action contemporaneous with the ice or to the subsequent removal of the fine silt which filled the spaces between the pebbles of gravelly till layers. The openings so formed are practically everywhere saturated with water, as are the small more or less tubular openings found in the clay itself. Both the gravel layers and the tubular passages in general have a distinct slope, and where the point of emergence is at some distance or the passage of the water is obstructed in any way considerable artesian pressure may be developed.

The water movement through the till is very slow, owing to the friction, and drainage takes place only with difficulty. As a result the water level stands very high, in many places within a few feet of the surface, especially where this is unbroken by near-by valleys. Even on narrow ridges much water is retained by the more clayey types of till.

The waters in the more clayey portions of the till are given up with difficulty, although enough will usually seep into a dug well to supply household demands. For stock, however, it is often necessary to go to considerable depth. To supply a driven or drilled well, a gravelly or sandy layer or a definite bed of sand or gravel must be tapped. Where the drift is deep such a layer can usually be found, especially over a buried valley, and in some places, as in the vicinity of Brookfield, flowing wells may be obtained. In general it may be said that there are few districts where the till is 30 feet or more thick where water can not be obtained in amounts ample for domestic and farm purposes. The great difficulty in such deposits is that it is frequently too easy to get water, especially in wet seasons. Many diggers stop at 10 or 12 feet and then see their wells fail in the first dry season, when a 25 to 40 foot well would have carried them through any ordinary period of drought.

OLD GRAVELS.

The waters of these old sands and gravels are nearly all derived from the overlying loess and till, which in turn are fed mainly by rainfall. Possibly a small amount may come from the rocks where the materials lie against the higher crests.

The water occurs in the pores of the sands and gravels and is not under pressure, for the beds, though overlain by relatively impervious till, are too flat for the development of artesian head.

The materials are everywhere reached by shallow wells, which generally obtain sufficient supplies for domestic uses within 15 feet of the surface.

ROCK FORMATIONS.

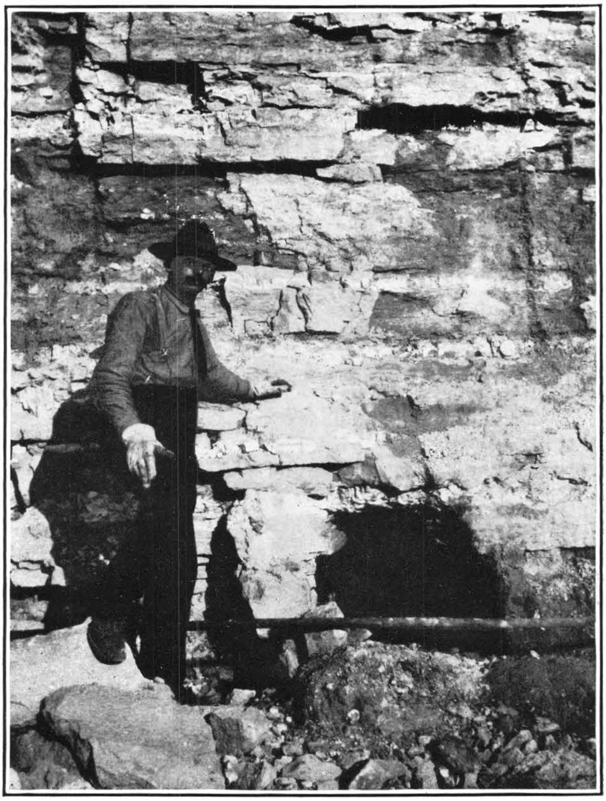
"NIAGARA" LIMESTONE.[1]

At a few localities, as at Limestone City, southwest of Springfield, the "Niagara" limestone lies very near the surface and may absorb considerable water directly from the rainfall. Throughout the greater part of the area, however, the "Niagara" is overlain by thick deposits of drift. On the uplands this drift is mainly till, but in the valleys much of it is stratified. The till is the main source of supply, being saturated with water (p. 43), which it constantly feeds to the underlying limestone. Little water probably enters the rock from the valley drift, as the movement is normally toward and not away from the valley.

The limestone, because of its general granular and open character, is commonly very soluble and permits the ready formation of water passages, especially in the weathered portion near the surface, where it is in some places almost honeycombed with openings (Pl. VI, *A*). Considerable water passes along the joints, which locally become enlarged into open passages (Pl. V, *A*, p. 36), and much flows along the bedding planes. The water generally works its way downward to the base of the formation, where it collects along the contact with the underlying more insoluble "Clinton" limestone, and passes laterally toward the outcrop of the beds in the valleys or elsewhere. A similar concentration also occurs along a number of the shale layers in the limestone.

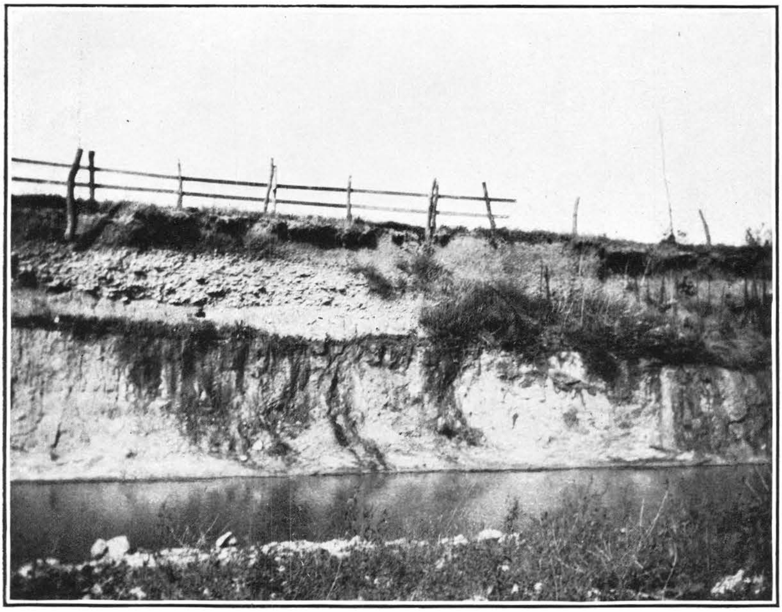
Usually, if there is a considerable thickness of the limestone and the boring is not too near an outcropping edge from which the water can readily drain, a well will procure water if carried to one of the shale layers or to the base of the limestone, where, as pointed out above, the water has a tendency to collect. In many places, however, it will not be necessary to go to this depth, wells generally procuring supplies from the upper weathered portion wherever there is any considerable coating of till to serve as a feeder. Some of the deep wells also obtain water from isolated joints, bedding planes,

[1] See footnote, p. 22.



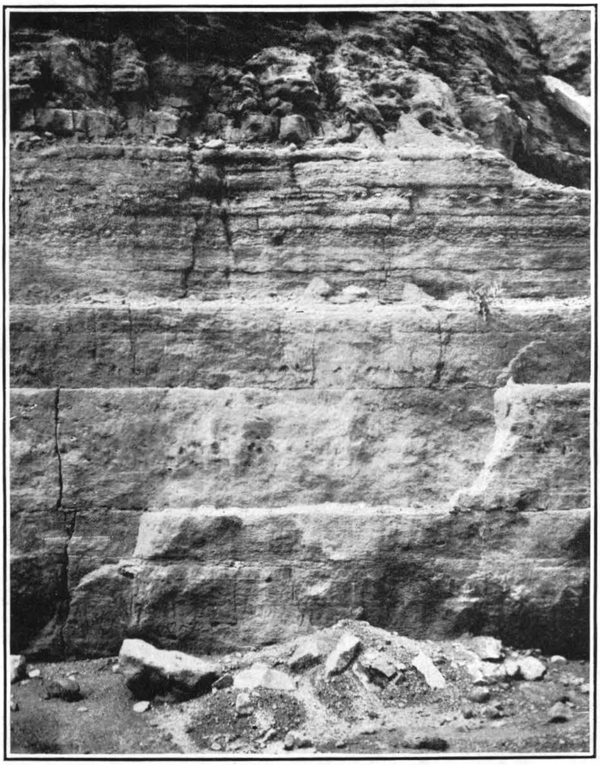
A. LARGE SOLUTION OPENING IN NIAGARA LIMESTONE.

Due to enlargement of bedding plane. Openings of this type afford important supplies to wells.



B. CEMENT-ROCK LAYER IN TERRACE GRAVEL.

Such layers may collect water and afford supplies to wells.



A. NIAGARA LIMESTONE.

Showing development of partings capable of carrying water in upper portion due to weathering, while lower, unweathered portion remains dense and massive.

B. CLINTON LIMESTONE.

Showing cliff character of outcrop and spring formed by waters collecting on an upper impervious layer.

and solution passages at levels intermediate between the top and bottom layers, but such openings are comparatively few in number and are often missed. In general, the "Niagara" limestone is a fairly reliable water bearer where it forms the bedrock and is overlain by till.

"CLINTON" LIMESTONE.[1]

The water of the "Clinton" limestone is derived mainly from the "Niagara" limestone, which overlies it in most localities and which conducts the water downward to it through joints and solution passages (p. 44). In some places near the outcropping edges of the formation the "Niagara" is absent and the saturated till rests directly upon the surface of the "Clinton," acting as an efficient feeder. The uncovered outcrops occur mainly in vertical bluffs, into which no rain can penetrate, but some doubtless directly enters the limestone where it is only thinly covered by soil, as it may be locally for some distance immediately back from the bluffs (Pl. VII, *B*).

The "Clinton" limestone usually contains some water in solution passages or in enlarged joint or bedding planes, especially in its basal portion. The value of the "Clinton" as a water bed depends chiefly on its action in collecting water from the overlying "Niagara" and conducting it along the contact to the nearest outcrop, where it emerges as springs (Pl. VII, *B*). So numerous are the springs at this contact that in many places they serve to show the position of the beds, it being not uncommon to see a line of seeps encircling a hillside at the "Clinton" horizon, even where the rock itself is covered with a considerable thickness of drift. In fact, the "Niagara" and "Clinton" contact is the chief spring horizon in the region.

The "Clinton" limestone, through the springs to which it gives rise, furnishes abundant supplies to many farms and even to some towns, and where it lies within the reach of surface weathering it may yield supplies to numerous shallow wells. Wells also encounter water passages within the rock itself, and especially at its base, obtaining from it a considerable supply.

RICHMOND AND MAYSVILLE FORMATIONS.

Over most of their extent in southwestern Ohio the Richmond and Maysville formations are covered with thick deposits of drift, consisting of till in the uplands and stratified gravel in the valleys. The till, which is generally saturated in its lower portion, is their principal water feeder, little entering them from the valley deposits, toward rather than away from which the ground water is moving. Considerable water also enters these formations from the loess in

[1] See footnote, p. 22.

the areas beyond the till boundary (Pl. II), and small amounts are derived directly from the rainfall on the bare exposures on some of the hillsides. Where the beds are overlain by the "Clinton" limestone the water generally enters at their outcropping edges, seeping down from the overlying till. Little, if any, water probably enters through the "Clinton," except possibly where the limestone is cut by joints.

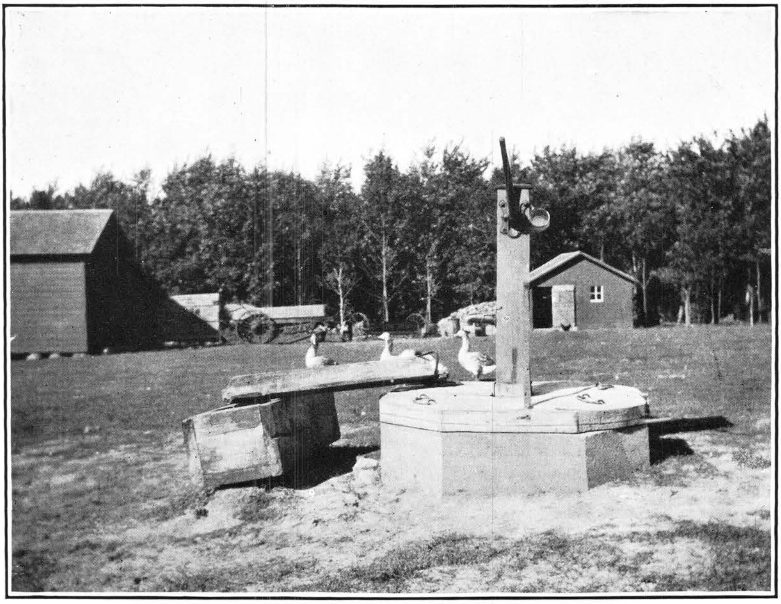
The water occurs in the Richmond and Maysville formations in several ways. Some doubtless percolates along the partings between the numerous laminæ of shale, some occurs in joints, and some appears along the bedding planes, marking the contact of limestone and shale layers. The water passing along this contact follows the top of the insoluble shale and gradually dissolves ramifying passages in the under surface of the overlying limestone. (See Pl. V, *B*, p. 36.) The size of the passages is generally limited by the thickness of the limestone beds, which is commonly from 1 to 10 inches (Pl. VIII, *B*), and also by the extent of the soluble layers, many of which are lenses inclosed above and below by shale or by layers grading laterally into shale. For these reasons water passages are neither numerous nor large.

As the Richmond and Maysville formations consist of alternate layers of shale and limestone, and as the shale readily crumbles on exposure and the limestone is dissolved by percolating waters, the beds disintegrate rapidly under the action of the weather, forming loose, porous masses which, under certain conditions, yield to open wells supplies sufficient for ordinary domestic and farm uses, especially on the broad flat crests, where the disintegrated rock is covered by 10 or 15 feet of loess and till. On the hillsides many wells fail to get satisfactory supplies because of the ease with which the water drains from the loose rock. Many wells sunk where the rock is very near the surface or on top of the sharp-crested ridges are likewise unsuccessful.

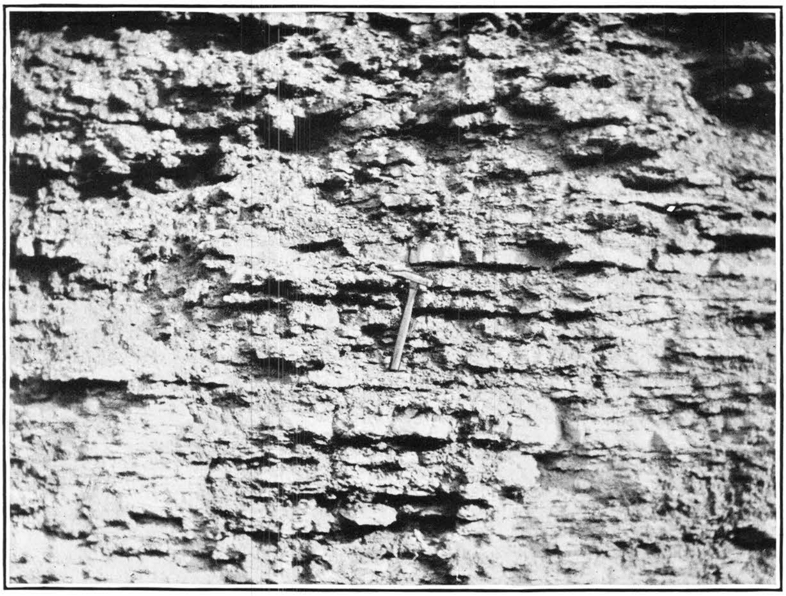
Most of the deeper wells, which penetrate below the weathered portion of the rock, obtain very small supplies and many fail entirely. The water of some is brackish from salt which it has dissolved during its slow circulation through the rock. A few wells obtain moderate supplies. The difference in the yield from well to well is due to differences in the size and distribution of the solution openings. A few wells encounter such openings and get supplies, but most of the wells fail to find them.

EDEN AND UTICA SHALES.

The disintegrated portion of the Eden shale derives most of its water directly or indirectly from rainfalls, the indirect supply passing through talus which has slipped down from overlying rocks to



A. WELL PROTECTED BY CEMENT CURB AND PLATFORM.



B. RICHMOND AND MAYSVILLE FORMATIONS.

Showing alternations of shale and limestone. The close spacing of the shale prevents the formation of large solution passages.

cover the outcrop of the shale. Where the shale lies beneath other rocks the water may reach it through joints connecting with the surface or with higher water-bearing beds, or it may penetrate along bedding partings or other openings. Besides the water in the disintegrated and weathered outcrops, the Eden and Utica doubtless carry small amounts in shaly partings or joints. Water also penetrates along the more soluble limestone layers but usually does not reach very far from the outcrop.

Except in their disintegrated superficial portion practically no supplies can be obtained from the Eden and Utica shales, the small amounts they contain being so held that practically none is given up to wells. Few if any drilled wells in these rocks yield supplies in southwestern Ohio.

POINT PLEASANT FORMATION.

The Point Pleasant formation outcrops in southwestern Ohio only along the banks of Ohio River, where it is generally covered with clayey or sandy silts, and it is entirely submerged at times of high water. In general (see p. 33), the movement of ground water, like the movement of surface waters, is toward and not away from the streams, and during normal stages of the river little or no water is absorbed by the rocks from the stream. During sudden floods, however, the river rises more rapidly than the ground water and then the river water doubtless backs up into the openings in the rock.

The Point Pleasant formation, or its equivalent, although outcropping in southwestern Ohio only along the river, comes to the surface farther south in Kentucky, where it doubtless absorbs considerable quantities of water, a part of which may even reach the Ohio. Small amounts also probably reach it through joints in the overlying rocks.

The water occurs mainly in meandering passages dissolved out of the limestone layers along their contact with impervious shaly beds. These passages commonly form a network, although some larger isolated passages occur. As the Kentucky outcrop is considerably higher than that in the Ohio Valley, the water may be under pressure sufficient to lift it considerably above the level at which it is encountered. Small amounts of water may also occur in joints.

Owing to the facts that the Point Pleasant is the country rock only in the Ohio Valley, and that even there it is overlain by flood-plain deposits carrying much larger quantities of water, it is seldom looked to as a source of water supply in southwestern Ohio, except where, as at Cincinnati, the demands are such as to necessitate the utilization of every possible source. Moreover, although it contains considerable quantities in the aggregate, the distribution of water in it is not only irregular and uncertain but is likely to be brackish, especially at a distance from the river. For these reasons and because of its considerable depth beneath the uplands this formation is not a promising source of supply.

"BIRDSEYE" LIMESTONE.

The "Birdseye" limestone outcrops in north-central Kentucky in the valley of Kentucky River and other streams 60 to 90 miles south of Cincinnati. Though exposed only in the valley bottoms, it probably absorbs considerable water, which penetrates downward to the north along the more soluble layers of the limestone. More or less water also probably reaches the rock through joints connecting with the surface or overlying water beds.

The water seems to occur mainly along open passages dissolved in the more soluble portions of the limestone or along joint or bedding planes. As there are few shale partings to limit the size of the openings, many of them are several inches or more in diameter; they are often recognized in drilling by the "dropping of the drill." Some of these passages have been encountered in central Ohio as much as 1,000 feet below the surface, and fragments showing solution action have been brought up, indicating a rather free circulation at some time in the past.

Most wells penetrating the "Birdseye" limestone to the bottom find water that is under considerable pressure and that rises somewhat when reached. Unfortunately, however, it is not only exceedingly hard but is generally more or less salty and is unfit for drinking or for boiler or industrial uses.

ST. PETER SANDSTONE.

It is believed that a large part of the abundant supply carried by the St. Peter sandstone has been derived from its Wisconsin outcrop, inasmuch as the head and volume is far greater than would be expected if the water were fed through the overlying "Birdseye" limestone.

The water occurs in the pores of the rock, occupying spaces that were either never filled by the lime cement or that were formed by the subsequent solution of the lime. These must be rather large, as sufficient head is transmitted from the outcrop, 350 miles away and approximately 850 feet in elevation, to lift the water to about 600 feet at Cincinnati, a very moderate loss considering the distance. The rock is not everywhere saturated, however, and wells must penetrate it for some 300 feet to obtain the best supplies.

Abundant water is generally obtained from the St. Peter sandstone when encountered by wells, and flows are obtained when the altitude is not over 600 feet above sea level. The many flowing wells at Cincinnati obtain their water from this formation. The main supply is found about 300 feet below the top of the bed, or 1,200 to 1,300 feet below the surface at Cincinnati, and the flows are not materially increased by going deeper. (See Pl. IV, p. 30.)

CAMBRIAN AND ORDOVICIAN DOLOMITE.

The Cambrian and Ordovician dolomite in Ohio is dense and not very soluble and probably permits little if any water to penetrate it from its outcrop. Where opportunities occur, however, water doubtless penetrates it from the overlying saturated St. Peter sandstone or from other sandstones which may be below it. Water, if it occurs, will probably be found in solution passages representing enlarged joints or bedding planes. Although the Moerlein well penetrated it for 1,000 feet the dolomite gave no material addition to the supplies obtained from the St. Peter sandstone, and there is no reason to think that it will yield any usable supplies in southwestern Ohio.

SUMMARY OF AVAILABLE WATER.

Southwestern Ohio is particularly unfortunate as regards rock waters, good water-bearing formations being absent. The "Niagara" and "Clinton," as has been seen, yield moderate supplies to relatively shallow wells; the Richmond and Maysville supplies are uncertain; practically no water at all is obtained from the Eden shale, and only small amounts from the Point Pleasant formation; the "Birdseye" limestone and St. Peter sandstone yield saline or sulphur water, and the underlying beds within reach of the drill appear to carry no water whatever.

In the drift, however, especially in the northern half of the area, the region has a source of supply that is ample for all domestic and farm uses, and except along the Ohio, the alluvial gravels of the valleys afford abundant water for public supplies and for manufacturing purposes.

PUBLIC WATER SUPPLIES.

The public water supplies in southwestern Ohio are derived from streams, artificial ponds, springs, and wells. Stream water in its raw or unfiltered state is used only where, as at Cincinnati, the demand is too great to be supplied from any other source. Artificial ponds are seldom used as sources of supply in the Ohio Valley, as in most places more and better water can be obtained from wells. Springs furnish supplies for several towns and would doubtless be more generally utilized if they were more widely distributed, but they have origin mainly in a single geologic formation—the "Clinton" limestone. Wells are by far the most important sources in the district, 90 per cent of the towns being so supplied. Most of them are in valleys and draw their supplies from the alluvium, but some are on the till uplands. The distribution of the public water supplies when the field work was done is indicated on Plate IV (p. 30).

The following table summarizes the principal public water supplies of southwestern Ohio in 1906, giving the ownership, source, number, diameter, depth, and head of wells, the system of distribution, services or taps, fire hydrants, daily consumption, domestic and fire pressure, and other data. Further particulars concerning many of the supplies are given in connection with the town notes, to which references are given in the table. Analyses of a considerable number of the waters will be found in the tables of analyses on pages 198 to 207.

Statistics of municipal water supplies in southwestern Ohio in 1906.

Town.	Population, 1910.	Ownership.	Source.	Geologic source.	Wells.			
					Number.	Diameter.	Depth.	Depth to water.
						Inches.	*Feet.*	*Feet.*
BROWN COUNTY.								
Georgetown	1,580	Public	Surface					
Ripley	1,840	do	Wells	Point Pleasant	4	4-6	108	
BUTLER COUNTY.								
Hamilton	35,279	Public	Wells	Alluvium	23	6-8	75-135	20
Middletown	13,152	do	do	do	1	a 25	36	16
					7	12	48	
Oxford	2,017	do	do	do	3		20-60	13
					1			
South Excello		Private	do	do	7	6	35	
CLARK COUNTY.								
Springfield	46,921	Public	Wells and filter galleries	Alluvium	1	b 30	22	20
CLERMONT COUNTY.								
Batavia	1,034	Public	Stream					
Loveland	1,421	Private	Wells	Alluvium	1	12	50	7
Milford	1,321	Public	do	do	3	6-8	64-72	24
New Richmond	1,733	do	Ohio River					
CLINTON COUNTY.								
Blanchester	1,813	Private	Surface					
New Vienna	793	Public	Wells	Niagara	4		60	±0
Wilmington	4,491	Private	do	Gravel under till	6	6-8	65-172	±0
DARKE COUNTY.								
Arcanum	1,361	Public	Wells	Niagara	6	8	38-80	
GREENE COUNTY.								
Osborn	866	Public	Wells	Alluvium	4	8		
Wilberforce		Private	Springs	Till				
Xenia	8,706	do	Wells and springs	Gravel under till	14	6-10	30-40	10
HAMILTON COUNTY.								
Arlington Heights	798	From Wyoming						
Bond Hill	1,081	From Cincinnati						
Carthage	3,618	Public	Wells	Alluvium	4	6	135	
Elmwood	3,423	From Carthage						
Glendale	1,741	Public	Wells	Alluvium	2	8		
Harrison	1,368	Private	do	do	4	3	100+	
Hartwell	1,823	From Wyoming						
Hyde Park	1,691	From Cincinnati						

a Feet.

Statistics of municipal water supplies in southwestern Ohio in 1906—Continued.

Town.	Population, 1910.	Ownership.	Source.	Geologic source.	Wells.			
					Number.	Diameter.	Depth.	Depth to water.
HAMILTON COUNTY—continued.						*Inches.*	*Feet.*	*Feet.*
Idlewild		From Norwood						
Kennedy Heights	598	From Cincinnati						
Lockland	3,439	From Wyoming						
Madisonville	5,193	Public	Wells	Glacial gravel	3	6-8	150	21
Norwood	16,185	do	do	do	2	10	260	
Pleasant Ridge	1,769	From Cincinnati						
Reading	3,985	Public	Wells	Glacial gravel	3	8	150	50
St. Bernard	5,002	do	do	Alluvium	2	14	270	40
Wyoming	1,893	do	do	do	4	8	164-197	45
HIGHLAND COUNTY.								
Hillsboro	4,296	Public	Wells	Alluvium	11			
Leesburg	828	do	do	Niagara (?)	4			
Lynchburg	923	do	Springs	Glacial drift at top of rock.				
MIAMI COUNTY.								
Tippecanoe	2,038	Public	Wells	Alluvium	3	6	55-65	12
West Milton	1,207	do	Springs	Top Clinton limestone				
MONTGOMERY COUNTY.								
Brookville	1,187	Public	Wells	Top Niagara	4	6-8	80	±0
Dayton	116,577	do	do	Alluvium	77		30-60	10
Miamisburg	4,271	do	do	do	5	8	60	
National Military Home		Government	do	Gravel under till	16	6	45-58	35
Oakwood	358							
Trotwood	348	Private	Wells	Alluvium	2	6	64	
West Carrollton	1,285	do	do	do		6-8	65	10
PREBLE COUNTY.								
Eaton	3,187	Public	Wells	Alluvium	2	6	50-100	±0
New Paris	870	Private	Well	Moraine	1		17	12
West Alexandria	1,030	Public	Wells	Alluvium	4	8	134	16
West Manchester	445	do	do	Till	3	9	64-67	
WARREN COUNTY.								
Franklin	2,659	Public	Wells	Alluvium	4	6-8	63	10
Lebanon	2,698	do	do	Glacial drift	4	6	96-104	±0
Waynesville	705	do	do	Alluvium	4		40	

Town.	Distribution or storage.	Taps.	Fire hydrants.	Average daily consumption.	Pressure.		Remarks.
					Domestic.	Fire.	
BROWN COUNTY.				*Gallons.*	*Pounds.*	*Pounds.*	
Georgetown							Not installed in July, 1906.
Ripley	Reservoir	240	90	100,000	140	140	
BUTLER COUNTY.							
Hamilton	Reservoir	4,300	265	2,500,000	96	96	More wells and larger pumps are planned.
Middletown	Direct	1,500	250	1,500,000	60	120	One 35-foot open well, others driven.
Oxford	do	350	53	135,000	45	45	Waterworks situated a mile from town and 175 feet lower.
South Excello	Reservoir	None.	7			80	Used for fire only.
CLARK COUNTY.							
Springfield	Standpipe	6,000	522	3,500,000	65	65	Eighty per cent from wells.
CLERMONT COUNTY.							
Loveland	Elevated tank	300	30				In process of installation, 1906.
Milford	Standpipe	160	40	55,000	85	85	
CLINTON COUNTY.							
New Vienna	Standpipe	125	35	10,000	60	100	
Wilmington	do	180	81	30,000	50	110	Raised by air lift.
DARKE COUNTY.							
Arcanum	Direct	225	35	25,000	58	75	
GREENE COUNTY.							
Osborn	Standpipe	160	32		125	125	
Wilberforce	Tank						Used in college buildings only.
Xenia	Standpipe	1,200	200	500,000	55	55	
HAMILTON COUNTY.							
Carthage	Direct	450	51		65	90	
Glendale	Standpipe	160	29	150,000	45	95	
Harrison	do			30,000	40	100	
Madisonville	Direct	350	85	125,000	50	85	
Norwood	Standpipe	2,100		750,000	100	100	
Reading	Reservoir	200	58	90,000	85	85	
St. Bernard	Standpipe		68		80	80	Well enters rock at 135 feet. Water at 128 feet.
Wyoming	Reservoir	800	125	480,000	110	110	Includes Arlington, Hartwell, and Lockland.

Statistics of municipal water supplies in southwestern Ohio in 1906—Continued.

Town.	Distribution or storage.	Taps.	Fire hydrants.	Average daily consumption.	Pressure.		Remarks.
					Domestic.	Fire.	
				Gallons.	*Pounds.*	*Pounds.*	
HIGHLAND COUNTY.							
Hillsboro	Standpipe	700	72	300,000	50	50	
Lynchburg	Elevated tank	150	24	20,000	50	140	Direct pressure during fires. Water possibly from base of Clinton limestone.
MIAMI COUNTY.							
Tippecanoe	Direct	500	55	115,000	40	80	
West Milton	Elevated tank	200	30	135,000	75	75	
MONTGOMERY COUNTY.							
Brookville	Air-pressure tanks	100	40	40,000			
Dayton	Direct	17,700	1,500	6,200,000	60	125	
Miamisburg	do	225	96	200,000	65	100	New system.
National Military Home	Reservoir						
Trotwood	Air-pressure tank	30			75		
West Carrollton	Direct	130			60		
PREBLE COUNTY.							
Eaton	Standpipe	570	76	120,000	58	150	
New Paris	Direct	20					
West Alexandria	Standpipe	170	14	50,000			
West Manchester	Compressed air				25–500	100	
WARREN COUNTY.							
Franklin	Direct	480	65	200,000	65	100	
Lebanon	Standpipe	670	78	125,000	70	120	
Waynesville	do	100		40,000	70	70	

USE OF REPORTS AND MAPS.

Determination of surface deposits.—Over the greater part of southwestern Ohio the unconsolidated surface deposits are more valuable as water-bearing beds than are the underlying rock formations and it is therefore important that their nature at any given point should be readily ascertainable. Their character at the larger cities and towns may be determined at a glance from Plate II, which shows the distribution of the glacial or surface deposits of the region. At smaller towns not shown on the map the nature of the surface materials can be determined from the table showing underground-water conditions given for each county (see county descriptions). Places away from a town or village may be approximately located on the map (Pl. II), and the surface formation readily determined.

Determination of country rock.—Like the unconsolidated or surface deposits, the country rock or bedrock immediately underlying any of the larger cities and towns can be determined directly from the geologic map (Pl. I), which shows the distribution of the rock formations beneath the surface deposits. Likewise, the rock formations beneath the smaller villages may be determined from the tables in the county description or from the map.

Best source of supply.—Although it is a common belief that good supplies can always be obtained by going "deep enough," this is not necessarily true. In some localities the deep supplies are the best; in others the shallower waters are preferable; and in still others no great difference exists between the two. To ascertain which is the best supply at a given town or village, the table of underground-water conditions in the county descriptions should be consulted. These will show the relative amounts of the supplies of the surface deposits and of the surface rocks and indicate the best of the rock sources and its probable supply. If the point at which the supply is desired is not in a town or village it should be located on the map of glacial or surface deposits (Pl. II) and on the geologic map (Pl. I), as already explained. The nature of the surface deposits and underlying rock being thus determined, the relative water-bearing capacities can be found by consulting the general table of rock formations (pp. 22–23) and the descriptions of surface deposits and rocks (pp. 23–30).

Thickness of surface deposits.—Many factors affecting the success of wells hinge on the thickness of the surface deposits. Some formations, like the till, which when thick are strong water bearers, are of little value when thin; hence the thickness of the deposit becomes a matter of great importance. Again, the cost of drilling and the length of casing required is materially affected by the relative amounts of surface and rock formations to be penetrated.

To determine the thickness of the surface deposits or the depth to rock, at a given city or village, reference should be made to the tables of underground-water conditions (see county descriptions), which give the exact depth where this has been disclosed by wells and the estimated depth where the actual depth is unknown. The thickness of the surface deposits outside the cities and villages may be found by locating the point on the map showing the thickness of the surface deposits (Pl. III).

Depth to water in the St. Peter sandstone.—For some uses, such, for instance, as cooling, volume of water is principally desired and quality is of minor importance. To obtain a supply for this use wells may be sunk to the St. Peter sandstone, whose water, though of little value if quality alone is considered, is cold and abundant. Too few wells have been sunk to the formation to permit accurate determination of its depth in this region. Fortunately, however, during the oil and gas boom 25 to 30 years ago many wells were sunk to the "Birdseye" limestone, and it has been possible, by means of contours on the artesian-water map (Pl. IV, p. 30), to fix the elevation with reference to sea level of that limestone throughout the area. To determine the depth to the "Birdseye" at any given point the elevation of the rock contour should be subtracted from the elevation indicated by the surface contour, the position of the rock contour above or below sea level as indicated by the plus or minus sign being considered. To find the depth to the water-bearing bed in the St. Peter add 700 feet (the approximate distance of the principal water bed of the St. Peter below the top of the "Birdseye") to the figure already obtained; the result will be the approximate total depth to the main supply in the St. Peter.

Flowing wells.—A few wells in the higher formations flow, but there is no general artesian bed in southwestern Ohio above the St. Peter sandstone which carries water that is under considerable head. Although this sandstone lies far below sea level, even at Cincinnati, its water will rise to 590 feet above the sea if penetrated by wells and will flow wherever the surface elevation is less than 590 feet, except where, as at Cincinnati, its head has been reduced by the drilling of numerous deep wells. To determine whether or not a flow may be expected it is, in general, simply necessary to find whether the well mouth is above or below the 590-foot level. This may be determined from the artesian-water map (Pl. IV, p. 30), on which the area below this level is indicated.

Water-bearing capacity of formations.—The character of each of the rock formations and their water supplies are concisely described in the generalized section of rock formations on pages 22–23 and are described in detail on pages 28–31.

Distribution of surface deposits and rock formations.—The general distribution of the rock formations is shown on the geologic map (Pl. I), and the distribution of the surface deposits is shown on Plate II. Further details of the distribution will be found in the county descriptions.

Quality of water in particular deposits and formations—The quality of the underground waters in southwestern Ohio is set forth in Table 2 (p. 208), in which the analyses are classified according to their occurrence in the several surface deposits and rock formations.

UNDERGROUND WATER BY COUNTIES.

ADAMS COUNTY (WESTERN HALF).

By M. L. Fuller.

In the field investigation for this report the work in Adams County was confined mainly to the western half, or to that part lying west of a north-south line drawn through a point about 2 miles east of West Union, and the following descriptions are limited to this area.

SURFACE FEATURES.

Adams County, like other counties similarly situated, is marked along Ohio River and its tributaries by a rather rough topography, crests standing 400 to 500 feet above the river, alternating with valleys or ravines of equal depth. Farther back from the river the streams have not cut so deeply, and the uplands are gently rolling or even flat. Even where the stream cutting is deepest the crests between the streams, although narrow, are generally flat. Along the Ohio the thin mantle of yellowish silt or loess somewhat softens the surface relief, and in the northwestern part of the county the drift, though very thin, helps to make the surface still flatter. The elevation of the uplands ranges between 950 and 1,000 feet.

WATER-BEARING FORMATIONS.

The water-bearing formations include the alluvium, the loess, and the pebbly clay or till, among the unconsolidated deposits, and the "Niagara" and "Clinton" limestones, the Richmond and Maysville formations, and the Eden shale among the harder rocks.

SURFACE DEPOSITS.

ALLUVIUM.

The most extensive alluvial deposits, those along the Ohio Valley, include not only the recently deposited materials of the present stream but also much gravelly outwash brought down by the glaciers which formerly occupied the region to the north. Although of diverse origin, the materials differ little in character and are not readily separated even on the ground. The alluvial deposits consist of silts, sands, and gravels, the latter two predominating in general, but including clays of considerable thickness at some localities. The general arrangement seems to be as follows: (1) A surface layer of loamy sand or sandy clay over the flood plain, (2) 10 feet or more of clay with some very fine sand, and (3) alternating layers of sand, gravel, or clay to a depth of 50 to 100 feet or more.

Along the smaller streams the alluvium is thinner and even more varied in composition, ranging from fine silts in the flat, shallow valleys on the upland plateaus to coarse gravel in the ravines.

The water supplies of the silty alluvium are small and uncertain, and in many of the flat upland valleys this material is therefore not available as a source of water. The gravels of the ravines will almost always yield water where they are 10 feet or more in thickness, provided the valleys do not slope so steeply that little water is retained. In the more extensive deposits, such as those along the Ohio, although certain layers, like the clay beds, may be destitute of available water, there are nearly always beds of gravel or sand within moderate depths which will yield abundant supplies.

LOESS.

The loess is a yellowish, more or less clayey silt, forming a mantle over the rocks of the uplands near the Ohio River. It is usually very thin, though locally reaching several feet in thickness. In Adams County it may furnish small supplies of water to dug wells, but is generally too thin to be of importance except as a feeder to collect and supply waters to the underlying rocks.

TILL.

The yellowish or bluish, more or less pebbly, clay known as till is found only near the northwest corner of Adams County, and even here it has a thickness at the most of only a few feet. In the counties to the north it is an important water bearer, but in Adams County it is of value only as a feeder to the underlying rock. In conjunction with the disintegrated underlying rock it affords in some localities a source of supply to shallow dug wells.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

The "Niagara" limestone may be roughly divided into a limestone bed a few feet thick at the base, an overlying shaly bed about 100 feet thick, and an upper limestone about 90 feet thick. It forms the upland levels between all the streams in the western part of Adams County, but is not found in the valleys, the streams having cut through it and the underlying "Clinton" into the Richmond formation.

Wells obtain more or less water throughout the thick upper limestone layer, but the principal source is at the bottom of this layer, along the contact with the underlying shale bed of the same formation. This contact, as elsewhere, is marked by a conspicuous line of springs. In places some water is afforded by the thin limestone at the base, but this bed is of less importance as a water bearer than either the shale contact above or the "Clinton"–Richmond contact below.

"CLINTON" LIMESTONE.

The "Clinton" limestone in Adams County is a semicrystalline pinkish or reddish limestone locally changing to an impure iron ore, especially along the Highland County boundary. It appears to have a thickness of 40 to 50 feet and is an upland formation, outcropping along the valleys just below the "Niagara" and at some of the lower spots on the general uplands.

The "Clinton" carries considerable water throughout its extent and is the source of many springs which emerge principally from the basal layers along the contact with the upper shaly beds of the underlying Richmond formation. Where not covered by the "Niagara," it commonly affords supplies to shallow wells, but where the "Niagara" is present most wells stop at the top of the 100-foot shale bed in that formation.

RICHMOND AND MAYSVILLE FORMATIONS.

Although 300 feet or more of the Richmond and Maysville formations is exposed in the county, most of the thickness is in the steep bluffs of the Ohio and its tributaries, only relatively small areas of the upland surface in the western and southwestern parts of the county being underlain by these formations. The top of the Richmond is marked by a 25-foot bed of blue and reddish shale, below which layers of limestone and shale alternate down to the river level. A zone in which shale commonly predominates occurs at the contact of the Richmond and the underlying Maysville, but in general the two formations show little difference in character and are best grouped together with respect to water supply. The line of separation would fall midway up the bluffs of the valley walls.

On the flat uplands in the western and southwestern parts of the county and to a certain extent on the more gentle valley slopes of some of the streams in the northern district shallow open wells obtain fair supplies of water from the Richmond. On the steeper slopes it may be necessary for wells to go down 40 or 50 feet to procure adequate supplies. In the valleys the overlying alluvium affords better supplies than the rock. Drilled wells, although they may find some water, lack storage capacity and many fail to yield adequate supplies.

EDEN SHALE.

The Eden shale consists of bluish to grayish shales, with local thin layers of limestone. It underlies the Maysville formation and outcrops in the lower part of the Ohio bluffs at the extreme southwest corner of the county. The formation is about 250 feet thick, but only a small part of this thickness is exposed in Adams County. It contains practically no available water, and there is great difficulty in obtaining from it the supplies necessary for domestic use, even in dug wells. This absence of water is due in part to the compactness of the shale and the general absence of porous or soluble layers and in part to the poor catchment conditions, its outcrop on steep hillsides allowing the water to drain from it readily without absorption.

SPRINGS.

The Adams County Mineral Springs, also known as the Arcadia Springs, are in eastern Adams County and, although occurring outside the immediate area investigated, merit consideration because of their interest and importance. The springs issue in masonry basins at the base of high hills bordering a small valley, the water coming from a blue slaty shale which is believed to represent the Ohio shale (Devonian). The volume of each of the two principal springs is small but is constant throughout the year, supplying enough for all the guests at the resort. The temperature on September 13, 1906, was about 58° F. The water, as shown by the analysis (pp. 198–199), is high in sulphates and contains free sulphuric acid. Rusty-looking growths or deposits can be seen about the springs, which, with the hotel, are owned by S. R. Grimes.

NOTES BY TOWNS.

WEST UNION.[1]

The town of West Union is situated on a high plateau underlain by "Niagara" limestone. Most of its open wells enter the rock at 4 to 6 feet and penetrate it from 22 to 35 feet to procure their supplies. At 40 to 45 feet they enter the thick shale bed forming the lower part of the "Niagara," but obtain no water from it. They appear not to reach the "Clinton."

Wells sunk in the Richmond and Maysville formations in the valleys rarely obtain much water. A strong spring, yielding about

[1] Conditions in 1906.

10 gallons a minute, occurs on the pike one-fourth mile north of the courthouse, the water issuing from a vertical joint in the limestone. An analysis will be found in the table, pages 198–199.

WATER PROSPECTS.

The following table indicates the general underground-water conditions and water prospects at each of the more important localities in the western part of Adams County:

Underground-water conditions in Adams County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Bentonville	Loess and soil.	20		"Niagara"	"Clinton"	Usually plenty.
Cherry Fork	Till	20		do	do	Do.
Eckmansville	do	20		do	do	Do.
Emerald	do	10		do	do	Do.
Fairview	do	8	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
Harshasville	do	14		"Clinton"	"Clinton"	Usually plenty.
Manchester	Alluvium.	130+	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
Seaman	Till	20		"Niagara"	"Clinton"	Usually plenty.
Stephens	Alluvium.	Deep.		Eden	Point Pleasant.	Small.
Tranquility	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
West Union	Residual soil.	4	Moderate	"Niagara"	"Clinton"	Usually plenty.
Wheat	do			do	do	Do.
Winchester	Till	20		do	do	Do.
Wrightsville	Alluvium.	64+	Plenty	Richmond and Maysville.	Eden	Small.

BROWN COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

Near the Ohio and its larger tributaries much of the surface of Brown County is decidedly rough, owing to the deep valleys and ravines cut by the streams. In the northern part, however, it is essentially a plateau 950 to 975 feet above sea level, but even there it is cut by a few deep valleys. Plateau remnants in the shape of flat-crested ridges appear between the streams in the southern half of the county, their average elevation being between 900 and 950 feet. The plateau surface in the north is rendered still more flat by a smooth sheet of till.

WATER-BEARING FORMATIONS.

The water-bearing formations of Brown County include among the surface deposits alluvium, terrace gravels, loess, and till, and among the rock formation the " Niagara," " Clinton," Richmond, and Maysville formations, and the Eden shale.

SURFACE DEPOSITS.

ALLUVIUM.

The principal deposits of alluvium in Brown County are along Ohio River, where they are commonly 100 to 150 feet thick and one-half mile to a mile or more wide. Smaller, but still fairly extensive deposits occur in the larger tributaries of the Ohio, and small accumulations are found in the ravines entering the streams mentioned.

The alluvial deposits of the Ohio consist of loamy sand or sandy clay at the surface, in many places grading downward into clay deposits more than 10 feet thick. Below the clay porous gravels or sands are commonly found in beds of considerable thickness, many of them alternating with clayey beds. The alluvium in the larger tributary valleys is similar, in a general way, to that in the Ohio Valley, but much of that deposited by the rapidly flowing streams in the ravines is very coarse and gravelly. Locally, thin tills may be included in the alluvium.

An abundant supply of water can usually be obtained from the gravel beds underlying the clays in the Ohio Valley and from the sandy and gravelly beds in the valleys of the tributaries and in certain of the ravines.

TERRACE GRAVELS.

Terraces of gravel, marking a stage of the Ohio when it flowed at a level higher than at present, occur at numerous points along the valley. Owing to their situation water entering them is quickly drained away to the river or into the underlying formations, and wells penetrating them must commonly go down nearly or quite to the river level to obtain supplies.

LOESS.

Along the crests of the bluffs facing the Ohio and for some distance inland the surface is covered by a few feet of the yellowish to white, somewhat clayey silt known as loess. Although capable of holding water this deposit is usually so thin that it is not a good source of supply. Wells pass through it into the underlying till or rock within a few feet of the surface.

TILL.

The yellowish or bluish pebbly clay or till covers the entire county except the southeast corner. The thickness varies from 10 to 20 feet in the northern part of the county to the vanishing point along the southern edge of the drift, which appears to extend a little north of east from Ohio River near Higginsport through Cedar Point, Red Oak, and Decatur.

Owing to the thinness of the drift it is much less important as a water-bearing formation in Brown County than in the counties to the north and west. It helps, however, to collect and hold the water and gradually feeds it to the underlying rocks. Together with the loess and the disintegrated rock due to surface weathering, it locally affords to shallow wells supplies that are very fair but that are much less likely to be permanent than where the drift is deeper.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

The "Niagara" limestone, which is so important as a water-bearing bed to the east, barely touches the eastern boundary of Brown County, in which it furnishes little or no water.

"CLINTON" LIMESTONE.

The "Clinton" limestone outcrops in the extreme eastern part of the county near the Adams County line, being found just west of the "Niagara" limestone outcrop. As elsewhere in southwestern Ohio a large number of springs emerge near its base and it supplies a few shallow wells, but its area in the county is so small that it is of little importance as a water-bearing bed.

RICHMOND AND MAYSVILLE FORMATIONS.

The Richmond and Maysville formations constitute the upland surface over almost the entire area of Brown County and form the upper part of the bluffs bordering the streams. In its upper few feet the Richmond is shaly, but not far below the top it exhibits the usual alternation of thin layers of limestone and shale. The Richmond is considerably thinner here than at many other points. The Maysville, into which it grades downward, is very similar in composition. Shale predominates near the contact.

The Richmond and Maysville formations contain considerable water, although, owing to the large amount of shale present, their water-bearing passages are neither large nor extensive. Shallow wells, especially where loess or drift coverings serve as feeders, yield fair supplies, but few drilled wells procure water except in small quantities.

EDEN SHALE.

The Eden shale consists of bluish to grayish shales, weathering yellow or brownish and containing some thin limestones, but few or no sandy layers. The total thickness of the formation is about 250 feet, nearly all of which is exposed in Brown County. The bed outcrops almost entirely in the bluffs bordering the Ohio and its tributaries, none of it being found on the upland flats.

Owing to the absence of porous sandy layers and of persistent limestone beds there is little opportunity for the circulation of water, so that the formation almost never yields supplies of any consequence, except to shallow wells at the surface, where it has been broken up and loosened by the action of the weather. No drilled wells are known to procure water in this formation.

NOTES BY TOWNS.

GEORGETOWN.[1]

The location of Georgetown on the upland plateau, the thinness of the drift, and the absence of alluvium or of any good water-bearing rock formations have made it impracticable to obtain a public supply from wells. A dam has, however, been constructed to impound surface waters on a small basin, and in the summer of 1906 a pumping plant was about to be erected.

RIPLEY.[1]

Ripley, in 1906, drew its public supply from four wells, two penetrating 100 feet of gravel and two striking the limestones of the Point Pleasant formation 68 feet below low water of the Ohio and penetrating them for 40 feet. Additional data will be found in the table, page 51.

SARDINIA.[1]

Sardinia, situated on the plateau, has some exceptionally strong shallow wells, the public well opposite Stephan Bros.' store, although only 11 feet deep, has been known to water 1,000 head of stock in a day without lowering the supply. An analysis of the water, which is derived from gravel, is given on pages 198–199.

WATER PROSPECTS.

The water prospects and general underground-water conditions in the several towns and villages of Brown County are indicated in the following table:

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[1] Conditions in 1906.

Underground water conditions in Brown County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Aberdeen	Alluvium			Eden	Point Pleasant.	Small.
Arnheim	Till	10	Plenty	Richmond and Maysville.	Richmond and Maysville.	Do.
Bardwell	do	25+	do	do	do	Do.
Bernard	do	15+	do	do	do	Do.
Biehn	do	35		do	do	Do.
Bondes Ferry	Alluvium			Eden	Point Pleasant.	Do.
Browntown	Till	45+	Plenty	Richmond and Maysville.	Richmond and Maysville.	Do.
Carlisle	do	15		do	do	Do.
Center Point	Alluvium	25		do	Richmond, Maysville, and Eden.	Do.
Centerville	Till	12	Fair	do	Richmond and Maysville.	Do.
Chasetown	do	12	do	do	do	Do.
Crosstown	do	15		do	do	Do.
Decatur	Till or	9	Moder	do	do	Do.
Desoto	Till	20		do	do	Do.
Eastwood	do	35		do	do	Do.
Ellsberry	Residual soil or loess.			do	do	Do.
Fayetteville	Till	20	Small	do	do	Do.
Feesburg	do	15		do	do	Do.
Ferristown	do	20		do	do	Do.
Fincastle	do	40		"Clinton"	"Clinton," Richmond, and Maysville.	Moderate.
Fivemile	do	20		Richmond and Maysville.	Richmond and Maysville.	Small.
Georgetown	do	15	Plenty	do	do	Do.
Greenbush	do	20		do	do	Do.
Hammersville	do	15		do	do	Do.
Hestoria	Alluvium			Eden	Point Pleasant.	Do.
Hiett	Residual soil and loess.			Richmond and Maysville.	Richmond and Maysville.	Do.
Higginsport	Alluvium	90+	Plenty	Eden	Point Pleasant.	Do.
Kirbysville	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Levanna	Alluvium	18	Plenty	Eden	Point Pleasant.	Do.
Locust Ridge	Till	18	Fair	Richmond and Maysville.	Richmond and Maysville.	Do.
Macon	do	14	Plenty	"Niagara"	"Clinton"	Usually plenty.
Maple	do	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Milltown	do	30		do	do	Do.
Mount Orab	do	50	Plenty	do	do	Do.
Neel	Residual soil or loess.			do	do	Do.
New Harmony	Till	30+	Plenty	do	do	Do.
New Hope	do	13	Fair	do	do	Do.
Prall	do	15	Small	do	do	Do.
Red Oak	Residual soil or loess.			do	do	Do.
Ripley	Alluvium			Eden	Point Pleasant.	Do.
Russellville	Till	20	Plenty	Richmond and Maysville.	Richmond and Maysville.	Do.

Underground water conditions in Brown County—Continued.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
St. Martins	Till	30+	Moderate.	Richmond and Maysville.	Richmond and Maysville.	Usually plenty.
Sardinia	do	30	Plenty	do	do	Do.
Skiffsville	do	15		do	do	Do.
Stickaway	Residual soil or loess.			do	do	Do.
Stringtown	Till	15		do	do	Do.
Sunshine	do	12		do	do	Do.
Surryville	do	30		do	do	Do.
Taylorsville	Residual soil or loess.			do	do	Do.
Union Plains	Till	25		do	do	Do.
Vera Cruz	do	20		do	do	Do.
Wallsburg	do	16	Fair	do	do	Do.
Whiteoak	do	25+		do	do	Do.

BUTLER COUNTY.

By F. G. Clapp.

SURFACE FEATURES.

The upland surface of Butler County forms a plateau which has a maximum altitude of 850 to a little over 900 feet above sea level. Across the uplands the broad, flat surface and even sky line are very noticeable, but in the lowlands the plateau character of the county is not apparent, because the surface has been eroded and cut into by the streams. The larger valleys are broad and deep and generally extend several hundred feet below the surface of the uplands.

The principal stream, Miami River, flows southwestward across the county from the northeast corner, near Middletown, to Venice, at an elevation of 500 to 600 feet, about 300 feet below the level of the surrounding hills. Its valley ranges in width from 1 to 3 miles and consists of a broad flood plain and bordering terraces. Several broad valleys at elevations of 550 to 650 feet, carved by Miami River and its tributaries, are not now occupied by any large stream. The largest of these abandoned valleys extends southeastward from Hamilton and is traversed by the Pittsburgh, Cincinnati, Chicago & St. Louis Railway and the Cincinnati, Hamilton & Dayton Railway. In places there are enlargements of the main valley, which consist of local basin-like valleys 2 to 4 miles in diameter. The tributary valleys are of all sizes; in width they range from a few hundred feet to over a mile, and in depth they descend from a few feet below the plateau surface on the uplands to the level of Miami River. The slopes along the main valleys are generally steep and in places form precipitous bluffs, but back on the uplands they are moderate and grade into the gentle undulating surface.

WATER-BEARING FORMATIONS.

SURFACE DEPOSITS.

ALLUVIUM.

As would be expected from the unusual width of the main valleys, deposits of alluvium are extensive in Butler County. Along the side valleys they range in width from only a few hundred feet to a mile or more, but along the main Miami Valley they are 1 to 2 miles broad. On Indian Creek, Fourmile Creek, and Sevenmile Creek they range from a quarter of a mile to a mile in width. In most of the valleys the depth of the alluvial deposits is not known, for in their centers few wells are sunk to bedrock. Wells at Hamilton and Coke Otto are 50 to 100 feet deep and do not reach rock, the average depth of the alluvium in the center of the valley being probably nearly 200 feet. In the broad abandoned valley southeast of Hamilton the depth may be 50 or 100 feet more on account of the greater elevation of the deposits.

The deposits classed as alluvium consist of silt, sand, gravel, and a few layers of clay and hardpan (a thin deposit of pebbly clay or till). The alluvial deposits are generally finer and more silty in the upper few feet than in the deeper beds, because they consist of the finer silty materials deposited by overflows of recent streams flowing at a gentle grade.

In the alluvial deposits water lies a few feet below the surface, the exact depth depending on the proximity to and elevation above the streams, the configuration of the surface, and other conditions. The finer portions of the alluvium contain little water because of their generally impervious nature. In the greater part of it, however, water is abundant in sand and gravel at all depths from 30 feet downward, the coarse gravels containing the largest amounts. In a few localities, which can not be detected by inspection of the surface, the silty or clayey deposits continue to greater depths, making successful wells impossible.

TERRACE GRAVELS.

Accompanying the deposits of alluvium along the sides of the Miami Valley and extending up Indian, Fourmile, Sevenmile, and other large creeks are broad, low terraces, consisting of sand and gravel, which stand at elevations of 10 to 50 feet above the flood plain. In certain localities along these main valleys, but especially along the Miami, flat gravel terraces a few hundred or a few thousand feet in extent stand 50 to 100 feet higher than the broader terraces. The gravels in some of these terraces are cemented and form a hard conglomerate, which in a few places along the sides of the valley breaks off in large bowlders. The water on the terraces is essentially the same as that on the flood plain, but it is not found so near the surface, for the terrace materials are more or less porous, and as they lie at higher elevations their water table is lower.

TILL.

The material known to geologists as till consists of a pebbly clay which for a few feet below the surface is yellowish but lower down is bluish gray, the change being due to the fact that near the surface it has been oxidized by the atmosphere. Till is found most abundantly on the uplands and occurs in the lowlands only beneath more-superficial deposits of alluvium and terrace gravels. In the uplands of the southern part and in some in the northern part of Butler County the till is only a few feet thick. In general, however, it thickens toward the north. In considerable areas north of Hamilton it forms broad, rather flat plains from a few hundred feet to half a mile or more in extent which are similar in surface configuration to the gravel terraces but differ in not having their upper surfaces at a definite level and in being less even. Along Fourmile Creek good sections of these terraces show till ranging from 10 to 50 feet in thickness, and in many places on the uplands the till is believed to be equally thick. On account of the abundance of morainal deposits in the northern part of Butler County the till is obscured and its thickness can not be determined, but it is believed to fill many abandoned valleys and in such places it may have a thickness of over 100 feet.

The greater part of the till is very clayey and impervious, and for that reason contains relatively small amounts of water. It includes, however, local gravelly portions which hold some water, and even the clayey portions are saturated at a few feet below the surface. Dug wells in it obtain moderate supplies of water in a wet season, but after a long dry spell they are likely to give out, making it necessary, where practicable, to resort to deep rock wells. In dug wells in till the water generally stands 5 to 15 feet below the surface of the ground. Generally it is under only a slight head and rises very little when encountered. No flowing wells are known in the till in this county.

MORAINAL DEPOSITS.

Morainal deposits are not so extensive in Butler County as they are in counties farther north. However, moraines composed of low knolls and ridges standing only a few feet above the surrounding surface cross the county in a general northeast-southwest direction.

One belt, not conspicuous on the surface, runs northeastward from a point near Shandon, passing just west of Hamilton. A second belt, broader and less definite and of somewhat greater thickness, extends northeastward from the vicinity of Oxford toward Preble County. Between these moraine belts lie many irregularly distributed deposits of gravel, sand, and pebbly clay which can not be definitely classified but which come under this type of deposit. Most of these morainal deposits are not shown on the maps, as they are not conspicuous on the surface. Of the broader and more prominent morainal deposits that are shown, one, touching the northeastern edge of the county, consists of conspicuous, well-defined undulating ridges and knolls of gravel. A less noticeable moraine, which forms the outer limit of the latest or Wisconsin ice advance, touches the southern border of the county at several places.

Owing to their general thinness, the morainal deposits in Butler County are not particularly important for water supplies, yielding only small amounts, which are found in dug wells and which vary in amount according to the season. The only morainal water of importance is found in the large moraine that touches the northeastern edge of the county, in which the supply is plentiful. In most places on this moraine, however, it is necessary to go to a considerable depth to get water.

ROCK FORMATIONS.

"NIAGARA" AND "CLINTON" LIMESTONES.

Both the "Niagara" and "Clinton" limestones occur near the southern edge of Preble County, but neither of them is known positively to extend into Butler County. They may be present east and west of Somerville, but if so they occur in small patches and have no effect on the underground water supply.

RICHMOND AND MAYSVILLE FORMATIONS.

The whole thickness of the Richmond and Maysville formations is exposed in Butler County, although the complete section is not exposed at any one point. These formations constitute the surface of the hard rocks throughout the county except for a few feet of the Eden shale, which is exposed along the Miami Valley near Venice and Shandon and extends northward a short distance toward Hamilton. It is possible also that a few small patches on the uplands in the extreme northern part of the county may consist of the "Clinton" and perhaps the "Niagara" limestone, but this can not be affirmed with certainty.

In general the Richmond and Maysville formations dip northwest. They consist of gray to blue limestone layers a few inches thick, alternating with prevailingly calcareous clay shales. The best sections can be seen in several quarries west of Miami River, between Hamilton and Coke Otto, where unfossiliferous blue shale alternates with crystalline and somewhat fossiliferous blue-gray limestone. The limestone beds are from half an inch to 6 inches thick, and the shale beds 1 inch to 6 inches thick.

Owing to the thinness of the limestone beds, to the scarcity of solution passages, to the absence of porous layers, and to the predominating shaly nature of the beds, the Richmond and Maysville formations are not strong water bearers. Where they are covered by a few feet of drift, as over the greater part of the uplands, the water held in the drift commonly penetrates downward into the upper part of the Richmond and yields moderate supplies to dug wells. Drilled wells in these formations are not very successful, as they are so small in diameter that they do not admit enough water.

EDEN SHALE.

The Eden shale consists of gray or bluish-gray shales which weather brownish and have a maximum thickness of about 250 feet. Only a few feet of the upper portion is exposed in Butler County, outcropping along the lower Miami Valley, near the Hamilton County line, southwest of Hamilton, and possibly also for a short distance below the old gravel-filled valley southeast of Hamilton. No water is found in the Eden shale.

NOTES BY TOWNS.

COKE OTTO.[1]

At Coke Otto the Hamilton Otto Coke Co. has three 6-inch driven wells about 65 feet deep in alluvium. The material was reported to be gravel. Water was obtained at a depth of about 19 feet and rises within about 12 feet of the surface. The maximum yield by pumping is reported as 500 gallons a minute. The water is used for cooling gas. The wells can be pumped continuously. The normal level of water, 12 feet below the surface, can be lowered by ordinary pumping to 20 feet from the surface. By hard pumping it will descend to 25 feet but can not be lowered farther. The water level in the well is higher when the river is higher. The water is reported to be suitable for drinking. (See analysis, pp. 198–199.) Other wells at Coke Otto which do not belong to this company are driven to a depth of 18 to 25 feet. The head of the water depends on the depth to which the well is sunk below the level of the ground water, which is 12 to 15 feet below the surface.

[1] Conditions in 1906.

DARRTOWN.[1]

About $1\frac{1}{2}$ miles southwest of Darrtown, on the flood plain of Fourmile Creek, the J. W. Nichols gas well was sunk several years ago to a depth of 2,051 feet. No reliable record of the formations passed through can be obtained, but it is known that gas was encountered at 608 feet and is now used for lighting a farmhouse near by. Salt water was obtained at about 1,100 feet. Very briny water was found somewhat below 1,200 feet and at other lower depths. The water in the well now stands about 100 feet below the surface, and gas comes up through it. This well was drilled in the hope of obtaining enough gas to supply the village of Darrtown, but it has never been used for this purpose.

HAMILTON.[1]

Hamilton is one of the largest cities in the region covered by this report. It is situated on both sides of Miami River and lies mostly upon the flood plain and gravel terraces but extends as much as 100 feet up the hills. The city is the center of a number of important manufacturing and other industries, and for that reason needs a large water supply. It has a good system of public waterworks, built in 1883, which supplies the greater portion of the inhabitants and industries. On the outskirts, however, many driven wells are sunk a few feet in gravel, obtaining ground-water supplies only 5 to 10 feet below the surface. It is recommended that where driven wells are used they should be sunk to somewhat greater depths, as the water near the surface is likely to be rather poor.

The waterworks consist of a pumping station obtaining water from 23 driven wells ranging from 75 to 135 feet in depth, situated on the flood plain at the north end of the city. The surface formation at that place is reported to consist of 175 feet of clean gravel, below which is 5 feet of blue clay resting on bedrock. The wells pass through some irregular pockets of sand, which contain little water. Owing to the fact that the wells are of various depths practically all the water available in the area in which they are sunk can be obtained. The water is pumped to a 6,000,000-gallon reservoir on Wilsons Hill 2 miles southwest of the pumping station, and 230 feet above low-water level in Miami River. The pumps have a capacity of 4,000,000 gallons. The water, though very hard, is believed to be of excellent quality as regards organic purity, but the amount is not sufficient and larger pumps, more wells, and a larger reservoir are contemplated.

The Champion Coated Paper Co., whose mills are situated on the west side of the river at Hamilton, has 24 driven wells 6 inches in

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[1] Conditions in 1906.

diameter and 80 to 120 feet deep, in gravel, from which water is obtained by pumps having a reported capacity of about 6,000,000 gallons. Ten of the wells are spaced 30 feet apart in two parallel rows 20 feet apart, and 10 more are similarly situated in two rows at right angles to the first 10. The other four wells were driven later. The water from these wells is mixed with river water and is used for cooling acid in the manufacture of paper. This plant is situated about half a mile southwest of the city waterworks, and the pumping is said to have affected the supply of the city wells.

The Champion Coated Paper Co. also has another well, which was drilled for gas to a depth of 3,120 feet. It found little gas, but large amounts of salt water. As shown by the analysis (pp. 198–199), the proportion of total solids (salt and other minerals) far exceeds that found in any other well which has been analyzed in the region covered by this report. The complete record of this well is reported by the company, as follows:

Record of Champion Coated Paper Co.'s deep well, at Hamilton.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone and shale (little gas)		510
Small flow of gas		1,015
Salt water		1,045
"Birdseye" limestone	539	1,055
Much salt water		1,075
St. Peter sandstone (salt water at 2,900 feet)	2,065	3,120

The drilling of the well lasted from June 4, 1904, to January 31, 1905. There was considerable trouble in casing and reaming, owing to the fact that the drill stuck several times. At 3,120 feet the well was abandoned and the casing taken out because the tools became fast and an attempt to drill around them proved unsuccessful. The casing ranges from 4 to 8 inches in diameter. The very strong brine was obtained 2,900 feet below the surface. A sample of water, which had been kept by the company in sealed hogsheads, was furnished to the Survey and analyzed by R. B. Dole and M. G. Roberts.

The Black-Clawson Co., the Niles Tool Works Co., the Miami Woolen Mills, the Hamilton Machine Tool Co., the Sterling Paper Co., the Becket Paper Co., and the Cincinnati Northern Traction Co. have driven wells ranging in depth from 40 to 200 feet, all obtaining water in alluvium. The water is hard but otherwise seems to be excellent. Some of these Hamilton wells are reported to have been pumped so continuously that they have drawn water away from other wells in the vicinity.

OXFORD.[1]

The water for the public supply of Oxford is drawn from one dug well and three driven wells, situated on the flood plain of the creek, about a mile north of the town and 175 feet below the main street. The system has been in operation since 1896. In all, seven wells have been sunk at the pumping station. Well No. 1 was sunk to 109 feet; at 29 feet gravel was struck, then a blue shelly material was penetrated, and at 109 feet "blue rock" was reached; all below 29 feet was abandoned. This is the deepest well in the group. The water reaches within 13 feet of the surface when it is being pumped. The other wells were sunk 60, 49, 22, 24, 23, and 22 feet.

In 1887 a well was sunk by the Oxford Gas & Oil Co. on the low flat opposite the railroad station. The following record[2] is based on samples of drillings preserved at the time:

Record of gas well, Oxford.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift: Sand and gravel	40	40
Richmond and Maysville formations:		
Limestone	190	230
Limestone and shale	18	248
Limestone	17	265
Limestone and shale	115	380
Eden shale and part of Point Pleasant formation: Blue shale	407	787
Point Pleasant formation:		
Soft dark limestone and shale	3	790
Hard dark limestone	40	830
"Birdseye" limestone:		
White to gray crystalline magnesian limestone, with a little shale	450	1,285
Coarse dark-bluish or greenish limestone	45	1,330
St. Peter sandstone: White to bluish calcareous sandstone or arenaceous limestone (salty water)	40	1,370

This well starts 465 feet above low water in Ohio River.

SEVENMILE.[1]

The village of Sevenmile, situated on a low terrace near the flood plain of Sevenmile Creek, is supplied by private dug and driven wells ranging from 40 to 60 feet in depth. The water is obtained from gravel underneath hardpan. It is of very good quality except in a few shallow dug wells, but its level is not within 25 feet of the surface. The dug wells are reported to stop on top of hardpan and to obtain softer water than the driven wells which penetrate hardpan. They are, however, likely to dry up during the summer, whereas the driven wells never give out. A 48-foot well in Sevenmile passed through 40 feet of gravel, 8 feet of stony hardpan, and then into gravel. Just south of the village a test hole was once sunk to a depth of 1,485 feet in a search for oil. No details are available.

[1] Conditions in 1906.

[2] Abbreviated from record of J. F. James, Jour. Cincinnati Soc. Nat. Hist., vol. 10, 1888, pp. 73–77. Based on assumption that samples were taken at change of rock.

TALLEWANDA SPRINGS.[1]

A short distance north of College Corner, on the edge of Preble County, are situated the Tallewanda Springs, owned by the Joseph R. Peebles Sons Co., of Cincinnati. Two springs are in use, both being situated near the base of the ravine along a small run. No rock is exposed at this place and none is known by the owners, but the springs may issue from the "Clinton" limestone underlying the surface till. An analysis of the water is given on pages 198–199. The immediate surroundings of the springs are slightly wooded and there are cultivated fields some distance back from the run. The buildings are not so situated as to affect the quality of the water. The temperature of the water, as reported by the owners, is 48° F. It issues from the springs with measured volumes of 5 gallons and 5¾ gallons a minute. A little more water is reported in winter than in the summer, but the spring is not seriously affected by dry weather. The water issues in small gullies 40 feet above the run and is piped downhill to spring houses near the base of the slope, where it is bottled. It is shipped to Cincinnati and some of it is carbonated. The "still water" retails at 10 cents a gallon. It is claimed to be of great medicinal value. There is a bottling house on the grounds in which the water stands 5 feet in depth in a cement-lined tank. In addition to the two springs described, there is a third spring which forms a fountain. The Tallewanda Springs are named after the Tallewanda tribe of Indians who are said to have once encamped at them.

WATER PROSPECTS.

The prospects for obtaining water in the principal villages and towns in Butler County are summarized in the following table, which shows the nature of the surface materials and rocks and the character of the water supplies at each locality:

Underground water conditions in Butler County.

Town.	Surface deposits.			Rock formation.		
	Material.	Average thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Coke Otto	Alluvium	Deep	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
College Corner	Morainal	30	do	do	do	Do.
Collinsville	Alluvium	Deep	do	do	do	Do.
Darrtown	do	do	do	do	do	Do.
Hamilton	do	200	do	do	do	Do.
Lindenwold	do	Deep	do	do	do	Do.
Millville	do	do	do	do	do	Do.
Oxford	Till	10	Small	do	do	Do.
Reiley	Alluvium		Plenty	do	do	Do.
Sevenmile	do	50	do	do	do	Do.
Shandon (New London).	do	Deep	do	Eden	None	
Somerville	do	do	do	Richmond and Maysville.	Richmond and Maysville.	Do.
Symmes Corners	do	do	do	do	do	Do.
Venice (Ross P.O.)	do	do	do	Eden	None	

[1] Conditions in 1906.

CLARK COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

The surface of Clark County is, in the main, a flat or gently rolling plateau, broken by the valleys of Mad and Little Miami rivers and their tributaries, which have been cut from 40 to 150 feet or more below the upland level. The valleys vary in width from a few hundred yards to about 2 miles, and the upland areas between the main streams are generally from 2 to 5 miles wide. Besides the irregularities due to stream cutting, there are many irregular hills representing morainal deposits left by the glaciers on their retreat from the region. Most of these hills are of no great height, but a few rise nearly or quite 100 feet above the surrounding territory. Though not forming connected ridges they fall into several general belts running from northeast to southwest, one lying along the eastern limits of the county, one east of and nearly parallel to Little Miami River, one west of the same stream, and one along the southeast side of Mad River.

WATER-BEARING FORMATIONS.

SURFACE DEPOSITS.

ALLUVIUM.

Alluvium is strictly a stream-laid deposit. Its upper part, in most places, is the work of the present streams, but its lower part may have been deposited by older streams which flowed before or between the several glacial advances in the region. The larger part of the alluvium is naturally found in the present surface valleys, but gravels deposited by old streams are present in many buried valleys beneath the pebbly clay. Probably the most notable of these buried valleys is the old channel of Mad River, near Sugar Grove, west of Springfield. North of this point the river flows on a filling probably over 100 feet in thickness, but to the south, at Limestone City, it flows not far above bedrock in a rock-walled valley only a few hundred feet wide. As the rock channel should normally be deeper, not shallower, at the downstream point, the conditions indicate that the river is out of its old channel. Railroad tests near Sugar Grove disclosed a deep rock channel beneath the surface deposits, cutting across the neck at this point and evidently marking an old channel of the river.[1] Another old channel, possibly marking a former course of the Miami, enters Clark County from the northwest near New Carlisle and joins the present Mad River Valley a few miles to the south. Other smaller buried channels have

[1] Orton, Edward, Geol. Survey Ohio, vol. 1, 1873, pp. 460–461.

been exposed in quarry excavations near Springfield, and it is probable that buried valleys abound throughout the county, although, owing to the fewness and shallowness of the wells, they can not be satisfactorily traced.

The valley deposits are not all alluvium, however, for between the deposition of the lower and upper portions ice advanced over the region, leaving sheets of pebbly clay over the old alluvium to be covered by later alluvium.

The alluvium or valley deposits, although embracing much fine silt, include large amounts of sand and gravel, which are usually saturated with water. Wells generally obtain water at or slightly above the level of the rivers flowing in the valleys, but as this water is generally so near the surface as to be liable to pollution, it is best to sink wells 20 or 30 feet below stream level. Few wells located near the center of the valleys fail to get adequate supplies, but the deposits near the borders are likely to be finer and to yield less water. The water is not usually under much pressure and rarely if ever flows at the surface.

TILL.

The pebbly clay or till which makes up the greater part of the surface deposits represents materials laid down beneath the ice sheets which once passed over the region and forms a mantle completely hiding the underlying rock. Although the surface of the till is generally flat and featureless, its thickness varies greatly owing to the irregularities of the rock surface on which it rests. In character it is mostly a sandy or pebbly clay containing sporadic bowlders, but it generally includes either definite beds of sand or gravel or zones that are predominantly gravelly. Near the surface it is usually yellow or brown from weathering, but at depths of more than 8 or 10 feet it is generally gray or bluish. The general thickness of the deposits is indicated on Plate III (p. 26) and local details are given in the town descriptions.

Although prevailingly clayey, the pebbly clay contains more or less gravelly layers or even beds of sand or gravel, in which water is usually present in abundance, standing in wet years within a few feet of the surface. In the flatter areas wells 25 or 30 feet in depth usually get sufficient supplies for ordinary use, and wells of 40 feet seldom if ever go dry. Near the borders of the deeper valleys, however, the supplies often drain away and wells have to be sunk considerably deeper. The water is sometimes under pressure, rising considerably when encountered, and flowing water may be obtained by wells here and there in the deeper ravines and along the base of the valley bluffs.

MORAINAL DEPOSITS.

Although the morainal ridges consist largely of sand and gravel deposited by waters that emerged from the ice margin during the glacial retreat, they contain a greater or less admixture of the unstratified pebbly clay or till. Generally, however, they are so open and porous that the water, instead of being retained, is drained away either to emerge as springs at their borders or to sink into the underlying pebbly clay. For this reason wells in the moraine areas must usually be carried to considerable depths, generally into the till, in order to procure adequate supplies, the morainal deposits themselves containing little or no available water.

ROCK FORMATIONS.

The rock formations known to underlie Clark County are the Richmond, "Clinton," and "Niagara." Later rocks may overlie the "Niagara" in the northeast corner, but because of the great thickness of the drift and the absence of borings their presence has not been established.

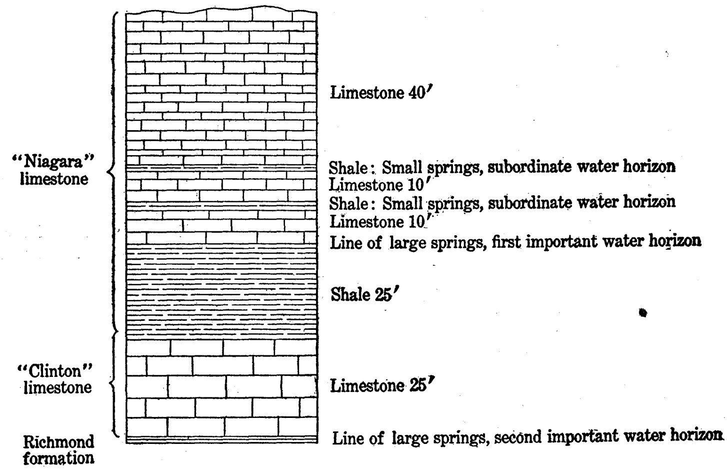

FIGURE 9.—Rock water-bearing beds of Clark County.

"NIAGARA" LIMESTONE.

The "Niagara" limestone, which is probably at least 100 feet in thickness, varies considerably in character in its different portions. Near the base of the formation, along the contact with the "Clinton" limestone, is about 25 feet of shaly limestone or calcareous shale, overlain in succession by about 8 feet of massive limestone, a thin parting of shale, about 15 feet of bedded limestone, known as the Springfield limestone, and about 40 feet of massive or irregularly bedded limestone unfit for building purposes. The "Niagara" limestone forms the surface of the entire county, outside the limits of the Richmond and "Clinton" formations, with the possible exception of a small area of more recent rock in the northeast corner. Of the subdivisions of the limestone the uppermost, or 40-foot bed, is the most important, underlying by far the greater part of the county.

The lower shaly portion of the formation carries little or no water, but the limestone layers abound in solution passages and joints (Pls. V, *A;* VI, *A*), in many of which water occurs in abundance. The shales are of importance chiefly because they limit the downward penetration of the water, which collects it in the lower part of the overlying limestone beds, where it is available to wells or emerges as springs. In fact, the top of the lower shale layer is an important water horizon, giving rise to numerous springs, especially on the south side of the valley of Mad River, toward which the rocks dip. On the north side, where the dip is away from the valley, the springs are fewer in number and smaller in size.[1] It is to this horizon that the best rock wells throughout the country are sunk. Eight or ten feet above the lower shale and also about 20 feet above it occur thin shale partings, which to some extent act as barriers to the underground waters, but, although some wells get supplies from the beds above these layers, the amount is usually small and uncertain. To insure permanency the wells should be carried to the lower shale.

"CLINTON" LIMESTONE.

In Clark County the "Clinton" limestone is an irregularly bedded semicrystalline yellowish, pinkish, or reddish limestone about 25 feet thick. Its outcrop enters the county from the west a few miles north of New Carlisle and follows the east side of the valley of Honey Creek (West Fork), bending southeastward and reaching the Mad River valley south of Donnelsville and following it eastward to Snyderville. Here the outcrop crosses the river and runs southward east of Enon to the valley of Mud Run, the south side of which it follows to the county line east of the southwest corner.

The "Clinton" limestone is somewhat sandy and porous in its lower portion and in places carries a considerable quantity of water, which is retained by the underlying shales and emerges as strong springs all along the line of outcrop. Much of the upper part of the "Clinton" is in itself dense and impervious and also gives rise to springs at many points. The formation may be expected to yield satisfactory supplies to wells for a distance of several miles back from its outcrop and will probably afford small or moderate supplies over nearly the entire county.

RICHMOND FORMATION.

The Richmond formation, which consists of thin alternating beds of limestone and shales, underlies the alluvial deposits of the Mad River valley up to the vicinity of Snyderville, those of Mud Run

[1] Orton, Edward, Geol. Survey Ohio, vol. 1, 1873, p. 466.

south of Enon, and those of the West Fork of Honey Creek north of New Carlisle; but in few places does it outcrop above the valley deposits.

This formation doubtless contains considerable water, but as it is overlain either by the "Clinton" and "Niagara" limestones, both of which are better water bearers, or by the saturated alluvial deposits of the valleys, there is little occasion to sink wells into it, and it need not be further considered as a source of supply. Its upper portion is shaly and serves as an impervious layer to prevent the downward passage of the waters of the "Clinton."

NOTES BY TOWNS.

NEW CARLISLE.[1]

A deep well bored at New Carlisle in 1887, in search of oil and gas, struck the white "Birdseye" limestone at 1,060 feet, or about 150 feet below sea level. No oil or gas was found and the amount and character of the water were not reported.

NORTHAMPTON.[1]

A deep boring, known as the Mower well, sunk in 1887 near Northampton, penetrated 93 feet of drift and 1,287 of rock, or 1,380 feet in all. The "Birdseye" limestone was found at 1,293 feet. No oil or gas was found and no record of the water conditions is available. Most of the water appears to have been found in the upper part of the rock, as the casing was set at 200 feet.[2]

SPRINGFIELD.[1]

Several deep wells have been drilled at Springfield in search of oil and gas. One of these, sunk by J. W. Churchill for a local company in 1885, affords a good record of the underlying water-bearing beds.

Record of deep well at Springfield sunk by J. W. Churchill, 1885.[a]

	Thickness.	Depth.
"Niagara" limestone (58 feet):	*Feet.*	*Feet.*
Blue limestone	15	
White clay	3	
Shale	40	58
"Clinton" limestone (42 feet): White limestone	42	100
Richmond-and Maysville formations (710 feet):		
Red slate	12	
Shale [and limestone]	226	
Shell and gritty shale	37	
Gray shale [and limestone]	305	
Light shale [and limestone]	130	810
Eden and Utica shales (230 feet): Dark shale	230	1,040
Point Pleasant formation (100 feet):		
Red sand [and shale]	76	
Black shale	24	1,140
"Birdseye" limestone (top 190 feet below sea level).		

[a] Orton, Edward, Geol. Survey Ohio, vol. 6, 1888, p. 280.

[1] Conditions in 1906.
[2] Adapted from Orton, Edward, The Trenton limestone as a source of oil and gas in Ohio: Report. Geol. Survey Ohio, vol. 6, 1888, p. 278. The geologic formations are chiefly the interpretations of the authors of this report.

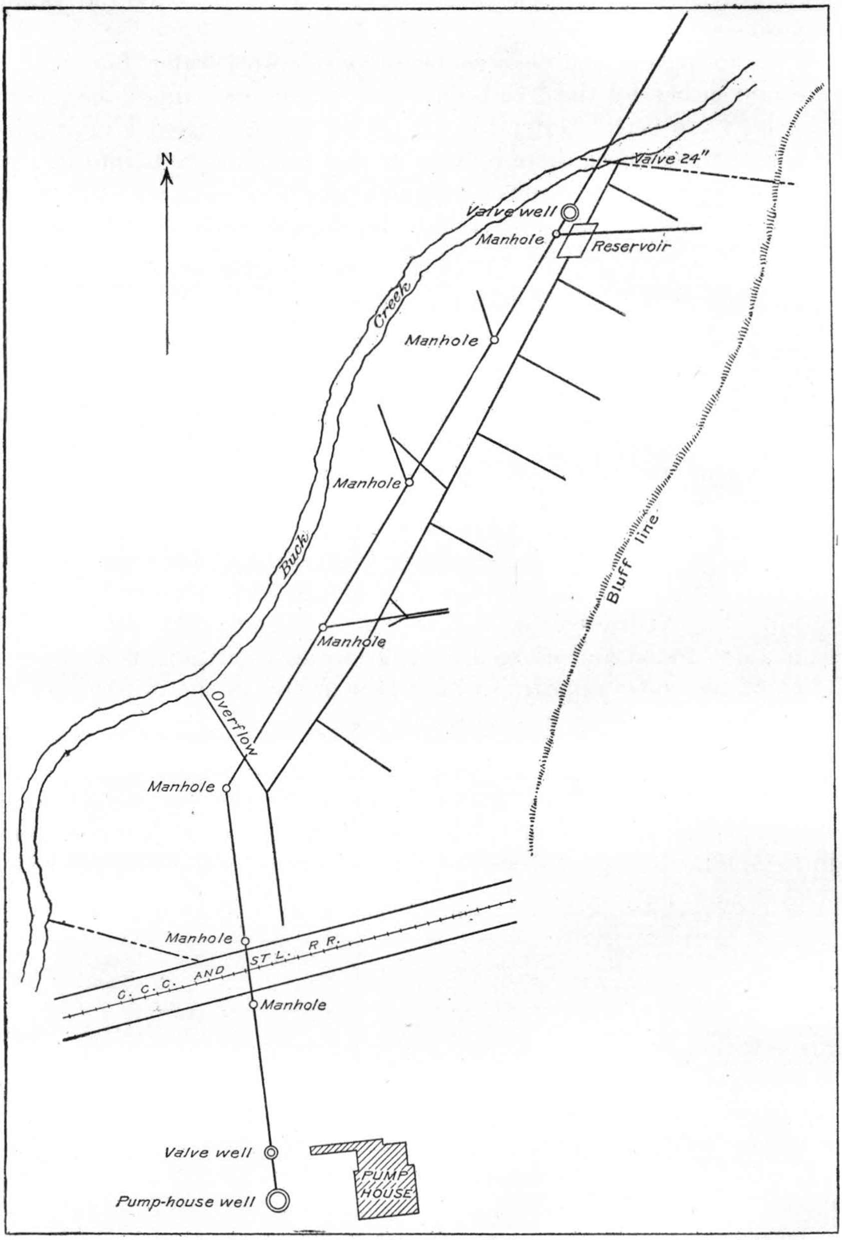

FIGURE 10.—Plan of infiltration galleries, public waterworks, Springfield.

About a year later, in 1886, a well drilled by the Champion Machine Co. to a depth of 2,400 feet or more developed the following strata:

Formations in Champion Machine Co.'s well, Springfield.

	Feet.
"Birdseye" limestone	1,200–1,900
St. Peter sandstone	1,900–2,000
Cambro-Ordovician dolomite (light colored)	2,000–2,400

Most of the fresh water appears to have been found in the first 250 feet, as the first casing was carried to this depth. Many salt-water supplies were encountered between 1,800 and 2,000 feet, probably mainly from the lower "Birdseye" and the St. Peter.

A public supply was first installed in Springfield in 1881, the water being obtained from a filter gallery, but on the speedy failure of this source, a reservoir 350 feet long, 200 feet wide, and 18 feet deep, with a capacity of 8,000,000 gallons, was built just above the junction of Beaver and Buck creeks, and a dam was built 300 feet below the junction of the creek to back up the ground water beneath the reservoir. In 1894 the combined supply of the original filter gallery and the reservoir, which was fed by seepage, having proved insufficient, an additional gallery 200 feet long, 32 inches wide, and 48 inches high was constructed, with laterals 20 feet below the surface in a gravel bed under and between the two creeks at their junction (figs. 10 and 11). This leads to a covered pump well 30 feet in diameter and 21 feet deep. Connection with the old gallery is also maintained (1906) and provision made for using creek water in case of severe fires. Statistical data regarding the waterworks will be found in the table on page 51 and an analysis of the water on pages 198–199.

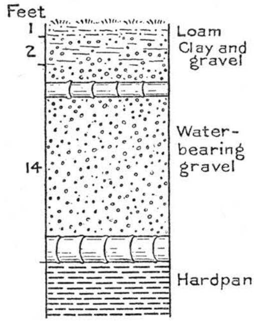

FIGURE 11.—Section of deposits at infiltration galleries, public waterworks, Springfield.

Several strong springs issue near the east end of the city park and are utilized for filling the large and picturesque artificial lagoons at this point. The water emerges from the base of the limestone cliff, in one place at a rate of 80 gallons and in another of 100 gallons a minute. No seasonal fluctuations have been observed. The water has a summer temperature of 52° and is rather hard. It is free from local pollution. Some difficulty has been experienced through the growth of algæ in the water, but this is now prevented by the use of copper sulphate, or blue vitriol, at intervals of about once a month. An analysis of this water is given on pages 198–199.

WATER PROSPECTS.

The following summary shows the character, thickness, and available water of the surface deposits and the underlying rocks in Clark County:

Underground water conditions in Clark County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rocks nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Beatty	Moraine on till	12	Plenty	"Niagara"	"Niagara"	Moderate.
Catawba	Till, moraine	50+		"Helderberg."	None as good as the till.	
Clifton	do	1–30	Moderate.	"Niagara"	"Clinton"	Do.
Cold Springs	Till	10	Small	do	"Niagara"	Do.
Donnelsville	do	12	Plenty	do	"Clinton"	Plenty.
Eagle City	Alluvium	Deep.	do	do	None as good as the alluvium.	
Enon	do	Deep.	do	Richmond	do	
Forgy	Till, moraine			do	Richmond	Small.
Hennessey	Till	15	Small	"Niagara"	"Niagara"	Moderate.
Hustead	do	15	do	do	do	Do.
Lagonda	do	80+	Plenty	do	do	Do.
Lawrenceville	do	100	Moderate.	do	do	Do.
Limestone City	do	0–5	Small	do	do	Do.
Midway	Alluvium	Deep.	Plenty	Richmond	None as good as the alluvium.	
New Carlisle	do	Deep.	do	do	do	
Northhampton	Till	90	Moderate.	"Niagara"	"Niagara"	Do.
Pitchin	Moraine, till	60+	do	do	do	Do.
Plattsburg	do	25+	do	do	do	Do.
Selma	Till, alluvium		Plenty	do	do	Do.
Snyderville	Till	10		"Clinton"	Richmond	Small.
South Charleston	Till, moraine	+50	Plenty	"Niagara"	"Niagara"	Moderate.
Springfield	Till, alluvium	20+	Moderate.	do	"Niagara" and "Clinton."	Do.
Spring Grove Park.	Till, moraine	35+	Plenty.	do	"Niagara"	Do.
Vienna Crossroads.	do	60+	do	do	do	Do.
Villa	do	50	do	do	do	Do.

CLERMONT COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

Clermont County, like the other counties of southwestern Ohio, lies on a table-land or plateau, the remarkably level surface of which stands about 500 feet above the Ohio, or about 900 feet above sea level. It is bordered on the south by the deep valley of the Ohio, but its interior is less cut by stream valleys than that of Hamilton County, to the west. Its deepest cut is that made by East Fork of Little Miami, which is the main drainage line of the county. Few tributaries of any consequence flow directly to the Ohio, although many short streams, occupying deep ravines, enter it. The bluffs facing the Little Miami and the East Fork are less steep than those of the Ohio and are only about 200 feet high. A few terraces border the larger streams.

WATER-BEARING FORMATIONS.

The water-bearing beds of the surface deposits include alluvium, terrace gravels, loess, and till; those of the harder rocks include the Richmond, Maysville, Eden, and Point Pleasant formations.

SURFACE DEPOSITS.

ALLUVIUM.

The most extensive alluvial deposits are those bordering the Ohio and occupying the valley of the East Fork of the Little Miami. As indicated above, most of the tributaries entering the Ohio are very small and the streams flow on bare rocks at many places. On some of the larger tributaries, however, small deposits of alluvium occur. The alluvium of the Ohio is generally a silty loam near the surface, merging downward into more or less clayey beds or tills, which in turn are underlain by sands and gravels. In the Little Miami Valley less silt is found, gravel and sand being more abundant.

Abundant water can be obtained from the sand and gravel beds below the clays of the Ohio flood plain, and similar supplies are yielded by the alluvium of the East Fork of the Little Miami. Water is also generally contained in the gravelly alluvium of the smaller valleys, provided the slope of the stream and of its deposits is not too great. In general the alluvium furnishes the most abundant and best supplies.

TERRACE GRAVELS.

Small patches of terrace gravels occur at points along the Ohio and the Little Miami, as, for instance, at Milford. The terraces are generally composed in the main of gravel and sand, but locally certain layers have been cemented by iron oxide into the hard sandstone or conglomerate, known to the inhabitants as cement rock. (See Pl. VI, *B*, p. 44.)

Owing to the gravelly nature of the terraces, water generally rapidly drains away or sinks into the underlying deposits, but in some places its downward passage is arrested by the cemented layers, which hold it in depressions and irregularities in their surface. (See fig. 8, p. 41.) It is not uncommon for wells to obtain water from the top of such beds, but if they do not find it they must generally continue to the level of the adjacent streams.

LOESS.

The entire surface of Clermont County, outside of the alluvial areas, is covered by a thin deposit of fine, more or less yellowish silt, which merges locally into whitish clayey deposit. The whitish clay, however, commonly grades downward into yellowish or bluish clay of the same composition. The loess is most abundant near the Ohio, where its thickness may reach 5 or 10 feet. North of the East Fork of the Little Miami, however, it is much thinner, ranging from a few inches to a few feet. In a few places near the edge of the bluffs, where it is thickest, it affords supplies to very shallow wells, but farther back from the river it is too thin and serves principally as a feeder to the underlying till.

TILL.

The till of Clermont County belongs entirely to the older drift and has weathered yellowish to a depth of 10 feet or more, below which it is compact blue clay. It contains many pebbles and a few bowlders. In some localities peaty deposits or deposits of bog-iron ore have been found between the blue and yellow till. Springs occur at this level at many points.

ROCK FORMATIONS.

RICHMOND AND MAYSVILLE FORMATIONS.

The Richmond and Maysville formations consist of alternating layers of limestone and shale, rarely over 10 inches thick, but aggregating over 700 feet in all, of which about 600 feet is exposed in Clermont County. The two limestones together form the surface throughout the uplands of the county, the Richmond outcropping mainly in the northern half of the county and the Maysville in the southern half.

The Richmond and Maysville formations have no porous layers or thick seams of soluble limestone, and although affording moderate supplies of water to open wells, yield but little to wells of the drilled type.

EDEN SHALE.

The Eden shale is gray and blue in color, weathering yellowish or olive green. It has a thickness of about 250 feet, extending from a little below the flood plain to a point midway up the bluffs of the Ohio. Its outcrop extends up the Little Miami almost to the northern edge of the county and up the East Fork nearly to the western edge.

The Eden shale, owing to its outcrop on steep bluffs where the conditions of catchment are unfavorable and also to its clayey and impervious character, is almost destitute of ground water except in its weathered upper portion. In general, wells can not expect to obtain supplies from it. Fortunately, however, because of the location of its outcrop on slopes where inhabitants are few, wells in this formation are seldom needed.

UTICA SHALE.

A few feet of Utica shale occurs at the base of the Eden, but as a water bearer this formation is to all intents and purposes similar to the Eden and can not be looked to as a source of supply.

POINT PLEASANT FORMATION.

The Point Pleasant formation extends from low water up to a level just below the flood plain of the Ohio, its total thickness being about 50 feet. It consists of alternating layers of gray-bluish limestone and hard, dark-gray, compact sandy shale. Some of the limestone layers are of considerable thickness and are quarried for building stone.

Owing to its position beneath the flood plain of the Ohio and to the fact that better supplies can usually be obtained from the alluvium, few wells penetrate the Point Pleasant. Those that do, commonly find water in small amounts, which is likely to be brackish or to carry considerable sulphur.

LOWER FORMATIONS.

Below the Point Pleasant beds exposed at the surface, and entirely below the level of the river, there is 600 feet of massive grayish "Birdseye" limestone and 400 feet of porous St. Peter sandstone. Water is usually found in both of these formations, but is generally salty in the "Birdseye" and highly charged with both salt and sulphur in the St. Peter.

NOTES BY TOWNS.

BATAVIA.[1]

The public supply of Batavia was intalled in 1900, water being obtained from East Branch of Little Miami River at a point above the village. The water is first treated with alum in sedimentation tanks, from which it is carried by gravity through filter tanks provided with metal screens to a receiving or "clear-water" well, whence it is pumped to a cement-lined reservoir and distributed by gravity. The water (see analysis, p. 214) is reasonably safe after treatment and is to be preferred to that of the shallow wells, many of which are badly polluted.[2]

FELICITY.[1]

During the oil boom in 1887 a deep boring, said to have reached a depth of 1,200 to 1,400 feet, was sunk at Felicity. Salt-sulphur

[1] Conditions in 1906.

[2] For further details see Water-Supply Paper U. S. Geol. Survey No. 91, 1904, pp. 63–65.

water was obtained near the bottom, but no other supply of consequence was found.

LOVELAND.[1]

In 1906 a new public supply was being installed at Loveland by the Loveland Citizens' Electric Co., the water being obtained from a well 50 feet in depth sunk in the gravelly alluvium of Little Miami River a little above the town. The water (see pp. 200–201) is of good quality. It is decidedly safer than the water of the shallow wells in the crowded parts of town and should be entirely safe if care is taken to guard against local pollution. (See also p. 51.)

MARATHON.[1]

The spring of T. D. Hartman, at Marathon, which has some local reputation as a medicinal spring, issues with a volume of 5 or 6 gallons a minute from the drift in a small gully just below the upland level. The water is chalybeate and deposits some iron oxide along the small stream in which it flows. The statement that the waters are magnetic is not borne out by careful tests, and, in fact, the existence of magnetic water, although frequently asserted, has never been proved at any locality in this country or any other.

MILFORD.[1]

The public supply of Milford is obtained from three wells driven in 1903 in the alluvium of Little Miami River just above the town. The wells are so situated that pollution is very improbable, and the public supply is to be preferred to that from private wells in the town. An analysis is given in the tables, pages 200–201, and further particulars of the supply will be found on page 51.

NEW RICHMOND.[1]

The wells of New Richmond, which is situated on a low terrace bordering the Ohio, range from 30 to 83 feet in depth, with an average of 40 feet. The wells are mainly driven, the best being sunk to the level of the river, where they generally obtain a good supply of hard water. No rock is encountered. The water-bearing sands are overlain by clayey deposits and the supplies will probably remain safe as long as privies or cesspools are not sunk to the sand underneath.

At the base of the bluff is a well, sunk about 1887 for oil and gas, the depth attained being reported as about 1,400 feet. A strong flow of salt water was encountered near the bottom, probably from the St. Peter sandstone, and a slight flow continued after a lapse of 19 years. (See analysis, pp. 200–201.)

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[1] Conditions in 1906.

The public supply of New Richmond is taken from Ohio River, the water being pumped to a settling reservoir on the bluffs for treatment, after which it is distributed by gravity to the town.

WATER PROSPECTS.

For the assistance of drillers or others seeking underground-water supplies the following table showing underground-water conditions is presented:

Underground-water conditions in Clermont County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Afton	Till	15		Richmond and Maysville.	Richmond and Maysville.	Small.
Amelia	do	10	Plenty	do	do	Do.
Baldwin	Alluvium, till	30		Eden	Point Pleasant	Do.
Bantam	Till	10	Fair	Richmond and Maysville.	Richmond and Maysville.	Do.
Batavia	Alluvium, till	Deep.		Eden	Point Pleasant	Do.
Baywood	do			do	do	Do.
Belfast	Till	30+	Fair	Richmond and Maysville.	Richmond and Maysville.	Do.
Bethel	do	20	Plenty	do	do	Do.
Blairsville	Alluvium			Point Pleasant	Point Pleasant	Do.
Blowville	Till, alluvium	20		Eden (?)	do	Do.
Boston	Till	15	Fair	Richmond and Maysville.	Richmond and Maysville.	Do.
Branch Hill	Alluvium			Eden	Point Pleasant	Do.
Cedron	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Charleston		12	Plenty			
Chilo	Alluvium	70+	do	Point Pleasant	Point Pleasant	Do.
Clermontville	do	Deep.		do	do	Do.
Clover	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Craver	do	15		do	do	Do.
Edenton	Alluvium	25+	Moderate	do	do	Do.
Elenor	Till	10	Fair	do	do	Do.
Elston	Alluvium			Eden	Point Pleasant	Do.
Epworth H'g'ts	Till			Eden (?)	do	Do.
Felicity	do	10	Plenty	Richmond and Maysville.	Richmond and Maysville.	Do.
Funston	do	15		do	do	Do.
Glen Este	do	15		do	do	Do.
Glenrose	do	10	Fair	do	do	Do.
Goshen	do	20	Plenty	do	do	Do.
Guinea	do	20		do	do	Do.
Hamlet	do	10	Plenty	do	do	Do.
Hennings Hill	do	20		do	do	Do.
Hillstation	Till, alluvium	20		do	Richmond, Maysville, Eden.	Do.
Hulington	Till	10		do	Richmond and Maysville.	Do.
Laurel	do	15		do	do	Do.
Lerado	do	15	Moderate	do	do	Do.
Lindale	do	10	Plenty	do	do	Do.
Locust Corner	do	20	Fair	do	do	Do.
Loveland	Alluvium		Plenty	Eden	Point Pleasant	Do.
Manila	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Marathon	do	30	Plenty	do	do	Do.
May	do	10		do	do	Do.
Merwin	do	10	Plenty	do	do	Do.
Miamiville	Alluvium			Eden	Point Pleasant	Do.
Milford	do	Deep.	Plenty	do	do	Do.
Modest	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Monterey	do	25+	Plenty	do	do	Do.
Moores Fork	do	30	Small	do	do	Do.
Moscow	Alluvium	90+	Plenty	Point Pleasant	Point Pleasant	Do.

Underground-water conditions in Clermont County—Continued.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Mount Carmel	Till	15		Richmond and Maysville.	Richmond and Maysville.	Small.
Mount Holly	do	8	Plenty	do	do	Do.
Mount Olive	do	15	Fair	do	do	Do.
Mount Pisgah	do	25	Moderate	do	do	Do.
Mount Repose	do	10	do	do	do	Do.
Mulberry	do	15	Plenty	do	do	Do.
Neville	Alluvium			Point Pleasant	Point Pleasant	Do.
New Palestine	do			do	do	Do.
New Richmond	do	75+	Plenty	do	do	Do.
Newtonsville	Till	8	do	Richmond and Maysville.	Richmond and Maysville.	Do.
Nice	do	15		do	do	Do.
Nichols	Nichols	10		do	do	Do.
Ninemile	Alluvium			Eden (?)	Point Pleasant	Do.
Ninevah	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Obannon	do	20		do	do	Do.
Olive Branch	do	9	Moderate	do	do	Do.
Owensville	do	15		do	do	Do.
Perintown	Alluvium	30+	Plenty	Eden	Point Pleasant	Do.
Pinhook	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Pleasant Hill	do	15		do	do	Do.
Point Isabel	do	20		do	do	Do.
Point Pleasant	Alluvium		Fair	Point Pleasant	Point Pleasant	Do.
Rocky Ford	do			Eden	do	Do.
Rural	do			Point Pleasant	do	Do.
Salem	Till	10	Plenty	Richmond and Maysville.	Richmond and Maysville.	Do.
Saltair	do	10		do	do	Do.
Simpkinson	do	12	Moderate	do	do	Do.
South Milford	Alluvium			Eden	Point Pleasant	Do.
Spann	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Stone Lick	Alluvium			Eden	Point Pleasant	Do.
Summerside	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Tobasco	do	15	Moderate	do	do	Do.
Utopia	Alluvium	100+	Plenty	Eden	Point Pleasant	Do.
West Woodville	do	10	Moderate	Richmond and Maysville.	Richmond and Maysville.	Do.
Wiggonsville	do	8	Fair	do	do	Do.
Williamsburg	do	20	Plenty	do	do	Do.
Willowville	do	15		do	do	Do.
Withamsville	do	9	Plenty	do	do	Do.

CLINTON COUNTY.

By M. L. Fuller.

The underground-water investigation for the present report covered all of Clinton County except a strip about 5 miles in width along its eastern border and included all the cities and villages except New Vienna, Memphis, Lees Creek, Sabina, and Reesville.

SURFACE FEATURES.

Clinton County, although somewhat rougher than many of the other counties of southwest Ohio, consists in the main of flat upland plateaus standing at elevations of 950 to over 1,100 feet. In the southwest corner of the county, southwest of a line extending from the vicinity of Clarksville through Cuba and Martinsville to the county boundary 3 or 4 miles northeast of Lynchburg, there is a relatively low and very flat surface commonly ranging from about 950 to 1,025 feet in altitude and but little cut by valleys, except near Clarksville. Along the line mentioned, however, a scarp or bluff rises 50 to 100 feet above this low surface, or to heights of about 1,000 feet above sea level. Back from the bluff the land again stretches northeastward as a broad flat. This flat, however, owing to its higher elevation, has been much cut by the streams into deep, sharp valleys, of which those of Todds Fork and Cowans Creek are the most striking, their channels being from 100 to nearly 200 feet below the adjacent uplands. The scarp described above lies near the outer limit reached by the latest or Wisconsin ice sheet, but the morainal deposits are not at all conspicuous and may be neglected. Another low but better-defined belt of morainal knolls crosses the county in a northwest-southeast direction midway between Wilmington and the northeast corner.

WATER-BEARING FORMATIONS.

SURFACE DEPOSITS.

ALLUVIUM.

No large rivers cross Clinton County, and the valleys, being mainly narrow, do not contain extensive deposits of alluvium, such as characterize those of the Miami and similar streams. Of the alluvial deposits, those of Todds Fork are the most important, having a breadth of half a mile and extending along the stream for 10 miles or more. Narrower deposits occur along Cowans and Little creeks, East Fork of Little Miami River, and other streams, but over a large part of the county, especially on the lower plateau to the southwest, very little alluvium is present. Near Clarksville, on Todds Fork, the alluvium probably has a depth of 50 feet or more, but at some other places on this and other creeks the streams flow on or near bedrock. Probably many old alluvial deposits occupy buried channels beneath the till, as indicated by deep wells scattered among shallow ones, but at present they can not be satisfactorily located and traced.

Where the alluvium is more than a few feet thick it usually holds abundant water in its sand and gravel layers, which are nearly always to be found in the centers of the valleys. Wells reaching to or below stream level usually get ample supplies. In many places toward the edges of the valleys rock is encountered before this level is reached, or the deposits are found to be finer and less porous, and under either of these conditions the procuring of water supplies is doubtful. Most of the alluvium of Clinton County, or at least its superficial portion, is later than the drift and contains few if any interbedded till sheets. The water rarely rises in the wells.

LOESS.

South of a line extending southeastward from a point near Clarksville through Cuba and Martinsville a coating of yellow clayey loam known as loess, varying from a few inches to a few feet in thickness, forms the surface. Farther south this material is thicker and in a few places is a factor in the water supply. In Clinton County, however, it is of no importance in this connection.

TILL.

The line from Clarksville through Cuba and Martinsville, just mentioned, also separates the pebbly clay or till into two parts, one thinner and older to the south and the other thicker and in part newer to the north. The thin sheet coincides in area with the lower plateau plain and ranges in average thickness from less than 10 feet along the southern border of the county to 30 feet or more along the Clarksville-Cuba line. Depths to rock of more than 70 feet are reported in some wells, but these wells appear to have been sunk in old buried chanels.

Northeast of the Clarksville-Cuba line the till abruptly thickens, forming the bluff described (p. 89). Near the edge the rock is usually 100 feet or more below the surface, but it appears here and there in valleys, as at Ogden, Todds Fork, and west and north of Wilmington, and in the eastern part of the county is not generally far below the general surface of the upland. Both till sheets are very clayey in Clinton County and do not contain so many sand and gravel layers as in the counties to the northwest.

Owing to the thinness of the deposit of the older till in the southeastern portion of the county water is not abundant in it and in a large number of wells can not be obtained short of rock, especially at Blanchester and vicinity. Where the till is 20 feet or more thick wells generally get fair supplies, but in many places, owing to the absence of gravelly layers, drilled and driven wells are unsuccessful. Many open and tubular wells sunk on the uplands or bluffs near the deep valleys and ravines which are so numerous in the western portion of the county are likewise unsuccessful, owing to the readiness with which the water drains away. On the whole the till is a decidedly less satisfactory source of supply in Clinton County than in the counties to the north and west.

MORAINAL DEPOSITS.

Morainal deposits are not very extensively developed in Clinton County, being limited to two belts that are of no great thickness. As in adjoining counties, they are in general prevailingly gravelly and readily permit the water to drain outward or to sink into underlying deposits. For this reason they are of no importance as a source of water.

ROCK FORMATIONS.

NIAGARA LIMESTONE.

Owing to the thickness of the drift over the region of its contact with the next lower formation the margin of the " Niagara " can be only approximately located. It probably enters the county nearly north of Wilmington and extends a little east of south to the county line between New Vienna and Lynchburg, passing east to Wilmington. The boundary is not regular, the formation extending farther westward in the highlands between the streams than in the valleys. Its lower layer, as seen resting on the " Clinton " limestone on Todds Fork, is a blue shale a foot or two thick, overlain by 12 to 15 feet of compact limestone suitable for local building purposes. Above this is a loose, porous limestone with many cavities. This series underlies the greater part of the county to the east, except at Snow Hill, some miles south of New Antioch, where higher and even more porous and friable beds are found. The total thickness of the " Niagara " in this county is probably not over 75 or 100 feet.

" CLINTON " LIMESTONE.

The " Clinton " limestone is a gray or pinkish granular limestone, massive or irregularly bedded, and 25 to 30 feet or more in thickness. Its outcrop lies just west of that of the " Niagara," and, being lower down, is much more irregular, following the complicated windings of the drainage system. It is exposed on Todds Fork at intervals from a point northwest of Ogden to a point north of Wilmington, here and there on Cowans Creek and its branches as far east as New Antioch, and at points a short distance northeast of Martinsville and south of Farmersville (Pl. I). Although its outcrops are numerous it does not form lines of conspicuous bluffs along the stream, as it does in certain of the counties both to the north and south.

The " Clinton " limestone, except in the valley bottoms, is generally covered with a considerable thickness of drift, and in such situations is not commonly used as a source of supply, although it probably carries considerable water. Some of the deeper wells of the higher uplands in the vicinity of New Antioch, Martinsville, and Farmersville, however, possibly draw from it. Its outcrop is so deeply covered in Clinton County that it does not usually give rise to springs, as it does in counties to the north.

RICHMOND FORMATION.

Much of the Richmond formation exposed in Clinton County is shaly, and varies from yellowish green to blue in color. It lies at an average depth of 10 to 30 feet beneath the lower plateau plain southwest of the Clarksville-Cuba-Martinsville Bluff, and is seen in the valleys of Todds Fork, Lytle and Cowans creeks, Little East Fork, and at places near the western edge of the county. Locally the stream bluffs, some of which are nearly 100 feet high, consist mainly of the rocks of this formation.

The Richmond formation is not a good water bearer. Many wells, even of the dug type, obtain only small supplies from it, and drilled wells are rarely successful. Where the drift is very thin, however, it is the only available source, and trial wells must be sunk until one yielding sufficient water is found.

DEEPER ROCKS.

Two wells, sunk to depths of about 1,500 feet at Lynchburg, failed to obtain water in any amount, indicating the futility of sinking to the deeper beds for water.

SUMMARY AND RECOMMENDATIONS.

In many ways the ground-water supplies of Clinton County are unsatisfactory. The drift carries less sand and gravel than at many other points, the alluvial deposits are restricted to narrow valleys, and the rocks, especially those of the Richmond formation, carry but little water. Under such conditions open wells afford the best supply. Drilled wells, because of their small size, not only fail to tap many of the small seeps, but afford no opportunity for storage. Wherever possible alluvium should be utilized. Next to this the drift will, in general, afford the best supplies, but in the area of the "Niagara" limestone waters can generally be obtained from the rock. No deep beds, affording water suitable for domestic, public, or industrial supplies, exist, and deep drilling should be avoided.

NOTES BY TOWNS.

BLANCHESTER.[1]

The problem of water supply in Blanchester is acute, owing to the thinness of the drift deposits, from which at other points water is usually obtained in relative abundance. Not only is the drift thin, but the underlying Richmond formation, which is in many places within 10 or 15 feet of the surface, is one of the poorest water bearers of southwestern Ohio. Fortunately, however, the region is relatively flat and the underground drainage slow, so that more or less water is

[1] Conditions in 1906.

held back in the thin till and in the upper part of the rock. Drilled wells rarely obtain large supplies, but dug wells carried to depths of 40 feet or more, on account of their large storage capacity, usually yield enough for ordinary domestic use. To insure safety from pollution, however, the shallow water in the drift and upper part of the rock should not be utilized; the well should be walled up and cemented from the surface to a level 3 to 5 feet below the top of the rock. Cisterns can be made to yield enough for ordinary demands, but to do this they should be not less than 10 feet in diameter and 15 feet deep and should have absolutely tight walls. The ordinary 6 by 10 foot cistern often fails when it is most needed because of its small storage capacity. Many cisterns develop cracks that permit leakage. This should be guarded against by frequent inspection.

An attempt was made at Blanchester in 1896 to procure water from three dug wells, 50 feet in depth and 6 feet in diameter, but, as was to be expected from the nature of the geologic formations, the supply was entirely inadequate for public purposes, and it was necessary to construct an artificial impounding reservoir in a shallow draw. The entire supply is derived from surface water collected in a settled and farming region and is not only offensive in odor and taste but unsafe to the health. Fortunately, however, no attempt is made to use it for domestic purposes.

CLARKSVILLE.[1]

Clarksville is located on the south side of the valley of Todds Fork, a part of the town being on the lower slopes. Owing to the fact that the stream is flowing in a comparatively recently developed valley, with only a thin coating of alluvium over the underlying till or rock surfaces, water is more difficult to obtain here than at most points in the larger stream valleys. Instead of finding extensive alluvial gravels, many of the wells penetrate blue clay or till or enter the scantily water-bearing Richmond formation within a short distance of the surface.

The town is badly in need of a public supply to afford adequate fire protection and to replace the unsatisfactory wells. An inspection of the vicinity leads to the belief that a system of driven wells across the valley just above the town would yield the necessary water.

CUBA.[1]

Cuba is situated on a sloping hillside of unconsolidated material. Many of the houses are located on the east-west pike running parallel with the slope, but others are on the hillside above. All the drainage from the privies and sinks enters the soil and moves downward

[1] Conditions in 1906.

toward the valley, more or less seriously contaminating the wells along the main street. The water of the public well at the crossroads in the center of the town is believed to be badly polluted. Tightly cemented cisterns of sufficient size to provide a supply for the whole year are suggested as a safe substitute for the questionable wells.

M'KAY.[1]

McKay shows somewhat exceptional underground-water conditions. The drift, although apparently more than 100 feet in depth, consists almost entirely of blue clay, the usual gravelly beds being entirely absent. Very few first-class wells are obtained either from the drift or from the underlying rock, although some fair dug wells from 12 to 25 feet in depth are found. The following is a record of a 175-foot well:

Record of well at McKay.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift: Blue clayey till	110	110
"Clinton" limestone: Limestone	8	118
Richmond formation:		
Red shale	7	125
Blue shale	50	175

MARTINSVILLE.[1]

The conditions in the vicinity of Martinsville are variable and uncertain. Near the railroad at the lower side the creamery and other wells get considerable water, but on the plateau on which the town is situated several wells have been unsuccessful, though some were carried to a depth of 115 feet. In general, although many shallow dug wells procure small supplies, water is notably short on the slopes and crest of the ridge. More water, however, is to be had on the flats just south of the town, few farms there having trouble with their supplies, which they obtain from gravelly beds in the till. In some places where water is scarce several wells have been connected and pumped by a windmill with good results. In the Martinsville region little is to be hoped from drilled wells in the rock, nearly all rock wells being either failures or only partial successes.

NEW BURLINGTON.[1]

On the bank of West Fork of Mill Creek, about half a mile southeast of New Burlington, a very peculiar well yields two different types of water from different depths. The well is dug 36 feet and drilled 12 feet. The rocks consist of limestone, with perhaps 30

[1] Conditions in 1906.

per cent of shale, and lie at the Richmond-Maysville horizon. Water stands 8 feet below the surface. There are two pumps in the well; the pipe of one extends 16 feet below the surface and that of the other 35 feet below, or within 8 inches of the bottom of the dug part of the well. The shorter pipe obtains fresh water and the longer one very strong salt water. The fresh-water bed is 8 feet below the surface; the salt-water bed 21 feet below it. The salt water is reported to have been used for medicinal purposes at various times. The analyses of these two types of water are given on pages 200-201.

WILMINGTON.[1]

Wilmington is situated on a broad drift plain formed mainly of blue clay or till. Most of the people not using the public supply depend on shallow dug wells, although a few use dug wells as much as 60 feet deep, or drilled wells, some of which are reported to be 172 feet deep. The shallower wells get water in the blue clay and the deeper ones from a gravel bed in or beneath the clay. It is said that no rock is encountered in the town, although it comes to the surface a short distance to the north.

A deep well drilled in 1887 for oil and gas afforded the following partial record:

Record of deep well at Wilmington, Ohio.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	84	84
"Niagara" limestone: Shale	4	88
"Clinton" limestone:		
Red rock fossil iron ore	3	91
Limestone	15	106
Richmond formation:		
Brown shales	5	111
Shale	850	961
Eden shale and Point Pleasant formation: Shale interbedded with limestones	[a] 250	[a] 1,211
"Bird's-eye" limestone.		

[a] Orton, Edward, Geol. Survey, Ohio, vol. 6, 1888, p. 296. The geologic formations are the interpretations of the authors of this report. The thickness of the Eden shale and Point Pleasant formation is not given in the published record, and to complete the record the approximate thickness in the well at New Vienna is inserted.

Wilmington is to be regarded as fortunate in procuring a supply from wells in a region where neither the drift nor the rocks commonly carry water in any considerable amounts. The supply is obtained from five deep wells owned by the Wilmington Water & Light Co., sunk to a gravel below the till in the eastern part of the town. The water appears to be safe and is to be preferred to that from private wells. So far, the supply seems to be sufficient for the needs of the town.

[1] Conditions in 1906.

WATER PROSPECTS.

The following table summarizes the more important facts concerning underground-water conditions at the principal villages and towns covered by the field work in Clinton County:

Underground-water conditions in Clinton County.

Towns.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Blanchester	Till	10	Small	Richmond	Richmond and Maysville.	Small.
Burtonville	do	75	Plenty	"Clinton" (?)	"Clinton" (?)	Plenty?
Clare	do	100+	Small	Richmond	Richmond and Maysville.	Small.
Clarksville	Alluvium moraine.	Deep.	do	do	do	Do.
Clinton	Till	75+		"Niagara"	"Clinton"	Usually plenty.
Cuba	Till, moraine	140+	Plenty	Richmond	Richmond and Maysville.	Small.
Deserted Camp	Till	75		"Niagara"	"Clinton"	Usually plenty.
Farmers station.	Moraine	35		"Niagara" (?)	"Clinton" (?)	Plenty?
Gurneyville	Till	100		Richmond	Richmond and Maysville.	Small.
Kingman	do	58+	Small	do	do	Do.
Lees Creek	do	30		do	do	Do.
Little Center	do	100		do	do	Do.
Lumberton	do	100+		do	do	Do.
McKay	do	100+		do	do	Do.
Martinsville	Till, moraine	40	Moderate	do	do	Do.
Melvin	Till	10		"Niagara"	"Clinton"	Usually plenty.
Midland	do	14	Moderate	Richmond	Richmond and Maysville.	Small.
Morrisville	do	100+		"Clinton" (?)	"Clinton" (?), Richmond and Maysville.	Moderate.
New Antioch	do	75		"Niagara"	"Clinton"	Usually plenty.
New Burlington.	Alluvium	65+		Richmond	Richmond and Maysville.	Small.
New Vienna	Till	40	Moderate	"Niagara"	"Clinton"	Usually plenty.
Oakland	do	110+	do	Richmond	Richmond and Maysville.	Small.
Ogden	Alluvium	20	do	do	do	Do.
Pansy	Till	30		do	do	Do.
Port William	do	10		"Niagara"	"Clinton"	Usually plenty.
Reesville	do	20		do	do	Do.
Sabina	do	64		do	do	Do.
Sligo	do	100	Small	Richmond	Richmond and Maysville.	Small.
Westboro	do	12	Moderate	do	do	Do.
Wilmington	do	75+		"Niagara"	"Clinton"	Usually plenty.
Vander vorts Corner.	do	75+		Richmond	Richmond and Maysville.	Small.

DARKE COUNTY (SOUTHERN).

By Frederick G. Clapp.

SURFACE FEATURES.

The part of Darke County included in this report ranges in elevation from 1,000 feet along Millers Fork and on the branch of White Creek to over 1,220 feet on some of the hills in the western part of the county. The area may be said to consist in general of three types of surface—(1) broad, gently undulating plains, which form by far the greater portion of the whole; in this type of surface hills over 20 feet high are rare; (2) a belt of north-south morainal hills, rising 100 feet or more above the surface of the clay plains and valleys on which they rest and crossing the western edge of the area; this region is very undulating; (3) the valleys of a few small creeks, from a few feet to 100 feet or more below the surrounding country and from a few feet to one-fourth mile broad.

Except in a few localities, rock is not exposed at the surface, but is buried under a few feet to nearly 300 feet of sand, gravel, and till. The underlying rock surface is known from well records to be very irregular and to bear no relation to the form of the present surface.

WATER-BEARING FORMATIONS.

By M. L. Fuller.

SURFACE DEPOSITS.

ALLUVIUM.

The material classed as alluvium includes that deposited by streams in present or former valleys. It ranges from coarse gravel to fine clay and silt. The silt commonly forms the surface of the present flood plains of the creeks and the other deposits lie underneath. Alluvial deposits not only include those of the present-day streams, but they underlie large areas of till plains, where they help to fill valleys that are now deeply buried but that existed as true valleys before the glacial epoch. These buried alluvial deposits, which are generally reported by well drillers as sand or gravel, commonly constitute the water-bearing gravels in the regions covered by till. Many of them were probably laid down as outwash deposits during the closing part of the earlier of the two glacial stages.

With the exception of the dug wells in till the great majority of wells in southern Darke County obtain their supplies in the alluvial sand and gravel deposits buried underneath till. The waters are hard but otherwise good. The till acts as a surface covering and prevents pollution by surface water.

TILL.

The material which forms the surface over most of southern Darke County and which makes up a large bulk of the deposits lying above bedrock is a hard, pebbly clay known as till. This material forms the greater part of the broad flats covering a large area in this county and is also abundant in the valleys and the areas of morainal deposits. From well records and from general geologic conditions it is believed to occur, where deep, in at least two different layers, each representing a glacial stage.

Many cliffs along the creeks and elsewhere show the character of the till. It is uniformly very hard and tough and generally pebbly. Its normal color is blue-gray, but in its upper few feet it is everywhere weathered to a buff. Water is not abundant in the till on account of its clayey and generally impervious nature, but perhaps a dozen wells in southern Darke County obtain small amounts from somewhat sandy lenses. The water in the till itself is of rather poor quality and is frequently contaminated by surface drainage. All good wells go through the till into underlying gravels or rock.

MORAINAL DEPOSITS.

The morainal deposits of Darke County are mostly confined to the portion west of New Madison. They are very hilly, are much cut up by ravines, and in places have what is known as the kettle-hole type of surface—that is, they contain small depressions without any outlets. The moraines are composed largely of sand and gravel, but contain also some irregularly intermixed pebbly clay or till. In places large numbers of bowlders, some of them several feet in diameter, cover the surface. These are sometimes struck in wells and are mistaken for bedrock.

Water is generally present in morainal deposits, but the heterogeneous mixture of sand, gravel, clay, and till, and the extremely undulating surface of the deposits make the depth to it uncertain. One well is said to have gone more than 200 feet before striking bedrock and to have found little water. This, however, represents an extreme case, for plenty of good water will generally be found within 100 feet of the surface.

ROCK FORMATIONS.

Rock outcrops in only one or two places in Darke County. Elsewhere it is buried beneath great depths of drift and is reached by only a moderate number of wells. So far as known the rock consists of the "Niagara" limestone from 100 to several hundred feet thick, underlain by the "Clinton" limestone and the Richmond and Maysville formations. The "Niagara" limestone is very hard, but contains numerous small solution passages through which water circulates. These may be tapped by the drill and good wells obtained. Some wells fail through reaching the bottom of the limestone without striking any of these water-bearing passages, but most of those to the "Niagara" are successful. Many of them penetrate the rock only a few feet. The water is of excellent quality and not so liable to pollution as that in the drift.

NOTES BY TOWNS.

ARCANUM.[1]

The waterworks of Arcanum consist of six wells 38 to 80 feet in depth and 8 inches in diameter, drilled on the plain at the southeast corner of the village. The plant was installed in 1906. The wells entered rock at 36 feet, and most of the water was encountered within 2 feet of the top of the rock. The water rises within 10 feet of the surface.

About a dozen wells have been drilled for gas at Arcanum, and some of these have met with success. No records were kept, but their maximum depth is believed to be about 1,200 feet. Gas was obtained in the "Birdseye," and the successful wells have been productive for 15 years. Little or no salt water is reported to have been found.

GORDON.[1]

At Gordon several small flowing wells situated along a small valley constitute an interesting feature. The wells consist of 1¼-inch pipe driven about 13 feet to rock. The water overflows at about a gallon a minute in a constant stream 2 feet above the surface. The head is derived from the slight rise of the surface deposits a few hundred feet to the east.

WATER PROSPECTS.

The following table shows the general underground-water conditions at each of the more important localities in southern Darke County:

Underground-water conditions in southern Darke County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rocks nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Arcanum	Till	27-36	Moderate	"Niagara"	"Niagara" and "Clinton."	Usually plenty.
Gordon	do	92	do	do	do	Do.
Ithaca	do	8-30	do	do	do	Do.
New Madison	do	28-50	do	do	do	Do.
Savona	do	115	do	do	do	Do.

[1] Conditions in 1906.

GREENE COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

The surface features of Greene County differ considerably in different parts. East of a north-south line drawn approximately through the center the surface is prevailingly high and, although cut by many valleys, is marked by rather wide stretches of relatively flat uplands between the streams. West of the line are the broad, deep valleys of Little Miami River and Beaver Creek and the sharper but still deeper valleys of their tributaries. In the northwest corner is a considerable area belonging to the valley of Mad River. From 100 to 200 feet above the streams are flat plateau remnants similar to though much smaller than those east of the Little Miami. The elevation of the valleys is usually from 800 to 850 feet, and that of the uplands ranges from 950 feet in the western part of the county to 1,100 feet in the east. The larger valleys, such as those of Little Miami River and Beaver Creek, are broad and open, but many of their tributaries head in deep, cliff-walled ravines, marked by picturesque waterfalls. Good examples of such ravines may be seen at Yellow Springs and Clifton.

WATER-BEARING FORMATIONS.

In Greene County alluvium, pebbly clay or till, and morainal materials constitute the chief surface deposits and "Niagara," "Clinton," and "Richmond" the chief rock formations.

SURFACE DEPOSITS.

ALLUVIUM.

The principal area of alluvial deposits is in the Mad River valley, at the extreme northwest corner of the county. This valley is 2 miles or more in width and contains many square miles of alluvium. In character the deposits are prevailingly gravelly, but interbedded with the gravels or overlying them in places, especially near the sides of the valley, is more or less till. In some places knolls of till project through the gravel surface. The valleys of Beaver Creek and of Little Miami River are locally of considerable width and contain important deposits of alluvium. The alluvium on Beaver Creek is connected with and partakes of the character of the deposits in the Mad River valley, both being largely the work of earlier streams or of earlier stages of the same stream. The alluvium of the Little Miami is to a somewhat greater extent the work of the present stream. The valleys of the smaller streams are not generally very wide nor their deposits extensive. As in adjacent counties, considerable alluvium doubtless exists in buried channels beneath the till.

Abundant water can be procured from the alluvium at almost all points, but the depth to it varies considerably, according to the elevation of the surface. On the lower bottoms near the streams water is often found at the level of the stream at depths of 10 to 15 feet, but farther back, where the surface rises to low terraces, the depths to water are somewhat greater. The wells on some of the low swells and knolls, although surrounded by alluvium, are themselves in till. A few wells starting in alluvium encounter till a short distance below the surface, but the water in these is scanty, and most wells must go considerably deeper for their supplies.

TILL.

The till, which is a yellowish pebbly clay at the surface, grades downward into blue clay at depths of 10 to 15 feet. It forms a mantle over the whole surface except in the alluvium-filled valleys, burying the rocks to depths of a foot to 50 feet or more. The variation in depth to rock is due mainly to the inequalities of the rock itself, the till surface being rather flat. The till is thinnest along the sides of the valleys, near which in many places the rock outcrops. Back from the valleys the drift gradually thickens, reaching 25 to 50 feet on the general uplands and being thicker over buried valleys. At Wilberforce it measures over 75 feet and at Bowersville 50 to 75 feet. There appear to be some sand and gravel layers in the till, but they are less numerous than in the counties to the northwest.

As would be expected from the scarcity of gravel and sand layers, the water supplies of the till are not so abundant as in areas where such layers are common. There is usually, however, enough water, even in the more clayey areas, for ordinary domestic and farm purposes, providing the till has a thickness of 20 feet or more. Where it is thinner than this the supplies are likely to be scant. This is especially true in Cedarville and Miami townships.

MORAINAL AND OTHER GRAVELS.

Two north-south belts of morainal deposits occur in Greene County, one along the eastern boundary and another just east of Xenia. The drift knolls constituting these belts are not very high and contain more pebbly clay and less gravel than are commonly found in moraines. Besides the morainal drift numerous more or less sheetlike deposits of sand and gravel occur, representing the outwash from the glacial ice during its retreat from the region and being in fact a glacial alluvium located on the uplands instead of the valleys. It is possible that in part at least the deposition took place in temporary glacial lakelets.[1]

The morainal belts, being composed either entirely of till or of a thin gravel spread over the surface, do not differ greatly from the pebbly-clay uplands as to their water supplies. The gravels and sands, because of their elevated position and the readiness with which they are drained, are not important sources of water, it being usually necessary for wells to penetrate to the underlying till.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

The "Niagara" limestone, the highest and youngest of the rock formations of Greene County, forms the surface beneath the drift over the entire eastern half. Its western boundary enters the county from the north just east of Osborn, passes with some irregularities southward to the vicinity of Byron, and then swings around to the east and up the valleys of Little Miami River and Clark and Massie creeks, whence it passes southeastward just east of Xenia, leaving the county in the center of Cæsars Creek Township. An outlier also appears on the highlands of southwestern Beaver Creek Township. In fact, the "Niagara" in Greene County is distinctly an upland formation.

In character is varies considerably in the different beds. At the base, separating it from the underlying "Clinton," is about a foot of blue clay. Over this comes a layer of bedded limestone, suitable for quarrying and as much as 10 feet in thickness. This is overlain in succession by 30 feet of shale and 85 feet or more of blue and drab massive to bedded limestone, making a total thickness of about 125 feet.[2] In Cedarville and Miami townships it is very near the surface, the rocks outcropping as cliffs along many of the ravines and being barely covered at numerous other points, as at Yellow Springs, Clifton, and Cedarville. Elsewhere the drift is in many places of considerable thickness.

The "Niagara" of Greene County carries considerable quantities of water and gives rise to a great number of springs. These emerge at two levels. The upper is at a thin shale parting 60 or 70 feet above the base of the formation and in general is less important as a spring horizon than the top of the shale bed 30 feet lower down, but the Chalybeate Spring of the Neff Grounds at Yellow Springs (Pl. IX, *B*), the most noted spring of the county and one which flows over 100 gallons a minute, occurs at this level. The springs at the top of the 30-foot shale bed are both numerous and copious, especially along the Little Miami below Clifton and on Massie Creek below Cedarville.

[1] Orton, Edward, Geol. Survey Ohio, vol. 2, 1874, p. 681.

[2] Idem, p. 668.

The lower springs, the Arctic and Magnetic of the Neff Grounds (p. 107), belong to this horizon. A few springs occur at the blue-clay parting between the " Niagara " and " Clinton " limestones.

Wells sunk into the " Niagara " limestone usually get fair supplies if carried to the 30-foot shale bed, along the top of which the water collects. Some shallow wells get water from the upper shale parting, but the supplies are small and not permanent.

" CLINTON " LIMESTONE.

The " Clinton " limestone is semicrystalline, is largely pinkish or reddish in color, and has a thickness varying from 25 feet near Spring Valley to 50 feet near Yellow Springs. It is irregularly bedded and is prevailingly sandy near its base. Its outcrop extends along the western border of the " Niagara " and occurs as outliers at short intervals along the western border of the county south of the Mad River valley. The outcrops in the vicinity of Mad River are extensive, and others occur at many points near Xenia, on Oldtown River, on Massie Creek, at the head of Ludlow Creek, etc. The " Clinton " is marked at several points by sink holes into which a few streams disappear, as near the junction of the Xenia-Fairfield and Dayton-Yellow Springs pikes, to reappear elsewhere as large springs.

The " Clinton " limestone carries much water in the form of underground streams occupying channels dissolved in the sandy and more soluble basal layers at the contact with the impervious shales of the underlying Richmond. Among the more important springs at this level are those at the head of Ludlow Creek and at Goes station. Most wells sunk to the same horizon would doubtless procure considerable water, but the supplies are no greater than those in the overlying " Niagara," and it is therefore seldom worth while to sink to the deeper bed for the supply.

RICHMOND FORMATION.

The Richmond formation underlies the drift and alluvium in the lower portions of the county, or in the area west of the outcrop of the " Clinton." Its upper part consists of a 25-foot bed of fine shale, bluish or reddish in color, lying just below the " Clinton " at Goes and elsewhere. Below this lie the usual alternations of thin layers of bluish limestone and shale, the total exposed thickness of these layers in the county being about 250 feet. Although it doubtless contains some water, the Richmond formation is far less important as a water bearer than the overlying limestones, and except where these beds and the water-bearing alluvium and drift are all absent, it will rarely be advisable to drill for water in the formation. Its chief importance is as an impervious bed concentrating the water in the overlying " Clinton."

NOTES BY TOWNS.

CEDARVILLE.[1]

The first deep well in the vicinity of Cedarville was sunk near the site of the Hager paper mill 25 years ago in search of oil and gas, reaching a depth of about 1,500 feet. A heavy stream of fresh water was encountered at about 250 feet. The well failed to obtain oil or gas and was later plugged at about 300 feet, and a deep-well pump, afterwards replaced by an air-lift system, was installed for raising the water for use in the manufacture of paper at the works of the Hager Straw Board & Paper Co. From 150 to 200 gallons a minute was obtained, the water standing under this draft at 75 feet below the surface.

In 1903 two additional 8-inch wells were sunk to a depth of 400 feet. Water was encountered at the same depth as in the original well, apparently coming from the same seam, as the pumping of one immediately affected the level of the others, and no additional supply was obtained. The wells are used only in dry seasons, the creek furnishing the supply at other times. The well water (see analysis, pp. 200–201) is distinctly harder than that of the creek. The drill is reported to have dropped some distance when the water seam was encountered, apparently indicating an open channel in the limestone.

The town of Cedarville is located on "Niagara" limestone, the rock in many places being almost at the surface. It is full of fissures, some of which conduct matter from privies, barns, etc., directly to the wells, badly contaminating some of them and increasing the danger of typhoid fever.

The cost of drilling deep wells and of properly casing them prohibits their construction by private parties, and it is highly desirable that some sort of a public supply be installed at the earliest possible date. The best water supplies would be those from alluvium (see p. 41), but, unfortunately, the creek at Cedarville flows on or near bedrock, and no deep deposits of alluvium occur. The next best supplies would be afforded by the gravelly or sandy layers in the pebbly clay or till (p. 43), but these also are very poorly developed at Cedarville, being represented by only the few feet of soil overlying the bedrock. A drilled well would probably find water similar to that in the paper-mill well at a depth of 250 to 300 feet, but if it does not it will be useless to go deeper, as the underlying rocks are not water bearing, and some form of surface supply must be installed instead. If a deep well is sunk, the casing should on no account be stopped at the rock surface, but should be carried to not less than 150 to 200 feet, to shut off all possibility of pollution through the crevices mentioned.

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[1] Conditions in 1906.

CLIFTON.[1]

What has been said of the conditions at Cedarville applies with equal force at Clifton, which is similarly situated on a limestone outcrop. Few towns have suffered more from cholera and typhoid than this, some epidemics, like the cholera epidemic of 1849, sweeping the town with disastrous effect. Most of this could have been avoided if pure water had been available.

The most promising source of water for a public supply is the thick clayey and gravelly deposit on which the higher part of the town is located. A well located 300 feet or more from any house and carried to the rock would probably obtain safe water, although several wells might be required to yield the necessary amount.

GOES.[1]

The " Clinton " limestone, which comes to the surface at Goes, gives rise to an unusually large number of fine springs on the hillsides above the village. Other good springs occur along the river; in fact, the springs are so abundant that they form the chief water supply in this vicinity. One was long used by the railroad; others supply the boilers, houses, and works of the Miami Powder Works; and many others supply private families.

JAMESTOWN.

A well, reported to be 1,776 feet deep and known as the "1776 well," was sunk in Jamestown some years ago in search of oil and gas. None was found, but a strong sulphosaline water, termed the "1776 water," was obtained and later put on the market for medicinal purposes. A partial analysis is given on pages 200–201.

OSBORN.[1]

A deep well sunk at Osborn during the oil boom 25 years ago reached the " Birdseye " limestone at 990 feet, or 170 feet below sea level. A record is given below:

Record of deep well at Osborn, Ohio.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	207	207
Blue shale (Richmond and Maysville)	500	707
Darker shale (Eden shale)	213	920
Gray rock (Point Pleasant formation)	70	990
Hard crystalline limestone ("Birdseye").		

[a] Orton, Edward, Geol. Survey Ohio, vol. 6, 1888, p. 290. Correlations by M. L. Fuller.

Gas was obtained at 750 to 850 feet, but no water seams of importance are recorded.

The public waterworks, which were installed in 1895, are operated in connection with the electric-light system. The water is obtained

[1] Conditions in 1906.

from alluvium at the north end of town at a depth of about 50 feet, an overlying layer of clay preventing the access of polluting matter to the water-bearing gravel. Other particulars will be found in the table on page 51.

PAINTERSVILLE.[1]

The wells near Paintersville are of interest as affording flowing water. The supply comes from a dark sand or gravel, locally known as "black" sand, occurring beneath a bed of clay at depths of 35 to 140 feet. In about half a dozen wells the water flows freely at the surface, but apparently will not rise much above it.

SPRING VALLEY.[1]

A well sunk at Spring Valley during the oil boom is said to have reached a depth of 1,460 feet and to have obtained a large amount of saline water. The "Birdseye" was reached at about 850 feet, or 100 feet below sea level. Neither oil nor gas was obtained. The principal seam of fresh water was found at 165 feet. The water has in late years been placed on the market by the Spring Valley Medicinal Water Co.

WILBERFORCE.[1]

Wilberforce is the site of a number of institutions of learning. The scattered residences depend on wells for their water, but the college buildings are supplied by a good-sized spring in an adjoining ravine. The spring is inclosed by cement walls and protected by a spring house, the water being pumped to the buildings on the plateau above by a gasoline engine.

XENIA.[1]

A number of deep wells have been drilled at or near Xenia. The record of one of them, drilled in 1887 by the Xenia Gas Co., is given below:

Record of deep well at Xenia, Ohio.[a]

	Thickness.	Depth.[b]
Drift:	*Feet.*	*Feet.*
Clay	6	6
Gravel	20	26
Sand	35	61
Quicksand	25	86
Cemented sand	8	94
Richmond formation: Light-colored shale, etc	210	....
Maysville, Eden, and Point Pleasant formations:		
Dark shale	325	....
Black shale	32	....
Shell rock	2	....
Black shale	114	1,040
"Birdseye" limestone (penetrated)	160	1,200

[a] Orton, Edward, Geol. Survey Ohio, vol. 6, 1888, p. 290. The identifications of geologic formations are by the author.

[b] The thickness of the formations above the "Birdseye," as published in the record, add up only to 777 feet, indicating the presence of unrecorded strata having a thickness of 263 feet, the position of which is not known.

[1] Conditions in 1906.

The record gives the depth to the top of the "Birdseye" as 1,040 feet, which would place it about 170 feet below sea level at this point.

The first public supply in Xenia, owned and operated by the Xenia Water Co., was installed in 1887, the water being obtained by impounding the run-off of several springs 1½ miles north of the city. Some surface water also entered the reservoir. Later a large well was sunk through the surface coating of till into the underlying gravel. From this the water was conducted to a receiving well at the reservoir, and both reservoir and well water pumped to the standpipe. The springs supply about 300,000 gallons and the well 100,000 gallons daily.

Since 1896 six 6-inch wells, six 8-inch wells, and two 10-inch wells, located southwest of the city and penetrating a bed of gravel below the till to depths of 28 to 40 feet, have been added to the system. About 25,000 gallons daily is obtained from these wells in wet seasons. A test well sunk in the rock to 315 feet found the seams to be filled with clay, and the small amount of water obtained tasted rank and oily. Two 150-foot wells at the old station likewise proved to be failures. An analysis of the public supply is given in the table on pages 200–201.

YELLOW SPRINGS.[1]

Yellow Springs has long been noted for its mineral waters. Even in the time of the "mound builders" it was much frequented, as is attested by the mound near the Chalybeate Spring, in the Neff Grounds, and by the deep pits sunk in the limestone. The old trail between the Indian villages of the Miamis, at Oldtown and at Mad River, below Springfield, passed the spring and glen. Early in the last century the spring was selected as a site for the socialistic experiment of Robert Owen, and a building was begun, but the locality was soon abandoned in favor of another at New Harmony, Ind. For many years after the Civil War Yellow Springs was a popular resort, and a hotel accommodating 500 people was built here in 1870. In later years more northern resorts drew away most of the visitors, and in 1901 the hotel was demolished. At present the springs are developed as a recreation park (the Neff Grounds), which caters to those caring for the natural scenery and water rather than for more artificial attractions.

The natural attractions include a wooded park, bordered by high limestone bluffs of "Niagara" limestone, the Chalybeate, Arctic, and Magnetic Springs, and a picturesque lake of 5 or 6 acres fed by springs. The Chalybeate (see Pl. IX, *B*) is the principal spring of the park. It issues from the "Niagara" limestone with a volume of about 100 gallons a minute and flows over a broad expanse of moss-covered tufa, plunging over the edge into the valley below

[1] Conditions in 1906.

(Pl. IX, *A*). The tufa mass, which is some hundreds of feet across and 20 feet or more thick, is not the least interesting feature of the park. It represents the accumulation of mineral matter brought out in solution by the spring in the course of centuries and deposited over the ground and the surface of grass, leaves, and twigs, a process which may still be seen in actual operation. The tufa varies considerably in composition, some parts carrying much more iron than others. Analyses of both the iron-bearing tufa and of the purer type are given below; an analysis of the water will be found on pages 200–201.

Analyses of tufa at Yellow Springs, Ohio.[a]

	Ferruginous.	Calcareous.
Carbonate of calcium	92.97	97.60
Carbonate of magnesium	2.42	1.21
Oxide of iron and alumina	3.80	....
Silica	.80	.60

[a] Geol. Survey Ohio, vol. 2, 1874, pp. 678, 692.

Besides the deposit at the Chalybeate Spring, other accumulations of tufa, or "red bank," as it is called locally, are found at other points in the park, especially on the east side of the lake a few hundred yards above the main spring.

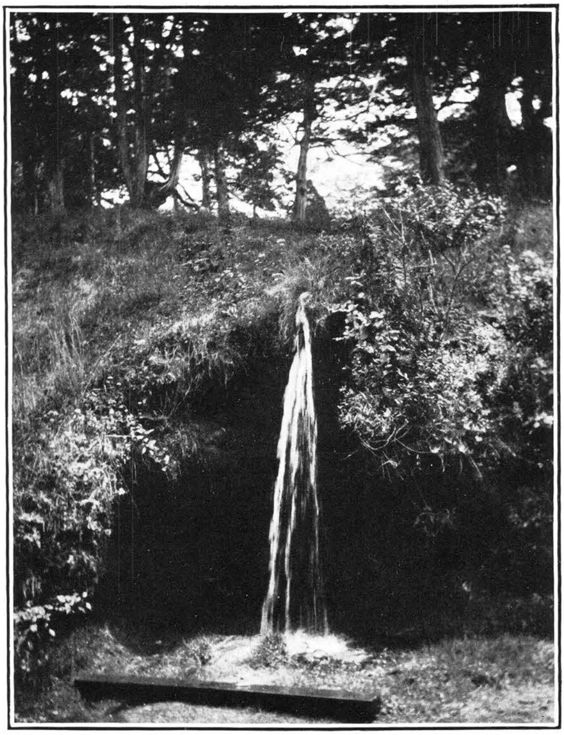
The Arctic Spring is situated at the base of the bluff on the east side of the lake and has a flow of about 5 gallons a minute. The Magnetic Spring is in a ravine entering from the east about a quarter of a mile below the Chalybeate Spring, and has a flow of about 15 gallons a minute. The water of the Arctic Spring is hard, but that of the Magnetic Spring appears to be relatively soft. Neither carries any iron or any notable amount of gas.

WATER PROSPECTS.

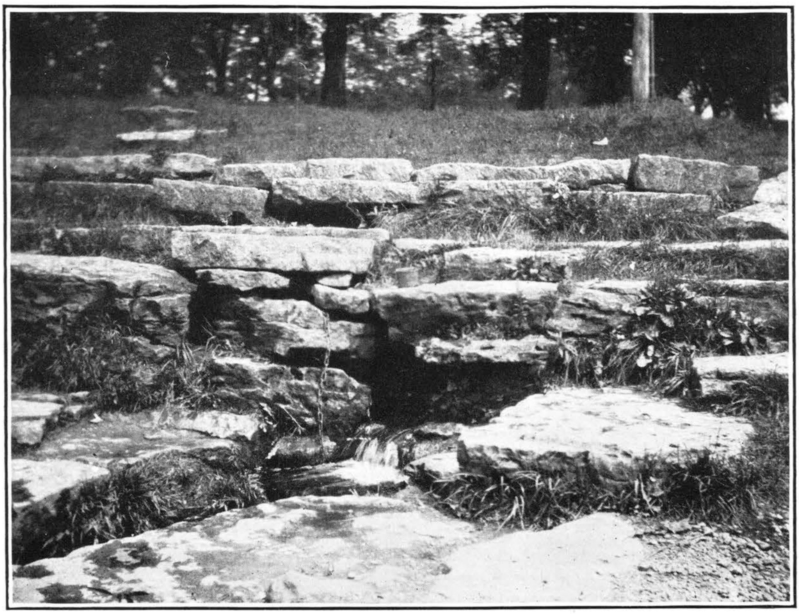
The table below gives summaries of the underground-water conditions at the principal villages and towns of Greene County:

Underground water conditions in Greene County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Alpha	Alluvium	35+	Plenty	Richmond	Richmond and Maysville.	Small.
Bellbrook	do	30+	do	do	do	Do.
Bowersville	Till, moraine	60	....	"Niagara"	"Clinton"	Usually plenty.
Byron	Till	30	Fair	Richmond	Richmond and Maysville.	Small.



A.



B.

SPRINGS ON NEFF GROUNDS, YELLOW SPRINGS, GREENE COUNTY.

A, Spring falling over tufa deposit; *B*, Chalybeate Spring emerging from "Niagara" limestone above a shale parting.

Underground water conditions in Greene County—Continued.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Cedarville	Till	5	Fair	"Niagara"	"Clinton"	Usually plenty.
Clifton	Till, alluvium.	5–20	Moderate.	do	do	Do.
Fairfield	Alluvium under till.	40+	Fair	Richmond	Richmond and Maysville.	Small.
Ferry	Till	25		do	do	Do.
Gladstone	Till, moraine	75		"Niagara"	"Clinton"	Usually plenty.
Goes	Till, alluvium.	25	Plenty	"Clinton", Richmond.	"Clinton," Richmond, Maysville.	Moderate.
Grape Grove	Till, moraine	70		"Niagara"	"Clinton"	Usually plenty.
Hawkers	Till	35		Richmond	Richmond and Maysville.	Small.
Hopkinsville	do	60		"Clinton" or "Niagara."	"Clinton"	Usually plenty.
Huffeysville	Alluvium	30+	Plenty	Richmond	Richmond and Maysville.	Small.
Jamestown	Till	40	Moderate.	"Niagara"	"Clinton"	Usually plenty.
New Jasper	do			do	do	Do.
Oldtown	Alluvium, till.			Richmond	Richmond and Maysville.	Small.
Osborn	Alluvium	30+	Plenty	do	do	Do.
Painterville	Till	140+	do	"Niagara"	"Clinton"	Usually plenty.
Roxanna	Terrace gravel.	50+	Moderate.	Richmond	Richmond and Maysville.	Small.
Spring Valley	Alluvium, etc.	30+	Variable	do	do	Do.
Trebeins	Alluvium	30+	Plenty	do	do	Do.
Wilberforce	Sandy till, moraine.	80	do	"Clinton"(?)	"Clinton"	Usually plenty.
Xenia	Till, moraine	50	Fair	Richmond	Richmond and Maysville.	Small.
Yellow Springs.	Till	5–15	Moderate.	"Niagara'	"Clinton"	Usually plenty.
Zimmerman	Alluvium, till.	90+	do	Richmond	Richmond and Maysville.	Small.

HAMILTON COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

Hamilton County is essentially a plateau, consisting of rather flat uplands lying about 500 feet above the Ohio or a little more than 900 feet above sea level. The surface, however, is not continuous but is broken by many valleys, among which are Miami, Little Miami, Mill Creek, Whitewater, and the streamless valleys connecting the Mill Creek and Little Miami valleys north of Cincinnati and the Whitewater and Miami valleys near the Butler County line, in the southwestern part of the county.

Many interesting features are presented by the valleys of Hamilton County. The main bottoms, where they join the Ohio, have an elevation of about 475 feet, agreeing approximately with that of the Ohio flats, but the tributary valleys, 10 or 15 miles back from the Ohio, generally stand at least 100 feet higher. The width of the valleys bears little or no relation to the size of the streams now occupying them. For instance, the valley of the Little Miami is decidedly wider than that of the Ohio, and the valley from the Little Miami to Mill Creek, which contains no stream, is fully as wide as that of the Little Miami. Mill Creek valley near its mouth is only about half a mile in width, but above St. Bernard, where it is joined by a valley connecting with the Little Miami, it is a mile or two wide. Again, the Miami in Hamilton County flows in a narrow valley, in many places less than half a mile wide, although a broad channel 2 miles or more in width but unoccupied by any continuous stream leads westward from it just south of the Butler County line, connecting with the Whitewater Valley at the western edge of the county and extending southward to the Ohio near the Indiana State line.

These anomalous features are the result of drainage changes which have taken place in late geologic time. Originally the Ohio, instead of flowing past Cincinnati, turned northward just east of that city, flowing up the valley now occupied by the Little Miami to Newton, thence past Madison, Norwood, etc., by way of the old valley to Mill Creek. Here, turning north, it flowed past Elmwood, Wyoming, Lockwood, etc., to the Miami south of Hamilton, where it appears to have turned westward and southwestward, entering the present Whitewater Valley near the county line and flowing southward to join its present channel just west of the Indiana line. At this time, there being no east-west channel past Cincinnati, the Licking probably flowed northward across the site of Cincinnati and through the valley now occupied by Mill Creek, joining the main Ohio at St. Bernard. As the streams continued to flow in the channels indicated their beds were gradually built up by sand, gravel, etc., brought down from higher points on the stream, until a level of 600 to 640 feet above the sea was reached. The streams flowing at this level found divides across which they could cut and seek shorter courses than those in which they were then flowing, and, on the uplift of the land, the present channels were begun and have since been gradually deepened. These old valleys are of great importance with reference to underground water.

WATER-BEARING FORMATIONS.

The water-bearing beds in the surface materials include alluvium, terrace gravels, loess, till, and morainal deposits. The rock formations outcropping at the surface are the Richmond, Maysville, Eden, Utica, and Point Pleasant. Beneath these, but not outcropping, are the "Birdseye" limestone, St. Peter sandstone, Cambro-Ordovician dolomite, and Cambrian sandstone.

SURFACE DEPOSITS.

ALLUVIUM.

The alluvium occurs mainly in the larger valleys, where it varies greatly in extent, character, and depth.

In the Ohio Valley the alluvium, or those beds which constitute the flood plains of the river, occurs mainly as narrow strips ranging from a quarter to half a mile in width. To a depth of 6 or 8 feet the material is usually a sandy loam. Beneath this occurs commonly 30 feet or more of alternating beds of clay and silty sands and gravels, below which lies a thick bed of clay, including some ocher layers and sporadic tree stumps and peaty material. Beneath this again, just above low-water level, is a considerable bed of clean gravel. From low-water level to bedrock, gravel and sands commonly predominate.

The alluvial deposits of the other valleys, especially those not now occupied by large streams, differ notably from those of the Ohio. In many places beneath about 10 feet of silty soil and a few feet of sand there lies a bed of blue clay that carries some pebbles and is over 35 feet thick. Some of this blue clay is clearly of glacial origin, representing an old till. Beneath the till gravelly deposits having a thickness of about 35 feet are again encountered, and beneath these is a 25-foot bed of blue clay, with sand and pebbles, possibly representing another till. At the base in Mill Creek valley there is 43 feet of sand and waterworn gravel with a little blue clay.

In the smaller valleys and ravines entering the Ohio the alluvial deposits consist generally of coarse gravels, but the streams commonly flow near bedrock and the deposits are of no great thickness.

In addition to the alluvium of the present and abandoned river channels, already described, indications of old stream deposits exist at an elevation of about 740 feet at the north end of the village of Mount Washington and on the American Flats southeast of that town. These consist of sands and gravels containing at one locality the remains of a mastodon and other mammals. They apparently represent the channel of some small stream flowing near the crest of the uplands before the present valleys were developed.

Ample supplies of water can be obtained from the alluvium in all the larger valleys, both of the present streams and of the abandoned Ohio channels. In general, a little water is found above the clay layers, but, as these are generally well above low-water level and are quickly drained whenever the river is low, the supplies are variable. It is only when the gravels beneath the clays are reached that permanent supplies are procured. At some places in the Miami and Little Miami valleys the clays are absent and the first water is found in the gravels approximately at the stream level. Similar conditions exist in the abandoned valleys of the Ohio, except that in places it is necessary, in order to obtain large supplies, to sink to the level of the main Ohio Valley, which is considerably below the level of the small surface streams occupying the old channels. Supplies can be obtained from the coarse gravel deposits of the small tributaries wherever the stream grade is not too steep or the rock too near the surface.

TERRACE GRAVELS.

Standing above the Ohio flood plain, which has an altitude of about 475 feet, are a number of gravel terraces rising to various elevations from 540 to 550 feet. Examples of such terraces are found at California, at Home City, and at Cincinnati. Similar terraces are present along Little Miami River at elevations from 560 to 620 feet. The terraces at Terrace Park and Milford are especially good examples. Along Mill Creek terraces rise to an altitude of over 600 feet, or more than 80 feet above the stream. These are especially conspicuous in the vicinity of Carthage, Hartwell, and Arlington Heights. Similar, though less extensive, terraces exist along the Miami. The deposits are of alluvial origin and were laid down by the Ohio when it was flowing northward at its higher level to the Miami and thence southwestward through the Whitewater Valley. These higher terraces are distinctly older than the lower ones along the Ohio, which were built by the stream at certain stages since it has been flowing in its present valley. Higher up the Little Miami, Mill Creek, and the Miami the streams have cut less deeply and are flowing nearer the terrace level. In most places near the northern edge of the county the streams are flowing on top of the deposits which farther down the valleys constitute the terraces. The higher terraces, where exposed, seem to be composed mainly of gravel and sand down to stream level, but borings are too few to indicate the character of the deposits below that level. One of the characteristic features of the terrace gravels is the occurrence in them of layers, locally called cement rock, which have been cemented into a hard crust by the deposition of iron oxide by percolating waters. The lower terraces, however, consist of the same succession of sands, clays, buried soils, trees, etc., that is found in the flood plains, the average section in the vicinity of Cincinnati being as follows: [1]

Generalized section of terrace deposits near Cincinnati.

	Feet.
Soil	2–5
Gravel and sand, with seams of loam	40–60
Brick clay, with sand and loam	20–30
Buried soil, trees, leaves, etc	5–10
Gravel and clay	5–10
	72–115

[1] Orton, Edward, Geol. Survey Ohio, vol. 1, 1873, p. 432.

Here and there small amounts of water accumulate in irregularities of the surface of the cemented layers in the gravelly portions of the high terraces, and some water is found in clay layers in the low terraces along the Ohio. To procure satisfactory supplies, however, wells must be carried to the general water level, which is commonly about at the elevation of the adjacent streams. As in the alluvial deposits, the terrace waters from the clays are high in phosphate of iron. The waters from the underlying gravels are likewise in all respects similar to those described under the alluvium.

LOESS.

Capping the flat uplands and certain of the high terraces is a thin mantle of a yellowish, somewhat clayey silt, known as loess. The deposits are best developed near the river, where they may have a thickness of 5 to 10 feet or more. From the river bluffs the thickness declines somewhat rapidly to the north, the deposits being of little importance except within a few miles of the Ohio. The loess, because of its thickness, is of no consequence as a water-bearing formation, but it assists materially in absorbing and holding rain water and in feeding it to the underlying till or weathered rock.

TILL.

Except on the steep bluffs facing the streams, Hamilton County is covered by a thin mantle of pebbly clay or till, ranging in thickness from 5 to 25 feet and in color from yellowish in the upper 5 or 10 feet to blue in the lower part. Much of the till is somewhat gravelly and some of it may even include beds of water-deposited sand or gravel.

The till affords supplies to shallow wells at many places on the upland plateaus, especially where it is 15 feet or more in thickness. Where it is thinner it is chiefly of importance in collecting the rain water and feeding it to the underlying rocks. Where gravelly layers are found on the flat uplands good supplies are procured, but near the edge of the bluffs, where the water may escape readily, they are more difficult to obtain.

MORAINAL DEPOSITS.

Morainal deposits are very sparingly developed in Hamilton County, being confined to a very small area near the point where Mill Creek enters the county. They consist largely of gravels and sands, but include some clay or till. They form knolls and small hills from 10 to 20 feet or more in height and constitute a part of the general belt which enters the county from the northeast near Sharonville and turns northwestward at Mill Creek, skirting the northern boundary on one side or the other as far as the Indiana line. Owing to the predominance of porous gravels water is rarely retained in the morainal deposits and wells in general must penetrate the underlying formations to procure adequate supplies. Where till predominates in the moraines the water supply is the same as in the sheet of pebbly till.

ROCK FORMATIONS.

RICHMOND AND MAYSVILLE FORMATIONS.

The Richmond and Maysville formations compose the upland surface throughout Hamilton County and occupy the upper parts of the bluffs down to about 300 feet above the Ohio. The surface of the rocks is generally much weathered and more or less disintegrated to a depth of several feet. The beds exposed appear to be between 400 and 500 feet in total thickness and to consist mainly of alternating layers of limestone and shale 1 to 10 inches thick; in some places, however, as near the junction between the two formations, shale beds predominate.

Owing to the presence of the loess and till considerable quantities of rain water are collected and fed to the disintegrated upper portion of the Richmond and Maysville formation. Open wells penetrating to this weathered surface usually get sufficient water for ordinary domestic and farm purposes, but drilled wells rarely procure adequate supplies.

EDEN SHALE.

The Eden consists of gray or bluish shales weathering olive or brownish and having a thickness of about 250 feet. Except for a few thin seams of limestone, it contains no porous or soluble layers in which water can circulate. The formation occupies the lower 250 feet of the bluffs, extending up the larger valleys to points beyond the county line. Its base is a little below the level of the Ohio flood plain.

The Eden shale affords no water whatever to drilled wells and in few places yields enough to supply even ordinary dug wells.

UTICA SHALE.

The Utica shale consists of a few feet of shale immediately underlying the Eden, which it closely resembles in character. It is likewise not water bearing.

POINT PLEASANT FORMATION.

The Point Pleasant formation consists of hard, compact, dark shale in layers up to 10 inches or more in thickness, alternating with similar layers of gray limestone. The total thickness is about 150 feet, of which not more than 50 feet is above river level. The formation shows below the flood-plain level of the Ohio at numerous points throughout the county.

Although this formation carries considerable water locally, the procuring of supplies is very uncertain and the water when found is likely to be salty or sulphurous.

"BIRDSEYE" LIMESTONE.

The "Birdseye" is a massive compact grayish limestone the top of which is about 100 feet below the level of the Ohio. Wells penetrating it obtain more or less water, which, however, is commonly salty. Fresh water is not to be expected.

ST. PETER SANDSTONE.

The St. Peter sandstone is a porous sandstone approximately 400 feet thick, the top of which lies about 700 feet below river level. Wells penetrating the formation get abundant supplies of sulpho-saline water, which will rise about 175 feet above the low water of the Ohio, but which, unfortunately, is unfit for anything but cooling purposes.

CAMBRIAN AND ORDOVICIAN DOLOMITE.

The Cambrian and Ordovician dolomite is a varicolored dolomitic limestone or marble, 3,000 feet or more in thickness, lying below the St. Peter. It has been penetrated at Cincinnati to a depth of nearly 1,000 feet without yielding any material supply of water.

CAMBRIAN SANDSTONE.

The Cambrian sandstone, which is a prominent water-bearing formation in other parts of the country, may possibly occur beneath Hamilton County, but its depth, which is at least 4,000 feet below river level, is so great as to make drilling unprofitable, especially as the water it carries is almost sure to be sulphurous and unfit for use.

NOTES BY TOWNS.[1]

ARLINGTON HEIGHTS.[2]

Within a short distance from the surface, wells at Arlington Heights enter blue clay, which is said to be at least 100 feet thick. Driving is very difficult and drilling or jetting is sometimes done. A layer of old wood, tree bark, etc., is reported at about 100 feet.

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[1] The notes on Carthage, College Hill, Elmwood, Harrison, New Burlington, and St. Bernard are by Frederick G. Clapp.

[2] Conditions in 1906.

CALIFORNIA.[1]

Eight test borings, extending in a northeast-southwest direction from the New Richmond pike at California to a point in the river near the Kentucky shore, were sunk in 1896 and 1897 by the board of trustees, commissioners of waterworks of Cincinnati. They brought out the interesting fact that the rock bottom of the Ohio is only about 50 feet below low-water mark. Sections of borings on the river bank and in the river bottom are given below:[2]

Section of boring on terrace at California.

[Elevation 59 feet above low water.]

	Ft.	in.
Yellow clay	28	
Clay and fine sand	3	1
Gravel and sand	8	8
Coarse sand	25	8
Sand and gravel	1	4
Coarse sand	8	3
Small gravel, sand, and large bowlders	1	6
Coarse sand and gravel	12	6
Coarse gravel	10	8
Bedrock	6	2
	105	10

Section of boring in river bed at California.

[Elevation of river bed 9 feet 2 inches below low water.]

	Ft.	in.
Coarse sand	4	
Fine gravel	4	8
Medium sand	8	9
Fine gravel	14	
Bedrock		10
	32	3

A 90-foot well, 4 inches in diameter, located on the river bank, fluctuates with the river. Where the rise is only 3 to 5 feet the well responds in a few hours, but with a rise of 50 feet the lag may be three or four days. During a small rise the well water stands 2 feet lower than the river, but during a large rise it is as much as 18 feet lower. The slowness of the response indicates the lack of free connection between the waters of the river and those of the alluvium, although the latter, as shown by the record, is nearly pure sand and gravel at this point. In the absence of analyses it can not be determined whether the rise in the well is due to the ponding of the ground water or to the penetration of waters from the river into the alluvium.

[1] Conditions in 1906.

[2] Second Ann. Rept. Board Trustees Com. Waterworks of Cincinnati, Jan. 1, 1899, following p. 70.

CARTHAGE.[1]

The waterworks of Carthage are situated on the valley bottom at the western edge of the village, close to the Miami & Erie Canal, below the base of the surrounding hills. The supply is obtained from four 6-inch driven wells, two 135 and two 137 feet deep. The water is found in gravel and is pumped by direct pressure into an 80,000-gallon cistern on the level of the pumping station and thence into the water mains. The pumps are run day and night. This water system was constructed in the year 1890, being the first plant in southern Ohio built and operated by an incorporated village. The same system supplies the towns of Elmwood and Winton Place and several factories.

In and near the village of Carthage there are a number of drilled wells. One of them, belonging to the Chatfield Manufacturing Co., on the corner of Fifth and Lebanon streets, is about 200 feet deep. The principal water supply was obtained at 60 feet in gravel, and bedrock was struck at 100 feet. The ordinary water level is 40 feet below the surface. The temperature is 55° to 60°, and 50 to 60 gallons of water a minute can be obtained.

On the slope of the hills directly east of Carthage is situated the Longview Hospital, which has an excellent supply of water from three drilled wells, 143, 146, and 150 feet deep. The wells are 8 and 10 inches in diameter and are sunk entirely in gravel, no rock being penetrated. They lie in line with the abandoned gravel-filled valley extending southeastward from the Miami to the Ohio. The principal water vein was struck at about 50 feet from the surface. The water is used for all domestic purposes and for boilers to supply 1,350 inmates. The pumps are run nine hours a day, pumping about 250,000 gallons of water from the station near the base of the slope to a reservoir on the hill. A mechanical filter is used. The water is good. For 25 years previous to the installation of the present supply a dug well 40 feet deep was used, but the water finally gave out. Another well was drilled to a depth of several hundred feet, but no data regarding it could be obtained.

CINCINNATI.[1]

General conditions.—Most of the business part of Cincinnati is situated on a gravel terrace standing 500 to 540 feet above sea level or 70 to 110 feet above low-water level of the Ohio, but the portions near the Ohio and bordering Mill Creek are 20 to 40 feet lower and are sometimes partly covered by water during floods. In the outskirts of the city and its suburbs the hills rise to heights of over 900 feet, or 300 feet above the terrace.

[1] Conditions in 1906.

As a consequence of the peculiar situation of the city, great variability in the underground-water conditions has always prevailed. Originally water was obtained by shallow wells, but as the houses became more crowded the water became polluted, making it necessary to go deeper for supplies. For a time moderately deep wells were entirely successful, but as manufacturing establishments multiplied the demand became too heavy for the supply or the water became polluted, so that many of these wells also had to be abandoned, although some are still used. Next, recourse was had to deep drilled wells, many of which were carried to 1,000 feet and some to more than 2,000 feet, but without finding any further fresh water of consequence, although plenty of the sulphosaline water was obtained. At present a few of the dug wells remain on the outskirts of the city and a number of the deep drilled wells are still in use, but most of the well water is obtained from the driven wells sunk in the alluvial or terrace deposits or for a few feet into the underlying rocks. The greater part of the business firms and practically all the citizens use the public supply.

Well records.—An unusually large number of wells have been sunk in Cincinnati owing to the large number of breweries and distilleries, the poor quality of the public supply, and other minor causes. As a result the possibilities of getting water in this way have been pretty well demonstrated. The probable amount of the water in both the unconsolidated deposits and the rock formations has already been discussed and numerous supplementary data are given in the tables (pp. 122–123, 130, 202–203). It only remains to present a few additional facts as to the nature of the materials and the position of the bedrock surface. The character of the deposits is best shown by the following log, which represents the best available record in the vicinity. The correlation of geologic formations is added by the writer.

Record of well of Cincinnati Gas Co., Front Street.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Artificial filling	5	5
Soil	5	10
Alluvium:		
Blue clay	20	30
Sand and gravel	90	120
Point Pleasant formation:		
Shale	3	123
Blue limestone	40	163
Blue and gray limestone	50	213
Sandstone	5	218
"Birdseye" limestone:		
Limestone	380	598
White limestone	240	838
St. Peter sandstone:		
Sandstone	65	903
Sandstone, very hard	15	918
Red sandstone	62	980
White sandstone	85	1,065
Coarse sandstone and limestone	15	1,080
Sandstone	140	1,220
Cambrian and Ordovician dolomite: Very hard red and white marble	25	1,245

[a] Bell, T. J., History of the water supply of the world, Cincinnati, 1882, pp. 1–7.

Of the shallower wells that of Timothy Kirby at Cumminsville is of interest as showing the succession of materials in the Mill Creek valley.

Record of Kirby well, Cumminsville.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and brick clay	12	12
Sand	4	16
Blue clay with gravel	34	50
Gravel	19	69
Coarse sand	3	72
Sand with coaly fragments	11	83
Blue clay with gravel (base level with low water of Ohio)	9	92
Blue clay, sand, and coaly fragments	16	108
Sand, gravel, blue clay, and coaly fragments	43	151

[a] Geol. Survey Ohio, vol. 1, p. 433.

The well of John Kaufman on Vine Street illustrates the character of the terrace materials in that part of Cincinnati. The distance to rock is among the greatest recorded at Cincinnati.

Record of Kaufman well, Vine Street.

	Thickness.	Depth.
	Feet.	*Feet.*
Blue clay	25	25
Sand and quicksand	75	100
Blue clay	55	155
Quicksand and gravel	35	190
Limestone	25	215

The borings made by the board of trustees bring out the character of the deposits in the narrow part of the Ohio Valley opposite Dayton, Ky.:

Record of boring in river between Torrence Road, Cincinnati, and Dayton, Ky.

[Starts 5 feet above low-water mark.]

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Coarse gravel and bowlders	11	8	11	8
Sand	2		13	8
Coarse gravel and bowlders	12	4	26	
Fine sand	13	2	39	2
Limestone	4	11	44	1

Record of boring at foot of Lumber Street, Cincinnati, opposite Dayton, Ky.

[Starts 54 feet 10 inches above low-water mark.]

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Sand and bowlders	3		3	
Blue clay	3	4	6	4
Brown and black clay	29	2	35	6
Gravel	4	10	40	4
Blue clay		7	40	11
Clay and soapstone	3	6	44	5

The borings represented by the next three records show the character of the materials along a section extending from East Cincinnati to California, across the valley of the Little Miami. The first is located about half a mile south of Columbia, the second on the west bank of the Little Miami, and the third on the terrace near California on which the filter beds are located.

Record of boring near junction of Turkey Bottom Road and Richmond Pike.

[Starts 59 feet 7 inches above low-water mark.]

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Loam	10		10	
Sandy loam	12		22	
Blue clay	13	1	35	1
Gravel	23	1	58	2
Brown sand	27	4	85	6
Gray sand	7	2	92	8
Gravel	6	11	99	7
Rock		10	100	5

Record of boring on west bank of Little Miami three-fourths of a mile above the mouth.

[Starts 40 feet 6 inches above low-water mark.]

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Clay	24	10	24	10
Gravel	9	7	34	5
Coarse sand	5	8	40	1
Fine sand	30		70	1
Gravel	5	6	75	7
Yellow and blue clay	1	2	76	9
Rock		7	77	4

Record of boring on site of filter beds, California, Ohio.

[Starts 98 feet 10 inches above low-water mark.]

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Sandy loam	10		10	
Yellow clay	3		13	
Fine sand	33		46	
Blue clay	49		95	
Gray sand	15		110	
Brown sand	9		119	
Black sand	2		121	
Sand, gravel	10	4	131	4
Bedrock		2	131	6

Rock floor.—A study of the well records brings out a number of interesting facts regarding the configuration of the rock surface beneath Cincinnati and the old channel. Near the bluff which borders the city on the northeast the rock is relatively high, generally being within 40 or 50 feet of the surface, or nearly 50 feet above low water in the Ohio. A quarter of a mile from the foot of the hills, however, the rock is between 50 and 75 feet from the surface, or only 20 feet above low-water mark, and a little farther out it drops abruptly to about 150 feet, or 50 feet or more below low water. These depths occur along a line extending from a point west of the suspension bridge northward and northwestward to the corner of John and Liberty streets, beyond which the depth to rock is not known. Rock is penetrated by wells between the Chesapeake & Ohio and suspension bridges, at the Gibson House, Emery Hotel, Palace Hotel, and near the corners of Elm and Canal streets, Dayton Street and Central Avenue, and Liberty and John streets. To the east, as shown by wells in the vicinity of Ludlow Street, rock is well above river level, coming within 30 or 40 feet of the surface. Similar depths are shown by wells near the Cincinnati, Hamilton & Dayton depot and near the corner of Front and Harriet streets. These depths indicate a deep channel running at right angles to the Ohio and connecting with an old channel of Licking River near the Chesapeake & Ohio Railway bridge, representing without doubt the course of the Licking when it flowed northward to join the old Ohio—then flowing in the vicinity of Norwood back of Cincinnati (p. 19) and north of St. Bernard.

The depth to rock in the Mill Creek valley south of the Liberty Street viaduct is not so great as it is in the old Licking channel, though greater than under the land immediately to the east and somewhat more than in the present Ohio channel above the mouth of the Licking, where the rock appears to be at no great distance below the bottom.

Deep wells.—A large number of wells have been drilled in Cincinnati and vicinity, particulars of a considerable number of which are given in the following table. Many of them were sunk years ago, and most of the data have long been lost; others were put down by drillers who have since died or moved to other localities; and still others were sunk by drillers who kept no memoranda. The information presented affords, however, an indication of the thickness of the surface deposits, the depth to the rock floor, and the character and volume of water supplies.

Data on wells at Cincinnati.

Owner.	Location.	Driller.	Diameter.	Depth.	Depth to rock.	Head.	Temperature.	Yield.	Beds penetrated.
			Inches.	*Feet.*	*Feet.*	*Feet.*	*°F.*	*Gallons per minute.*	
American Oak Leather Co.		—— Koehne	8	180	100	−100		200	Point Pleasant.
Bank & Safe Co.	Front Street opposite Rose Street.	Ed. Boluss		90	90			Plenty	Alluvium.
Banner Brewery Co.	Canal and Walnut streets	John Pepper		800	60			Abandoned	"Birdseye," top St. Peter.
Banner Ice Co.		A. D. Cook	10	80	80	− 53			Alluvium.
Broadway Electric Plant	Broadway, above Court Street.	Bradford Well Co.		1,200				Abandoned	St. Peter.
Christian Moerlein Brewing Co.	2000 Elm Street	Christian Moerlein Brewing Co.	8	90		− 81		2½ inch stream	Alluvium.
Cincinnati Gas Co.	Front Street, between Rose Street and Gas Alley.	Ed. Boluss		1,125	125				St. Peter.
Do.	West Front Street		4½	1,360		82	60	138	Do.
Do.	Eastern Avenue		6	1,475		104	61	500	Do.
Cincinnati, Hamilton & Dayton depot.	Sixth Avenue	John Pepper		250	35			No water; a little gas	"Birdseye."
Cincinnati Ice Co.			6	265–300		− 0			Do.
Clifton Springs Distilling Co.	Ludlow Avenue, Twenty-third ward.	J. J. Groves	8	1,960	50	+ 0	63	158	St. Peter.
Coast & Coast	Spring Grove Avenue	William Hendrigsman	4	85	85	− 60			Alluvium.
Consumers' Ice Co.		E. Hendrigsman	8	405	35				"Birdseye."
Crystal Springs Ice Co.	Cumminsville	—— Hendrigsman	6	120	120	− 25	56	35	Alluvium.
Tom E. & N. Davis	Cincinnati, Hamilton & Dayton Railway and Gest Street.	Ed. Boluss		60	60			Plenty	Do.
Diamond D. Co.	Gest Street and Mill Creek	do		68	68			do	Do.
Frank Douglas	Monroe Street (Straker Swamps).	H. Pegg		250	132			Good water at intervals of about 15 feet.	Point Pleasant, "Birdseye."
Eggerr Sanger Planing Mill	Foot of Harriet Street	Ed. Boluss		150	35			No water	Point Pleasant.
Emery Hotel	Vine Street, between Fourth and Fifth streets.	do	3	148	148			Hard water; iron.	Alluvium.
Foss-Schneider Brewing Co.		A. D. Cook	6	85	No rock.	− 55			Do.
Freiberg & Workum	Sycamore and Main streets	Ed. Boluss		240	48			Little gas	Point Pleasant, "Birdseye."
Gaff Distilling Co.	Sixth Street and Mill Creek	John Pepper		1,265	110				St. Peter.
Gambrino Stock Co.	Sycamore Street	Ed. Boluss		60	60			Little water	Alluvium.
A. Gander Packing Co.		—— Cook	8	80	80	− 33			Do.
Gerkie Brewery Co.	Plum and Canal streets	John Pepper		160	160				Do.
Gibson House				370	146				Point Pleasant, "Birdseye."
Do.	Walnut Street, between Fourth and Fifth streets.	Ed. Boluss		564	168				Do.
Globe Rolling Mill	Front and Smith streets	J. E. Yingling		110	110				Point Pleasant.
Globe Soap Works	Water and Walnut streets	—— Cook		70	70			Little water; abandoned.	Alluvium.

Hall Safe & Lock Co.	Pearl and Plum streets	Ed. Boluss		110	110			Plenty	Do.
J. Hanck	Corner Dayton Street and C Avenue.	do.		170	150				Point Pleasant.
James Heakin Spice Co.	Front Street, between Walnut and Vine streets.	do.		90	90			Lots of it.	Alluvium.
Holders Tannery	Colerain Pike		4	215					Point Pleasant.
—— Hulsman	John Street, near Liberty		4	161	161				Alluvium.
Hygeia Ice Plant	Court Street	Bradford Well Co.		500	70			No water	"Birdseye."
W. W. Johnson	Sycamore and Yeatman streets.		3	80	80				Alluvium.
Jung Brewery Co.		Ed. Hendrigsman	8	165	165	−100			Do.
Kauffman Brewing Co.	Vine Street, between Liberty and Green streets.	Ed. Boluss		140					Do.
John Kaufman	Vine Street		4	215					Point Pleasant.
Keck's Fertilizing Works	Cumminsville			1,380			60		St. Peter.
Herman Lackman	Sixth Street	John Pepper		60	60				Alluvium.
Liberty Street viaduct				145	142				Point Pleasant.
				143					
Longview Hospital		J. D. Cook	8	146		− 45	50	500	Alluvium.
		Bradford Well Co.	10	150	No rock.	− 50			
Mayflower House	Gest Street and Mill Creek	Joe Sands		60	60			Plenty	Do.
Meter Furniture Factory	Front Street, between Rose and John streets.	Ed. Boluss		90	90			do.	Do.
Mill Creek Distillery	West of Mill Creek		4½	1,440		+ 90		267	St. Peter.
Moerlein Brewing Co	North Elm Street		4	2,408			62	400	Do.
Mosler Safe & Lock Co	Elm Street, between Pearl and Second streets.	Ed. Boluss		110	110			Plenty	Alluvium.
National Lead Co.	Seventh and Freeman streets.	do.		60	60			Small quantity	Do.
Ohio & Kentucky Kid Leather Co.		Bradford Well Co.		265	60	− 25		25	Point Pleasant, "Birdseye."
Ohio Butterine Co.	Walnut and Second streets	Ed. Boluss		68	68			Lots of it	Alluvium.
Palace Hotel	Sixth and Vine streets	J. E. Yingling		140	140			Too little	Do.
Pugh Printing Co.	Lawrence Street, between Fourth and Fifth streets.	Ed. Boluss		200	40			No water	Point Pleasant.
Rabes Distillery	Cumminsville		4½	1,400		+ 70		100	St. Peter.
J. C. Roth Packing Co.		A. D. Cook	8	85	85	− 65			Alluvium.
Russell Morgan Printing Co.	Lock Street and Eggleston Avenue.	Ed. Boluss		300	25			No water	Point Pleasant, "Birdseye."
Schaller Brewery Co.	McMicken Street	do.		600				do.	Do.
Jacob Schlachter		—— Cook	6	80	80	± 60	56		Alluvium.
J. Schlachter & Son, Packers	2833 Colerain Avenue		6	90		− 74	56		Do.
Schmats Brewery Co.	McMicken Street	John Pepper		400–500				No water	Point Pleasant, "Birdseye."
Schmidlapp & Senior Clifton Springs Distilling Co.		Hutchinson Construction Co.	10	160	40	− 0			Point Pleasant.
Do.		—— Rose	8	1,750	100	+ 0			St. Peter.
J. & F. Schroth Packing Co.		—— Isenbr.	6	150		− 0			Alluvium.
Walker Brewing Co.	Sycamore Street	Ed. Boluss		140	60				Do.
Windisch Muhlhausen Brewing Co.		Bradford Well Co.	6	170	160	−70 to −90			Point Pleasant.
Do.	Canal		4	180	180				Alluvium.

Public supplies.[1]—The public supply of Cincinnati has for many years been obtained from Ohio River, the water being used without treatment. The water is nearly always muddy and is at all times more or less polluted by sewage from cities farther up the stream, giving rise to numerous cases of typhoid fever and other filth diseases. Of late years, owing to accidents to the machinery and other causes, the supply has often been entirely inadequate, the upper part of the town being practically without water for days at a time. The urgent need of new supplies was finally recognized and steps taken to investigate the available sources.

The great advantages of well water over river water in palatability and in safety were apparent. The possible sources of supply suggested were rock wells and alluvium wells or infiltration galleries. It was quickly concluded, however, that none of these sources was practicable. Cincinnati is, in fact, very poorly located for obtaining supplies from underground sources. As it is underlain by limestones and shales extending to a depth of 900 feet or more and carrying water only in smallest amounts—insufficient even for private wells—a public supply from these formations is out of the question. Below the limestone lies the St. Peter sandstone, which, as has been shown by the success of many of the deep brewery wells, yields larger supplies. The head of the water, however, has already been lowered and the supply decreased by the relatively few private wells drawing upon it, making it clear that the supply would be insufficient for the city's needs, even if the water were suitable. This, however, is not the case, the water being exceedingly hard and highly charged with salt, iron, and sulphur, which gives it a very strong and objectionable taste. Moreover, some of the constituents would actively attack boilers and pipes and greatly shorten their lives. As there is no known method of treating such waters economically, their use is out of the question.

The alluvium, although present over considerable areas along Ohio and Little Miami rivers and yielding enough water for many industrial establishments, does not afford at any point sufficient supply to warrant the belief that enough for the city's use could be obtained from a single or even from several localities. To obtain the desired amount, in fact, it would be necessary to construct a considerable number of scattered and entirely separate pumping plants, the cost of operating which would be prohibitive. Besides, the waters of the ordinary alluvium are very hard, containing several times the amount of incrusting constituents carried by the river water. This is brought out in the following summary:

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[1] Conditions in 1906.

Comparative composition of water from alluvium and river water.

[Parts per million.]

Source.	Chlorine.	Incrustants.		Total solids.
		Sulphates.	Carbonates.	
Alluvium (average of 50 samples)	18	95	331	350
River (daily analyses 1898)	10	33	45	120

A source of supply that has been successful at other localities is a series of infiltration wells or galleries sunk in sand bars in the river or along the river banks. Where the demands are relatively small this method works admirably, but it is open to several objections for a large city like Cincinnati. One of the strongest of these is the liability of the uncovering of the wells or galleries by changes in the bottom of the stream or in its banks in times of flood, leading either to the destruction of the entire plant or, at least, to the removal of filtering materials and an influx of raw water. Moreover, between floods, silts are likely to collect over the infiltrating surfaces, resulting in a clogging of the pores. Again, though this method would yield more water than would wells in ordinary alluvium, it is almost certain that several plants would have to be maintained in order to procure the necessary amounts. The supplies under this system can not be so readily increased under new demands as can those directly from the river. Forced pumping would be dangerous for the reason that the water would be drawn through with insufficient filtration.

On the whole it seems certain that the obtaining of supplies for the city of Cincinnati from underground sources is out of the question, or, at least, would be more costly than filtered river water, which it was finally decided to introduce. If the plant is efficiently managed the filtered water should be safe for domestic use and it has the advantage of being much softer and more suitable for boilers than waters from underground sources.

COLLEGE HILL.[1]

The village of College Hill lies on the uplands, where the glacial drift averages about 15 feet in depth. The water supply is purchased from the city of Cincinnati, but there are a few dug wells in the village that range from 18 to 35 feet deep and one drilled well that extends to a depth of 201 feet. The wells are reported to yield a fair amount of water, but that from the dug wells is not recommended for drinking. The water of the public supply at College Hill is reported to be of much better quality than the same water in

[1] Conditions in 1906.

Cincinnati, for the reason that it is pumped from the Mount Auburn Reservoir to the standpipe at College Hill, and in both of these places it has a chance to settle.

ELMWOOD.[1]

At the western edge of Elmwood the works of the Laidlaw-Dunn-Gordon Co. are supplied by eight drilled wells 8 inches in diameter, which seem to give satisfaction. The record of one of them is as follows:

Record of deep well of Laidlaw-Dunn-Gordon Co., Elmwood.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Earth	4	0	4	0
Sand and gravel	6	0	10	0
Fine sand		6	10	6
Blue clay	57	6	68	0
Bowlders	3	0	71	0
Water-bearing sand	41	0	112	0
Very rough bowlders.				

The water in three wells stands 4 feet from the surface; and 280 gallons a minute can be obtained from a single well for an hour at a time, one well being pumped by an air lift, the rest by steam head.

HARRISON.[1]

The town of Harrison is supplied with water by the Harrison Water & Light Co., which owns four driven wells on the flood plain of Whitewater River, situated 200 feet from the river, a short distance west of Harrison, in Indiana. From the wells the water is pumped to a standpipe 110 feet in height. The wells are about 40 feet in depth and are entirely in river gravel.

IVORYDALE.[1]

At Ivorydale, about one-fourth mile west of the waterworks at St. Bernard, on the flood plain of Mill Creek, are the works of the Procter & Gamble Co., which are supplied by eight wells sunk in gravel and four wells drilled into rock. The rock wells are 1,200 to 1,600 feet in depth, and obtain very salty but very cold water, which is used for condensing. The gravel wells are only 117 to 150 feet deep and struck rock at 117 to 120 feet. They are 8 to 10 inches in diameter. It is reported that 3,000,000 gallons a day are pumped from the eight wells by an air compressor. The water is used for drinking, for condensing, and, after being treated, for boilers. When not pumped it stands 20 to 25 feet below the surface.

[1] Conditions in 1906.

The following record of a well at the Procter & Gamble works is of interest as showing the large preponderance of "clay" in the deposits of Mill Creek at this point, the proportion being much greater than at Connorville, a short distance farther down the valley. It is quite possible that a considerable part of the clay is in reality a clayey till. The well is located 74 feet above low water of the Ohio.

Record of well of Procter & Gamble, Ivorydale.[a]

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Loam	5	8	5	8
Gravel	5	0	10	8
Clay	49	4	60	0
Sand and gravel	5	0	65	0
Yellow sand	11	6	76	6
Clay	20	6	97	0
Gravel and sand	1	0	98	0

[a] James, J. F., Proc. Cincinnati Soc. Nat. Hist., vol. 11, 1888, pp. 102–103.

Two other wells were drilled at this place, but in them the gravel was cut out by clay and the water vein was not struck.

MADISONVILLE.[1]

The public supply of Madisonville is obtained from three 140-foot wells sunk in the deep gravel and sand deposits filling the old Ohio River channel (p. 20). Plenty of water is obtained, a large proportion of the inhabitants of the town availing themselves of the public supply. Very few private wells are to be found. Further tem will be found in the table on page 52.

NORWOOD.[1]

Norwood, like Madisonville, is located on the gravels occupying the old channel of the Ohio and has very few private wells, most of the people depending on the public supply. A number of the manufacturing establishments, however, have wells, some of which are of considerable depth and yield large supplies.

The deepest well in town is said to be that of the United States Playing Card Co., which has a diameter of 10 inches and a depth of 400 feet, all but 148 feet of which is reported to be in rock. This well will yield with an air lift 425 gallons a minute without lowering the supply.

[1] Conditions in 1906.

Another well sunk in 1906 struck rock at 220 feet. The record of this well, by 20-foot intervals, is as follows:

Record of deep well, Norwood, Ohio.

	Feet.
Soil and coarse sand	20
Blue clay	40
Gravel and rock	60
Fine gravel	80
Blue clay	100
Blue clay and gravel	120
Sand	140
Coarse sand with pebbles	160
Water sand	180
Gravel	200
Blue clay or shale	220
Rock	240

The record is of interest in showing a considerable amount of blue clay, a part of which is probably till. A generalized section of the deposits at Norwood is given by a local driller as follows:

Generalized section of wells at Norwood, Ohio.

	Thickness.	Depth.
	Feet.	*Feet.*
Clayey sand and gravel	100	100
Water-bearing gravel	15	115
Hard shaly clay	15	130
Fine sand	35	165
Gravel and cobbles	60	225
Rock.		

Norwood has a public supply derived from two deep wells sunk in materials similar to those of the section given in the preceding paragraph. The water is of good quality and is abundant, supplying both Norwood and the village of Idlewild. Particulars of the system will be found in the table on page 52.

ST. BERNARD.[1]

The public supply of St. Bernard is drawn from two 15-inch drilled wells, sunk on the inner edge of the flood plain of Mill Creek at the base of the surrounding hills. The water is raised by an air lift and is pumped by direct pressure to a 270,000-gallon standpipe 125 feet above the main street. Five wells were originally drilled, to depths of 105 to 270 feet, but the casing of three of them gave

[1] Conditions in 1906.

out and they were abandoned. One of the wells still in use obtains 90 gallons of water a minute with a steam-head pump. The second well is pumped by an air lift, by which a maximum yield of 550 gallons a minute can be obtained. The water stands 41 feet from the surface and is lowered 7 feet when pumped for three to five hours. Although the water is obtained in gravel at a depth of 132 to 135 feet, one of the wells is 270 feet deep, having struck rock at 135 feet. The waterworks wells are reported to have robbed all the shallow wells within a mile. Some of the shallow wells went to depths of 30 to 60 feet. The water in dug wells here is not so hard as that in the wells of the public supply.

SYMMES TOWNSHIP.[1]

Chappendocia Springs, located in Symmes Township, in a ravine on the west side of Little Miami River, about 2 miles below Loveland, emerge from a yellow clay resulting from the weathering of the underlying limestone and shale. The water, which is chalybeate in character, was formerly extensively distributed in Cincinnati but is not at present sold, although it may be put on the market again in the near future.

WYOMING.[1]

The waterworks of Wyoming, situated on the west side of the Cincinnati, Hamilton & Dayton Railway, near the north end of town, comprise four 8-inch driven wells in the valley gravels. One well is 104 feet deep and the other three 197 feet deep. The latter pass through 8 feet of gravel and strike bedrock at the bottom. The water in all of them occurs in gravel and rises within 45 feet of the surface. An air compressor is used and 450 gallons of water a minute can be obtained. At least 1,000,000 gallons of water is reported to have been pumped in 24 hours. By pumping 1,400 gallons a minute from three of the wells for 24 hours, the water in the other well is lowered 5 feet. These waterworks supply not only Wyoming, but also the villages of Hartwell, Lockland, and Arlington. The water is pumped into a reservoir 234 feet above the pumping station, the capacity being 4,000,000 gallons. The system was installed in 1892.

WATER PROSPECTS.

A summary of the underground water conditions in Hamilton County is presented in the following table:

[1] Conditions in 1906.

Underground-water conditions in Hamilton County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Addyson	Terrace gravel.		Plenty	Eden, Point Pleasant.	Point Pleasant	Small.
Andersons Ferry.	do	100±	do	do	do	Do.
Asbury	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Avondale	do			do	do	Do.
Bevis	do	15		do	do	Do.
Blue Ash	do	15	Moderate	do	do	Do.
Bond Hill	Gravel, glacial.	Deep.		Point Pleasant	Point Pleasant	Do.
Brecon	Till	60+	Fair	Richmond and Maysville.	Richmond and Maysville.	Do.
Bridgetown	do	15		do	do	Do.
California	Alluvium			Point Pleasant	Point Pleasant	Do.
Camp Dennison	do	100+	Plenty	Eden	do	Do.
Carthage	Alluvium, glacial gravel.	250±	do	Point Pleasant	do	Do.
Cedar Point	Till	15	Moderate	Richmond and Maysville.	Richmond and Maysville.	Do.
Cherry Grove	do	10	Plenty	do	do	Do.
Cheviot	do	15	Moderate	do	do	Do.
Cincinnati	Alluvium, till, terrace gravel.	5–150	do	Eden, Point Pleasant.	Point Pleasant (see also notes).	Do.
Cleves	Alluvium		Plenty	Point Pleasant	Point Pleasant	Do.
Cluff	do			Eden	do	Do.
College Hill	Till	15	Small	Richmond and Maysville.	Richmond and Maysville.	Do.
Creedville	do	15	do	do	do	Do.
Crescentville	Drift			Eden	Point Pleasant	Do.
Delhi	Terrace sands	100+	Plenty	Eden, Point Pleasant.	do	Do.
Dent	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Dunlop	do	15		do	do	Do.
Eightmile	Alluvium, talus.			Eden	Point Pleasant	Do.
Elizabethtown	Alluvium	50	Moderate	Point Pleasant	do	Do.
Elmwood	do	Deep.	Plenty	do	do	Do.
Fernbank	do	70	do	do	do	Do.
Forestville	Till	15	Moderate	Richmond and Maysville.	Richmond and Maysville.	Do.
Fruit Hill	do	20	do	do	do	Do.
Glendale	do	200+	Plenty	Eden	Point Pleasant	Do.
Groesbeck	do	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Harrison	Alluvium, glacial gravel.	100+	Plenty	Eden, Point Pleasant.	Point Pleasant	Do.
Hartwell	Alluvium	200±	do	Eden	do	Do.
Hazelwood	Till	20+	do	Richmond and Maysville.	Richmond and Maysville.	Do.
Home City	Terrace sands.	140+	do	Eden, Point Pleasant.	Point Pleasant	Do.
Hyde Park	Till	15	Small	Richmond and Maysville.	Richmond and Maysville.	Do.
Ivorydale	Alluvium	100	Plenty	Point Pleasant	Point Pleasant	Do.
Kennedy	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Lockland	Alluvium	Deep.	Plenty	Eden	Point Pleasant	Do.
Mack	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Maderia	Alluvium	20	Moderate	Eden (?)	Point Pleasant	Do.
Madisonville	Glacial gravel.	150	Plenty	Point Pleasant	do	Do.
Miami	Alluvium	Deep.		Eden	do	Do.
Miamiville	Terrace gravel.	50+	Plenty	do	do	Do.
Monfort	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Montgomery	do	15	Fair	do	do	Do.
Mount Airy	do	15		do	do	Do.
Mount Healthy	do	18	Moderate	do	do	Do.
Mount St. Joseph	do			Eden	Point Pleasant	Do.
Mount Summit	do	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Mount Washington.	Till, old gravels.	20	Plenty	Eden	do	Do.
New Haven	Alluvium		do	Point Pleasant	Point Pleasant	Do.
Newtown	do	Deep.	do	do	do	Do.
North Bend	Terrace gravel.	100±	do	do	do	Do.
Norwood	Glacial gravels	Deep.	do	do	do	Do.

Underground-water conditions in Hamilton County—Continued.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Oakley	Glacial gravels	Deep.	Plenty	Point Pleasant	Point Pleasant	Small.
Plainville	Alluvium	35+	do	Eden	do	Do.
Pleasant Ridge	Till	12	Moderate	Richmond and Maysville.	Richmond and Maysville.	Do.
Pleasant Run	do			Eden (?)	Point Pleasant	Do.
Preston	Alluvium			Point Pleasant (?)	do	Do.
Price Hill	Till	10		Richmond and Maysville.	Richmond and Maysville.	Do.
Reading	Alluvium			Eden	Point Pleasant	Do.
Remington	Terrace gravel.	50+	Plenty	do	do	Do.
Riverside	do	100±	do	Eden, Point Pleasant.	do	Do.
Rossmoyne	Till		Small	Richmond and Maysville.	Richmond and Maysville.	Do.
St. Bernard	Glacial gravels	120	Plenty	Point Pleasant	Point Pleasant	Do.
Sater	Terrace gravel.			Eden	do	Do.
Sedamsville	Alluvium, terrace gravel.	100±	Plenty	Eden, Point Pleasant.	do	Do.
Sekitan	Terrace gravel.	100±	do	do	do	
Sharonville	Till, moraine			Eden	do	Do.
Silverton	Till	20		Richmond and Maysville.	Richmond and Maysville.	Do.
Sixteenmile Stand.	do	30+	Fair	do	do	Do.
Snyder	Alluvium			Eden (?)	Point Pleasant	Do.
Springdale	Till, moraine			Eden	do	Do.
Sweetwine	Alluvium, talus.			Point Pleasant	do	Do.
Symmes	Alluvium	25	Plenty	Eden	do	Do.
Taylors Creek	do			do	do	Do.
Terrace Park	Terrace gravel.	75+	Moderate	do	do	Do.
Transit	Till	15		Richmond and Maysville.	Richmond and Maysville.	Do.
Trautman	Terrace gravel.	100±	Plenty	Eden, Point Pleasant.	Point Pleasant	Do.
Westwood	Till	15	Small	Richmond and Maysville.	Richmond and Maysville.	Do.
Whitewater	Alluvium	Deep.	Moderate	Point Pleasant	Point Pleasant	Do.
Woodlawn	Till	200±	Plenty	Eden	do	Do.
Wyoming	Alluvium	200	do	do	do	Do.

HIGHLAND COUNTY.

By M. L. Fuller.

In Highland County the investigations for the present report were confined mainly to the central and western parts, relatively little attention being paid to the eastern third, which was reserved for future study.

SURFACE FEATURES.

Highland County is characterized by greater diversity of surface than the counties to the north and may be divided into a number of districts according to the nature of its physical features. Along the western border, where the land is lowest, the surface is a flat and to a large extent a marshy drift plain at an elevation of 930 to 1,030 feet, underlain by blue limestone (Richmond). The central part of the county, which is about 100 feet higher, consists of flat-crested, plateau-like ridges alternating with wide, deep valleys, as in the vicinity of Hillsboro. In the northern part of the county the land is still higher and in general is covered by a smooth mantle of drift, with a few sharp valleys cut in the drift and limestone. At the south boundary the drift is thinner and the land lower and cut by many streams, the average elevation being under 1,000 feet. The highest land in the county is along the eastern boundary, where hills rise to an elevation of over 1,300 feet, or several hundred feet above the adjacent lowlands. The county is crossed in a northwest-southeast direction by two low morainal ridges, one in the northeastern part and the other southwest of Hillsboro.

WATER-BEARING FORMATIONS.

SURFACE DEPOSITS.

ALLUVIUM.

The streams of Highland County are in general of small size, flow in relatively small channels, and are bordered by narrow deposits of alluvium. In the valleys occupied by the gently flowing streams of the flatter portions of the county much of the alluvium is rather fine, sands and silts predominating, but in those of the more swiftly flowing streams, in the more hilly regions the alluvium, if present at all, is commonly in the form of coarse gravel. In some places the streams flow locally on bare rock, no alluvium whatever being present.

The alluvium will usually afford satisfactory supplies to wells, especially in the broader and flatter valleys. In the smaller ravines the gravels are not usually so situated as to be readily available as sources of supply.

TILL.

The pebbly clay or till covers the entire county except the extreme southeast corner, but it is very thin toward its outer edge in the southeast and in many places is difficult to detect. Farther west and north it thickens considerably. In the northwestern half of the county the older drift just described is covered by a younger sheet, which adds materially to the total thickness. The lowest till is usually a blue pebbly clay 20 feet or less in thickness, but in some places yellow, white, or black clays rest on the rock. On top of the blue clay in some localities, especially on the plateaus, is a layer of soil or of more or less peaty deposits, these being in turn covered by 20 or 30 feet of gravelly drift.

The water supplies of the till are not large but are generally abundant enough to supply ordinary wells wherever the till has a thickness of 20 feet or more. Wells encountering the soil zone usually find plenty of water, but it has an objectionable taste and is little used for drinking.

MORAINAL DEPOSITS AND STRATIFIED DRIFT.

Under morainal deposits and stratified drift are included deposits overlying the ordinary till, or pebbly blue clay. In some of the true morainal deposits till forms a considerable part of the materials, but in others the deposits are prevailingly gravelly, with here and there a layer cemented to sandstone or conglomerate by iron or lime. In some places this gravelly material is as much as 90 feet thick. The morainal material reaches its greatest thickness in the belt southwest of Hillsboro and in the northeast corner of the county.

The stratified drift that lies in valleys may carry considerable water, and even on the uplands moderate amounts may be found in the thicker deposits if the land is fairly flat. Where the peaty bed occurs in the till very strong mineral water unfit for use is often obtained.

ROCK FORMATIONS.

CARBONIFEROUS SANDSTONE, OHIO SHALE, AND "HELDERBERG" LIMESTONE.

The Carboniferous (Mississippian) sandstone, 100 feet thick, is the uppermost formation in the county. Just below it lies the Ohio shale (Devonian), 250 feet thick, succeeded by the "Helderberg" limestone (Silurian), 100 feet thick. These formations occupy small areas among the high hills near the eastern border of the county but are outside of the scope of the present investigation, which considers only the "Niagara" and lower rocks.

"NIAGARA" LIMESTONE.

The "Niagara" formation in Highland County has a total thickness of 275 feet and consists, from the base upward, of a few feet of bedded limestone, 60 to 100 feet of shales, 45 feet of yellowish magnesian limestone, 45 feet of blue limestone, 20 to 90 feet of massive magnesian limestone, mainly capping the hilltops, and 30 feet of white to yellow sandstone, known as the Hillsboro sandstone, occurring on the higher hills near this town and at points to the east. The "Niagara" limestone as a whole forms the surface over all but the eastern fourth of the county, with the exception of a few of the higher hills north of Hillsboro and the creek beds along the southern boundary, underlying the higher plateaus east of the lower drift-covered plateau of the Richmond formation.

As in the adjacent counties, the "Niagara" is the best of the water-bearing rock formations, affording large numbers of springs from the top of the shaly layers and nearly everywhere yielding fairly good supplies to wells sunk to the same beds. Considerable water also occurs in the thick limestone beds independently of the shales, but the supplies are smaller and less certain than those on top of the shale beds. The sandstone forming the top of the formation also doubtless contains water where it is of considerable extent, especially if it is under cover of younger formations. In the part of the county investigated, however, it is found only on one or two of the higher isolated crests, where its water is readily drained away into the adjacent valleys.

"CLINTON" LIMESTONE.

The "Clinton" limestone in Highland County is a semicrystalline pinkish limestone, grading in places into a red limestone or even an impure iron ore, as at Rocky Fork, south of Hillsboro. Its lower part is in many places sandy and in the southern part of the county locally includes a conglomerate. In thickness it ranges from 25 to 50 feet, with an average of about 35 feet. Its outcrop occurs along the western border of the "Niagara" area, as described above, along the sides of the deeper valleys in the southern part of the county, and for several miles along Rocky Fork south of Hillsboro.

The "Clinton," as everywhere else in this part of Ohio, is characterized by numerous springs emerging mainly from its base along the contact with the shaly layers of the underlying Richmond formation and here and there from points higher in the formation. It usually affords a fairly satisfactory source of supply for wells, except when it occurs at the surface without the drift covering. Where it is overlain by the "Niagara," water is usually found in the higher formation, and it is as a rule not necessary for the wells to penetrate to the "Clinton."

RICHMOND FORMATION.

The upper 10 or 20 feet of the Richmond formation is in places a red shale, as at Belfast, on Brush Creek, but is probably more commonly a blue shale. Below this comes a thick series of thin alternating layers of limestone and shale, of which only the upper 50 or 100 feet is exposed in Highland County. The formation occurs beneath the low drift-covered plateau in the western fourth of the county and in the deeper valleys along the southern edge.

The Richmond is not a strong water-bearing formation, but it usually yields enough water to open wells for ordinary domestic and farm requirements, especially where it is overlain by 10 feet or more of drift. Many drilled wells, however, have difficulty in obtaining sufficient water from it. It is of importance in furnishing an impervious layer to retain the waters of the overlying "Clinton."

NOTES BY TOWNS.

HILLSBORO.[1]

Hillsboro, like nearly every other town of importance in southwestern Ohio, sank a deep well in search of oil or gas during the boom in 1887. The well was carried to a depth of 1,750 feet, striking the "Birdseye" at 1,200 feet, or 100 feet below sea level, and obtaining salt water, presumably from the St. Peter sandstone, at 1,750 feet.

A number of springs emerge from the "Niagara" limestone on the uplands near Hillsboro. One of these, which may be taken as a type, is that of J. L. West, 3½ miles north of town. It has a constant flow, independent of seasons, of about 5 gallons a minute, emerging from a bedding plane of the limestone and forming a small pond. A spring house serves also as a dairy. An analysis of the water will be found in the table on pages 204–205.

Hillsboro has a public water supply obtained from eleven wells located near or in the bed of Clear Creek north of town. No pollution seems possible at present, and the water is to be regarded as safer than that from shallower private wells. Other particulars regarding the supply will be found on page 52.

LEESBURG.[1]

Leesburg is located on a drift-covered Niagara plateau most of the wells entering the rock at about 15 feet. All water is from the limestone. The materials encountered are somewhat as follows:

Section in wells at Leesburg, Ohio.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift	15	15
"Niagara" limestone:		
Limestone	85	100
Shale	100	200

A public system was in process of installation at Leesburg in 1906, the supply being obtained from four drilled wells 100 to 200 feet in depth, with sections similar to that given above. The estimated capacity is 100,000 gallons a day. For other particulars the table on page 52 should be consulted.

LYNCHBURG.[1]

Two deep wells have recently been sunk at the Freiberg & Workum distillery, Lynchburg, to depths of about 1,550 feet in search of water,

[1] Conditions in 1906.

but the amounts obtained were so small that an hour's pumping with an air-lift system exhausted the wells. The St. Peter sandstone was entered but was not penetrated far enough to secure the sulpho-saline water which is generally encountered at about 300 feet from the top. Shooting the well did not materially increase its yield. The following is a record compiled by the writer from samples furnished by the company.

List of samples from well of Freiberg & Workum, Lynchburg, Ohio.

	Depth of sample in feet.
Richmond and Maysville formations:	
Light-gray calcareous shale	115
Gray argillaceous limestone	180
Light-gray shale and argillaceous limestone	270
Gray argillaceous limestone	420
Dark-gray limestone and gray shale	520
Eden shale: Gray shale and dark-gray limestone	650
Point Pleasant formation:	
Light-gray limestone, highly ferruginous, cemented	850
Nearly black calcareous shale and limestone with some white limestone	920
Gray and white limestone and black argillaceous shale	960
"Birdseye" limestone:	
Light-gray to white limestone and light-gray shale	980
Fine-grained compact grayish limestone resembling lithographic stone	1,100
Same, with slight pink or buff tinge	1,210
Dark compact brownish-gray limestone and gray calcareous shale	1,420
St. Peter sandstone:	
Dark argillaceous and light-gray sandy shale	1,460
Very fine quartzose and biotitic sandstone with a little calcareous cement	1,500
Very fine white to bluff dolomite, ferruginous stains	1,520
Buff to gray dolomite and fine gray biotitic sandstone	1,525
Gray dolomite	1,534

A number of good-sized springs, some of which are utilized by the distillery and others by the town, emerge on the east side of East Fork a mile or more north of town. The distillery springs are four in number and emerge from quicksand, although it seems probable that the water comes mainly from the "Clinton" limestone near its contact with the underlying Richmond formation. The water is piped by gravity to a receiving well at the distillery, from which it is pumped to the works as needed. About 50,000 gallons daily is used from the springs, the remainder being taken from the creek. The water carries some iron and is very hard and seems to be becoming harder. (See pp. 204–205 for analysis.)

The first public supply, derived from a large dug well near town, was installed in 1896. but soon failed. Connection was then made with the infiltration gallery of the distillery, a trench 120 feet long, 15 feet wide, and 15 feet deep, located near town and subject to pollution from surface drainage. A few years later it became necessary for the distillery to use the entire supply, and the town had to seek a new source, which was finally found in a spring north of town, not far from the distillery spring described above. The spring was dug out, cleaned, and inclosed, and the water was piped by gravity to a receiving cistern in town, from which it is pumped to the standpipe. Other data regarding the supply will be found in the table on page 52.

WATER PROSPECTS.

For the purpose of assisting the driller or well owner in determining the underground water conditions in western Highland County the following table has been prepared:

Underground-water conditions in Highland County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Allensburg	Till	40+	Plenty	Richmond	Richmond and Maysville.	Small.
Bell	do	10		"Niagara"	"Clinton"	Usually plenty.
Berrysville	do	10		do	do	Do.
Bridges	do	10		do	do	Do.
Buford	do	25		Richmond	Richmond and Maysville.	Small.
Careytown	do	10		"Niagara"	"Clinton"	Usually plenty.
Danville	do	10		Richmond	Richmond and Maysville.	Small.
Dodsonville	do	2	Fair	do	do	Do.
Fairfax	do	7	Moderate.	"Niagara"	"Clinton"	Usually plenty.
Fairview	do	10		Richmond	Richmond and Maysville.	Small.
Fallsville	do	10		"Niagara"	"Clinton"	Usually plenty.
Folsom	do	20	Moderate.	do	do	Do.
Gath	do	20		Richmond	Richmond and Maysville.	Small.
Highland	do	100		"Niagara"	"Clinton"	Usually plenty.
Hillsboro	do	10		do	do	Do.
Hollowtown	do	10		Richmond	Richmond and Maysville.	Small.
Leesburg	do	10	Plenty	"Niagara"		
Littleton	do	10		Richmond	Richmond and Maysville.	Do.
Ludwick	do	10		"Niagara"	"Clinton"	Usually plenty.
Lynchburg	do	10–45	Moderate.	Richmond	Richmond and Maysville.	Small.
Mowrystown	do	20		do	do	Do.
Needful	do	20		do	do	Do.
Nevin	do	10	Small	do	do	Do.
New Lexington	do	100		"Niagara"	"Clinton"	Usually plenty.
Newmarket	do	8	Fair	do	do.	Do.
Pricetown	do	10	Plenty	Richmond	Richmond and Maysville.	Small.
Pulse	do	20		do	do	Do.
Russell	do	10		"Clinton" (?)	"Clinton," Richmond, and Maysville.	Usually plenty.
Samantha	do	20		"Niagara"	"Clinton"	Do.
Strasburg	do			Richmond	Richmond and Maysville.	Small.
Sugartree Ridge	do	8	Moderate.	"Niagara"	"Clinton"	Usually plenty.
Taylorsville	do	10		Richmond	Richmond and Maysville.	Small.
Willettville	do	8	Plenty	"Niagara"	"Clinton"	Usually plenty.
Winkle	do	10		Richmond	Richmond and Maysville.	Small.

MIAMI COUNTY (SOUTHERN).

By M. L. Fuller.

Only the southern third of Miami County (the part lying south of an east-west line drawn midway between Troy and Tippecanoe) falls within the area covered by the present report, and it is to this portion only that the following descriptions relate.

SURFACE FEATURES.

Southern Miami County is essentially a flat or gently sloping plateau, standing from 800 to 1,000 feet above sea level, or about 400 to 700 feet above the Ohio. It is cut in the eastern part by the valley of Honey Creek, in the center by the broad valley of the Miami, and in the western part by the sharp but narrow valleys of Stillwater River and its tributaries. The valley bottoms are usually 100 feet or more below the adjacent uplands, or 200 to 250 feet lower than the high, flat divides between the streams. Irregular morainal hills are strongly developed in the southeastern portion, especially along Honey Creek, but are not present over most of the remaining territory.

WATER-BEARING FORMATIONS.

The unconsolidated surface materials include the sandy and gravelly alluvium of the valleys, the pebbly clay of the flat upland surfaces, and the irregular morainal hills of sand, gravel, or pebbly clay of the Honey Creek region. The rock formations immediately underlying the surface deposits in southern Miami County are the "Niagara," "Clinton," and Richmond.

SURFACE DEPOSITS.

ALLUVIUM.

The alluvial deposits are best developed in the valley of the Miami, in which they have a width varying from half a mile at the southern boundary of the county to 2½ miles a little north of Tippecanoe. The thickness of the deposits is unknown, wells 65 feet in depth failing to reach rock even near the edge of the valley, but it is probably at least 100 feet. Along Stillwater River the alluvial deposits are generally less than half a mile in width and are probably less than 50 feet in depth. In southern Miami County both rivers flow in relatively new channels, their older and wider valleys being buried by glacial drift. The old channel of the Miami is probably toward Mad River near Osborn, along the valley of the present Honey Creek, beneath whose irregular morainal hills thick deposits of old alluvium probably exist. A broad channel of the

Stillwater may extend through Kessler and Nashville and along Brush Creek, although wells in this vicinity generally strike rock near the surface. The location of the main channel and alluvial deposits of the preglacial Stillwater, if this river then existed, has not been determined. Many smaller buried valleys and alluvial deposits doubtless occur but have not been traced owing to the lack of sufficient well borings.

The alluvial deposits include gravel, sand, and silt, with perhaps in some places one or more beds of till. In the central portions of the valleys the sands and gravels usually predominate and are saturated with water, but toward the sides the deposits are in places finer and contain less water. Wells can almost everywhere obtain water by sinking to river level, but to insure abundant and safe supplies should be carried at least 20 feet deeper. In few wells is the water under much pressure, and artesian flows are not to be expected.

TILL.

Till is the surface material of the uplands and forms a mantle covering the rock, except at a few points near the rivers, where natural outcrops and cliffs occur. In thickness it varies from 75 feet at places in the uplands to the vanishing point along the edges of the valleys. On the uplands it is in general thinnest in the east, where in many places it measures less than 25 feet, and thickest in the west, where it reaches a thickness of 50 to 75 feet at several points. (See Pl. III.) The variations in thickness are due in part to inequalities of the underlying rock surface and in part to more extensive accumulations toward the west. The till is prevailingly a clay mixed with pebbles and a few bowlders, but in places it is more or less gravelly and may even contain definite beds of sand or gravel. To a depth of 5 or 10 feet it is commonly weathered to a yellowish brown, but at greater depths it is usually gray or bluish. The pebbly clay itself contains relatively small amounts of water but will usually yield enough for domestic use to dug wells. Much more water is found in the interbedded gravel or sand layers, which ordinarily furnish supplies ample for all farm purposes and in some places even sufficient for public supplies. Unfortunately such beds are absent in many places where the till is thin, and there wells have to enter the rock to get water, especially near the valleys, where the water readily drains from the deposits. Where the till is 30 feet or more in thickness, however, adequate supplies will usually be obtained from it. In some wells the pressure is sufficient to lift the water nearly or quite to the surface.

MORAINAL DEPOSITS.

The morainal hills along Honey Creek consist of great numbers of small but steep and very irregular mounds, composed of gravel and sand and some till, interspersed with deep undrained kettle-like depressions. They commonly rise 60 or 70 feet above the valleys.

The morainal deposits of southern Miami County are composed mainly of porous sands and gravels which permit the water to drain away to the nearest valley or to sink downward into the underlying deposit, which, in the Honey Creek region, is probably alluvium. Wells are generally sunk into this underlying formation at least to the level of the surrounding valleys before procuring satisfactory supplies, and there is rarely any difficulty in obtaining adequate amounts if this is done.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

The "Niagara" limestone is seen in several quarries along Ludlow Creek and, although in few places naturally exposed, appears to underlie the section south of the creek to the county boundary. Little, if any, "Niagara" is present between Stillwater River and Brush Creek, but considerable areas of the formation probably occur on the higher uplands between these streams and the Miami and also east of the Miami. The entire thickness of the "Niagara" is not represented in southern Miami County, there being in few places, if anywhere, more than 50 feet of the formation remaining. Hussy [1] says that the lower part is shaly but gives no localities in the area where such shales exist, and none were seen or reported in the present field work. The rock in the main is a grayish or bluish granular to compact limestone, in places occurring in beds suitable for quarrying.

The "Niagara" generally contains considerable water, especially where covered with thick drift, but in southern Miami County it has no great amount of drift over it and is itself very thin, the lower and nonwater-bearing portion being in many places the only part represented. At Brandt, south of Honey Creek, it is reported as yielding plenty of water to shallow wells, but at Phoneton, near the Miami, and in the area west of Stillwater River, only fair to moderate amounts are reported. On the whole, the "Niagara" in the area under consideration will yield only a fair supply to wells, many of them having to penetrate to the "Clinton" or even to the Richmond to procure the necessary amounts. However, the formation, especially the lower portion, gives rise to many springs, some of which are sources of water for stock or for domestic use.

"CLINTON" LIMESTONE.

The "Clinton" is an irregularly bedded limestone, probably about 35 feet in thickness and somewhat sandy in its lower part. It is readily distinguished by its pinkish color, by its granular or sandy

[1] Hussy, John, Geology of Miami County: Geol. Survey Ohio, vol. 3, 1874, pp. 468–481.

character, and by the cliffs to which it gives rise along the valleys. The steep bluffs which border practically the entire valleys of the Stillwater and Miami in the portion of the county under consideration, are capped by this resistant formation, over which the small tributaries plunge to the valleys below. (See Pl. VII, *B*.) On the uplands between the valleys the " Clinton " is usually covered by drift or by the " Niagara " limestone, and is in few places exposed. What is probably the " Clinton " limestone, however, outcrops at several points on the lower slopes of the upland south of Brown (Rex post office), on Honey Creek.

The " Clinton " is the most important water-bearing formation in the county, being notable throughout the region for the great number of large springs issuing from it. These appear to come from the middle or upper part of the limestone, although a few emerge from its contact with the underlying shale of the Richmond formation, just below the cliffs along the rivers. One of the largest of these springs formerly furnished power for a mill but is now utilized as the public supply of Milton. Along the borders of the valleys only the lower part (which is below the level of the springs) is present, and even this is drained of its water by the deep valleys. Farther back from the streams the " Clinton " will probably afford good supplies to wells.

RICHMOND FORMATION.

The Richmond formation, consisting of thin alternating layers of blue shale and limestone, underlies the alluvium in the valleys of Miami and Stillwater rivers and Honey Creek and is to be seen below the cliffs formed by the " Clinton " limestone in the bluffs bordering the two rivers. In these localities the upper 20 or 25 feet is generally a blue shale, below which the characteristic shaly limestone occurs to the base of the exposures. About 75 feet of the beds occur above the river level at Milton and about 40 feet near Tippecanoe.

The Richmond is not an important water-bearing formation, owing to its large content of shale, which hinders the circulation of the water. It carries, nevertheless, moderate amounts and yields supplies to a number of wells at Fidelity, Ludlow, West Milton, Pigeye, and other places where, because of its thinness or of its drainage by deep valleys, the " Clinton " is unavailable as a source of supply. A few springs emerge at the top of its upper shaly member just below the " Clinton " cliffs.

NOTES BY TOWNS.

TADMOR.[1]

On the Kreitzer property, at the point where the National Road descends the bluff between Phoneton and Tadmor, a small spring

[1] Conditions in 1906.

near the base of the "Clinton" limestone is utilized for operating a ram which lifts the water to the buildings on the bluff above. It is of interest as demonstrating the possibilities of obtaining fine supplies of spring water at the houses along the edge of the bluffs, a situation in which it is difficult to obtain water from wells.

TIPPECANOE.[1]

A deep well sunk at Tippecanoe about 25 years ago in a search for oil and gas. The "Birdseye" limestone was struck at 1,025 feet, or about 180 feet below sea level, but no other data concerning the materials penetrated or the water encountered are available.

The city is situated on the "Clinton" limestone, and previous to 1897 obtained its water from private wells. Owing to the numerous fissures which permitted pollution to enter the wells, many became badly contaminated and the introduction of a public supply became imperative. This is obtained from wells averaging about 60 feet in depth, located on the flats of the Miami; although there are a few houses in the vicinity, there is little danger of pollution owing to the considerable depth (50 feet) to which the wells are carried below the water level. Since the installation of the public supply the private wells have been examined by the health officers at intervals and those found contaminated have been closed and the owners ordered to connect with the public supply. Other information regarding the waterworks and supply will be found on page 52.

WEST MILTON.[1]

West Milton, like Tippecanoe, is situated on the outcrop of the "Clinton" limestone, the fissures of which allow more or less impurities from the surface to penetrate to the wells. The unsatisfactory character of the well water, the cost of drilling, and the need of better fire protection led, a few years ago, to the installation of the present water system, which obtains its supply from Haskett Spring, issuing from the upper part of the "Clinton" limestone about a mile west of town. The water is conducted by a cemented pipe to a receiving well in the village, from which it is pumped to the standpipe. The supply appears to be safe and in every way superior to the water from the wells formerly used. Further particulars are given on page 52 and an analysis on pages 204–205.

Of the numerous springs in the vicinity of West Milton, Haskett Spring, which furnishes the public supply, is the most important. It emerges, as noted above, from the "Clinton" limestone. Its surplus water above that taken for the city supply formed, in August, 1906, a stream 8 feet wide and 4 inches deep, flowing with a velocity

[1] Conditions in 1906.

of 1 foot a second. By adding the equivalent volume to the 135,000 gallons consumed by the city, a total yield of about 1,750,000 gallons daily is obtained. The stream from the spring formerly furnished power to a mill in the town.

WATER PROSPECTS.

The following summary of the underground water conditions will help to determine the prospects of obtaining supplies at the towns and villages in this county:

Underground water conditions in southern Miami County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Brandt	Till, moraine.	12	Plenty	"Niagara"	"Niagara"	Plenty.
Fidelity	do	20	Small	"Clinton"	Richmond	Small.
Ginghamsburg	do	100+	Fair	Richmond	do	Do.
Grayson	Alluvium, moraine.	75+	Moderate	do	do	Do.
Kessler	Till	25	Small	"Clinton"	do	Do.
Laura	do	50	Moderate	"Niagara"	"Clinton"	Moderate.
Ludlow	do	65	Small	"Clinton"	Richmond	Small.
Phoneton	Till, moraine.	20	Moderate	"Niagara"	"Clinton"	Moderate.
Pigeye	Till	3	Small	"Clinton"	Richmond	Small.
Potsdam	do	35	Fair	"Niagara"	"Clinton"	Moderate.
Rex	Till, gravel.	5-50	Moderate	"Clinton"	Richmond	Small.
Tippecanoe	Till	0-10	Small	do	do	Do.
West Milton	do	3	Fair	do	do	Do.

MONTGOMERY COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

To speak broadly, the surface of Montgomery County is a plateau, the plateau characteristics being especially pronounced in the northwest, where very extensive, nearly flat surfaces, broken only by shallow valleys, are found at elevations of 950 to 1,050 feet. In the southern half of the county and in the portion bordering Miami River in the eastern part the plateau character is less distinct, the upland level being broken by the deep valley of the Miami and by the shallower valleys and ravines of its tributaries, between which only relatively narrow-crested ridges remain. Some of these, however, show flat surfaces, having an elevation of 870 to 950 feet, marking the old plateau level that originally extended over the region. The valleys of many of the larger rivers are broad, that of the Miami being from 2 to 3 miles wide in places, although elsewhere, as a few miles northeast of Dayton and near Miamisburg, it is only a quarter to half a mile wide. Tributary valleys vary in width from a few feet to three-fourths of a mile or more, but some of them expand locally to 2 miles or so, for example, Twin Creek in the vicinity of Germantown. The valley sides rise from 100 to 200 feet above the bottoms in the southern part of the county, but in the main have moderate slopes and show few if any rock outcrops. Near the northern edge many of the valleys, although only about half as deep, are broader and are bordered by vertical cliffs, which are very characteristic features of Miami and Stillwater rivers in this region. The valleys slope considerably, descending from 775 feet in the north to 675 feet in the south.

WATER-BEARING FORMATIONS.

SURFACE DEPOSITS.

ALLUVIUM.

The alluvial deposits, as would be expected from the great width of the valleys, are very extensive in Montgomery County, ranging in width from about half a mile near Miamisburg to nearly 4 miles at the junction of Mad and Miami rivers near Dayton. The Stillwater River deposits average three-fourths of a mile in width, those of Mad River between 2½ and 3 miles, and those of the smaller tributaries from a few feet to a quarter of a mile. The depth of the deposits is not known, few if any wells located near the center of the valleys having reached their bottom, though many wells from 50 to 60 feet in depth have been sunk. At Dayton wells have gone 75 feet or more without having found the bottom, and at West Carrollton a well 175 feet deep in the alluvium is reported. It is not improbable that the average depth in the larger valleys is more than 100 feet. Where the streams are flowing in new channels, as is the Miami in the rock-walled valley at the north edge of the county, the depth of the alluvium is probably very much less, possibly not more than 30 feet. The alluvium consists of silt, sand, and gravel, with some included beds of blue pebbly clay or till. The upper 30 or 40 feet of it seems on the average to be somewhat finer and more silty than the deeper beds, in many of which sand or gravel predominates. Till is especially likely to be encountered in the broader valleys, as in the Mad River and Miami bottoms in the vicinity of their junction near Dayton. In this locality many partly buried knolls of till project above the alluvium.

Nearly all wells in the alluvial deposits find water at or slightly above the level of the streams. The deposits from the surface down to 30 or 40 feet are in many places more or less silty, but good water-bearing sands or gravels are generally present at depths of 40 to 60 feet and afford very large supplies of water. Here and there, however, the silty deposits continue to greater depths, and some wells, especially those near the sides of valleys, may have to go down 60 to 90 feet to get adequate supplies. As much as 400 gallons a minute is obtained by some wells in the gravels.

Like all waters in southwestern Ohio, those of the alluvium are hard. They are, however, perfectly pure and suitable for public supplies. The water is clear and free from sediment and is well adapted for paper manufacture, in which it is used at a large number of mills in the Miami Valley.

TERRACE GRAVELS.

Bordering the alluvial deposits at the valley sides at a number of points, especially along Mad and Miami rivers, are low terraces standing from 10 to 25 feet above the flood plains of the streams. They consist very largely of fine to medium gravel, from which the water drains quickly to the adjacent streams or sinks into the underlying formations. For this reason most wells must be carried at least to the level of the nearest stream before they can obtain adequate supplies.

TILL.

The till is a yellowish clay carrying some pebbles and a few bowlders and fragments of wood. Beneath its yellowish upper portion, which is generally 5 to 10 feet in thickness, the till grades downward into gray or blue clay. In the rougher southern portion of the county it is commonly thin, being in many places less than 25 feet thick. It is also thin in the eastern half of the county, especially along the edges of the Stillwater and Miami valleys, in which much bare rock shows at the surface. Within short distances back from the bluffs, however, its thickness increases from 15 to 40 feet. The greatest thickness is in the western half of the county, where the drift is in few places less than 25 feet in depth and in many is 50 feet or more. It is possible that in certain buried channels, as in the vicinity of Brookville, the drift may be considerably more than 100 feet thick. Gravelly or sandy zones or definite beds of sand or gravel are not uncommon, especially in localities where the till is of considerable thickness.

The clayey portion of the till contains considerable water, but yields it rather slowly. Dug wells, however, generally succeed in obtaining moderate supplies. Where gravelly beds are present water is much more abundant, and many driven and drilled wells obtain large quantities. The water is under pressure in many wells. It rises when encountered, but usually does not reach the surface. In a few places, however, as in the vicinity of Brookville, the water is under sufficient head to produce flowing wells.

MORAINAL DEPOSITS.

Montgomery County is characterized by rather extensive morainal deposits, which in places, especially along the east side of Miami River and the south side of Mad River, reach a thickness of 50 to 100 feet. Generally, however, they are limited to low knolls and disconnected ridges standing not more than 20 to 30 feet above the surrounding surface. The morainal deposits fall into several fairly well defined belts. One extends along the east side of the Mad and Miami valleys from the Greene County line southwestward to the south line of Miami County and along it to the southwest corner. Another less-pronounced belt extends from the Miami in the vicinity of West Carrollton westward through Farmersville to the county line. A third extends from the Miami in the northeastern portion of the county southwestward to the county line, passing just south of Brookville and north of Pyrmont. The deposits do not fall into definite belts, but are scattered irregularly over the general upland surface. The morainal deposits, where thickest, consist to a large extent of gravels and sands, but contain a few beds of pebbly clay or till. In some of the minor deposits till predominates.

Where the morainal deposits consist entirely of sand or gravel they yield very little water to wells, owing to the ease with which they drain into depressions or into the underlying materials. In such places wells, in order to obtain satisfactory supplies, must penetrate to the level of the ground water in the adjacent lowlands. In some places, where layers of till or clay occur in the moraines, the water is prevented from draining away, small amounts being held in irregularities in the clay or till surfaces. Wells reaching such surfaces may obtain supplies sufficient for ordinary domestic or farm purposes. (See fig. 8, p. 41.) Springs not uncommonly occur where the impervious layers come to the surface. In the lower and predominantly clayey knolls the supplies are similar to those of the till, but the wells, being mostly on elevations, have to go somewhat deeper for supplies than on the flats.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

The "Niagara" limestone is found beneath the till in the northern and northwestern portions of the county and also on the flat crests of the high isolated hills representing plateau remnants in the southeastern portion. Except in the north and northwest, however, the

"Niagara" is generally of no great thickness, the few feet which remains being preserved because of the resistance to erosion and weathering of the underlying "Clinton" limestone. The thickness does not seem to exceed 50 feet and in many places is only 5 to 10 feet. At the base of the formation is a few inches of shale, over which lies 5 to 10 feet of limestone suitable for building purposes, known as the Dayton limestone. Above the Dayton are other layers of more irregularly bedded limestone to a thickness of 30 or 35 feet. Some shale probably occurs in places between this and the underlying Dayton. The "Niagara" limestone is usually a gray or bluish granular rock containing a few small cavities, but in some places it is buff and brownish.

The "Niagara" limestone, where overlain by the till, contains considerable water, which it readily yields to dug wells. Owing to the drift covering, springs are not so common at the base of the formation in Montgomery County as they are elsewhere.

"CLINTON" LIMESTONE.

The "Clinton" limestone underlies all the area in which the "Niagara" is found and extends considerably beyond the outcrop of that formation. Large areas occur between Mad and Miami and between Miami and Stillwater rivers, as well as west of Stillwater River to the county line, except perhaps beneath the valley of Wolf Creek. "Clinton" limestone also occurs beneath the "Niagara" on the high plateau remnants southeast of Dayton to the southeast corner of the county. It varies in thickness from 30 feet in the northern portion of the county to 10 feet in the southeastern portion. The lower part is a calcareous sand, and the upper part is a semicrystalline, in places almost marble-like limestone. Its color varies from nearly white, through gray to pink, yellow, and red. The pink or red color, although not predominating, can almost always be seen where any considerable body of the rock is exposed, and it assists in identifying the formation. The bedding is very irregular.

The "Clinton" limestone contains much water and generally yields satisfactory supplies to wells, especially dug wells. It is probably this limestone that yields the water of the public supply at Brookville, which, before the wells were pumped, flowed at the surface. The lower part of the "Clinton" and also to some extent the upper crystalline part give rise to numerous springs, some of them of large volume. The streams formed by these springs may be seen flowing over the bare limestone surfaces and plunging over vertical cliffs at a number of places along the Stillwater (Pl. VII, *B*, p. 45).

RICHMOND AND MAYSVILLE FORMATIONS.

The Richmond and Maysville formations underlie all the lowlands of Montgomery County and in the southern part of the county extend up the hillsides to the base of the "Clinton" at an altitude of nearly 900 feet. Owing to their northward dip, however, they reach an altitude of only about 800 feet near the northern border. They probably underlie most of the uplands up to a point about 2 miles south of Brookville. The upper 6 to 20 feet is a reddish or yellowish shale, but below this shale thin layers of limestone and shale, generally from 2 to 10 inches in thickness, alternate down to the valley level. Probably somewhat over 200 feet of these beds is exposed in the county.

Owing to the thinness of the limestone beds and the scarcity of solution passages, as well as the absence of porous layers, the Richmond and Maysville are not strong water-bearing formations. Where covered, however, by 10 to 20 feet of drift, which serves to hold and feed the water to the upper part of the series, fair supplies are obtained by many dug wells. Few drilled wells in these formations are successful.

NOTES BY TOWNS.

BROOKVILLE.[1]

The public supply at Brookville has been installed only a few years and is not yet so generally used as it should be in view of its much greater safety compared with the average private well, especially the shallow-dug well. It is derived from four 80-foot wells sunk through a considerable thickness of clay and other material, shutting off polluting matter, into the underlying limestone. The water would flow at the surface if not pumped. Other particulars of the supply will be found on page 52.

CHAUTAUQUA GROVE.[1]

The Chautauqua Grove summer resort and camp-meeting grounds are supplied from six driven wells, sunk about 25 feet in the river alluvium. The water is used for drinking and other domestic purposes, supplying without difficulty the campers and visitors, who at times number nearly 5,000. It is pumped by a gasoline engine for flushing and other purposes.

DAYTON.[1]

Dayton is situated mainly upon the broad flats at the junction of Miami and Mad rivers, but the outskirts of the city rest on terraces somewhat above the flood plain, even extending up the slopes of the

[1] Conditions in 1906.

surrounding rock hills. The public water supply has been in use for many years and supplies by far the greater portion of the population, few private wells being used, except those at the large industrial establishments and those on the outskirts.

Most of the wells now in use are in the lower part of the city and consist of 4 to 8 inch pipes driven 40 to 70 feet to gravel beds in the soft alluvial deposits. Abundant supplies are nearly everywhere obtained, although where the sands are unusually fine or silty only moderate amounts may be found. On the hills shallow dug wells obtain fair supplies from the drift or upper part of the rock, but deep drilled wells are almost invariably failures, the Richmond formation, which they penetrate, being almost destitute of water. One well on the hill above the town was carried to 800 feet without success. Additional data regarding the wells will be found on page 52 and analyses of the waters on pages 204–205.

Several wells were put down in search for oil and gas in 1886 and 1887. One of these, located at the corner of Brown and Cemetery streets, afforded the following record:

Record of deep well at Dayton.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
[Drift]	40	40
Richmond and Maysville formations: Blue limestone	420	460
Maysville formation and Eden shale: Blue slate, dark at bottom	415	875
Point Pleasant formation:		
Sand (?)	25	900
Limestone interstratified with shale	80	980
"Birdseye" limestone:		
White limestone	30	1,010
Blue limestone	10	1,020
Brown limestone	280	1,300
Limestone and shale	120	1,420
St. Peter sandstone (?):		
White sand	10	1,430
White siliceous, calcareous, and magnesian rock	250	1,680
Cambrian and Ordovician dolomite: White magnesian limestone	760	2,440

[a] Orton, Edward, Geol. Survey, Ohio, vol. 6, 1888, p. 286. Correlations by M. L. Fuller.

Some water was found in the upper parts of the boring, the casing of which was carried to 425 feet. Salt water was struck in the "Birdseye" at 1,360 feet and in the St. Peter at 1,450 feet. The water rose within 200 feet of the surface from the lower bed. The top of the "Birdseye" is about 115 feet below sea level. Some gas was obtained.

Another well sunk at the corner of First and Finlay streets reported 247 feet of unconsolidated deposits, mainly gravel. The first public supply at Dayton was installed in the city in 1869, the water being obtained from Mad River, but this supply was replaced in 1887 by a system of wells driven 30 to 60 feet in the alluvium bordering Mad River, just above the city. In 1906 seventy-seven 8-inch wells were in use, and seventeen had been abandoned. The wells extend along the river bank for 4,000 feet, the pumping station being near the middle. In 1906 a new supplementary system was about to be installed to serve the higher parts of the town and the residences on the surrounding hills. It was planned to obtain water from wells near the old plant and to raise it to the required level, 200 feet above the station, by high-pressure pumps. No sewage enters Mad River above the wells, but it receives some water from straw-board works. Unless, however, the entire ground water of the vicinity is lowered 30 to 60 feet below the surface and the river water drawn down to the level of the bottom of the wells, a condition not likely to result, there is little danger of pollution from the source mentioned. If, however, large quantities of sewage or other waste entered the valley from the sides it would be liable to work its way toward the river and contaminate the wells. If such contamination ever occurs the remedy will be to sink wells to 100 feet or more instead of 30 to 60 feet, as no pollution is likely to reach the greater depth. Further particulars of the public supplies will be found on page 52.

The National Military Home, a few miles west of Dayton, has an independent water supply from sixteen 6-inch steam-blown wells (see p. 52), penetrating a gravel lying at the base of the drift at depths of 45 to 58 feet. The wells are $1\frac{1}{4}$ miles east of the home, and from them the water is pumped to a reservoir. Other particulars will be found on page 52.

FARMERSVILLE.[1]

Farmersville has 8 or 10 drilled wells, the supplies being obtained from sand and gravel beneath a bed of blue clay or till that underlies the surface morainal deposits. The wells are said to range from 78 to 168 feet in depth. A field analysis of the water will be found on pages 206–207.

GERMANTOWN.[1]

Germantown is without a public water system, notwithstanding the fact that it is so situated that a supply could probably be procured from wells at a relatively small cost, the broad alluvial flats of Twin Creek, upon which the town is situated, carrying abundant water within a short distance of the surface. The wells should preferably be of the driven type and should be carried to a depth of not less than 60 feet in order to be safe from pollution. The supply would probably be of good quality and would be a great improvement over that afforded by the common shallow surface-water wells. The gain in convenience and in security against fire would also be factors of great importance.

[1] Conditions in 1906.

MIAMISBURG.[1]

The ground-water conditions are somewhat variable at Miamisburg. Near the center of the valley most of the wells get abundant supplies from the alluvium, but near the base of the hills water is often difficult to obtain, owing to the more silty character of the deposits and to the slight depth to rock. On one lot six unsuccessful attempts to procure water were made, although in the neighborhood all wells obtained water. West of the railroad most of the wells are driven, but east of it drilling must be resorted to.

Two wells, one 1,300 feet and the other 800 feet in depth, were drilled during the oil boom, in 1887. Considerable volumes of gas were encountered, but not enough for permanent commercial purposes. In the deeper well a sulphurous brine was encountered in large quantity at the bottom, presumably in the St. Peter sandstone, rising within 300 feet of the surface. The record of the 800-foot well is as follows:

Record of deep well at Miamisburg.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Drift: Mainly gravel	181	181
Richmond and Maysville formations:		
Blue slate	260	441
Lighter slate	40	481
Eden shale: Dark shale, becoming black	220	701
Point Pleasant formation: Limestone and shale	99	800

[a] Orton, Edward, Geol. Survey, Ohio, vol. 6, 1888, p. 289. Correlations of formations are by the author of this report.

The town of Miamisburg has recently installed a public waterworks, the water being obtained from wells sunk in the alluvium near the base of the hills at the southeast edge of town. There are no buildings in the vicinity and no chance of pollution at the present time. The supply is claimed to be ample for the needs of the town, although the water at the point where the wells are located seems to be less abundant than in the wells in the center of the valley. If at any time the wells should fail and it should be necessary to seek a new locality, a spot located above rather than below the town and near the center of the valley rather than toward the side should be selected. Other particulars regarding the wells will be found on page 52.

OAKWOOD.[1]

Oakwood has a public supply derived from two flowing wells. It is extensively utilized, but a few private wells are still used. Other particulars will be found on page 52.

[1] Conditions in 1906.

TROTWOOD.[1]

Trotwood is one of the smallest villages in the county having a public water supply, the installation following a destructive fire in 1899. It is owned by a private stock company and obtains its supply from two 6-inch wells sunk to a bed of gravel below the till. The water from the wells, together with compressed air, is pumped by a gasoline engine into a horizontal steel tank, in which it is held under a pressure of 40 to 80 pounds. The water is used for extinguishing fires, sprinkling, and washing, but is not popular for drinking, owing to the length of time it stands in the tank. It appears, however, to be perfectly safe. Further statistics are given on page 52 and a partial analysis on pages 206–207.

UNION.[1]

Union is located on the outcrop of the "Clinton" limestone, only a thin covering of drift overlying the rock surface. Open wells, which generally go through the limestone into the underlying shale, commonly find moderate supplies, the limestone affording the water, which is stored in the lower part of the well in the impervious shales. Drilled wells are much less successful, as they draw mainly from the relatively dry shale. Wells of both kinds are liable to contamination by the entrance of polluting matter through fissures in the limestone. The record of one of the deeper wells is given below. A partial analysis of the water will be found on pages 206–207.

Record of Eby well at Union.

	Thickness.	Depth.
	Feet.	*Feet.*
"Clinton" limestone: Limestone	15	15
Richmond formation:		
Blue clay	7	22
Gray rock	10	32
Blue clay and rock	35	67
"Drift rock" (cavernous rock?)	12	79
Blue clay	6	85
Gray rock	8	93

WEST CARROLLTON.[1]

The public waterworks at West Carrollton was installed by the village in 1897, the water being obtained from wells driven 60 to 80 feet in the sand beneath the lowlands along the Miami & Erie Canal and pumped by the G. H. Friend Paper & Tablet Co. into the mains. The well water is free from pollution and suitable for all domestic purposes. Additional particulars regarding the supply will be found on page 52; an analysis of the water is given on pages 206–207.

[1] Conditions in 1906.

WATER PROSPECTS.

Underground water conditions in the villages and towns of Montgomery County are summarized in the following table:

Underground-water conditions in Montgomery County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Air Hill	Till	50		"Clinton" (?).	"Clinton" (?)	Usually plenty.
Alexandersville	Alluvium	30+	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
Amity	Till	60		"Clinton"	"Clinton," Richmond, and Maysville.	Moderate.
Arlington	do	40	Plenty	"Niagara"	"Clinton"	Usually plenty.
Bachman	do	50	do	do	do	Do.
Beavertown	do	13	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Bridgeport	Alluvium	Deep.	do	do	do	Do.
Brookville	Till	70	do	"Niagara"	"Clinton"	Usually plenty.
Centerville	do	12	do	"Clinton"	"Clinton," Richmond, and Maysville.	Moderate.
Chambersburg	do	40	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Clayton	do	30	do	"Niagara"	"Clinton"	Usually plenty.
Crown Point	do	40		Richmond and Maysville.	Richmond and Maysville.	Small.
Dayton	Alluvium	70+	Plenty	do	do	Do.
Dean	Till	35		do	do	Do.
Dodson	do	60	Plenty	"Niagara"	"Clinton"	Usually plenty
Drexel	do	60		"Clinton"	"Clinton," Richmond, and Maysville.	Do.
Ebenezer	do	50		Richmond and Maysville.	Richmond and Maysville.	Small.
Ellerton	Till, moraine	40		do	do	Do.
Englewood	Till	10	Small	"Clinton"	Richmond, "Clinton," and Maysville.	Moderate.
Fairmount	do	12	Plenty			
Farmersville	Till, moraine	140+	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Fort McKinley	Till	100+	do	do	do	Do.
Fourmile House.	do	12	do	"Clinton"	"Clinton," Richmond, and Maysville.	Moderate.
Germantown	Alluvium		do	Richmond and Maysville.	Richmond and Maysville.	Small.
Gettersberg	Till	35	Moderate	do	do	Do.
Happy Corners	do	35		"Clinton"	"Clinton"	Usually plenty.
Harshman	Alluvium	Deep.	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
Hayes Store	Till	11	do	"Clinton"	"Clinton"	Usually plenty.
Kingsville	do	35	Moderate	do	"Clinton," Richmond, and Maysville.	Moderate.
Kinsey	do	20	Plenty	do	"Clinton"	Usually plenty.
Kreitzer Corner	do	100+	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Lambertine	do	40		do	do	Do.
Liberty	do	20		do	do	Do.
Little York	do	25		do	do	Do.
Miamisburg	Alluvium	60+	Plenty	do	do	Do.
Mummaville	do	50+	Variable	do	do	Do.
National Military Home.	Till	60+	Plenty	do	do	Do.
New Lebanon	do	60	do	do	do	Do.

Underground-water conditions in Montgomery County—Continued.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Phillipburg	Till	30	Fair	"Niagara"	"Clinton"	Usually plenty.
Pyrmont	do	60	Plenty	do	do	Do.
St. Richmond	do	60	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Sixmile	do	20	do	do	do	Do.
Spanker	do	16	do	do	do	Do.
Sulphur Grove	do	20	do	"Niagara"	"Clinton"	Usually plenty.
Swanktown	do	60	do	do	do	Do.
Tadmor	Alluvium	80+	Fair	Richmond and Maysville.	Richmond and Maysville.	Small.
Taylorsburg (on Dry Run).	Till	40	Plenty	do	do	Do.
Taylorsburg (on Miami River).	Alluvium	Deep.	do	do	do	Do.
Trotwood	Till	50	do	do	do	Do.
Union	do	3	Small	"Clinton"	"Clinton," Richmond, and Maysville.	Moderate.
Vandalia	do	30	Moderate	"Niagara"	"Clinton"	Usually plenty.
Verona	do	40	Plenty	do	do	Do.
Vorhees	do	40		do	do	Do.
Wengerlawn	do	60		do	do	Do.
West Carrollton.	Alluvium	80+	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
Woodbourn	Till	25	Small	do	do	Do.

PREBLE COUNTY.

By Frederick G. Clapp.

The following description applies to all of Preble County except the quarter lying north and northeast of Eaton, which could not be examined during the short time spent in the field.

SURFACE FEATURES.

The surface of Preble County is rather diversified in its features, depending on the distribution of the glacial drift. Most of the northern portion consists of a plateau-like surface, having a maximum elevation of about 1,250 feet along the western border and descending to about 1,050 feet on the eastern border. In the southern part of the county the surface is more diversified, the hills being somewhat dissected by streams, whereas the uplands in the northern part of the county are broad and flat and contain few streams. The creeks descend from shallow depressions on the uplands into deep and narrow valleys, with flood plains ranging from a few hundred feet to a quarter of a mile in width. The larger streams—Banta, Twin, Sevenmile, and Fourmile creeks—descend to elevations of 700 to 800 feet on the southern and eastern borders of the county. The valley flats consist of alluvium. The county is crossed in a general northwest-southeast direction by three broad morainal ridges.

WATER-BEARING FORMATIONS.

SURFACE DEPOSITS.

ALLUVIUM.

As the streams of Preble County are not large, their deposits are not very extensive. Twin, Banta, Sevenmile, and Fourmile creeks have flood plains reaching, in places, a width of a quarter of a mile or more. They are generally flat and low and lie between steep bordering hillsides. The surface portion of the alluvium is mostly fine, with sands and silts predominating, but well sections show that in many places coarse gravels lie below the surface.

Except where it is very thin, the alluvium generally yields satisfactory water supplies to driven wells, especially in the deeper and broader valleys. At Eaton such wells are sunk to a considerable depth in alluvium and furnish the public supply.

TERRACE GRAVELS.

Narrow deposits of coarse gravel border some of the principal streams, where they rise to heights of 50 to 100 feet above the bottom of the valley and form flat terraces. Water on these terraces is generally scanty, the supply draining out on the sides to the valleys.

TILL.

The greater portion of Preble County, as of other counties in the vicinity, is covered by pebbly clay or till of varying thickness, which is rather uneven in its distribution, in some places overlying gravels and in others underlying them. Generally, however, a considerable thickness of till overlies the bedrock of the region, and beds of till, generally called hardpan by the drillers, are penetrated in sinking deep wells. Along many creeks can be seen deep sections of till, in some places only a few feet in thickness and in others 100 feet or more thick. Where characteristic the till is hard and compact and contains many pebbles and in places large bowlders. The upper 5 to 10 feet may be yellowed by oxidation, but the underlying portion is generally blue-gray. Over most of the county there are at least two beds of till, the one resting on bedrock being the more clayey, solid, and tough, and the one forming the surface or lying near it being generally looser, with a larger proportion of bowlders and sand.

The water supplies of the till are, as a rule, not large. Wells sunk in it may obtain plenty of water during the greater part of the year, but the supply is liable to become exhausted in summer. The old-fashioned dug or open wells are most successful in the till, as driven wells are generally not of large enough diameter to form a sufficient reservoir for the water which seeps in from the surrounding till. The open wells, however, are not so safe from pollution as those of other types.

MORAINAL DEPOSITS AND OUTWASH PLAINS.

Under morainal deposits and outwash plains are included the deposits which in general overlie the thicker or deeper of the two till sheets. They include, first, broad undulating morainal deposits of sand and gravel, which are easily recognizable by their surface features, and, second, broader and flatter deposits of sand and gravel, which in places stretch for many miles with a surface apparently as level as a floor, and which are made up of fairly horizontal beds of sands and gravel overlain only by superficial till a few feet in thickness. The thickness of these plains deposits is in places very great. They are believed to be best developed on the uplands within a few miles of Eaton.

The true moraines of Preble County consist of three principal belts. The outermost, a mile or two wide, enters the county near its southeast corner, runs westward to Camden, crosses Sevenmile Creek, takes a north-northwesterly sweep, and strikes the northwest corner of the county north of New Paris. The second moraine is not so conspicuous and, except at its east end, is broader and flatter. It enters from Montgomery County south of West Alexandria, sweeps northward, passing between West Alexandria and Eaton, and at the northwest corner of the county merges with the outer moraine. The third line of moraines, which is still less conspicuous, crosses the northeast corner of the county northeast of Lewisburg.

In the morainal deposits of the typical hilly type, such as those in the outer belt, it is necessary to drill to a considerable depth to reach water. On the inner moraines, however, and on the broad flat areas surrounding them, water has less chance to drain away and is encountered at several depths below the surface, the different water beds being known accordingly as the "first," "second," and "third." In the vicinity of Eaton and elsewhere flowing artesian wells have been obtained by short pipes driven into these deposits, and near West Alexandria deep-driven wells obtain flows from them.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

Probably more than half of the bedrock in Preble County consists of "Niagara" limestone. The "Niagara" constitutes the entire area north, northwest, and west of Eaton, extending southward almost uninterruptedly beyond Sugar Valley, whence a strip of it, with an apparent width of more than a mile, stretches southward between Sevenmile and Fourmile Creeks nearly to the edge of Butler County, southeast of Morning Sun. Another arm of the "Niagara" limestone stretches southeastward from Eaton nearly to Winchester. In the southeast corner of the county there are only a few scattered patches of it. The " Niagara " covers most of the northeast quarter of the county but is not present along the valley south of Lewisburg.

In the northwest corner of the county, on the uplands, the " Niagara " limestone may be over 100 feet in thickness, but where it outcrops in the southern part of the county it has in places a thickness of only a few feet, the rest of it having been eroded.

The " Niagara " is quarried for building stone in a number of places, one of which is near a shallow creek about 2 miles northeast of Eaton. The most important quarries, however, are at New Paris, in the northwest corner of the county, where the workings are 30 or 40 feet deep and the rock makes excellent building stone.

The " Niagara " limestone probably contains more water than any other of the rock formations lying near the surface in Preble County. It is generally a bedded or massive gray to buff limestone. Some water is found in it by shallow wells, but the greatest amounts are generally obtained by deep wells which penetrate nearly to the top of the underlying " Clinton " limestone. The " Niagara " limestone contains a great many irregular solution passages, through which water is flowing, and when these passages are tapped by the drill they yield a large amount of water. (See Pl. V, *A*.)

" CLINTON " LIMESTONE.

The " Clinton " limestone underlies the entire area in which the " Niagara " is found and extends somewhat beyond the outcrop of that formation. Owing to the thick drift covering in Preble County, little of the " Clinton " is believed to be exposed, but it can be seen in a few places along the uplands west of Sevenmile Creek and probably at other points. Owing to the scarcity of exposures and to the fact that in well records it is generally reported with the " Niagara " simply as " limestone," its thickness is not known with certainty, but it is believed to measure not over 50 feet. Where characteristic, it consists of massive buff to pinkish, horizontally or cross bedded limestone, composed largely of minute shell fragments.

Although the " Clinton " limestone can not be differentiated from the " Niagara " where penetrated by wells, the fact that many wells find water near the base of the material reported as limestone seems to indicate that the " Clinton " yields moderate amounts. Generally, however, it acts as an impervious bed; along its upper portion numerous springs issue from the " Niagara " limestone.

RICHMOND AND MAYSVILLE FORMATION.

The lowlands in southern Preble County, as far north as Fairhaven on Fourmile Creek, nearly to Eaton on Sevenmile Creek, and as far as Lewisburg on Twin Creek, consist of the Richmond and

Maysville formations, which form the bottoms of the valleys and extend for considerable distances up the hillsides. In the southern part of the county these formations form many entire hills, except perhaps for a thin capping of "Clinton" and "Niagara" limestones.

Owing to the fact that the county is so thickly covered by drift, little can be said of the lithologic character of the Richmond and Maysville formations. Doubtless it is similar to that of these formations as seen in Butler and other counties, where they consist of 1 to 10-inch layers of interstratified shale and limestone.

Owing to the thinness of the limestone beds and the consequent scarcity of solution passages, the Richmond and Maysville formations contain only a moderate amount of water. They yield very little to shallow wells, and practically none to most drilled wells. Where water is found it is generally inferior in quality to that in the "Niagara" and "Clinton" limestones and in some wells is sulphurous or brackish.

NOTES BY TOWNS.

CAMDEN.[1]

Three gas wells have been sunk by the town of Camden. One of them is 85 feet deep; the depths of the others are unknown. One well still yields gas, under 35 pounds pressure, which is used for running an engine and which was at one time piped all over the town.

One of the gas borings penetrated 180 feet of drift before reaching bedrock, showing that a deep buried valley extends northward from the Miami Valley and was formerly occupied by a stream of considerable size.

CEDAR SPRINGS.[1]

About a mile south of New Paris is the Cedar Springs Hotel, a popular summer resort on the New Paris and Westville branch of the Dayton & Western Electric Railroad. The Cedar Springs, several in number, are situated in the valley near this hotel. They are dug 6 or 8 feet in the bottom of the valley near a small run. The water occurs in gravel underneath hardpan, and one of the springs extends into the "second-gravel" bed. The hardpan and gravel layers rise into the morainal hills in the opposite direction from the hotel, and for that reason there is no danger of pollution; moreover, excellent sanitary precautions are taken in the curbing of the springs. The springs, which are known individually as the Navahoe, Iron, Glycerine, and Cathartic springs, have been analyzed (see pp. 206–207), and the composition of the water seems to depend on whether it occurs in the "first" or "second" gravel. Around several of the springs there is a slight iron stain, due to the iron in the water. The volume of flow

[1] Conditions in 1906.

can not be conveniently measured, but is estimated at 5 to 10 gallons a minute. The surroundings of the springs are thickly wooded. In addition to being used at the summer hotel, the water is bottled for shipment to a distance as "Navahoe water," though all of it does not come from Navahoe Spring. These springs have a history dating back to the days of the aborigines, and great medicinal value is claimed for them.

EATON.[1]

Public supply.—Eaton has a fair public supply, derived from drilled wells 6 inches in diameter, sunk on the flood plain of Sevenmile Creek west of the village within 50 rods of the pumping station. The system was installed in 1891. In all, ten wells have been sunk to depths of 60 to 100 feet, but only two are used. These are pumped with an air lift. A sample record is as follows:

Record of driven well of the Eaton Waterworks.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4	4
Hardpan	55	59
Coarse blue gravel	20	79

This is believed to be an average record. Under the blue gravel is another bed of "hardpan," and bedrock is entered at depths of 57½ to 99 feet. Several of these wells found very little water on account of the fine-grained nature of the sediments penetrated. The wells which are in use will sometimes overflow after standing several days without pumping. By pumping the two wells 18 hours a day an average of 120,000 gallons of water is obtained. The water is delivered by an air lift from the wells to a cistern at the pumping station and then pumped to a standpipe whose top is 150 feet above the station or 135 feet above Main Street. During the summer the supply is insufficient and it is necessary to stop lawn sprinkling, etc. For this reason it has been suggested that the mains be extended to some springs situated a short distance up the creek. The composition of the water is given on pages 206–207.

In 1894 a 10-inch pipe-line was run 1,500 feet west from the pumping station to a spring at the foot of a bluff across the creek. While the surface was wooded plenty of water was obtained, but since much of the forest has been cut away the spring has failed and has been abandoned. Water was also drawn from two cisterns and 24 rods of tile at the base of the bluff, being obtained mostly from a bed of water-bearing gravel 4 feet thick which outcrops 14 feet below the

[1] Conditions in 1906.

top of the bluff. Only about one-tenth the original supply is now obtained.

Flowing wells.—In the northeast corner of Eaton a number of wells bored with an auger in sand and gravel to depths of 25 to 35 feet flow as "fountains." The wells were sunk about 1820[1] and recently the flow in all of them has diminished greatly owing to the sinking of new wells. The water has a temperature of 52° and contains iron, but it otherwise of good quality and is satisfactory to the residents in that part of town. The water, which will rise several feet above the surface, comes from gently inclined gravel beds in the morainal deposits which rise gradually toward the northwest.

Drilled wells.—A number of drilled wells have been sunk at Eaton. Two of them, 186 and 326 feet deep and 8 inches in diameter, are situated at the plant of the Eastern Electric Light & Power & Ice Manufacturing Co. They obtained very little water, probably because they were mostly in the Richmond and Maysville formations. Rock was struck at 24 feet.

Several wells in the village seem to furnish water of excellent quality. One of these is a dug well at the courthouse.

Several attempts have been made to find oil and gas in the vicinity of Eaton About 1885 a deep well, sunk on the William Acherman lot, penetrated the "Birdseye" limestone and a bed of sandstone and obtained salt water. It is reported to have been about 1,600 feet deep and was cased for about 300 feet; the record, however, has been lost. Another test well, about 1,200 feet deep, was put down at the electric-light plant, then owned by Josiah N. Robinson. Persons who were interested in the borings report that the "Birdseye" limestone dipped markedly from the Acherman well toward the well at the electric-light plant.

Springs.—In the vicinity of Eaton there are a number of springs of considerable importance. One of them, situated at the picnic grounds about a mile southeast of the village, issues from the foot of a slope about 5 feet above a run in a shallow ravine with a flow estimated at about 3 gallons a minute. It is supposed to come from the "Niagara" limestone.

Four miles northeast of Eaton, on the Lewisburg Pike, an enormous spring issues from drift deposits in a slight depression. The water bubbles up from sand with an estimated volume of at least 50 gallons a minute. This is the largest spring known in the county.

[1] History of Preble County, Ohio, H. Z. Williams & Bro., 1881, p. 134.

LEWISBURG.[1]

Lewisburg is situated on a gentle till slope, rising from Swamp Creek. The base of the "Niagara" limestone outcrops along the bluffs bordering the creek, but on the plain the rock is covered by 10 to 20 feet of till. Most of the wells are the old-fashioned dug wells, but some of them are drilled.

Most of the drilled wells yield water of good quality. Probably the deepest well in Lewisburg is that at the Handle (?) factory. It is 101 feet deep and strikes limestone 15 feet from the surface. The water tastes very strongly of sulphur. It can not be exhausted with a steam pump. About a mile north of Lewisburg a well was drilled 185 feet, nearly all in solid rock. In the surrounding country there are a number of drilled wells that are not so deep.

A gas well drilled on the eastern border of the village to a depth of about 1,300 feet is reported to have struck the "Birdseye" limestone at 950 to 1,050 feet and to have found an abundance of salt water. A fine supply of water was struck about 300 feet from the surface and was used in drilling. A little gas was obtained from the shale and is still used, but none was found in the "Birdseye."

NEW PARIS.[1]

At New Paris rock outcrops at the surface, but its extremely irregular character is shown by the fact that about a mile north of the village a well is reported to have been sunk to a depth of 285 feet before striking rock. No water was found. Other deep wells in the drift show that there are deep gravel-filled valleys in this neighborhood which represent the former courses of the streams. It is probable that East Fork of Whitewater Creek once followed a course very different from its present one.

C. W. Bloom, of New Paris, draws a small public supply from a dug well 17 feet deep in gravel below "hardpan." The well can be pumped at the rate of 125 gallons a minute and the water is of excellent quality. Analysis is given on pages 206–207.

The largest limestone quarries in the northwestern part of the county are at New Paris, the most important one now in operation being that of Reinheimer Bros., near the south end of town. The "Niagara" limestone at this place is overlain by till ranging from a few inches to 4 feet in thickness. The limestone here is a fine-grained bluish-gray rock containing numerous layers of "flint rock" up to a foot in thickness and some flint nodules. The joints in the limestone are, in general, tightly closed. Two systems exist, one running east and west and the other north and south. The cracks are nearly vertical. Throughout the limestone many small solution

[1] Conditions in 1906.

passages follow the joint cracks, forming channels for several springs of excellent quality, which issue from the rock. One flows from a solution cavity about a foot in diameter with an estimated volume of 2 or 3 gallons a minute. The most interesting spring is at the south end of the quarry, where (Pl. V, *A*, p. 36) a conspicuous solution channel a few inches in diameter follows the rock vein along the joint crack for several rods. During the quarrying operations within the last few years the spring has been traced downward into the hill for a distance of about 500 feet. The volume of flow is now about 7 gallons a minute but is diminishing as the quarrying operations progress. The water is of excellent quality and is used by the workmen for drinking. The measured temperature is 52°. Analyses of springs in this quarry are given on pages 206–207. These springs and solution channels furnish a clue to the probable mode of occurrence of well water in limestone at great depths below the surface and show that wells sunk in the "Niagara" limestone may be expected to find moderate or even large amounts of water of good quality by striking one of these solution channels. If, on the other hand, as sometimes happens, they do not chance to strike a vein of water, the well will be unsuccessful.

WEST ALEXANDRIA.[1]

West Alexandria has a public supply owned by the village. The system consists of four drilled wells 134 feet in depth. A record of the strata passed through is as follows:

Section of deep wells of West Alexandria waterworks.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay (till containing numerous large bowlders)	16	16
Gravel (containing water)	13	29
Blue clay	31	60
Gravel (containing water)	12	72
Hardpan	49	121
Quicksand	7	128
Gravel (containing water)	6	134

The water used comes from the gravel bed at the bottom. The well of which the record is given above was the last to be installed in the system and was drilled in January, 1905. Originally the town had wells 65 and 95 feet deep, but enough water was not obtained from them, and drilling was carried into the "third gravel." The water in the "second gravel," which was originally used, rose nearly to the surface. The actual yield is not known, but nearly 1,000 gallons a minute has been obtained without lowering the water over 4

[1] Conditions in 1906.

feet from the surface. The amount pumped ordinarily is reported as about 35 gallons a minute. The wells are arranged in the form of a square 400 feet on a side. From them the water is pumped to a standpipe 119 feet above the pumping station and 100 feet above the ground. The system is reported very satisfactory.

Several flowing wells have been obtained in West Alexandria. The best three were sunk for S. S. Black near the south end of the village. Two of them were 112 and 121 feet deep, but only one of these is now in use, the second well being drilled when the first one was accidentally ruined. This well is the finest flowing well in the county, and Mr. Black uses it to supply a fountain which stands in his front yard and a fishpond covering half an acre. The water is also used for all domestic purposes. It will rise unconfined 14 feet above the surface. The temperature is 52°. Mr. Black's third well is 112 feet deep and supplies a canning factory. The water will rise 12 feet from the surface and is piped to the second story of the factory. The water in these wells comes from some of the deeper gravels of morainal deposits and probably owes its head to a long descent along beds dipping from the north or northwest.

WEST ELKTON.[1]

True flowing wells are not known in the vicinity of West Elkton, but at the west end of the village Elijah Mendenhall has a dug well 16 feet in depth, from which the water flows in a constant stream through a pipe connected with the well 4 feet below the surface. This water is very high in iron. (See analysis, pp. 206–207.) The morainal hill on the side of which this well is situated rises about 40 feet higher within 400 feet north of the well, and the head is believed to be due to the presence of an inclined gravel bed.

WEST MANCHESTER.[1]

West Manchester is situated on a very flat till plain several miles broad. Part of the residents use the public supply, but some still use dug wells 20 to 40 feet in depth. Many of these are in poor locations and the sanitary quality of their water is doubtful. The public supply is excellent and should be more widely used.

Data regarding the public supply are given on page 52. The waterworks, which were installed in 1903–4, are situated on the plain at the southeast corner of the village and consist of a small pumping station and three drilled wells. The water is pumped from the wells each morning into two large tanks, 36 by 8 feet. The tanks are filled about half full, compressing the air above, and the water is distributed by the consequent pressure, which ranges from 25 to 55 pounds.

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[1] Conditions in 1906.

Before the waterworks were installed a test well was sunk to a depth of 150 feet. It is reported to have struck rock at 70 to 80 feet, but some of the inhabitants doubt whether rock was really struck. As no water was found below 65 feet the well was abandoned below that depth.

The water in the wells stands about 10 feet below the surface without pumping and can not be pumped down below 23 feet.

WATER PROSPECTS.

The underground-water conditions in the several cities and villages in Preble County are summarized in the following table:

Underground water conditions in Preble County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water bearing rocks.	Water supply.
		Feet.				
Camden	Alluvium	Deep.	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
Campbellstown	Moraine			"Niagara"	"Niagara"	Plenty.
Eaton	Moraine and till.	40 to deep.	Plenty	do	do	Do.
Eldorado	Moraine	80–100	do	do	do	Do.
Euphemia	Till	0–20	Moderate.	do	"Niagara" and "Clinton."	Do.
Fairhaven	Alluvium	15	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Gettysburg	Moraine and till.			"Niagara"	"Niagara"	Plenty.
Greenbush	Till	6	Moderate.	Richmond and Maysville.	Richmond and Maysville.	Small.
Ingomar	Moraine			do	do	Do.
Lewisburg	Till	10–20	Moderate.	"Niagara"	"Niagara" and "Clinton."	Plenty.
Morning Sun	do	Shallow.	do	Richmond and Maysville.	Richmond and Maysville.	Small.
Oklahoma	do	+30	Plenty	"Niagara"	"Niagara"	Plenty.
New Hope	Moraine and till.			do	do	Do.
New Lexington	Till			Richmond and Maysville.	Richmond and Maysville.	Small.
New Paris	Moraine	25	Plenty	"Niagara"	"Niagara"	Plenty.
Sugar Valley	do			do	do	Do.
West Alexandria.	do	Deep	Plenty	Richmond and Maysville.	Richmond and Maysville.	Small.
West Elkton	Till and Moraine.	10	Moderate.	"Clinton" (?)	"Clinton"(?)	Plenty.
West Florence	Moraine			"Niagara"	"Niagara"	Do.
West Manchester.	Till	−80 ?	Plenty	do	do	Do.
West Sonora	Till and Moraine.	+40	do	do	do	Do.
Winchester (Gratis post office).	Till	10	Moderate.	Richmond and Maysville.	Richmond and Maysville.	Small.

WARREN COUNTY.

By M. L. Fuller.

SURFACE FEATURES.

Warren County is essentially a plateau, standing for the most part 800 to 900 feet above sea level but rising at some points to 1,000 feet or over. The plateau is divided into eastern and western parts by the deep valley of the Little Miami, the bottom of which is 200 feet or more below the upland surface. The plateau is also cut at the extreme northwest corner by the valleys of the Miami and the numerous tributaries to the two rivers, as well as by certain other valleys not now occupied by streams of any size. The uplands are much less cut by ravines than those in counties nearer the Ohio, the plateau surface being flat or gently rolling throughout the greater part of its extent. Among the valleys formed by streams other than those now occupying them may be mentioned that extending from the Miami near Middletown southeastward to the Little Miami at Deerfield and that leaving the Little Miami near Freeport and passing southwestward past Lebanon and thence southward to the main valley at Deerfield. These appear to have been drainage channels carrying glacial waters set free by the melting of the ice sheet when it occupied the region a short distance to the north (Pl. II, p. 24).

Other surface features of importance are the morainal hills, the most pronounced belt of which crosses the county from the northeast to the southwest corner, passing Lebanon. Another belt starts near Little Miami River at Waynesville and extends southeastward into Clinton County. These hills are best developed in the valleys, where they have an elevation of 50 to 100 feet above the surrounding bottoms. On the uplands they are far less conspicuous, few of them being over 20 feet in height.

WATER-BEARING FORMATIONS.

The water-bearing beds of Warren County include, among the surface deposits, alluvium, till, and moraines, and among the rock formations the "Niagara," "Clinton," Richmond, and Maysville formations.

SURFACE DEPOSITS.

ALLUVIUM.

The alluvial deposits in Warren County are extensive, occurring in the valleys of both the present streams and the old glacial streams. Of the recent deposits those of Miami and Little Miami Rivers are the most extensive, the alluvial plain of the former having a width of 2 miles or more in places and that of the latter a width of one-half to three-fourths of a mile. Considerable alluvium is also found in the valleys of Todds Fork and some of the minor streams. The deposits of glacial alluvium of the two valleys mentioned in the preceding section also reach a considerable width, especially in the valley connecting the Miami and Little Miami.

The alluvium of the Little Miami is prevailingly sandy or gravelly even near the surface, doubtless owing to considerable velocity of the waters during the excavation of the narrow gorge. In the valley of the Miami the alluvium includes more silt, especially in its upper portion, many wells having to be sunk 40 feet or more to procure supplies. Some till appears either to be included with or to underlie the older deposits of Miami River and also those in the two glacial valleys mentioned.

The sandy and gravelly alluvium of the Little Miami and of some of the other streams is in places very extensive and affords abundant water to wells from 40 to 60 feet in depth. On the Miami, also, water is obtained in abundance, although some silt is present and wells are not so uniformly successful, at least at shallow depths, as on the Little Miami. The same is true to a still greater extent in the old valley connecting the two streams and in the Lebanon cut-off of the Little Miami.

LOESS.

South of a line stretching from the northeastern to the southwestern corner of the county the surface drift is much older than in the deposits to the north, belonging to an earlier glacial stage. This older drift is covered throughout by a thin sheet, ranging from a few inches to several feet in thickness, of a bluish or brownish loamy silt known as loess. Owing to its thinness it is of no importance as a water-bearing formation in Warren County, but it assists in collecting the rainfall and in feeding water to the underlying till and rock.

TILL.

The pebbly clay or till varies in color from yellowish or brownish near the surface to blue or gray at depths of 5 or 10 feet or more. It contains many small pebbles and a few bowlders. Its thickness is usually under 25 feet and in some places under 10 feet, but it seems to be considerably thicker at points near the eastern border of the county, possibly reaching 100 feet or more in the vicinity of Todds Fork. Here and there, even on the plateau, the rock is almost at the surface, some wells encountering it at less than 10 feet.

The thin till is of little importance as a water-bearing formation, but that from 15 to 25 feet thick absorbs considerable quantities, which it supplies to shallow dug wells. The till is also important in absorbing and retaining water falling upon the surface and feeding it to the underlying rocks.

MORAINAL DEPOSITS.

The morainal deposits, which lie in a belt stretching from the northeast to the southwest corner of the county, reach their greatest development in the valleys, in some of which they have a thickness of 100 feet. Where conspicuously developed the moraines seem to be composed largely of sand and gravel, from which the water rapidly drains away to the near-by valleys or sinks to the underlying formations. For this reason wells almost never obtain supplies in the gravelly moraines, at least not until a depth equivalent to that of the general water level in the vicinity is reached. However, where the till is mixed with the gravel the downward passage of the water may be obstructed and accumulations take place in irregularities of its surface. Some wells sunk at such points procure water, but the supplies are generally uncertain.

ROCK FORMATIONS.

"NIAGARA" LIMESTONE.

Very little "Niagara" limestone is found in Warren County, the total thickness exposed being not over 50 feet and the area only a few square miles even where it is most extensively developed in the region northeast of Springboro, not far from the north line of the county. The lower part of the formation is a bedded limestone suitable for building (Dayton limestone) but only a few feet thick. Above this comes a bed of shale, which is in turn overlain by limestone making up the remainder of the 50 feet.

The "Niagara" limestone is found in so small an area that it is unimportant as a water-bearing formation in Warren County, although it contains considerable water and yields moderate supplies to the open wells that penetrate it.

"CLINTON" LIMESTONE.

In Warren County the "Clinton" limestone is only 15 or 20 feet thick and consists of a lower calcareous sand and an upper pinkish semicrystalline limestone. It underlies the "Niagara" in the hilltops northeast of Springboro and caps small hills a few miles north of Todds Fork on the eastern line of the county. Southeast of Freeport about three-fourths of an acre of "Clinton" overlies the drift, appearing to have been moved from its original position.

The "Clinton" outcrops, except that northeast of Springboro, are too small to contain much water and are so deeply covered by drift as to be unavailable. It is probable that northeast of Springboro, however, the formation carries considerable water which it yields to wells penetrating it. Some springs occur near its base, but, owing to the scanty outcrops of the formation, these are of little importance.

RICHMOND AND MAYSVILLE FORMATIONS.

The Richmond and Maysville formations consist of a shaly layer several feet in thickness at the top and alterations of thin limestone and shale in the remaining portion. About 400 feet of the formations is exposed in the county, and this seems to be nearly their entire thickness, for the underlying Eden shale appears beneath them not far from the south line of the county. The two formations underlie the entire county, except for the small patches of "Niagara" and "Clinton" described above.

Where either the alluvium or the "Clinton" limestone is available it constitutes the principal source of supply, but elsewhere in the county shallow wells are obliged to rely mainly on the Richmond and Maysville formations. Owing to the covering of drift, which serves as a feeder to these formations, moderate amounts of water are concentrated in their upper weathered portion and furnish fair supplies to open wells. Few drilled wells get water from the Richmond and Maysville formations in Warren County.

NOTES BY TOWNS.

FRANKLIN.[1]

In the central and northern parts of Franklin an abundance of water can usually be obtained from gravel beds in the alluvium at depths of 20 to 175 feet, the largest supplies generally being found at 60 and 80 feet. At the south end of the town the alluvium valley filling is apparently much thinner, wells soon reaching a till or clay in which there is little water, or entering dry rock. Most wells in this part of town have been failures.

The wells from which Franklin originally obtained its supply were located in the vicinity of the Franklin Mills, near the side of the valley, but later the mill wells withdrew so much water that the supply became insufficient and new wells were sunk by the town near the river on the opposite side from the town. These wells are a little more than 60 feet in depth, are so situated as to be free from all danger of pollution, and appear to yield enough for all ordinary demands. Further particulars are given on page 52.

KINGS MILLS.[1]

Kings Mills consists of the works of the Peters Cartridge Co. and the K. P. Co., located in the valley of the Little Miami, and of a small but neat and well-kept town on the plateau above. The residents of the older part of the village mainly use dug wells 20 to 40 feet in depth, sunk through blue clay or till to the top of the rock. In the newer part of town drilled wells have been substituted because they can be sunk more quickly and cheaply and are much safer. They are said to go down to the rock, which they reach at depths similar to those in the old part of town. One well was drilled to 160 feet, and several to depths of 50 or 60 feet, but generally without material increase of supply. In some the water found in the upper part was lost through "gravel" (crevices?) farther down. An analysis of the water from the well at the Homestead Hotel is given

[1] Conditions in 1906.

on pages 206–207. In the valley several large springs occur, one of them yielding, it is estimated, nearly 35,000 gallons daily.

The town has a public supply for extinguishing fires, the water being taken from the river.

LEBANON.[1]

Two wells were sunk at Lebanon during the oil and gas boom in 1887. The first, which reached a depth of 1,300 feet, obtained large quantities of salt water near the bottom, but no oil nor gas in paying quantities. Chalybeate water was encountered in the drift gravels. The second well, sunk in the valley of Turtle Creek, gave the following record:

Record of deep well at Lebanon.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift: Mainly gravel and sand	256	256
Maysville formation: Blue limestone and shale	244	500
Eden shale and Point Pleasant formation: Dark shale and limestone	162	662
"Birdseye" limestone: Hard white limestone	38	700

A public supply was installed by Lebanon in 1896, the water being obtained from a number of wells driven from 96 to 104 feet through alernations of clay, sand, and gravel on low ground near a small tributary of Turtle Creek. The water flows feebly at the surface, and is siphoned to a receiving well, from which it is pumped to the standpipe. Other information concerning the supply will be found on page 52. It appears to be safe and suitable for all domestic uses. A partial analysis will be found on pages 206–207.

MASON.[1]

Two deep wells, the second completed late in 1906, have been drilled for oil and gas at Mason. The first, sunk a quarter of a mile north of town, had approximately the following record:

Record of deep well at Mason.

	Thickness.	Depth.
Drift:	*Feet.*	*Feet.*
Clay, till, and quicksand	100	100
Blue clay	10	110
Richmond, Maysville, and Eden formations: Alternating layers of bluish limestone and shale	555	665
Point Pleasant formation: Dark shales and limestone	155	720
"Birdseye" limestone:		
Limestone	50	770
Blue mud	2	772

The record of the second well was substantially the same as that of the first. Some strong pockets of gas were encountered, but they

[1] Conditions in 1906.

soon blew off. A little salt water was obtained in both wells. In the new well, a mile southwest of town, flowing water was obtained from a sandy bed in the till at about 85 feet. An analysis of this water appears on pages 206-207.

MORROW.[1]

Although a town of considerable size, Morrow has no public water supply, doubtless because of the accessibility of Little Miami River in case of fire. Most of the people formerly depended on dug wells, but many of these were filled a few years ago by material washed in during a flood and have been replaced by wells driven in the fillings of the old wells. Many entirely new driven wells have also been sunk and a few drilled wells put down. Owing to the situation of the town at the base of a bluff and the movement of the ground water toward the river there is considerable danger that the shallower wells may become polluted, especially along the edge of the valley. It is believed that wells sunk near the center of the valley at a point above the town would afford a safer and more satisfactory supply than the present shallow wells.

MURDOCK.[1]

A deep well was sunk many years ago for oil and gas in a ravine not far from Murdock. A strong brine, utilized at one time in the manufacture of salt, was obtained, but neither oil nor gas nor any large amount of fresh water was found.

SPRINGBORO.[1]

The spring emerging from the drift near Springboro is of interest as being, according to reports, one of the largest in this part of Ohio. It was formerly used as a source of water power for a flouring mill and woolen factory.

WAYNESVILLE.[1]

The public supply of Waynesville was installed in 1900-1901, the water being obtained from driven wells sunk at the upper edge of the Little Miami flat south of the village. The wells are about 40 feet in depth and penetrated a succession of clays, sands, and gravels, stopping in a gravel resting on top of the underlying rock. The wells are so situated as to be free from pollution and are to be preferred to the private wells, especially the shallow open wells in the limestone and shale. Additional data regarding the supply will be found on page 52.

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[1] Conditions in 1906.

WATER PROSPECTS.

The underground-water conditions in the towns and villages of Warren County are indicated in the table below:

Underground water conditions in Warren County.

Town.	Surface deposits.			Rock formations.		
	Material.	Thickness.	Water supply.	Rock nearest surface.	Water-bearing rocks.	Water supply.
		Feet.				
Blackhawk	Till	15	Moderate	Richmond and Maysville.	Richmond and Maysville.	Small.
Blue Ball	do	15	do	do	do	Do.
Butlerville	do	15	do	do	do	Do.
Camargo	do	15	do	do	do	Do.
Camp Hagerman.	Alluvium		Plenty	do	do	Do.
Carlisle	do	65+	do	do	do	Do.
Corwin	do	30+	do	do	do	Do.
Cozzadale	Till	15	Moderate.			
Dodds	do	15	do	do	do	Do.
Edwardsville	do	25	do	do	do	Do.
Fort Ancient	Alluvium		Plenty	do	do	Do.
Foster	Alluvium, talus.		do	do	do	Do.
Franklin	Alluvium	40-120+	Fair	do	do	Do.
Harveysburg	Till, moraine	25	Moderate	do	do	Do.
Hopkinsville	Till	18	Very small.	do	do	Do.
Kings Mills	do	20	Plenty	do	do	Do.
Lebanon	Till, alluvium	50+	Moderate	do	do	Do.
Leeland	Moraine, till	25	do	do	do	Do.
Level	Till	20	do	do	do	Do.
Lytle	do	10	Small	"Clinton" (?)	"Clinton" (?)	Usually plenty.
Maineville	Alluvium		Moderate	Richmond and Maysville.	Richmond and Maysville.	Small.
Mason	Till, moraine	30	do	do	do	Do.
Merrittstown	Till	12	do	do	do	Do.
Middleboro	do	10	Plenty	do	do	Do.
Morrow	Alluvium		do	do	do	Do.
Mount Holly	do		do	do	do	Do.
Murdoch	Till	25	Moderate	do	do	Do.
Osceola	Alluvium		Plenty	do	do	Do.
Oregonia	do	25+	do	do	do	Do.
Pekin	Till	15	Fair	do	do	Do.
Pleasant Plain	do	16	Plenty	do	do	Do.
Red Lion	do		Moderate	do	do	Do.
Ridgeville	do	15	do	do	do	Do.
Roachester	do	25	Fair	do	do	Do.
Rossburg	do	15	do	do	do	Do.
Socialville	Moraine, till	20	Moderate	do	do	Do.
South Lebanon	Alluvium		Plenty	do	do	Do.
Springboro	Till	15	Small	do	do	Do.
Twentymile Stand.	do	10	Fair	do	do	Do.
Union	Till, alluvium	Deep.	Plenty	do	do	Do.
Waynesville	Alluvium		do	do	do	Do.
Wellman	Till	20	do	do	do	Do.
Zoar	do	30	Moderate	do	do	Do.

CHEMICAL CHARACTER OF THE WATERS OF SOUTHWESTERN OHIO.

By R. B. Dole.

INTRODUCTION.

The purpose of the following discussion is to suggest standards that may assist intelligent study of the analytical data and may show the broad general relations with respect to quality between the wells and other sources of supply in southwestern Ohio and in other regions. The methods of testing the waters are briefly outlined, the chief uses of water reviewed, and the qualities peculiar to waters of each class discussed. In conclusion a brief summary of the general characteristics of the waters of the area is presented. Discussion of individual waters is not attempted, the interest in these being too local to merit space here.

ANALYTICAL RESULTS.

Many analyses quoted in the succeeding pages were made by industrial chemists, chiefly to determine the value of the waters as sources of railroad supply. Such estimates are usually made in accordance with accepted procedures for industrial work and the results are sufficiently accurate for most purposes. These analyses, originally stated in hypothetical combinations in grains per gallon, have been recomputed to ionic form in parts per million in order that they may be compared with other analyses.

The analyses by Dole and Roberts were made in a special laboratory of the United States Geological Survey in accordance with the methods outlined in Water-Supply Paper 236, pages 9 to 26, inclusive. The probable accuracy of the methods and their sources of error are discussed in the same publication. The samples of water for these tests were collected in 1-gallon glass-stoppered bottles supplied to the field force from the laboratories, and the waters were examined as soon as practicable after collection.

Field assays of water by Parker and Evans, reported in the table of analyses, were made in accordance with the methods outlined in

Water-Supply Paper 151, and though only a few estimates were made for each water they furnish some additional information concerning the quality.

The results of the analyses in this paper are stated in parts per million, and though the amounts of water used for examination were measured by volume the mineral content is generally so low that the figures may be considered to represent parts per million by weight. Simplicity of computation, avoidance of fractions, and certainty of the basic unit make this decimal system especially satisfactory for practical purposes. Expression of the results of water analyses in parts per million has been generally adopted by sanitary and research chemists and by many technical chemists, and the exclusive employment of this unit industrially is delayed only by more or less objectionable precedent.

For the convenience of those who may desire to transform the results to other forms of expression it may be stated that multiplying the number of parts per million by 0.058 gives the equivalent in grains per United States gallon of 231 cubic inches; multiplying it by 0.07 gives the equivalent in grains per imperial gallon; and multiplying it by 0.00833 gives the equivalent in pounds per thousand gallons.

The analytical methods commonly employed in examining water permit the estimation of the elements and radicles present, the determination of the total amount of mineral matter in solution, and the more or less approximate separation of the incrusting from the nonincrusting constituents. Further than this, however, ordinary chemical tests give little knowledge regarding the chemical composition of mineral waters, and consequently the exact amounts of the different salts in solution are largely conjectural. Though such salts as sodium chloride, potassium carbonate, and magnesium sulphate are probably present, they are not determined as such, and their exact amounts can not be computed from the analytical data. The ionic form of stating the analyses—that is, stating the radicles present—has been adopted in this report because it gives fact and not opinion. The form is entirely practical and presents the actual results for the consideration and criticism of persons other than those making the tests.

WATERS IN GENERAL.

MINERAL CONSTITUENTS OF WATER.

All natural waters contain dissolved or suspended in them more or less of all materials with which they have come into contact. Such materials are taken up in amounts determined principally by their chemical composition and physical structure, by the temperature, pressure, and duration of contact, and by the condition of substances that have previously been incorporated in the water. To designate such suspended and dissolved matter as "impurities" is hardly correct, because they are introduced normally—in strict accordance with natural conditions and not necessarily by human agency. It has become customary, however, to call such substances impurities when they are detrimental or injurious in some proposed use of a water supply. For purposes of examination the substances that may be present are classified as suspended matter, such as particles of clay or leaves; dissolved matter, either of mineral or organic origin; microscopic animals or plants; and bacteria. The presence or absence of very small animals and plants likely to affect the quality of waters is determined by microscopic examination, and the chance of contracting disease by drinking the water is ascertained by bacteriological processes. The amount and the nature of the mineral ingredients are usually determined by estimating total suspended matter, total dissolved matter, total hardness, total alkalinity, silica, iron, aluminum, calcium, magnesium, sodium, potassium, carbonates, bicarbonates, sulphates, nitrates, chlorides, free carbonic acid, and free hydrogen sulphide. These estimates measure the materials most commonly present and most likely to affect the value of the waters. Articles describing the methods employed in making these estimates have already been cited (p. 172).

In judging the value of a water from the data afforded by analysis it is necessary to consider the supply both in relation to the use to which it is to be put and in its relation to other available supplies. Besides being used for drinking and for general domestic purposes, water is essential in steam making, paper making, starch manufacture, and many other industrial processes. The medicinal properties of the dissolved minerals are supposed to give many waters special significance. For each of these applications the amounts of certain ingredients in the water determine its value and assist in its classification. For example, considerable iron in a water may be harmful in one industrial process and harmless in another. The value of a water for another process may be directly measurable by the amount of suspended matter, the amount of dissolved matter not being significant. Furthermore, many waters that are considered of great medicinal value are unfit for boiler use.

To catalogue waters as good or bad, hard or soft, pure or impure, is indefinite and may be misleading. Absolutely pure water (H_2O) does not exist in nature, and, as stated before, a water should not be called impure when it contains only substances derived by natural means from natural sources. The arithmetical values of terms ordinarily employed to describe the quality of water, like those of many other words, are variable and largely dependent on local usage. In New England, for instance, water to be considered soft must have much less than 100 parts per million of total hardness, and water containing 30 or 40 parts of sulphates would not be used. In southwestern Ohio, however, it would be difficult to find a well water with total hardness less than 100 parts per million, yet many well waters in that region are called soft, and many waters containing 30 to 40 parts of sulphates are used in boilers without occasioning much comment. This example illustrates the uncertain significance of general descriptive words in classifying waters and emphasizes the advisability of knowing the intended use of a water and the composition of other available supplies before pronouncing judgment on its quality.

WATER FOR DOMESTIC USE.

PHYSICAL QUALITIES.

Suspended mineral matter clogs pipes, valves, and faucets, and growths of microscopic plants suspended in water commonly cause stains in clothes and bad odors. The red or reddish-brown masses of suspended matter sometimes occurring in well waters of this region are usually growths of *Crenothrix*, which is described by Whipple[1] as a small filamentous plant having a gelatinous sheath colored by a deposit of ferric oxide. It grows especially in ground waters containing considerable iron, forming tufts or layers in water pipes and well casings and sometimes clogging them. Detached particles escaping through faucets give the water an unsightly appearance and cause rusty stains on clothes washed in it. So far as is known, *Crenothrix* in drinking water does not cause disease.

True color in water is usually due to dissolved vegetable matter and causes serious objection among consumers only when it exceeds 20 or 30 parts per million.

In general the well waters of this area are satisfactory in respect to suspended mineral matter and color. In some places finely divided material from quicksands enters driven wells, but such trouble is not nearly so serious as in some other parts of the country. A few of the waters, especially those containing iron, develop a turbidity of 10 to 30 parts per million on exposure to the air, owing to the precipitation of dissolved matter, which gives rise to an apparent though not a real color. Most of the color recorded in analyses of these well waters is due to this cause, and true colors are so low as to be insignificant. Odors may be due to several causes. An odor like that of rotten eggs, encountered in many waters in the oil belt, is due to free hydrogen sulphide (H_2S). Growths of microscopic organisms in tanks and water mains often have unpleasant odors that make the water objectionable. Perfectly acceptable drinking supplies are free from color, odor, taste, and turbidity.

[1] Whipple, G. C., The microscopy of drinking water, New York, 1899, p. 144.

BACTERIOLOGICAL QUALITIES.

Before a water is used for domestic purposes it should be reasonably certain that it is free from disease-bearing organisms, and since present bacteriological technique does not permit positive statement regarding the presence or absence of such organisms, it is advisable to guard supplies against all chances of infection. The disease germs most commonly carried by water are those of typhoid fever. The bacilli enter the supply from some spot infected by the discharges of a person sick with this disease, and, though comparatively short lived in water, they persist in fecal deposits and retain their power of infection for remarkable lengths of time. Consequently, wells should be so located that their waters are guarded against the entrance of filth of any kind, either over the top or by infiltration. Pumps and piping should also be protected. Water from a carefully cased well more than 20 or 30 feet deep is acceptable if the well is located according to reasonable judgment in regard to privies, cesspools, and other sources of pollution. Many open dug wells and many pits constructed as reservoirs around the tops of casings are exposed to fecal contamination from above or through cracks in poorly built side walls. Care should be taken that the casings of deep wells do not become leaky near the surface of the ground so as to allow pollution to enter. As a matter of ordinary precaution the ground should be kept clean and water should not be allowed to become foul or stagnant near any well, no matter how deep. If shallow dug wells are necessary, they should be constructed with water-tight casings extending as far as practicable into the well and also a short distance above ground. The floor, or curbing, should be water-tight and pumps should be used in preference to buckets for raising the water. Every possible precaution should be taken to prevent feet scrapings and similar dirt from getting into the water by way of the top of the well. Underground water is not only less likely to become contaminated if protected from surface washings, air, and light, but it keeps better and is less likely to develop microscopic plants that give it an unpleasant taste.

CHEMICAL QUALITIES.

Amounts of dissolved substances permissible in a domestic supply depend much on their nature. No more than traces of barium, copper, zinc, or lead should be present, because these substances are poisonous. The occurrence of these elements in measurable amounts in ordinary well waters is so rare that tests for them are not usually made. Any constituent present in sufficient amount to be clearly perceptible to the taste is objectionable. Water containing two parts per million of iron is unpalatable to many people, and even this small amount can cause trouble by discoloring washbowls and tubs and by producing rusty stains on clothes. Tea or coffee can not be made satisfactorily with water containing much iron, because a black, inky compound is formed. Four or five parts of hydrogen sulphide make a water unpleasant to the taste, and this dissolved gas is objectionable also because it corrodes well strainers and other metal fittings. The amounts of silica and aluminum ordinarily present in well waters have no special significance in relation to domestic supply. The alkalies, sodium and potassium, are high in most Ohio waters in which chlorides are high.

Approximately 250 parts of chlorides make a water taste "salty" and less than that amount causes corrosion. In regions where the chloride content runs as low as 5 or 10 parts in normal waters unaffected by animal pollution the amount of chlorides is frequently taken as a measure of contamination. But such practice in southwestern Ohio is out of the question because (1) the normal chloride content in most of the well waters is so high that the small changes possibly caused by animal pollution are insignificant and (2) because wells near together and free from contamination may differ 200 or 300 per cent in their content of chlorides, owing to difference in the composition of the materials from which they draw their respective supplies. Therefore the establishment of isochlors, or lines of equal chlorine, in this area would be of no value whatever to the sanitarian.

Calcium and magnesium are the chief causes of what is known as the hardness of water. This undesirable quality is indicated by increased soap consumption and by deposition on kettles of scale composed almost entirely of calcium, magnesium, carbonates, and sulphates. Calcium and magnesium unite with soap, forming insoluble curdy compounds with no cleansing value and preventing the formation of a lather until all of these two basic radicles has been precipitated. Hardness is measured by the soap-consuming capacity of a water expressed as an equivalent of calcium carbonate ($CaCO_3$), and it can be computed from the amounts of calcium and magnesium in a water or can be determined by actual testing with standard soap solution. The use of soda ash (sodium carbonate) to "break" hard waters or to precipitate the calcium and magnesium is common and effects a saving in the amount of soap. Some large cities in other States have found it advisable to soften their public water supplies instead of leaving that task to the individual consumer.

WATER FOR BOILER USE.

FORMATION OF SCALE.

The most common trouble caused in boilers by the mineral constituents of natural waters is formation of scale or deposition of mineral matter within the boiler shell. When water is heated under pressure and concentrated by evaporation, as in a steam boiler, certain substances go out of solution and solidify on the flues and crown sheets or within the tubes. These deposits increase fuel consumption, because they are poor conductors of heat, and they also increase the cost of boiler repairs and attendance, because they have to be removed. If the amount of scale is great or if it is allowed to accumulate, the boiler capacity is decreased and disastrous explosions are likely to occur. In two years the inspectors for one insurance company[1] found more than 86,000 boilers, or nearly one-fifth of all those examined, to be defective on account of sediment, incrustation, and scale.

The scale or incrustation consists of the substances that are insoluble in the feed water or become so within the boiler under conditions of ordinary operation. It includes practically all the suspended matter or mud; the silica, probably precipitated as the oxide (SiO_2); the iron and aluminum, appearing in the scale as oxides or hydrated oxides; the calcium, precipitated in the form of carbonate and sulphate; and the magnesium, found in the deposits principally as the oxide but partly as the carbonate. The scale constituted by these substances is therefore a mixture of compounds, which varies in amount, density, hardness, and composition with different conditions of water supply, steam pressure, type of boiler, and other circumstances. Calcium and magnesium are the principal basic substances in the scale, over 90 per cent of which usually is calcium, magnesium, carbonates, and sulphates. If much organic matter is present part of it is precipitated with the mineral scale, as the organic matter is decomposed by heat or by reaction with other substances. If magnesium and sulphates are comparatively low or if suspended matter is comparatively high the scale is soft and bulky and may be in the form of sludge that can be blown or washed from the boiler. On the other hand, a clear water relatively high in magnesium and sulphates may produce a hard, compact scale that is nearly as dense as porcelain, clings to the tubes, and offers great resistance to the transmission of heat. Therefore the value of a water for boiler use depends not only on the quantity of scale produced by it, but also on the physical structure of the scale.

[1] The Locomotive (Hartford), new ser., vol. 21, 1900, p. 29; vol. 22, 1901, p. 21.

CORROSION.

Corrosion or "pitting" is caused chiefly by the solvent action of acids on the iron of the boiler. Free acids capable of dissolving iron occur in some natural waters, especially in the drainage from coal mines, which usually contains free sulphuric acid, and also in some factory wastes draining into streams. Many ground waters contain free hydrogen sulphide, a gas that readily attacks boilers; dissolved oxygen and free carbon dioxide also are corrosive. Organic matter is probably a source of acids, for it is well known that waters high in organic matter and low in calcium and magnesium are corrosive, though the exact nature and action of the organic bodies are not understood. Acids freed in the boiler by the deposition of basic radicles as hydrates are the most important cause of corrosive action. Iron, aluminum, and magnesium are precipitated as hydrates that are later partly or completely converted into oxides. According to the chemical composition of the water the acid radicles that were in equilibrium with these bases may pass into equilibrium with other bases, displacing equivalent proportions of weaker acids, or they may decompose carbonates that have been precipitated as scale, or they may combine with the iron of the boiler shell, thus causing corrosion; or they may do all these. If these acids exceed the amount required to decompose the carbonate and bicarbonate radicles present the iron of the boiler is attacked and the results are pits or tuberculations of the interior surface, leaks, particularly around rivets, and consequent deterioration of the boiler.

FOAMING.

Foaming is the formation of masses of bubbles on the surface of the water in the boiler and in the steam space above the water, and it is intimately connected with priming, which is the passage from the boiler of water mixed with steam. Foaming results when anything prevents the free escape of steam from the water. It may be due to particles of suspended matter, but the principal cause is usually an excess of dissolved substances that increases the surface tension of the liquid and thereby reduces the readiness with which the steam bubbles break. Therefore the tendency of a water to foam varies inversely with the concentration it will undergo before developing an excessive surface tension. As the sodium and potassium salts remain dissolved in the boiler water while the greater portion of the other substances is precipitated, the foaming tendency is commonly measured by the degree of concentration of the alkaline salts in solution, because this figure, considered in connection with the type of boiler, determines the length of time that a boiler may run without danger of foaming.

REMEDIES FOR BOILER TROUBLES.

The best remedy for troubles caused by substances in feed waters is treatment of supplies before they enter boilers. (See p. 195.) When such treatment can not be given there are various ways of reducing potential injury. Low-pressure, large-flue boilers are used with hard waters in many stationary plants in the central States and it is said that the scale formed in them is softer and more flocculent and can therefore be more readily removed than that in high-pressure boilers. Blowing off is about the only practical means of preventing foaming, because this trouble is due principally to concentration of soluble salts in the residual water of the boilers. Accumulated sludge, or soft scale, can be removed by blowing, particularly in locomotive practice. In condensing systems much of the trouble due to mineral matter in the feed water is obviated because the quantity of raw water supplied is proportionately small. The problem is not completely solved in such systems, because the incrusting or corrosive action is transferred from the boiler to the condenser, which requires more or less cleaning and repairing in proportion to the undesirable qualities of the water supply.

BOILER COMPOUNDS.

Boiler compounds are widely used in regions where hard waters abound, but treatment within the boiler should be given only when it is impossible to purify the supply before it enters the boiler. If previous purification is not practicable many feed waters can be improved by judicious addition of chemicals. Many substances, ranging from flour, oatmeal, and sliced potatoes to barium and chromium salts, have been recommended for such use, but only two or three have proved to be truly economical. Cary[1] has classified these substances according to their action within the boiler. Those that attack chemically the scaling and corroding constituents precipitate the incrusting matter and neutralize the acids. Soda ash, the commercial form of sodium carbonate, containing about 95 per cent Na_2CO_3, is the most valuable substance of this character, because it is cheap and its use is attended with the least objectionable results. Tannin and tannin compounds are also used for the same purpose. Palmer[2] mentions the use of limewater to prevent corrosion and to obviate foaming, and it is probable that waters high in organic matter and very low in incrustants would be improved by such treatment. When soda ash is used it neutralizes free acids and prevents

[1] Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, 1899, p. 1153.
[2] Palmer, Chase, Quality of the underground waters in the Blue Grass region of Kentucky; Water-Supply Paper U. S. Geol. Survey No. 233, 1909, p. 187.

the precipitation of calcium sulphate by causing the precipitation of calcium carbonate. At the same time the sodium content of the feed is increased in proportion to the amount of soda ash added. The proper amount to be used depends on the chemical composition of each water and the style of the boiler. Cary's second class of boiler compounds comprises those that act mechanically on the precipitated crystals of scale-making matter soon after they are formed, surrounding them and robbing them of their cement-like action. Glutinous, starchy, and oily substances belong to this class, but they are not now used to any considerable extent, because they thicken and foul the water more than they prevent the formation of hard scale. The third class comprises compounds that act mechanically, like those of the second class, and also partly dissolve deposited scale, thus loosening it and aiding in its ready removal. Kerosene is the most effective of such materials.

Many boiler compounds possessing or supposed to possess one or more of the functions just described are on the market, and are widely sold. Some are effective and some are positively injurious. Most of them depend for their chief action on soda ash, petroleum, or a vegetable extract, but all are costly compared with lime and soda ash. It can readily be understood that boiler compounds can not in any manner reduce the total amount of scale, but may increase it. Their only legitimate functions are to prevent deposition of hard scale and to remove accumulations of scale that have become attached to the boiler. Every engineer should bear in mind that a steam boiler is an expensive piece of apparatus and that fuel and boiler repairs also are expensive. Therefore he should hesitate to add substances to his feed water without competent advice regarding their effect. It is far more economical to have the water supply analyzed and to treat it effectively by well-known chemicals in proper proportion, either within or without the boiler, than to experiment with compounds of unknown composition.

CLASSIFICATION OF BOILER WATERS.

Stabler[1] in his excellent mathematical discussion of the quality of waters with reference to industrial uses gives several formulas by which waters may be classified. His methods of calculating the amount and the character of scale likely to result from use of a water are given in slightly altered form:

$$A = Sm + Cm + 1.3Fe + 1.9Al + 1.66Mg + 2.95Ca.$$

[1] Eng. News, vol. 60, 1908, p. 355; also Water-Supply Paper U. S. Geol. Survey No. 274, 1911, p. 165.

A, Sm, Cm, Fe, Al, Mg, and Ca represent, respectively, the amounts in parts per million of scale, suspended matter, colloidal matter (silica plus oxides of iron and aluminum), iron, aluminum, magnesium, and calcium in the water. In this formula Ca should not exceed $.668CO_3+.328HCO_3+.417SO_4$, in which CO_3, HCO_3, and SO_4 represent, respectively, the amounts in parts per million of the carbonate, bicarbonate, and sulphate radicles in the water. It is uncertain in some waters whether iron and aluminum are in solution or in colloidal state, but in applying these formulas to Ohio ground waters little error is introduced by assuming that Cm equals silica only. If it is desired to compute the scale-forming ingredients of waters whose analyses in this report give no values for silica, iron, or aluminum, Cm may be taken as 20 and Fe and Al as zero without introducing great error. In clear waters Sm would of course be zero; consequently for most Ohio ground waters the amount of scale may be estimated practically from the figures representing silica, calcium, and magnesium.

In the following Stabler formula B represents the amount of hard scale in parts per million; SiO_2, Mg, Cl, So_4, Na, and K represent the respective amounts in parts per million of silica, magnesium, chlorides, sulphates, sodium, and potassium. If the alkalies are not separated, the figure representing sodium and postassium together and computed as sodium may be used with the Na coefficient in place of the last two terms of these formulas.

$$B=SiO_2+1.66Mg+1.92Cl+1.42SO_4-2.95Na-1.74K.$$

The ratio between the amount of hard scale and the total amount of scale is an index of the probable hardness of the scale; if the computed quantity of hard scale constitutes one-half or more of the total scale the scale may be considered hard; if the hard scale is less than one-fourth of the total the scale would be soft; and if B divided by A is between one-fourth and one-half, the scale may be classified as medium. For other formulas and comments on those quoted the original article should be consulted.

The committee on water service of the American Railway Engineers and Maintenance of Way Association have offered a classification of waters in their raw state that may be employed for approximate purposes, but, as the report states, "it is difficult to define by analysis sharply the line between good and bad water for steam-making purposes." The following table gives this classification with the amounts transformed to parts per million. In many Ohio waters the total incrusting and corrosive constituents are equivalent approximately to total solids.

Approximate classification of waters for boiler use according to proportion of incrusting, foaming, and corroding constituents.

Incrusting and corroding constituents[a] (parts per million).			Foaming constituents[b] (parts per million).		
More than—	Not more than—	Classification.	More than—	Not more than—	Classification.
....	90	Good.	....	150	Good.
90	200	Fair.	150	250	Fair.
200	430	Poor.	250	400	Bad.
430	680	Bad.	400	....	Very bad.
680	....	Very bad.			

[a] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 5, 1904, p. 595.
[b] Idem, vol. 9, 1908, p. 134.

These limits must be interpreted liberally in practice, because they are modified by the comparative hardness of the incrustation and the comparative extent of corrosion effected by waters of the same mineral content but of different chemical composition. Very hard waters may be improved by treatment in softening plants. How bad a water may be used without treatment depends on the cost of artificially softening the water and the amount saved by the use of the softened water. A report[1] of the committee on water service just quoted describes the principles on which such calculations should be based. In general, it is economical in locomotive service to treat waters containing 250 to 850 parts per million of incrustants and those containing less than the lower amount if the scale contains much sulphates.[2] As the incrusting solids may commonly be reduced to 80 or 90 parts per million, the economy of treating boiler waters deserves consideration in a region where most of the supplies contain 300 to 500 parts per million of incrusting and corrosive matter. The amount of mineral matter that makes a water unfit for boiler use depends on the combined effect in boilers of the softening reagents used with such waters and of the constituents not removed by softening. Sodium salts added to remove incrustants or to prevent corrosion increase the foaming tendency, and this increase may be great enough to render a water useless for steaming. It is not of much benefit to soften a water containing more than 850 parts per million of nonincrusting material and much incrusting sulphates.[2] Though waters containing as high as 1,700 parts per million of foaming constituents have been used, it is usually more economical to incur considerable expense in replacing such supplies by better ones.

These numerical standards are only roughly approximate, and they should be interpreted liberally in practice. The value of natural waters for boiler use depends primarily on their corroding and foam-

[1] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 8, 1907, p. 601.
[2] Idem, vol. 6, 1905, p. 610.

ing tendencies and on the amount and character of scale likely to be deposited by them, but this value should always be considered in connection with local standards, for no matter how low a water may be in undesirable constituents it can not be classed as good if it is poorer in quality than the average water of the region in which it occurs. On the other hand, if the best available supply is poor the economy of purifying it, even at large expense, is obvious.

WATER FOR MISCELLANEOUS INDUSTRIAL USES.

GENERAL REQUISITES.

The manufacture of many articles is affected by the ingredients of natural waters. The quality of water for boiler service has already been discussed; with reference to factories it need only be added that increase of boiler efficiency often justifies purification of poor water when increased value of the manufactured product alone may not be considered to do so. This observation applies particularly to paper, pulp, and strawboard mills, laundries, and other establishments where large quantities of water are evaporated to furnish steam for drying, and to ice factories and similar plants where distilled water is produced. But besides its use for steam making water plays a specific part in many manufacturing processes. In paper mills, strawboard mills, bleacheries, dye works, pickle factories, creameries, slaughterhouses, packing houses, nitroglycerin factories, distilleries, breweries, woolen mills, starch works, sugar works, canneries, glue factories, soap factories, and chemical works water becomes a part of the product or is essential in its manufacture. As the principal function of water in most of these establishments is that of a cleansing agent or a vehicle for other substances, a supply free from color, odor, suspended matter, microscopic organisms, and especially bacteria of fecal origin, and fairly low in dissolved substances, especially iron, is generally satisfactory; but there are some exceptions. Water hygienically acceptable is necessary where it comes into contact with or forms part of food materials, as in the making of beverages and dairy or meat products. As all these ideal conditions are found in but few natural supplies, the manufacturer is confronted with the problems of ascertaining what degree of freedom from these substances is necessary to prevent injury to his machinery or to his output and whether the cost of obtaining such purity is counterbalanced by decreased cost of production and increased value of product.

The effects in some industries of the substances most commonly found in water are here outlined, the object being to offer approximate standards to aid in classification.

FREE ACIDS.

Free mineral acids, such as the sulphuric acid in drainage from coal mines, or the hydrochloric acid in the effluents of some industrial establishments, are especially injurious and nearly always necessitate purification of the water. In paper mills, cotton mills, bleacheries, and dye works acids decompose chemicals and streak the fabrics besides rotting them. They also corrode metal work, rapidly destroying screens, strainers, and pipes. Such effects are likely to follow the use of water that contains a measurable amount of free mineral acid.

SUSPENDED MATTER.

Suspended matter in surface waters may be of vegetable, mineral, or animal origin, as it consists of particles of sewage, bits of leaves, sawdust, sticks, sand, and clay. The silt so common in rivers of the West is largely derived from sand and clay. Few well waters contain suspended animal or vegetable matter, but many carry finely divided sand and clay and many become turbid by precipitation of dissolved ingredients. Suspended matter is objectionable in all processes in which water is used for washing or comes into contact with food materials, because it is likely to stain or spot the product. Suspended matter due to precipitated iron is especially injurious even in small amount on that account. Suspended vegetable or animal matter liable to decomposition or to partial solution is much more objectionable, even in small amounts (10 to 20 parts per million), than are equal quantities of mineral matter. For these reasons water should be freed from suspended matter before being used for laundering, bleaching, wool scouring, paper making, dyeing, starch making, sugar making, brewing, distilling, and similar processes. In making the coarser grades of paper, such as strawboard, a small amount of suspended matter is not especially injurious, but for the finer white and colored varieties clear water is essential.

COLOR.

Color in water is due principally to solution of vegetable matter, and materials bleached, washed, or dyed light shades in colored water are likely to become tinged. Highly colored waters can be used in making wrapping or dark-tinted papers but not the white grades, and paper manufacturers are put to great expense for water purification on that account. The lower waters are in color, therefore, the more desirable they are for use in bleacheries, dye works, paper mills, and other factories where brown tints are undesirable.

IRON.

Iron is the most undesirable dissolved constituent, comparatively small quantities of it necessitating purification. Many ground waters contain 1 to 20 parts per million of iron, which may be precipitated by exposure to the air and by release of hydrostatic pressure, causing the waters to become turbid; many such waters develop growths of *Crenothrix* (see p. 175) that may interfere with industrial operations. In all cleansing processes, especially if soap or alkali is used, precipitated iron is likely to cause rusty or dull spots. In contact with materials containing tannin compounds iron forms greenish or black substances that discolor the product. Therefore many waters containing amounts even as small as 1 or 2 parts per million of iron have to be purified before they can be used industrially. In water for dye works iron is especially objectionable and commonly prevents the use of the water without purification.[1] Iron in the water supply of paper mills may be precipitated on the pulp, giving a brown color, or during sizing or tinting, giving spotty effects. Water containing much iron can not be used in bleaching fabrics, because salts that spot the goods are formed. The dark-colored compounds that iron forms with tannin discolor hides in tanning and barley in malting, and also give beer bad color, odor, and taste.[2]

CALCIUM AND MAGNESIUM.

Calcium and magnesium are similar in their industrial effects. In amount they bear a more or less definite relation to each other, most waters carrying 10 to 50 per cent as much magnesium as calcium. Both are precipitated on whatever is boiled in water containing them, forming a deposit that may interfere with later operations. As they decompose equivalent amounts of many chemicals employed in technical operations they are a cause of waste. Moreover, the alkaline-earth compounds thus formed on fabrics interfere with later treatment. For instance, some of the chemicals used to disintegrate the fibers in making pulp are consumed by the calcium and magnesium in the water supply, though the loss from this source is not nearly so great as that occurring later when the resin soap used in sizing the paper is decomposed by the calcium and magnesium. The insoluble soaps thus created do not fix themselves on the fibers, but form clots and streaks. Similar decomposition of valuable cleansing materials and subsequent deposition of insoluble compounds take place in laundering, wool scouring, and similar processes. In the manufacture of soap calcium and magnesium form with the fatty acids curdy precipitates that are insoluble in water and therefore have no cleansing

[1] Sadtler, S. P., A handbook of industrial organic chemistry, Philadelphia, 1900, p. 483.
[2] De la Coux, M. A. J., L'eau dans l'industrie, Paris, 1900, pp. 187 and 232.

value. Many dyeing operations are interfered with by calcium and magnesium, which neutralize chemicals and change the reaction of the baths besides forming insoluble compounds with many dyes. Highly calcareous waters can not be used for boiling the grain in distilleries because proper action is hindered by the deposition of alkaline-earth salts on the particles of grain, nor for diluting spirits because they cause turbidity.[1] Very soft water, on the other hand, is said to be undesirable in paper mills for loading papers with any form of calcium sulphate, because such waters dissolve part of the loading materials.[2] Probably waters high in chlorides would also be bad for this purpose, because chlorides increase the solubility of calcium sulphate.

CARBONATES.

The effects of carbonates and bicarbonates in waters used in industrial processes are not differentiated in this paragraph. It is not uncommon to estimate the combined carbonic acid and to state it as the carbonate (CO_3) without distinguishing between the carbonate (CO_3) and bicarbonate (HCO_3), though in many natural waters the carbonate radicle is absent and the combined carbonic acid is present in the form of bicarbonates. If hard waters proportionately high in carbonates and low in sulphates are boiled the bicarbonate radicle is decomposed, free carbonic acid is given off, and the greater part of the calcium and magnesium is precipitated. For this reason waters of that character are generally more desirable for industrial operations than waters high in sulphates and low in carbonates, as boiling does not greatly reduce the amount of the hardening constituents under the latter conditions. In beer making waters high in corbonates are said to produce dark-colored beers with a pronounced malt flavor because the carbonates increase the solubility of the nitrogenous bodies, whereas water high in suphates yield pale beers with a definite hop flavor because the sulphates reduce the solubility of the malt and the coloring matters.[3]

SULPHATES.

The influence of sulphates in beer making has been noted. Hard waters with sulphates predominating are desirable in tanning heavy hides because they swell the skins, exposing more surface for the action of the tan liquors.[4] Sulphates interfere with crystallization in sugar making by increasing the amount of sugar retained in the mother liquor.

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[1] De la Coux, M. A. J., op. cit., p. 251.

[2] Cross, C. F., and Bevan, E. J., A textbook of paper making, New York, 1900, p. 294.

[3] Brewing water, its defects and remedies, American Burtonizing Co., New York, 1909, p. 19. Also De la Coux, op. cit., p. 169.

[4] Parker, H. N., and others, The Potomac River basin: Water-Supply Paper U. S. Geol. Survey No. 192, 1907, p. 194.

CHLORIDES.

High chlorides in the waters of southwestern Ohio are usually accompanied by high alkalies. Appreciable amounts of chlorides are injurious in many industrial processes, and this is particularly unfortunate, as no practicable way of removing or reducing this radicle except by distillation has been discovered. Beverages and food products, of course, can not be treated with waters very high in chlorides without becoming salty. In tanning, chlorides cause the hides to become thin and flabby.[1] Animal charcoal used in clarifying sugar is robbed of its bleaching power by absorption of salt, and the quality of sugars is affected by chloride-bearing waters, because saline salts are incorporated in the crystals.[2] In the preparation of alcoholic beverages chlorides in large amount prevent the growth of the yeast and interfere with the germination of the grain.

ORGANIC MATTER.

Organic matter of fecal origin is of course dangerous in any water that comes into contact with food products, and water so polluted should be purified before being used. Care in this respect is particularly necessary in creameries, slaughterhouses, canneries, pickle factories, distilleries, breweries, and sugar factories. Organic matter not necessarily capable of producing disease is undesirable in industrial supplies because it induces decomposition in other organic materials, like cloth, yarn, sugar, starch, meat, or paper, rotting and discoloring them, and because it causes slime spots on fabrics by supporting algæ growths.

HYDROGEN SULPHIDE.

Hydrogen sulphide (H_2S) is a gas with an odor like that of rotten eggs. It occurs dissolved in some underground waters. It is corrosive even in small quantities, and it also injures materials by discoloring and rotting them. It occurs in many waters otherwise unfit for industrial use by reason of their large content of dissolved salts.

MISCELLANEOUS SUBSTANCES.

Silica and aluminum are usually not present in sufficient quantity to have any appreciable effect in industrial processes except when water is evaporated. Large quantities of sodium and potassium, by adding to the amount of dissolved matter, are objectionable in some manufacturing operations. Phosphates, nitrates, and some other

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[1] Parker, H. N., loc. cit.
[2] De la Coux, M. A. J., op. cit., p. 152.

substances not noted in this outline interfere with industrial chemical reactions, but they are present in few natural waters in sufficient quantity to have noticeable effect.

WATER FOR MEDICINAL USE.

The relation between the constituents of natural waters and their physiologic action has been discussed at length in the works of Cohen,[1] Crook,[2] and others. To note a few features that are often forgotten or disregarded in considering the application of mineral waters may, however, not be out of place.

The term "mineral" may reasonably be applied to all natural waters, as all contain dissolved mineral matter, but in general practice it is restricted to those that are exploited on account of their supposedly specific physiologic action. The term "medicinal" is sometimes used to distinguish highly mineralized waters from those that are low in mineral constituents and are especially acceptable as table waters by reason of their physical characteristics. The most logical classification of waters for discussing their chemical constituents in relation to therapeutics is that of Peale [3] as modified by Haywood [4] for the ionic form of stating analyses of water, though Haywood's system is somewhat misleading in a few minor details. It is a strictly chemical classification, by which waters are grouped according to their reaction and their predominating basic and acidic radicles, so that the name conveys a statement of the principal active substances.

The therapeutic application of water, or its use for the correction of diseased conditions of the human body, has always been recognized in scientific writings, and the continued and increasing patronage of mineral-spring resorts and the undoubted improvement of many patients treated there clearly indicate that some natural waters have curative properties. Yet the frequent claims of miraculous recovery by the use of mineral waters, together with the extravagant statements regarding the waters, can but rouse skepticism as investigation reveals how meagerly such claims are supported by evidence. Statement of analyses in hypothetical combination adds to the confusion, because the identity and the number of the compounds calculated depend on the judgment of the analyst and not on his laboratory data. Therefore comparison of the analyses of different waters is rendered difficult and misleading. Lithium, for instance, is said to

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[1] Cohen, S. S., System of physiologic therapeutics, vol. 9, Philadelphia, 1902.

[2] Crook, J. K., The mineral waters of the United States and their therapeutic uses, 1899.

[3] Peale, A. C., The natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, pt. 2, p. 53; also, The classification of American mineral waters: Trans. Am. Climatological Assoc., May 31, 1907; also, introductory chapter on the classification of mineral waters in Cohen's System of physiologic therapeutics, vol. 9, 1902, p. 299.

[4] Haywood, J. K., and Smith, B. H., Mineral waters of the United States: U. S. Dept. Agr., Bur. Chemistry, Bull. 91, 1905, p. 9.

be a particularly valuable ingredient; yet many analysts report lithium carbonate, sulphate, or chloride in waters, in spite of the fact that possible physiologic action is due to the lithium ion and not to lithium carbonate in distinction from lithium chloride or lithium sulphate; or, in other words, that the action takes place only when the salt is dissociated. If different lithium compounds are reported, it is impossible to measure the effect of the lithium, unless it is recognized that 5.3 parts per million of lithium carbonate, 6.1 parts of lithium chloride, 7.9 of lithium sulphate, and 9.7 of lithium bicarbonate contain each exactly 1 part of lithium. The curative properties of some waters are attributed to minor ingredients that are present in comparatively insignificant quantities, and many waters containing much less than 1 part per million of lithium are widely advertised as lithia waters. Though it is true that many drugs are as efficient when given in very small but frequent doses as when given in one large dose, the therapeutic value of 1 part per million of lithium may well be questioned, for 200 tumblerfuls of the water contain only one ordinary minimum dose of lithium. The physiologic effect of these minor ingredients is usually overshadowed by that of other substances present in much larger quantities. Many strong brines, for example, contain considerable amounts of lithium, but, as Hessler states,[1] the effect of 10 parts of lithium in the presence of 1,000 or more parts of chlorides would probably be insignificant as compared with the effect of the saline constituents. Many mineral springs are found to possess radioactivity, and this characteristic has been advanced as explaining their curative qualities. So far as the writer is informed, however, no acceptable proof of this theory has been offered. On the other hand, the beneficial effect on the human body of water itself, both hot and cold, used internally or externally, is thoroughly recognized in therapeutics, and the curative qualities of waters not containing appreciable amounts of physiologically active substances may be attributed as reasonably to the action of water itself, combined with a normal regimen of diet, exercise, and other hygienic restrictions, as to some mysterious quality or substance yet undiscovered.

PURIFICATION OF WATER.

GENERAL REQUIREMENTS AND METHODS OF PURIFICATION.

Purification of water is removal or reduction in amount of substances that render waters in their raw state unsuitable for use. It is practiced on a large scale with one or more of three objects in view: First, to render the supply safe and unobjectionable for drinking; second, to reduce the amount of the mineral ingredients injurious to boilers; third, to remove substances injurious to machinery

[1] Hessler, Robert, The mineral waters of Indiana, with indications for their therapeutic application: Trans. Indiana State Med. Soc., 1902.

or to industrial products. The largest purification plants in this country have been constructed almost solely for the purpose of producing potable waters, and some waters need no further treatment before being suitable for steaming and for general industrial purposes. But many other waters are hard, and increased appreciation of the value of good water has resulted in demand for the removal of the hardening constituents also. An excellent example of the result of such insistence is the recently installed plant at New Orleans, where hard, colored, turbid, sewage-polluted river water is brought up to practically all industrial and domestic standards of purity.

Removal of bacteria, especially those causing disease, and removal of turbidity, odor, taste, and iron are the principal requirements in purification of a municipal supply, elimination of bacteria and suspended matter being the most important. The common methods of effecting such purification are slow filtration through sand and rapid filtration after coagulation, both methods usually being combined with sedimentation. The first process is known as slow sand filtration and the second as mechanical filtration. The efficiency of such filters is measured primarily by the ratio between the number of bacteria in the applied water and the number in the effluent. This figure, stated in percentage of removal, should be as high as 98, and it often reaches 99.8 per cent under normal conditions with a carefully operated filter of either kind.

Removal of scale-forming and neutralization of corrosive constituents are the chief aims in preparing water for steam making. For this two general methods are employed, namely, cold chemical precipitation followed by sedimentation, and heating with or without chemicals, usually followed by rapid filtration. The first process is carried on in cold-water softening plants and the second in feed-water heaters.

The requirements of the water supplies for industries are so varied that classification of purification methods is difficult. Water properly prepared for domestic and boiler use is suitable for most industrial establishments, and it is more economical for small manufacturers in large cities to buy such water from water companies than to maintain private supplies and purification apparatus. It is usually cheaper, however, for large factories to be supplied from separate sources, not only because of saving in actual cost of water but also because of the opportunity thus afforded of procuring water specially adapted to the needs of the factory. The common methods of industrial-water purification are those already mentioned or combinations of them modified to meet particular needs. In a few industrial processes, notably the manufacture of ice by the can system, water practically free from all dissolved and suspended substances is necessary and distilled water must be manufactured.

Distillation is expensive, though the employment of multiple-effect evaporators has greatly reduced the cost of operation.

Besides the four common systems of purification many minor processes are used, sometimes alone, but more frequently as adjuncts to filters or softeners. Surface waters may be screened through wooden or iron grids or through revolving wire screens to remove sticks and leaves before other treatment. Coarse suspended matter can be removed by rapid filtration through ground quartz or similar material, in units of convenient size, provided with arrangements for washing the filtering medium similar to those used in mechanical filters. Very turbid river waters may be first allowed to stand in large sedimentation basins to reduce the cost of operating the filters by preliminary removal of part of the suspended solids. Supplies undesirable only because of their iron content are aerated by being sprayed into the air or by being allowed to trickle over rocks or by other methods that cause evaporation of carbonic acid and absorption of oxygen, thus precipitating and oxidizing the iron solution so that it can be readily removed by rapid filtration. Similar aeration is often employed to evaporate and oxidize dissolved gases that cause objectionable tastes and odors.

Disinfection by ozone, copper sulphate, calcium hypochlorite, and many other substances kills organisms that may cause disease or may impart bad odors and tastes. Purification of this character must be done with substances that destroy the objectionable organisms without making the water poisonous to animals. Such treatment is especially adapted for sewage-polluted waters,[1] and it is now widely practiced either as an adjunct to filtration of municipal supplies or as an emergency precaution where otherwise untreated supplies are believed to be contaminated. Natural purification of water is accomplished largely through the biological processes mentioned by Hazen,[2] in which the organic matter is oxidized by serving as food for bacteria and objectionable organisms are destroyed by producing conditions unfavorable to their existence. Action of this kind takes place in reservoirs and lakes, and it is also relied upon in many processes for the artificial purification of sewage.[3]

SLOW SAND FILTRATION.

Slow sand filtration consists in causing the water to pass downward through a layer of sand of such thickness and fineness that the requisite removal of suspended substances is accomplished. The slow sand filter is also called the "continuous" and the "English" filter. On the bottom of a water-tight basin, commonly constructed

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[1] Phelps, E. B., The disinfection of sewage and sewage-filter effluents: Water-Supply Paper U. S. Geol. Survey No. 229, 1909.

[2] Hazen, Allen, Clean water and how to get it, New York, 1909, p. 83.

[3] Winslow, C.-E. A., and Phelps, E. B., Investigations on the purification of Boston sewage, with a history of the sewage-disposal problem: Water-Supply Paper U. S. Geol. Survey No. 185, 1906.

of concrete, perforated tiles or pipes laid in the form of a grid are covered with a foot of gravel graded in size from bottom to top, and a layer of fine sand 3 to 4 feet in depth is put over the gravel, which serves only to support the sand. When water is applied on the surface it passes through the sand and the gravel, and flows away through the underdrain. The suspended materials including bacteria are removed by the sand, the action of which is rendered more efficient by the rapid formation of a mat of finely divided sediment on the surface. When this film has become so thick that filtration is unduly retarded the water is allowed to subside below the surface and about half an inch of sand is removed, after which filtration is resumed. The sand thus taken off is washed to free it from the collected impurities and is replaced on the beds after they have been reduced by successive scrapings to a thickness of about 20 inches. As cleaning necessitates temporary withdrawal of filters from service, they are divided into units of convenient size, usually half an acre each, so that the operation of the system may not be interrupted. Filters may be roofed and sodded; this facilitates cleaning by preventing the formation of ice, permits work on the filter beds in all kinds of weather, and inhibits algæ growths.

The foregoing are the essential features of a slow sand filter, but several adjuncts render this system more efficient. A clear-water basin for the filtered supply, covered to prevent deterioration of the water, is provided in order that the varying rate of consumption may not affect the rate of filtration. Clarification of turbid water is rendered more economical by allowing it to stand for one to three days, during which a large portion of the suspended matter is deposited, thus lengthening the time between sand scrapings. Another form of pretreatment is passage through roughing or preliminary filters consisting of beds of slag, sponge, or stone, through which the water flows at fifteen to twenty times the rate in sand filters, a very large proportion of the suspended matter being thus removed. Objectionable odors and tastes may be obviated by aeration before or after filtration. Killing the bacteria before filtration by the use of ozone, chlorine, or other germicides is also practiced.

Slow sand filtration removes practically all the suspended matter and the bacteria. Color is only slightly reduced, and the hardness is not changed. The process is especially adapted to waters low in color, suspended matter, and animal pollution. Very small particles of clay are not removed by these filters, and for waters carrying such particles only for short periods the addition of a coagulant before filtration has been proposed.[1] It can readily be seen that the efficiency of this kind of filter depends largely on the character of

[1] Report of Hering, Fuller, and Hazen on the methods of purifying the water supply of the District of Columbia: Sen. Rept. 2380, 56th Cong., 2d sess.

the sand, as the ability to prevent the passage of suspended matter is governed by the size of the spaces between the sand particles. The rate of filtration depends on the average size of the sand particles, the thickness of the sand bed, the head of water, and the turbidity. Under ordinary conditions of operation in the United States the rate in slow sand filters of water already subjected to sedimentation is 2,000,000 to 4,000,000 gallons per acre per day.

MECHANICAL FILTRATION.

The distinctive features of the mechanical process are the coagulant and the high rate of filtration. The term "mechanical" is applied because of the contrivances for washing the filtering medium; the filter is also known as the American filter. While the raw water is entering the sedimentation basin, which is smaller than that used with slow sand filters, it is treated with a definite proportion of some coagulant, which forms by its decomposition a gelatinous precipitate that unites and incloses the suspended material, including the bacteria, and that absorbs the organic coloring matter. This combined action destroys color and makes suspended particles larger and therefore more readily removable. When aluminum sulphate, the coagulant most commonly used, is decomposed, aluminum hydrate is precipitated and the sulphate radicle remains in solution, replacing an equivalent amount of the carbonate, bicarbonate, or hydroxyl radicle. The natural alkalinity of many waters is sufficient to effect this reaction. One part per million of ordinary aluminum sulphate requires somewhat more than 0.6 part of alkalinity expressed as $CaCO_3$ to insure complete decomposition.[1]. If the alkalinity is not sufficient part of the aluminum sulphate remains in solution and good coagulation does not take place. Therefore lime or soda ash is added if the alkalinity is too low. The proper amount of aluminum sulphate to be used is determined by the amounts of color, organic matter, and suspended matter and by the fineness of the suspended matter, and it is best ascertained by direct experimentation with the water to be purified. Ferrous sulphate instead of aluminum sulphate is sometimes used as a coagulant; lime must always be added with it in order to bring about proper coagulation.

The water, after having been mixed with the coagulant, is allowed to stand three or four hours in the sedimentation basin, where a large proportion of the suspended particles is deposited. It is then passed rapidly through beds of sand or ground stone to remove the rest of the suspended matter. Many filters now in use are built of wood or iron in cylindrical form 10 to 20 feet in diameter, and some are so designed that filtration can be hastened by pressure. The sand, 30 to 50 inches deep, rests on a metallic floor containing perforations large enough to allow ready issue of the water, but small enough to

[1] Hazen, Allen, Report of the filtration commission of the city of Pittsburgh, 1899, p. 57.

prevent passage of sand grains. When the filter has become clogged the flow of water is reversed, filtered water being forced upward through the sand to wash it and to remove the impurities, which pass over the top of the filter with the wasted water. A revolving rake with long prongs projecting downward into the sand mixes it during washing and prevents it from becoming graded into spots of coarse or fine particles. In recently constructed rectangular filters 300 to 1,300 square feet in area compressed air forced through the sand at intervals is used instead of a revolving rake for agitating the sand during washing. The rate of filtration is from 80,000,000 to 180,000,000 gallons per acre per day. The time between washings is 6 to 12 hours, depending principally on the turbidity of the water applied to the filter, and 4 to 8 per cent of the filtered water is consumed in washing.

Mechanical filtration removes practically all suspended matter, reduces the color to an amount that is unobjectionable, and under some conditions removes part of the dissolved iron. The permanent hardness of the water is increased in proportion to the amount of sulphates added as aluminum sulphate, and if only enough lime to decompose the coagulant is added the total hardness is increased. If larger amounts of lime are added, however, the total hardness is reduced. If soda ash is used in place of lime the foaming constituents of the water are slightly increased. As this method of filtration is used almost entirely for river waters with fluctuating contents of suspended and dissolved matter, proper operation requires constant and intelligent attention.

COLD-WATER SOFTENING.

The principal objects of water softening are to remove the substances that cause incrustations in boilers, particularly calcium and magnesium, and to neutralize those that cause corrosion. Chemicals of known strength properly dissolved in water are added to the raw supply in such proportion as to precipitate all the dissolved constituents that can be economically removed by such treatment. The water is then allowed to stand long enough to permit the precipitate to settle, after which the clear effluent is drawn off or the partly cleared effluent may be filtered very rapidly through thin beds of coke, sponge, excelsior, wool, or similar material in order to remove particles that have not subsided in the tanks. The water softeners on the market differ only in the precipitant, in the filtering medium if one is used, and in the mechanism regulating the incorporation of the chemicals with the water. Among the substances proposed as precipitants are sodium carbonate, silicate, hydrate, fluoride, and phosphate, barium carbonate, oxide, and hydrate, and calcium oxide, but of these substances lime and soda ash are almost exclusively used on account of their excellent action and comparative cheapness.

When soda ash (Na_2CO_3) and lime dissolved in water to form a solution of calcium hydrate [$Ca(OH)_2$] are added to a water in proper proportion free acids are neutralized, free carbon dioxide is removed, the bicarbonate radicle is decomposed, and iron, aluminum, and magnesium hydrates and calcium carbonate are precipitated. The four basic substances are removed to the extent of the solubility of these compounds in water; the calcium added as lime also is precipitated, but the sodium from the soda ash remains in solution in the softened water. The precipitate in settling takes down with it a large proportion of the suspended matter. Such treatment with lime and soda ash removes the incrusting constituents. Sodium, potassium, sulphates, and chlorides are left in solution, and the alkalies are increased in proportion to the quantity of soda ash added; that is, the foaming constituents are increased, and this fixes the maximum amount of incrustants that can be treated. The maximum amount of incrustants in a treated water is determined by the solubility of the precipitated substances and by the completeness of the reaction between the added chemicals and the dissolved matter. The sulphate radicle can be removed by using barium compounds, which precipitate barium sulphate, but the poisonous effect of even small amounts of barium is a great objection to its use. The chlorides are not changed in amount by water softening. The chemicals should be very thoroughly mixed with the raw water and sufficient time should be allowed for complete reaction, which proceeds rather slowly, for otherwise precipitation will occur later in pipe lines or in boilers.

FEED-WATER HEATING.

Water heaters are designed primarily to utilize waste heat in stationary boiler plants by raising the temperature of the feed water and thereby lessening the work of the boilers themselves, but they effect also some purification, and many heaters have been specially constructed with that end in view. The heat is derived from exhaust steam or from flue gases; the heaters utilizing steam either are open—that is, operated at atmospheric pressure—or are closed and operated at or near boiler pressure. In accordance with these three conditions, all of which result in distinct purifying effects, feed-water heaters are classified as "open" or "closed" or "economizers," the last named being those using flue gases. Open heaters are best adapted for removing large quantities of scale-forming material. In most forms the steam enters at the bottom and the water at the top, and intimate contact between the two is obtained by spraying the water or by allowing it to trickle over or to splash against plates. In this manner the water is quickly heated nearly to boiling temperature. Dissolved gases are expelled, the bicarbonate radicle is decomposed, and iron, aluminum, part of the magnesium, and calcium equivalent to the carbonates after decomposition of the bicarbonates are precipitated as hydrates, oxides, or carbonates under varying conditions of temperature, pressure, and time. The precipitate agglomerates the particles of suspended matter and makes them more readily removable by sedimentation and filtration. The slowness with which the reactions take place and the presence of acidic radicles other than carbonates to hold the bases in solution prevent complete removal of calcium and magnesium. The addition of soda ash in proper proportion, however, effects fairly complete precipitation of the alkaline earths, and apparatus for constant introduction of this chemical in solution may be provided. After the precipitate has been formed the water passes through filters of burlap, excelsior, straw, hay, wool, coke, or similar materials arranged in units that can be readily cleaned. Open heaters operated without a chemical precipitant remove substances that are soft and bulky and leave in the water the constituents that form hard scale; scale from water treated in such heaters is therefore not so great in amount but is harder than that formed by the raw water.

In closed heaters the water is passed through metal tubes surrounded by steam or around steam pipes, and manholes or other openings are provided for cleaning the scale from the tubes. As the water is heated under pressure some precipitation takes place, but closed heaters are not nearly so efficient in this respect as open heaters, because they do not permit the escape of the gases liberated from the water.

Economizers consist essentially of water tubes set in the flues leading from the furnaces. Facilities are provided for cleaning scale from the inside and soot from the outside of the tubes. As economizers are heated by flue gases, the water in the tubes can be heated under boiler pressure to a much higher temperature than in open or closed heaters, and boiler conditions described in the section on water for boiler use are approximated. The precipitation of incrustants varies greatly with the normally fluctuating temperature of the flue gases.

UNDERGROUND WATERS.

CHEMICAL ANALYSES.

The results of analyses of underground waters in southwestern Ohio are presented in Table 1, which was prepared by M. L. Fuller. The tests by M. L. Fuller, H. N. Parker, and J. R. Evans are field assays made in accordance with the methods described in Water-Supply Paper United States Geological Survey No. 151, and the figures are therefore more or less approximate. The analyses by R. B. Dole and M. G. Roberts were performed in the water-testing laboratory at Washington. The other analyses originally stated in hypothetical combinations in grains per gallon have been recomputed into ionic form in parts per million in order to facilitate comparison of the data.

TABLE 1.—*Chemical composition of*

[Parts per million

Location.	Source.	Owner, etc.	Depth.	Water-bearing formation.	Date of collection.[a]	Analyst.
ADAMS COUNTY.			*Feet.*			
Blue Creek	Well	G. B. Lewis	35	Alluvium	Sept. 22	H. N. Parker
Manchester	do	Hotel Brit	67	do		R. B. Dole and M. G. Roberts.
Mineral Spring No. 2.	Spring	S. R. Grimes		Ohio shale (?)		
Vineyard Hill	Well	Martha McHenry	64	Terrace gravel	Sept 22	H. N. Parker
West Union	do	Samuel Charles	14	"Niagara"	do	do
Do	Spring			do		R. B. Dole and M. G. Roberts.
Winchester	Well	Methodist Church.	25±	Moraine	Sept. 25	H. N. Parker
BROWN COUNTY.						
Browntown	Well	D. O. Dunn	22	Till	Sept. 22	H. N. Parker
Chasetown	do	Burns Bros	55	Richmond and Maysville.	Sept. 7	do
Fayetteville	do	Livery stable	100	do	do	do
Higginsport	do	Schoolhouse	90	Alluvium	Sept. 22	do
Mount Orab	do	Harvey Day	36	Till	Sept. 7	do
New Hope	do	John Young	20	Richmond and Maysville.	Sept. 22	do
Russellville	do	Public well	38	do	Sept. —	R. B. Dole and M. G. Roberts.
Sardinia	do	do	11	Till	Sept. 22	H. N. Parker
Union Plains	do	J. P. Reed	32	do	Sept. 7	do
BUTLER COUNTY.						
Coke Otto	Well	Jno. W. Caldwell	20	Alluvium	Sept. 22	H. N. Parker
College Corner	do	Dr. C. A. Clarke	38	do	do	do
Do	Spring	Tallewanda Spgs				
Darrtown	Well	Ed Phillips	25	Till	Sept. 22	H. N. Parker
Hamilton	do	Becket Paper Co	65-100	Alluvium	Dec. 31	
Do	do	Champion Coated Paper Co.	3,120	St. Peter	Sept. —	R. B. Dole and M. G. Roberts.
Do	do	Hamilton Otto Coke Co.		Alluvium		Hamilton Otto Coke Co.
Do	3 wells	Niles Tool Works.	65	do	Sept. 22	H. N. Parker
Do	Well	Black-Clawson Co.	59	do	Sept. 11	do
Millville	do	Charles Falkenstein.	24	do	do	do
Do	do	John Lody	25	Richmond and Maysville.	do	do
Do	do	Peter Swope	42	Alluvium	do	do
Do	do	William Titus	12	do	do	do
Monroe	do	J. F. Constiner	85	Richmond and Maysville.	Aug. 12	M. L. Fuller
New London	do	Morgan Howells	14	Till(?)	Sept. 22	H. N. Parker
Oxford	Spring	W. A. Gawne		Richmond and Maysville.	do	do
Do	Wells	City supply			1903	J. W. Ellms
Do	do	do			1904	do
Do	do	Town of Oxford	22-60	Alluvium	Sept. 22	H. N. Parker
Sevenmile	Well	A. Houser	48	do	do	do
Symmes Corner	do	J. C. Hoovenden	17	Richmond and Maysville.	do	do
Trenton	do		18	Alluvium	Aug. 30	J. R. Evans
CLARK COUNTY.						
Donnelsville	Well		41	"Niagara"	Aug. 17	J. R. Evans.
Eagle City	do	Grist mill	22	Alluvium	Sept. 7	H. N. Parker
Lawrenceville	do		20	Till	do	do
North Hampton	do		36	do	Aug. 17	J. R. Evans
Pitchin	do	W. B. Kitchen	22	do	Sept. 7	H. N. Parker
Springfield	do	City supply	22	Alluvium	Aug. 20	R. B. Dole and M. G. Roberts.
Do	Spring	Snyder Park		"Niagara"	Sept. 7	H. N. Parker
Do	Well	(2 miles southeast of city).	20	Gravelly till	do	do

[a] Dates are 1906 unless otherwise specified.

[b] Free acid as H_2SO_4, 20 parts.

waters of southwestern Ohio.

unless otherwise stated.]

Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
....	0.0	....	....	....	....	....	121	40	....	20	....
14	Tr.	90	19	6.3		14	293	11	16	3.1	309
....	Tr.	16	22	28	2.1	.0	0	170	....	12	[b] 250
....	0	....	....	....	....	....	365	35	....	10	....
....	0	....	....	....	....	....	265	Tr.	....	24	....
19	.3	95	48	18	12	.0	420	49	54	38	537
....	0	....	....	....	....	....	463	108	....	55	....
....	0	....	....	....	....	....	365	146	....	55	....
....	.5	....	....	....	....	....	348	157	....	105	....
....	2.5	....	....	....	....	....	359	Tr.	....	238	....
....	0	....	....	....	....	....	308	41	....	14	....
....	0	....	....	....	....	....	259	255	....	100	....
....	0	....	....	....	....	....	256	70	....	90	....
19	.2	135	24	53	6.7	.0	300	102	100	72	667
....	0	....	....	....	....	....	458	201	....	191	....
....	0	....	....	....	....	....	324	91	....	80	....
....	0	....	....	....	....	....	276	Tr.	....	10	....
....	3	....	....	....	....	....	362	Tr.	....	10	....
....	50	64	22	7		.0	196	....	....	11	....
....	0	....	....	....	....	....	306	121	....	129	....
6	....	87	33	.9		.0	350	39	2.5	12	378
22	13	15,900	1,900	34,700	916	.0	10	740	....	100,440	[c] 138,900
4.4	....	89	59	31		.0	540	63	....	16	540
....	0	....	....	....	....	....	362	140	....	24	....
....	0	....	....	....	....	....	314	68	....	20	....
....	0	....	....	....	....	....	275	47	....	10	....
....	0	....	....	....	....	....	314	95	....	20	....
....	0	....	....	....	....	....	274	Tr.	....	24	....
....	0	....	....	....	....	....	354	56	....	14	....
....	1	....	....	....	....	....	486	([d])	....	528	....
....	0	....	....	....	....	....	466	362	....	161	....
....	0	....	....	....	....	....	362	Tr.	....	10	....
....	....	79	20	2.4		.0	313	24	....	3.6	....
....	....	68	24	7.5		.0	300	35	....	2.1	....
....	0	....	....	....	....	....	324	43	....	10	....
....	0	....	....	....	....	....	282	56	....	24	....
....	0	....	....	....	....	....	336	186	....	29	....
....	1	....	....	....	....	....	456	256	....	20	....
....	2	....	....	....	....	....	396	221	....	10	....
....	0	....	....	....	....	....	336	77	....	20	....
....	0	....	....	....	....	....	392	116	....	110	....
....	Tr.	....	....	....	....	....	414	136	....	5	....
....	0	....	....	....	....	....	427	50	....	20	....
15	Tr.	88	32	7.2		.0	310	63	8.0	2.4	382
....	0	....	....	....	....	....	398	125	....	55	....
....	0	....	....	....	....	....	316	44	....	14	....

[c] Specific gravity, 1.110.

[d] More than 850 parts.

TABLE 1.—*Chemical composition of*

Location.	Source.	Owner, etc.	Depth.	Water-bearing formation.	Date of collection.	Analyst.
CLERMONT COUNTY.			*Feet.*			
Amelia	Well		20	Richmond and Maysville.	Sept. 7	H. N. Parker
Bantam	do	Fair ground	42	do	do	do
Bethel	do	Town well	26	Till	do	do
Edenton	do	Public well	20	Alluvium	do	do
Felicity	do	Town well	30	Richmond and Maysville.	do	do
Loveland	do		23	Alluvium	Aug. 30	J. R. Evans
Milford	do	Public well	70	do	Aug. 22	R. B. Dole and M. G. Roberts.
Moscow	do	Town well	70	do	Sept. 22	H. N. Parker
Neville	do	do	65	do	do	do
New Richmond	do	(Test well for gas and oil).	1,400	St. Peter	Sept. 7	do
Do	do		68	Alluvium	Sept. 22	do
Newtonville	do		28	Richmond and Maysville.	Sept. 7	do
Tobasco	do		15	do	Aug. 24	R. B. Dole and M. G. Roberts.
West Woodville	do	Public well	20	do	Sept. 7	H. N. Parker
Williamsburg	do	Curry's livery stable.	26	Till	do	do
CLINTON COUNTY.						
Blanchester	Well	R. F. Botts	50	Richmond and Maysville.	Sept. 7	H. N. Parker
Clarksville	do		20	Till	do	do
Cuba	do	Town well	22	do	do	do
Midland	do	Dan Hopewell	14	do	do	do
New Burlington	do	W. S. Huston	36	do	Sept. 11	R. B. Dole and M. G. Roberts.
Do	do [b]	Charles Hartman rolling mill.	36	Richmond and Maysville.	Sept. 20	do
Do	do [b]	do	36	do	Sept. 11	do
Oakland	do	Town well	47	Till	Sept. 7	H. N. Parker
Ogden	do	David Jenks	20	Richmond and Maysville.	do	do
Wilmington	do	Public supply	172	Till	Aug. 28	R. B. Dole and M. G. Roberts.
DARKE COUNTY.						
New Madison	Well		35		1898	C. B. Dudley
Do	do		25		1899	do
Do	do		18		1900	do
Do	do		16		1898	do
Do	do		15		1898	do
Pitsburg	do	J. B. Young	60	"Niagara"	Aug. 17	J. R. Evans
Woodington	do		14		1893	C. B. Dudley
Do	do		22		1902	do
Do	do		20		1902	do
GREENE COUNTY.						
Bellbrook	Spring	Bellbrook magnetic spring.			(Old)	
Cedarville	Well	Hager Straw-Board & Paper Co.	1,500	"Niagara"		
Clifton	do		14	do	Sept. 7	H. N. Parker
Jamestown	do	Methodist parsonage.	65	do	do	do
Do	do	"1776 Mineral Spring."	1,776	St. Peter		
Xenia	do		19		1902	C. B. Dudley
Do	Spring	City supply	35	Till	Aug. 25	R. B. Dole and M. G. Roberts.
Do	Well		40		1901	C. B. Dudley
Do	do		138		1901	do
Yellow Springs	do	Neff Grounds Park		"Niagara"	1901	R. B. Dole and M. G. Roberts.
Do	Well	Public well	70	do	Aug. —	H. N. Parker
HAMILTON COUNTY						
Blue Ash	Well	Farm well	80	Richmond and Maysville.	Aug. 30	J. R. Evans

[a] More than 850 parts. [b] Both samples from same well; see page 95.

waters of southwestern Ohio—Continued.

Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
...	0	...	...	...	...	...	206	229	...	39	...
...	.5	...	...	...	...	...	391	124	...	25	...
...	.3	...	...	...	...	...	372	313	...	171	...
...	0	...	...	...	...	...	451	168	...	70	...
...	0	...	...	...	...	...	414	362	...	373	...
...	2	...	...	...	...	...	420	146	...	10	...
21	.1	87	24	13		.0	342	17	27	7.2	359
...	0	...	...	...	...	...	384	46	...	10	...
...	1	...	...	...	...	...	360	185	...	40	...
...	0	...	...	...	...	...	414	626	...	92,920	...
...	0	...	...	...	...	...	326	47	...	10	...
...	0	...	...	...	...	...	330	(*a*)	...	191	...
14	.2	179	80	124		.0	427	274	5.0	302	1,203
...	0	...	...	...	...	...	365	229	...	181	...
...	0	...	...	...	...	...	398	138	...	216	...
...	0	...	...	...	...	...	443	530	...	20	...
...	0	...	...	...	...	...	470	66	...	20	...
...	0	...	...	...	...	...	266	71	...	65	...
...	0	...	...	...	...	...	442	181	...	105	...
26	.1	122	35	48	3.5	6.2	333	80	62	102	637
9.0	11	1,100	268	5,750	34	.0	229	9.9	.0	15,000	20,150
14	.3	171	37	144	31	5.8	332	209	60	280	1,132
...	0	...	...	...	...	...	379	56	...	10	...
...	0	...	...	...	...	...	443	71	...	75	...
19	.3	72	41	9.6		.0	297	48	3.5	6.0	340
...	...	...	...	...	...	...	...	...	...	50	601
...	...	...	...	...	...	...	...	...	...	119	1,057
...	...	...	...	...	...	...	...	...	...	32	615
...	...	...	...	...	...	...	...	...	...	42	650
...	...	...	...	...	...	...	...	...	...	21	502
...	1	...	...	...	...	...	438	56	...	10	...
...	...	...	...	...	...	...	...	...	...	6.8	483
...	...	...	...	...	...	...	...	...	...	69	714
...	...	...	...	...	...	...	...	...	...	8.9	542
11	...	112	36	5.9	8.2	.0	501	25	...	8.8	459
...	...	117		21		.0	392	...	...	12	484
...	0	...	...	...	...	...	372	49	...	30	...
...	2.5	...	...	...	...	...	470	94	...	50	...
69	57	2,351	854	7,951	90	.0	329	2,015	...	17,110	*c*33,658
...	...	...	...	...	...	...	...	...	...	7.5	445
19	Tr.	77	29	6.1		.0	338	9.9	20	2.2	332
...	...	...	...	...	...	...	...	...	...	19	465
...	...	...	...	...	...	...	...	...	...	5.5	367
24	1.4	89	37	6.9		.0	406	16	.1	2.5	394
...	Tr.	...	...	...	...	.0	412	66	...	151	...
...	...	...	...	...	...	...	462	246	...	210	...

c Organic and volatile matter 2,431; sulphur (S), 55; hydrogen sulphide (H_2S), 377; thiosulphate radicle (S_2O_3), 18; bromine (Br.) 422; iodine (I), 73; traces of barium (Ba) and phosphates (PO_4); free carbon dioxide (CO_2), 68 parts per million.

TABLE 1.—*Chemical composition of*

Location.	Source.	Owner, etc.	Depth.	Water-bearing formation.	Date of collection.	Analyst.
HAMILTON COUNTY—Continued.			*Feet.*			
Camp Dennison	Well	Well at store	18	Alluvium	Aug. 30	J. R. Evans
Carthage	Wells	Public supply	135	Glacial gravels	do	do
Cincinnati	Well	Cincinnati Gas Works.	1,245	St. Peter	(Old)	E. S. Wayne
Do	do	Sulphosaline spring.	240	"Birdseye"	(Old)	do
Do	Wells(6)	Clifton Springs Distilling Co.	100	Alluvium (?)	Sept. 22	H. N. Parker
Do	Wells(2)	do	1,917	St. Peter	do	do
Do	Well	American Oak Leather Co. No. 1.	180	Point Pleasant	do	H. N. Parker
Do	do	American Oak Leather Co. No. 2.			do	do
Do	do	American Oak Leather Co. No. 3.			do	do
Do	do	Banner Ice Co.	80	Alluvium	do	do
Do	do	Crystal Springs Ice Co.	150	Point Pleasant	do	do
Do	do	Foss-Schneider Brewing Co.	85	Alluvium	do	do
Do	do	do	88	do	do	do
Do	do	French Brothers Dairy Co.	176	Point Pleasant	do	do
Do	do	Gambrino Stock Co.	284	Point Pleasant and "Birdseye."	do	do
Do	do	do	264	do	do	do
Do	do	Gibson House well	370?	do	do	do
Do	do	Grand Hotel	100	Alluvium (?)	do	do
Do	do	James Heakin Co.	90	do	do	do
Do	do	Joseph Joseph Bros	180	Point Pleasant	do	do
Do	do	Jung Brewing Co.	305	Point Pleasant and "Birdseye."	do	do
Do	do	John Kaufman Brewing Co.	215	Point Pleasant	do	do
Do	do	Keeling and Bridge	198	do	Sept. 11	do
Do	do	Kirchmer Construction Co.	90	Alluvium	do	do
Do	do	A. Lander Packing Co.	180	Point Pleasant	Sept. 22	do
Do	do	John H. McGowan Co.			do	do
Do	do	Moerlein Brewing Co.	85	Alluvium	do	do
Do	do	do	2,408	St. Peter		
Do	do	National Lead Co.	60	Alluvium	Sept. 22	H. N. Parker
Do	do	Ohio Butterine Co.	68	do	do	do
Do	do	Palace Hotel	140	do	do	do
Do	do	Riverside Malting and Elevator Co.	100	do	do	do
Do	do	Roth & Co.	85	do	do	do
Do	do	J. Schlachter	90	do	do	do
Do	do	Standard Marble Works.		do	do	do
Do	do	Walker Brewing Co.	140	do	do	do
Do	do	do	100	do	do	do
Do	do	Crystal Springs Ice Co.	150		1905	Dearborn Chemical Co.
Do	do	Philip Wernsing	15	Alluvium	Sept. 22	H. N. Parker
Do	do	White Star Laundry.	60	do	do	do
Do	do	Windisch - Muhlhausen Brewing Co.	170	Point Pleasant.	do	do
College Hill	do	Cincinnati Northern Traction Co.	35	Till	Sept. 8	do
Do	do	C. D. and O. C. Peter's Ice Co.	201	Richmond and Maysville.	Sept. —	R. B. Dole and M. G. Roberts.
Do	do	W. T. Simpson	24	do	do	do
Creedville	do	Fred Schmelch	30	do	Sept. 8	H. N. Parker
Elmwood	do	Laidlaw - Dunn-Gordon Works.	114	Glacial gravels	Sept. —	R. B. Dole and M. G. Roberts.

[a] Strong odor of hydrogen sulphide.
[b] Iodine (I), 4.7; bromine (Br), 5.8; phosphate radicle (PO_4), 16; organic and volatile matter, 13 parts per million; odor of hydrogen sulphide.

waters of southwestern Ohio—Continued.

Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
							384	138		80	
	Tr.						630	154		30	
8.4	4.4	394	120	3,504	29	.0	553	329		5,891	10,567
14	5.2	417	122	3,614	53	.0	630	375		6,042	10,992
	1						422	154		218	
	0						504	[a]460		Much.	
	5						518	328		238	
	10						607	287		538	
	9						780	197		420	
	6.5						707	383		218	
	7						479	Tr.		289	
	2.5						629	406		228	
	4						679	362		239	
	15						563	344		319	
	Tr.						587	Tr.		1,073	
	.5						468	Tr.		400	
	10						445	130		218	
	Tr.						304	138		146	
	Tr.						397	186		202	
	11						494	146		60	
	11						607	300		214	
	7						521	202		1,022	
	0						378	Tr.		10	
	.5						298	Tr.		10	
	20						630	362		260	
	0						401	191		308	
	1						728	383		268	
14	5.2	417	121	3,615	53	.0	1,273	375		6,043	[b]10,992
	0						554	287		106	
	2.5						514	287		202	
							68	46		14	
	.5						420	103		34	
	1						467	383		218	
	6						384	Tr.		20	
	0						600	287		176	
	Tr.						504	Tr.		760	
	0						550	Tr.		380	
9.9		109	35	153		.0	467	36		233	[c]820
	0						511	276		106	
	0						504	215		120	
	1						707	431		242	
	Tr.						348	Tr.		34	
13	53	212	94	303		.0	610	367	.0	702	1,990
27	.05	265	120	37		14	526	678	30	47	1,480
	0						451	47		152	
26	.2	70	24	8.6		.0	320	18	.5	6.5	293

[c] Organic and volatile matter, 16 parts; oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$), 20 parts.

TABLE 1.—*Chemical composition of*

Location.	Source.	Owner, etc.	Depth.	Water-bearing formation.	Date of collection.	Analyst.
HAMILTON COUNTY—continued.						
			Feet.			
Harrison	Well	George Dole	100+	Alluvium	Sept. 8	R. B. Dole and M. G. Roberts.
Do	Wells(4)	Harrison Water & Light Co.	40	do	do	do
Do	Well	Town hall	32	do	do	do
Do	do	T. P. Oyler	110	do	Sept. 22	do
Hartwell	do	Store	25	do	Aug. 30	J. R. Evans
Ivorydale	do	Procter & Gamble		Glacial gravel	1901	J. E. Weber
Do	do	do		do	1906	do
Ludlow Grove	do	Eikenbrecker salt well.	271		1882	E. S. Wayne
Madisonville	do	Public supply	150	Glacial gravel	Aug. 30	J. R. Evans
Mount Washington.	do		30	Old gravels	Aug. 23	R. B. Dole and M. G. Roberts.
Do	do		30	Eden shale(?)	do	do
Norwood	do	Public supply	260	Glacial gravel	Aug. 26	do
Oakley	do		35	do	Aug. 30	J. R. Evans
Riverside	do	Fleishman Distilling Co.	90	Terrace gravel or alluvium.	Sept. 22	H. N. Parker
Rossmoyne	do	Store	95	Richmond and Maysville.	Aug. 30	J. R. Evans
St. Bernard	do	Public supply		Alluvium	do	do
Do	Wells	do			1905	J. W. Ellms
Valley Junction	Well	Clif. Walker estate	65	Alluvium	Aug. —	R. B. Dole and M. G. Roberts.
Wyoming	do	Public supply	104–197	do	Aug. 25	do
HIGHLAND COUNTY.						
East Monroe	Well	Town	45	"Niagara"	Sept. 11	H. N. Parker
Hillsboro	do	City supply	45	Alluvium		R. B. Dole and M. G. Roberts.
Do	Spring	John L. West		"Niagara"	Sept. —	do
Leesburg	Well	Dewey Bros. Co	112	do	Sept. 11	H. N. Parker
Lynchburg	do	Freiberg & Workum Distillery.	1,534	St. Peter		A. Lasche
Do	Spring	do			1905	do
Do	do	Town			1905	do
Marshall	Well	W. A. Elliott	18	Till	Sept. 11	H. N. Parker
Newmarket	do	Town	60	"Niagara"	do	do
New Petersburgh	do	D. R. Cunningham	30	do	do	do
Pricetown	do	J. W. Abraham	42	Till	do	do
MIAMI COUNTY.						
Fletcher	Well		60		1902	C. B. Dudley
Do	do		24		1900	do
Laura	do	H. H. Coppock	25	Till	Aug. 17	J. R. Evans
Ludlow	do	H. O. Miles	45	"Niagara"	do	do
Potsdam	do		9	Till	do	do
Rex	do			"Clinton"	Aug. 18	do
1 mile northwest of Rex.	do			Moraine	do	do
Tippecanoe	do	Public supply	55	Alluvium	Aug. 21	R. B. Dole and M. G. Roberts.
5 miles northeast of Tippecanoe.	do			"Clinton"	Aug. 18	J. R. Evans
West Milton	Spring	Public supply		do	Aug. 22	R. B. Dole and M. G. Roberts.
Do	do				1902	J. W. Ellms
MONTGOMERY COUNTY.						
Bachman	Well	Mr. Hammel	35	Till	Aug. 15	J. R. Evans
Brookville	Wells	City		"Niagara"	Aug. 23	R. B. Dole and M. G. Roberts.
Centerville	Well			"Clinton"	Aug. 18	J. R. Evans
Clayton	do		51	"Niagara"	Aug. 15	do
Dayton	Wells(6)	Ætna Paper Mill	45–48	Alluvium	do	do
Do	Well	Brownell Co	54	do	do	do
Do	do	Davis Sewing Machine Co.		do	1900	A. C. Ehrenfelt
Do	do	National Cash Register.		do	1906	W. B. Scaife & Sons.
Do	Wells	Public supply	30–60	do	Mar. 7	J. W. Ellms

a Less than 5 parts.

waters of southwestern Ohio—Continued.

Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
...	.8	...	...	...	...	...	354	38	...	10	...
...	0	...	...	...	...	...	290	35	...	10	...
...	0	...	...	...	...	...	336	42	...	14	...
...	0	...	...	...	...	...	247	Tr.	...	10	...
...	Tr.	...	...	...	...	...	390	136	...	30	...
16	...	102	27	8.1		.0	390	45	...	12	...
18	...	95	27	21		.0	366	44	...	35	426
21	403	4,936	2,436	29,112		.0	479	73	...	60,638	98,222
...	...	...	...	...	...	...	426	35	...	30	...
25	.3	128	25	24		.0	459	46	8.0	25	516
16	1.9	80	17	15		.0	270	50	16	13	346
48	.2	72	26	14		.0	348	23	.6	2.2	353
...	2	...	...	...	...	...	408	138	...	165	...
...	Tr.	...	...	...	...	...	406	Tr.	...	20	...
...	Tr.	...	...	...	...	...	510	344	...	100	...
...	Tr.	...	...	...	...	...	672	68	...	40	...
...	...	101	24	18		.0	406	40	...	12	...
17	.1	96	28	10		.0	324	46	31	8.9	388
38	2.2	70	23	13		.0	314	19	.9	10	318
...	Tr.	...	...	...	...	...	334	41	...	14	...
18	.2	90	30	7.0		Tr.	366	51	Tr.	2.9	371
16	Tr.	52	32	4.7		7.0	273	2.0	16	1.8	242
...	0	...	...	...	...	...	355	66	...	20	...
...	1.0	86	30	347		.0	329	66	...	533	1,392
...	1.2	78	29	2.3	...	...	164	41	...	3.5	390
...	1.0	79	29	3.5	...	...	165	40	...	5.3	371
...	0	...	...	...	...	...	305	70	...	55	...
...	Tr.	...	...	...	...	...	380	Tr.	...	55	...
...	0	...	...	...	...	...	443	78	...	85	...
...	0	...	...	...	...	...	330	113	...	24	...
...	...	...	...	...	...	...	...	...	...	1.5	493
...	...	...	...	...	...	...	...	...	...	8.9	476
...	1	...	...	...	...	...	544	76	...	(a)	...
...	...	...	...	...	...	...	276	362	...	40	...
...	2	...	...	...	...	...	390	186	...	47	...
...	Tr.	...	...	...	...	...	461	102	...	20	...
...	2	...	...	...	...	...	374	102	...	10	...
12	.1	77	27	7.8		.0	313	36	8.0	6.5	342
...	Tr.	...	...	...	...	...	413	53	...	10	...
13	.2	60	33	6.3		.0	305	8.4	25	1.3	290
...	...	59	40	...	...	...	...	15	...	3.0	...
...	0	...	...	...	...	...	535	176	...	141	...
21	.6	84	46	17		.0	343	22	1.0	3.0	420
...	Tr.	...	...	...	...	...	535	208	...	126	...
...	1	...	...	...	...	...	389	168	...	86	...
...	4	...	...	...	...	...	341	168	...	25	...
...	2	...	...	...	...	...	365	116	...	10	...
12	.5	110	43	...	...	...	...	81	...	13	...
18	Tr.	148	52	6		.0	459	78	48	38	635
16	...	52	28	21		...	270	53	...	11	...

TABLE 1.—*Chemical composition of*

Location.	Source.	Owner, etc.	Depth.	Water-bearing formation.	Date of collection.	Analyst.
MONTGOMERY COUNTY—contd.			*Feet.*			
Dodson	Well	Mr. Smith	40	Till	Aug. 15	J. R. Evans
Englewood	...do	W. L. Weyner	50	"Clinton," Richmond, and Maysville.	Aug. 17	...do
Farmersville	...do	John Holt	78	Till	Aug. 15	...do
Fort McKinley	...do		24	...do	...do	...do
Kinsey	...do	Wm. Kinsey	45	"Clinton"	Aug. 17	...do
Krietzer Corner	...do	John Hill	98	Till	Aug. 15	...do
Do	...do	Andy Isble	32	...do	...do	...do
Do	...do	W. E. Snyder	35	...do	...do	...do
Little York	...do	G. W. Fair	17	...do	Aug. 17	...do
Miamisburg	...do	Public supply	60	Alluvium	Aug. 28	R. B. Dole and M. G. Roberts.
Mummaville	...do		50	...do	Aug. 15	J. R. Evans
New Germany	...do			"Clinton"	...do	...do
Do	...do		30	...do	Aug. 17	...do
Oakridge	...do		66	Till	Aug. 18	...do
Phillipsburg	...do	School well	18	...do	Aug. 17	...do
Pyrmont	...do	Mr. Bower	30	...do	Aug. 15	...do
St. Richmond	...do	Wm. Fairbanks	28	...do	...do	...do
Sixmile	...do	D. Kleppinger	32	...do	Aug. 17	...do
Trotwood	Wells	City	60	Alluvium	Aug. 15	...do
Union	Well	T. P. Eby	93	"Clinton," Richmond, and Maysville.	Aug. 18	...do
Wengerlawn	...do	Mr. Gray	25	Till	Aug. 15	...do
West Carrollton	...do	Public supply	65	Alluvium	Aug. 28	R. B. Dole and M. G. Roberts.
PREBLE COUNTY.						
Camden	Well	Ed Gingerich	130±	Alluvium	Sept. 22	H. N. Parker
Do	...do	Town	31	...do	...do	...do
Eaton	Wells	Eaton Waterworks.	80-85	...do	Sept. 25	...do
Do	Well		95		1896	C. B. Dudley
Do	...do	Jonathan Flora	29	Moraine	Sept. 20	R. B. Dole and M. G. Roberts.
Do	...do		18		1893	C. B. Dudley
Do	...do	Frank Siebert	34	Moraine	Sept. 25	H. N. Parker
Do	...do		15		1898	C. B. Dudley
1 mile southeast of Eaton.	Spring			"Niagara"	Sept. 25	H. N. Parker
Greenbush	Well		28	Richmond and Maysville.	Aug. 12	J. R. Evans
3 miles southeast of Greenbush.	...do		25	...do	...do	...do
New Paris	...do	C. W. Bloom	17	Moraine	Sept. 25	H. N. Parker
Do	Springs	Cedar Springs		...do	(?)	J. N. Hurty
Do	Spring	Reinheimer Bros.		"Niagara"	Sept. 25	H. N. Parker
Do	...do	...do		...do	...do	...do
Do	Well	Henrietta Wilcox	24	...do	...do	...do
Verona	...do	Store	30	Gravel in till	Aug. 15	J. R. Evans
West Alexandria	...do	S. S. Black	112	Moraine	Sept. 18	R. B. Dole and M. G. Roberts.
West Elkton	...do	Elijah Mendenhall	16	...do	Sept. 22	H. N. Parker
Do	...do	Town		"Clinton"	...do	...do
WARREN COUNTY.						
Butterville	Well	T. H. Starkey	30	Richmond and Maysville.	Sept. 7	H. N. Parker
Camp Hagerman	...do	Valley Packing Co.	66	Alluvium	Aug. 12	
Franklin		Public supply	63	...do	Aug. 30	J. R. Evans
Harveysburg	Well		25	Till	Sept. 7	H. N. Parker
Kings Mills	...do	Homestead Hotel	30	...do	Aug. 28	R. B. Dole and M. G. Roberts.
Lebanon	...do		20	Alluvium	Sept. 7	H. N. Parker
Mason	...do	Oil well	485	Till	Aug. 29	R. B. Dole and M. G. Roberts.
Morrow	...do		22	Alluvium	Sept. 7	H. N. Parker
Roachester	...do		70	Richmond and Maysville.	Aug. 27	...do
Waynesville	...do	City supply	40	...do	...do	...do

a Less than 5 parts.

waters of southwestern Ohio—Continued.

Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
...	Tr.	...	...	...	...	...	461	191	...	80	...
...	...	...	...	...	...	...	440	124	...	30	...
...	9	...	...	...	...	...	535	64	...	20	...
...	1.5	...	...	...	...	...	559	106	...	86	...
...	Tr.	...	...	...	...	...	432	106	...	20	...
...	2	...	...	...	...	...	240	362	...	(a)	...
...	Tr.	...	...	...	...	...	461	150	...	126	...
...	Tr.	...	...	...	...	...	607	113	...	(a)	...
...	Tr.	...	...	...	...	...	392	104	...	20	...
15	Tr.	88	31	10		.0	332	51	17	12	399
...	.5	...	...	...	...	...	365	70	...	(a)	...
...	Tr.	...	...	...	...	...	438	154	...	945	...
...	1	...	...	...	...	...	396	222	...	24	...
...	Tr.	...	...	...	...	...	480	106	...	101	...
...	1	...	...	...	...	...	456	154	...	60	...
...	Tr.	...	...	...	...	...	510	300	...	91	...
...	Tr.	...	...	...	...	...	535	208	...	66	...
...	1	...	...	...	...	...	372	98	...	30	...
...	2	...	...	...	...	...	413	91	...	(a)	...
...	4	...	...	...	...	...	533	222	...	50	...
...	0	...	...	...	...	...	413	222	...	185	...
14	.1	70	25	12		.0	294	29	10	2.9	316
...	Tr.	...	...	...	...	...	259	108	...	50	...
...	0	...	...	...	...	...	288	44	...	10	...
...	0	...	...	...	...	...	301	Tr.	...	20	...
...	...	...	...	...	...	...	...	...	...	64	548
19	2.8	70	28	15		.0	361	13	Tr.	2.8	322
...	...	...	...	...	...	...	...	...	...	37	479
...	1.8	...	...	...	...	...	337	Tr.	...	10	...
...	...	...	...	...	...	...	...	...	...	43	487
...	0	...	...	...	...	...	272	Tr.	...	10	...
...	.3	...	...	...	...	...	437	83	...	81	...
...	.1	...	...	...	...	...	269	64	...	30	...
...	0	...	...	...	...	...	343	61	...	10	...
16	2.9	88	32	8		.0	403	25	...	12	383
...	0	...	...	...	...	...	312	43	...	10	...
...	0	...	...	...	...	...	316	38	...	10	...
...	0	...	...	...	...	...	373	68	...	24	...
...	Tr.	...	...	...	...	...	607	208	...	646	...
20	1.0	62	28	32	2.4	.0	396	2.1	4.0	5.9	344
...	3.8	...	...	...	...	...	434	Tr.	...	10	...
...	0	...	...	...	...	...	486	Tr.	...	130	...
...	0	...	...	...	...	...	330	(b)	...	171	...
...	3	...	...	...	...	...	437	Tr.	...	Tr.	...
...	Tr.	...	...	...	...	...	432	276	...	20	...
...	Tr.	...	...	...	...	...	206	Tr.	...	14	...
21	.3	102	31	12		.0	355	87	12	5.0	463
...	0	...	...	...	...	...	294	64	...	14	...
26	1.2	64	28	85		.0	438	.7	7.0	94	510
...	0	...	...	...	...	...	353	108	...	45	...
...	.3	...	...	...	...	...	284	94	...	50	...
...	0	...	...	...	...	...	342	60	...	10	...

b More than 850 parts.

RELATION OF QUALITY TO WATER-BEARING STRATUM.

The principal water-bearing strata in most of the wells of whose waters analyses are given in Table 1 comprise, as noted by Fuller, the alluvium, the sands and gravels of the glacial deposits, the till, the " Niagara " and " Clinton " limestones, the limestones and shales of the Richmond and Maysville formations, the Point Pleasant formation, and the St. Peter sandstone. Other formations yield some water, but sufficient information regarding the quality of their waters is not at hand. After the analyses had been grouped in accordance with the formations noted by Fuller, the figures representing the amounts of the principal constituents were averaged. The averages, rounded off to avoid appearance of fictitious accuracy, are given in Table 2, the first part of which shows the chemical composition of the waters in parts per million and the second the percentage composition of the anhydrous residues.

TABLE 2.—*Chemical composition in relation to geologic strata.*

Mineral content in parts per million.

Principal water-bearing stratum.	Number of analyses averaged.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na + K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Alluvium	63	15	1	90	30	....	0	380	100	60	500
Gravel	17	25	1	90	30	20	0	400	50	25	440
Till	40	20	.5	100	40	50	0	400	140	90	640
"Niagara"	20	20	.5	80	40	20	0	360	80	25	440
"Clinton"	7	15	.2	....	....	....	0	430	100	50	....
Richmond and Maysville	25	20	.2	190	70	140	0	380	300	160	1,100
Point Pleasant	12	....	7	....	....	....	0	530	190	360	....
St. Peter	6	30	10	5,000	800	14,000	0	350	700	36,000	57,000

Percentage composition of anhydrous residue.

Principal water-bearing stratum.	Number of analyses averaged.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na + K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Alluvium	....	3	0	18	6	[a]4	37	....	20	12	....
Gravel	....	6	0	20	7	5	45	....	11	6	....
Till	....	3	0	16	6	8	31	....	22	14	....
"Niagara"	....	4	0	18	9	5	40	....	18	6	....
"Clinton"	....	....	....	....	....	....	....	....	....	....	....
Richmond and Maysville	....	2	0	18	6	13	18	....	28	15	....
Point Pleasant	....	....	....	....	....	....	....	....	....	....	....
St. Peter	....	0	0	9	2	25	0	....	1	63	....

[a] Estimated.

Definite general conclusions regarding the chemical composition of the waters from the several water-bearing strata must be made with extreme caution. Consideration of the conditions under which the samples were collected and tested makes this evident. It is by no means certain that water from a well is a fair average sample of the water from a single sharply differentiated water-bearing stratum; indeed it is certain that many wells in this region are supplied from two or more distinct beds. As the primary purpose of the well driller is to obtain an abundant supply he usually does not attempt to shut out any water that he may encounter except possibly that near the surface, which is known to be polluted. Consequently any deep well that penetrates more than one water-bearing stratum is likely to yield a mixture and though one kind of water may predominate the other kinds modify its quality by diluting it or by increasing its mineral content. Even if all the supplies but one were excluded during construction subsequent deterioration of the casing might cause holes and cracks through which they could enter. It is possible also that wells drawing water from one stratum may not afford samples that are typical of that stratum over a wide area, as seepage from other strata may cause local changes in character. Especially might such modification occur in the waters of the alluvium, which could be locally and also intermittently affected by entrance of water from near-by formations whose supplies are under greater hydrostatic pressure. The water entering shallow wells is intermittently modified by the diluting effect of rain, and deep wells may be indirectly but appreciably affected by similar dilution. Last but not by any means least important is the recognized fact that the draft on a well affects the quality of the water; such influence has been noticed by different observers in widely separated districts. The water from most new wells contains more mineral matter than that from the same wells after they have been used for some time. Waters from strata on which there is heavy draft are commonly lower in mineral content than those in strata not under heavy draft, probably because of the decreased duration of contact of the waters with the minerals; increased draft on some wells, however, results in increased mineral content, a phenomenon doubtless due to percolation of strongly mineralized waters from contiguous formations. No figures for the bases appear in many of the analyses in Table 1, and this lack of data casts still more uncertainty on general conclusions. After consideration of all these circumstances it can readily be understood that statements regarding the quality of the waters can not be interpreted too literally, and it is not surprising to find in Table 1 great variations in the chemical composition of waters presumably from the same bed.

WATERS OF LOW MINERAL CONTENT.

The most noticeable feature in Table 2 is the great similarity in composition of the waters from the alluvium, gravel, till, "Niagara," and "Clinton." The averages indicate that they are all alkaline-saline waters with calcium and bicarbonates predominating but with appreciable amounts of magnesium, sulphates, and chlorides. The similarity in composition is brought out still more forcibly in the second part of the table, in which the statement in percentage of anhydrous residue removes the differences due to dilution. The waters are practically alike in their proportionate contents of calcium, magnesium, and the alkalies. The combined carbonic acid exceeds all other negative radicles in amount; it is present almost invariably in the bicarbonate form with free carbon dioxide, and when any normal carbonates occur they are very small in amount. According to the averages the waters in the till are most strongly mineralized, and study of the separate analyses seems to confirm this conclusion, many of them showing high chlorides and sulphates. The waters of the gravels apparently are lowest in their relative amounts of chlorides and sulphates. The greatest differences between the waters occur in the proportion of chlorides.

Examination of the individual analyses in Table 1 affords additional proof not only that these waters are all of the same type but also that the wells yield from the same formation waters more radically different from each other than the averages of the analyses of waters from different formations; thus it can be seen that the sources of supply in the alluvium, gravel, till, and upper limestones can not be differentiated from the data at hand. The normal variations of bicarbonates, sulphates, chlorides, and total solids of waters from these strata are given in Table 3. Some evidently erroneous figures have been omitted from consideration and some of the amounts are estimates. The figures opposite the designation "approximate mean" have been rounded off to avoid fictitious accuracy.

TABLE 3.—*Differences in mineral content of wells in southwestern Ohio.*

[Parts per million.]

Source of water.	Bicarbonate radicle (HCO_3).		Sulphate radicle (SO_4).		Chlorine (Cl).		Total solids.	
	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
Alluvium	679	121	406	Tr.	380	Tr.	635	309
Gravel	630	320	154	Tr.	165	2	516	293
Till	607	206	362	Tr.	216	2	637	332
"Niagara"	470	265	362	Tr.	86	3	537	242
"Clinton"	535	305	222	Tr.	126	1	700	290
Approximate mean	600	240	300	Tr.	200	2	600	300

These figures give the highest and lowest amounts of certain substances according to the analyses in Table 1. The information regarding the amounts of calcium, magnesium, and sodium is insufficient to justify similar figures for them, but the amounts of the bases are roughly proportional to the amounts of the acids. The supplies from these strata range from 300 to 600 parts per million of total solids and they may contain from 2 to 200 parts of chlorides, from a trace to 300 parts of sulphates, from 240 to 600 parts of bicarbonates, and calcium, magnesium, sodium, and potassium in proportion. There is no proof that any stratum may not yield waters reaching the highest or the lowest limits in mineral content, though the waters of the alluvium are likely to show the greatest and those of the "Niagara" and the "Clinton" the least differences. Probably this is due to the fact that the alluvium is exposed to greater modification by seepage from other formations and by percolation of surface water. It is evident from Table 3 that waters apparently from the same stratum differ very widely in mineral content, and consequently the averages in Table 2 can be interpreted as being indicative only of the general similarity of the waters.

The alluvium in some parts of the United States yields waters lower in mineral content than other local formations, and that might be thought to be a general condition, as the alluvial matter has been more thoroughly leached both during and after its deposition. The alluvial deposits in southwestern Ohio, however, are essentially calcareous, and they will furnish calcium and magnesium to the waters percolating through them just like other lime-bearing beds. In addition, most of the water entering this alluvium has previously become impregnated with mineral matter from other underground deposits which it has traversed. As a result the waters of the alluvium, though abundant, are not distinctly less mineralized than those of the other unconsolidated beds.

WATERS OF HIGH MINERAL CONTENT.

Though the waters of the unconsolidated deposits and of the upper limestones are similar, waters below the "Clinton" are sharply differentiated. Reference to Table 2 shows that the Richmond and Maysville formations yield supplies two to four times as high in mineral ingredients as those in the later formations and distinctly different in character. The percentages of calcium, magnesium, and chlorides are about the same, though the actual amounts are greater; the percentages of alkalies and sulphates are much greater, and the proportion of bicarbonates is much less. Tests of the water in the Point Pleasant are available only at Cincinnati, and these are incomplete, so that definite statements can not be made regarding the character of the supply; apparently it is similar to that of the Richmond and Maysville formations, possibly being higher in chlorides and in iron. No analyses of water from the Eden shale or from the "Birdseye" limestone are at hand, but the water in the former probably is as highly mineralized as that of the Richmond and Maysville, and the water in the "Birdseye" limestone is salty. The St. Peter sandstone yields in this region a very hard and very salt water, ranging from 1,000 to 100,000 parts per million of dissolved matter. Its characteristics as a strong brine can be seen in Table 2.

RELATION TO OTHER UNDERGROUND WATERS.

Table 4 presents figures by which the underground waters of southwestern Ohio may be compared with those of north-central Indiana, where limestones are abundant. Both regions are well supplied with rain and are areas of hard limestone, and it is therefore interesting but not surprising that their characteristic waters are similar in mineralization and in composition.

TABLE 4.—*Comparison of the quality of ground waters in southwestern Ohio and north-central Indiana.*

Mineral content in parts per million.

	Number of analyses averaged.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Dissolved solids.
A	120	20	0.8	90	35	30	0	390	90	50	500
B	169	18	.8	91	31	18	0	306	76	47	467
C	20	20	.5	80	40	20	0	360	80	25	440
D	80	18	1.8	82	31	27	0	341	70	19	466
Percentage composition of the anhydrous residues.											
E	....	4	0	18	7	5	38	....	18	10	....
F	....	4	0	21	7	4	35	....	18	11	....
G	....	4	0	18	9	5	40	....	18	6	....
H	....	4	0	20	7	7	40	....	17	5	....

A, E, Unconsolidated deposits of southwestern Ohio.
B, F, Unconsolidated deposits of north-central Indiana (Water-Supply Paper U. S. Geol. Survey No. 254, 1910, pp. 260 and 261).
C, G, "Niagara" limestone of southwestern Ohio.
D, H, Fresh-water limestones of north-central Indiana.

SURFACE WATERS.

Samples of water collected daily from Miami River at Dayton by B. F. Glass were united in sets of 10 and analyzed, with the results stated in Table 5. Daily readings of the gage maintained at Dayton by the Weather Bureau were averaged in groups corresponding to the sampling periods, and these averages are given in the last column of the table. By comparing the gage heights with the amounts of suspended and dissolved solids an idea may be gained of the relation between the quantity of the water and its quality at this place.

TABLE 5.—*Mineral analyses of water from Miami River at Dayton.*[a]

[Parts per million unless otherwise designated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 16	Sept. 25	32	75	2.34	3.1	16	Tr.	58	28	10	9.0	264	38	0.9	5.0	300	0.7
Sept. 26	Oct. 5	32	58	1.81	.9	21	Tr.	65	28	9.0	9.0	280	35	2.8	5.8	318	.8
Oct. 6	Oct. 15	18	32	1.78	.4	17	Tr.	63	26	9.6	.0	297	37	3.1	5.0	309	.6
Oct. 16	Oct. 25	14	26	1.86	.10	18	Tr.	65	27	9.0	.0	301	40	2.9	5.0	317	.8
Oct. 26	Nov. 4	5	14	2.80	.15	20	Tr.	66	28	11	8.2	291	41	2.0	5.5	327	1.0
Nov. 5	Nov. 14	8	20	2.50	Tr.	20	Tr.	69	29	9.8	Tr.	317	41	2.0	5.3	335	2.0
Nov. 15	Nov. 24	75	89	1.19	2.1	14	0.24	64	27	9.8	11	250	40	7.0	4.3	304	2.8
Nov. 25	Dec. 4	16	21	1.31	.5	19	.05	75	28	7.4	3.6	278	60	15	4.0	346	2.4
Dec. 5	Dec. 14	26	34	1.31	.7	26	.07	75	28	8.2	10	269	62	12	4.7	355	2.5
Dec. 15	Dec. 24	80	54	.67	1.4	15	.23	64	23	6.8	.0	239	32	13	3.0	296	3.0
Dec. 25	Jan. 4	....	177	.....	3.2	16	.19	68	24	7.1	.0	272	52	12	3.5	318	4.2
Jan. 5	Jan. 14	210	118	.56	3.0	14	.5	50	17	6.5	.0	184	36	18	3.6	238	6.5
Jan. 15	Jan. 24	450	223	.50	6.7	15	.7	42	14	7.1	.0	161	29	11	3.4	212	7.5
Jan. 25	Feb. 4	75	49	.65	1.8	16	.6	61	23	8.8	12	229	44	16	4.1	301	3.3
Feb. 5	Feb. 14	45	42	.93	.5	8.8	.05	60	26	8.0	12	215	51	10	3.8	282	2.9
Feb. 15	Feb. 24	11	28	2.55	.4	24	.06	58	25	6.9	13	212	42	11	4.1	298	2.8
Feb. 25	Mar. 6	260	143	.55	4.2	25	.08	67	25	7.4	8.4	246	49	9.0	3.8	320	2.9
Mar. 27	Apr. 6	37	52	1.41	1.0	15	.12	64	24	8.0	12	228	44	10.0	4.6	299	2.2
Apr. 7	Apr. 16	25	67	2.68	.3	20	.14	50	26	8.4	12	200	44	15	5.4	282	2.1
Apr. 17	Apr. 26	25	32	1.28	.6	19	.11	58	25	3.5	16	217	41	15	4.2	298	2.2
Apr. 27	May 6	20	36	1.80	.4	15	.16	62	24	6.3	13	229	39	19	3.8	297	2.5
May 7	May 16	18	35	1.94	.4	23	.11	58	23	3.3	14	217	40	18	4.3	292	2.0
May 17	May 28	37	79	2.14	1.3	14	.10	52	26	3.0	12	218	41	15	3.8	275	1.8
May 29	June 8	240	186	.77	4.4	19	.19	53	20	12	10	197	34	15	4.8	264	3.8
June 9	June 18	280	252	.90	7.0	18	.7	49	18	11	9.6	180	27	17	3.8	252	5.2
June 19	June 28	75	75	1.00	2.6	17	.12	60	22	11	2.4	249	33	6.2	4.8	283	2.5
June 29	July 8	90	168	1.86	1.6	17	.03	42	26	8.2	.0	206	37	1.2	4.2	240	1.9
July 9	July 19	....	351	.....	7.9	30	.35	51	20	14	.0	.....	26	6.4	2.4	254	4.0
July 20	July 29	....	234	.....	3.2	8.6	.04	26	18	12	.0	.....	32	Tr.	.6	163	3.4
July 30	Aug. 8	....	125	.....	1.6	9.2	Tr.	56	24	12	.0	.....	37	1.5	.6	258	2.2
Aug. 9	Aug. 18	....	77	.....	1.0	18	.03	55	25	11	.0	.....	39	1.5	1.4	273	1.4
Aug. 19	Aug. 28	35	48	1.37	.9	9.8	.05	69	29	12	.0	323	34	.0	5.4	331	1.1
Aug. 29	Sept. 7	43	46	1.07	.9	15	.04	63	24	14	.0	287	41	2.5	5.8	304	1.2
Sept. 8	Sept. 17	140	130	.93	2.6	19	.13	59	25	13	.0	251	36	2.2	4.8	289	1.7
Mean		84	94	1.46	2.0	17	.15	59	24	9.0	5.8	244	40	8.6	4.1	289	....
Per cent of anhydrous residue		....	....	.....	......	5.9	[b].1	20.5	8.3	3.1	43.8	.....	13.9	3.0	1.4	....	....

[a] Analyses Sept. 9 to Dec. 4, 1906, by R. B. Dole; Dec. 5, 1906, to Mar. 6, 1907, by R. B. Dole and M. G. Roberts; Mar. 27 to June 28, 1907, by Chase Palmer and M. G. Roberts; June 29 to Sept. 17, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins. Water-Supply Paper U. S. Geol. Survey No. 236, 1909, p. 72.

[b] Fe_2O_3.

During 1898 daily samples of water were taken from one of the intakes in Ohio River at Cincinnati, and the average, maximum, and minimum conditions of the water of Ohio River as shown by these analyses are given in Table 6.[1]

TABLE 6.—*Mineral analyses of water from Ohio River at Cincinnati, 1898.*

[Parts per million.]

	Maximum.	Minimum.	Average.
Suspended solids	2,333	24	230
Dissolved solids	233	67	120
Carbonate radicle (CO_3)	.0	.0	.0
Bicarbonate radicle (HCO_3)	85	24	55
Sulphate radicle (SO_4)	46	13	24
Nitrate radicle (NO_3)	1.34	.37	.60
Chlorine (Cl)	44	3.0	10

[1] Fuller, G. W., Report on the investigations into the purification of the Ohio River water for improved water supply of the city of Cincinnati, Ohio, 1899, pp. 493–494.

The miscellaneous analyses of surface waters in southwestern Ohio presented in Table 7 are not absolutely comparable because of differences in the analytical procedures employed by the analysts. The greatest difference probably is in total solids. It has been customary in the laboratory of the Geological Survey to dry residues at 180° C. for one hour. Horton dried his residues at slightly less than 100° C. and Dudley at 110° C. Therefore varying amounts of water, organic matter, and other volatile material are included in the figures for total solids. Most of the large differences, however, are probably due to actual differences in the waters at the time of collecting the samples.

TABLE 7.—*Miscellaneous analyses of surface waters in southwestern Ohio.*

[Parts per million unless otherwise designated.]

Source.	Analyst.	Date.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Probable incrustants.
East Fork of Little Miami River:												
Lynchburg	E. G. Horton	April, 1905	....	....	55	25	....	....	48	4.0	223	....
Batavia	do	(a)	....	....	....	....	....	165	....	14	258	....
Little Miami River:												
South Charleston	do	(a)	....	....	....	....	....	298	....	.9	244	....
Goes	C. B. Dudley	Sept. 12, 1901	....	....	....	....	....	....	....	6	315	262
Do	Kennicott Water Softener Co.	Apr. 21, 1903	5.5	2.0	87	16	8.0	286	44	12	316	....
Trebeins	J. W. Ellms	Mar. 21, 1902	....	....	74	22	....	272	45	....	....	282
Do	do	Aug. 8, 1904	....	....	56	29	5.6	300	24	3.6	....	252
Xenia	E. G. Horton	(a)	....	....	....	....	....	304	....	.9	371	....
Do	Kennicott Water Softener Co.	Aug. 12, 1902	2.4	2.9	75	37	....	286	60	24	....	....
Morrow	C. B. Dudley	Oct. 24, 1893	....	....	....	....	....	....	....	7	260	220
Loveland	do	Sept. 28, 1896	....	....	....	....	....	....	....	7	304	253
Do	do	June 30, 1898	....	....	....	....	....	....	....	14	307	244
Do	E. G. Horton	(a)	....	....	....	....	....	244	....	1.9	364	....
Linwood	do	(a)	....	....	....	....	....	205	....	2.3	679	....
Mad River:												
Urbana	do	(a)	....	....	....	....	....	340	....	1.2	456	....
Springfield	do	(a)	....	....	....	....	....	332	....	.5	431	....
Dayton	do	(a)	....	....	....	....	....	311	....	2.8	417	....
East Dayton	J. W. Ellms	July 23, 1904	....	....	71	32	9	314	51	8	....	303
Do	do	Jan. 23, 1904	....	....	61	20	....	224	37	8	....	238
Mill Creek:												
Reading	C. B. Dudley	Sept. 29, 1893	....	....	....	....	....	....	....	Tr.	329	271
Ivorydale	J. W. Ellms	Dec. 9, 1904	....	....	75	28	18	312	58	14	....	299
Do	do	July 23, 1904	....	....	45	23	11	220	35	10	....	202
Do	do	Nov. 16, 1903	....	....	89	26	26	328	56	41	....	335
Do	do	Sept. 16, 1902	....	....	101	31	21	442	16	31	....	368
Do	do	Feb. 21, 1902	....	....	94	34	....	364	69	13	....	....
Miami River:												
Sydney	do	Feb. 18, 1901	....	....	86	35	4	284	115	7	....	377
Do	do	May 22, 1902	....	....	81	33	3	294	77	10	....	346
Do	E. G. Horton	(a)	....	....	....	....	....	268	....	.7	404	....
Piqua	do	(a)	....	....	....	....	....	245	....	1.2	484	....
Troy	do	(a)	....	....	....	....	....	262	....	2.4	388	....
Do	J. W. Ellms	Feb. 11, 1902	....	....	75	32	34	372	67	6	....	298
Do	do	Nov. 10, 1903	....	....	64	23	16	262	54	12	....	251
Do	do	July 27, 1904	....	....	53	23	4	222	45	3	....	229
Do	do	Dec. 9, 1904	....	....	64	23	5	262	41	5	....	256

a Average of 8 analyses of water collected between April and November, 1900.

TABLE 7.—*Miscellaneous analyses of surface waters in southwestern Ohio*—Continued.

Source.	Analyst.	Date.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Probable incrustants.
Miami River:												
Dayton	E. G. Horton	(a)	....	....	....	....	....	278	....	4.2	407	....
Do	J. W. Ellms	(b)	....	....	79	30	4	292	64	11	....	323
Middletown	E. G. Horton	(a)	....	....	....	....	....	259	....	3.3	423	....
Hamilton	do	(a)	....	....	....	....	....	230	....	3.1	626	....
Twin Creek:												
Carlisle	J. W. Ellms	(c)	....	....	62	25	3	272	27	2	....	247
Whitewater River:												
New Paris	C. B. Dudley	Feb. 23, 1893	....	....	....	....	....	....	....	....	334	248
Pond:												
College Corner	J. W. Ellms	(d)	....	....	60	33	16	236	79	30	....	294

[a] Average of 8 analyses of water collected between April and November, 1900.
[b] Average of 20 analyses of water collected at intake, North Dayton, at Second Street, Dayton and at Perry Street, between Feb. 28, 1901, and Mar. 7, 1906.
[c] Average of 4 analyses of water collected between Feb. 21, 1902, and Dec. 9, 1904.
[d] Average of 5 analyses of water collected from a pond between Dec. 8, 1900, and Dec. 9, 1904.

Comparison of Table 6 with Tables 5 and 7 indicates that the water of Ohio River at Cincinnati is lower in mineral content than the other surface waters of this region. This is due to the fact that the greater portion of the Ohio comes from areas of soft water. The Allegheny at Kittanning, Pa., carries 87 parts per million of dissolved solids and the Monongahela at Elizabeth, Pa., 81 parts; and though Youghiogheny River at McKeesport, Pa., carries 197 parts of dissolved solids it contributes only about one-eighth of the discharge of Ohio River at Pittsburgh, Pa., and therefore its water does not much increase the mineral content of the main stream. The tributaries from the State of Ohio are similar to Miami River in mineral content, but their effect is more than counterbalanced by the drainage from Kentucky and West Virginia, which is much lower in dissolved solids.

RELATION BETWEEN UNDERGROUND AND SURFACE WATERS.

The surface supplies are much lower in mineral content than the ground supplies, and are therefore better for industrial use. The relation between the quality of the water of Miami River at Dayton and those of the underground sources is shown in Table 8. The ground waters in general exceed the Miami water in their content of all constituents, but the character of the mineral matter is much the same in both.

TABLE 8.—*Comparison of the mineral content of surface and underground waters.*

Mineral content in parts per million.

	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.
A.......	17	0.15	59	24	9.0	5.8	244	40	8.6	4.1	289
B.......	20	.8	90	35	30	0	390	90	....	50	500
Percentage composition of anhydrous residues.											
C.......	5.9	a.1	20.5	8.3	3.1	43.8	....	13.9	3.0	1.4	....
D.......	4	0	18	7	5	38	....	18	....	10	....

a Fe_2O_3.

A, C, Water of Miami River at Dayton.
B, D, Underground water; from gravel, till, "Niagara," and "Clinton."

ECONOMIC VALUE OF THE WATERS.

The best source of large amounts of water for industrial purposes in this region is Ohio River, whose waters are much lower in dissolved solids than its tributaries from southwestern Ohio and only from one-fifth to one-third as high in dissolved solids as the ground waters of low mineral content. Practically all the surface waters are lower in mineral content than the ground waters and consequently are better for industrial use. In addition to dissolved matter, the water of Ohio River averages 230 parts and that of Miami River 94 parts per million of suspended solids, but it would be much less expensive to remove the suspended matter from these waters than to soften available ground waters that do not contain suspended matter. If the turbidity were removed by sedimentation or by filtration the surface waters could be classified as good to fair for boiler use and most of them could be used without further treatment.

The waters from the alluvium, gravel, till, "Niagara" limestone, and "Clinton" limestone are similar in mineral content and in the character of their dissolved matter. Dissolved solids range from 300 to 600 parts per million and average about 500 parts, chlorides from 2 to 200 parts, sulphates from a trace to 300 parts, and bicarbonates from 240 to 600 parts. The waters are hard, but they can readily be softened, and in their natural condition they range from fair to bad for boiler use; they deposit considerable scale and some of them are corrosive, but they do not foam under ordinary conditions of boiler operation.

The waters from the Richmond and Maysville formations and from the Point Pleasant are distinctly less desirable as industrial supplies, being much higher in incrustants, chlorides, and sulphates.

Though some of the waters from the Richmond and Maysville are as low in incrustants as some of the waters from the later beds, the results of the few analyses available indicate that this is not their general condition.

The St. Peter sandstone yields water so heavily mineralized as to be unfit for industrial use except for cooling, and even for that purpose the water would be corrosive.

As practically all the surface waters in this region are likely to be polluted by sewage and most of them by factory wastes they should not be used for domestic supplies without careful purification. Filtration under competent supervision would probably make them safe for drinking and satisfactory for laundry use. Nothing in the averages of the analyses of fresh underground waters indicates that they are not suitable for drinking and for general domestic use, though those from the earlier formations are very hard. Consideration of the individual analyses, however, shows that some of the waters contain so much iron that they would stain fabrics washed in them. The pollution of streams in this region and the sources of waters in relation to municipal use have been studied in much detail by the State board of health.[1]

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[1] Ann. Repts. Ohio State Board of Health, 1897 to date.

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