ply and Irrigation Paper No. 145 Series O, Underground Waters, 46

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS

TO THE

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1905

MYRON L. FULLER

GEOLOGIST IN CHARGE

WASHINGTON

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., January 28, 1905.

SIR: I transmit herewith, for publication as a water-supply and irrigation paper, a manuscript entitled "Contributions to the Hydrology of Eastern United States, 1905," which forms the third of a series of progress reports relating to the hydrology of the eastern portion of the country, submitted by M. L. Fuller, as geologist in charge of the eastern section of the division of hydrology. The report embraces 20 contributions by 14 geologists, and presents the results of a considerable number of subordinate lines of investigation, the descriptions of which are not of sufficient length to warrant separate publication.

The report covers a wide range of subjects and, in general, the papers form concise summaries of the subjects covered, rather than elaborate treatises. They may be grouped under five heads and include: (1) Papers dealing with special artesian problems, (2) reports describing the water resources of more or less extensive areas, (3) description of special localities, (4) papers on the water supplies of special types of deposits, and (5) descriptions of important springs.

It is believed that a composite report of this type not only reaches a much larger number of readers than any other form of publication, but puts on record a considerable amount of interesting data which, because of its brief nature, could not otherwise be made available.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

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

CONTRIBUTIONS TO THE HYDROLOGY OF EASTERN UNITED STATES, 1905.

MYRON L. FULLER,
Geologist in Charge.

HYDROLOGIC WORK IN EASTERN UNITED STATES AND PUBLICATIONS ON GROUND WATERS.

By MYRON L. FULLER.

WORK OF DIVISION OF HYDROLOGY.

The work of the division of hydrology deals with underground waters, or those found beneath the surface of the earth, in the same manner that the work of the division of hydrography deals with surface waters, the aim being to obtain and publish for the benefit of the people information relating to the occurrence, movements, methods of obtaining, and uses of artesian and other underground waters, including those reaching the surface both as wells and as springs

Organization.—In the earlier years of the Survey no special provision was made for the study of underground waters, although a considerable amount of information was gathered in connection with the investigation of other problems and a number of reports were published. Beginning with 1894 provision was made by Congress for the investigation of underground currents and deep wells, and from 1894 to 1902 a considerable number of special reports on underground waters were prepared under this authority. In the latter year, in order to satisfactorily meet the new demands resulting from the great increase in the use of underground waters in recent years and to develop, specialize, and systemize the work, the investigations relating to underground waters were segregated from the division of hydrography and placed in charge of a distinct organization known as the division of hydro-geology or hydrology. This division is divided into two sections, eastern and western, the first embracing the States east of the Mississippi and those bordering that river on the west, and the second including the remaining, or the so-called "reclamation" States and Territories and Texas. The two sections have been placed in charge of geologists, Mr. N. H. Darton acting as chief of the western section and the writer as chief of the eastern.

The work of the division includes the gathering, filing, and publication of statistical information relating to the occurrence of water in artesian and other deep wells; the gathering and publication of data pertaining to springs; the investigation of the geologic occurrence, from both stratigraphic and structural standpoints, of underground waters and springs; a study of the laws governing the occurrence and flow of subterranean waters and springs, including the investigation of variations due to tidal, temperature, and barometric fluctuations; direct measurements of rate of underflow; detailed surveys of regions in which water problems are of great importance and urgency; and the publication of reports on irrigation, city water supplies, and other important uses of underground waters.

Recent work.—In connection with hydrologic investigations there has grown up a large correspondence, the handling of which makes considerable demands on the time of the members of the section. Among the notable requests received were those from the colonial secretary of Bermuda, for information as to the methods of obtaining water supply for that island; from the Peruvian Government, for the recommendation of a hydrologist to organize and take charge of a bureau of hydrology in that country similar to the hydrographic branch of the Survey; and from the secretary of the Eleventh International Congress of Hygiene and Demography, held in Berlin in 1903, for information in regard to the pollution of limestone waters.

The information requested in each case was furnished, and a member of the Survey, Mr. George I. Adams, was recommended to the Peruvian Government for the service required. Mr. Adams entered on his duties in May. Estimates for boring a deep artesian well at the American legation in Peking, China, were also obtained and submitted at the request of the Secretary of State.

In addition to answering requests from corporations and private parties in this country, the eastern section furnished information to the War Department in regard to water conditions at forts in South Carolina, Michigan, and New Hampshire, and elsewhere. In New Hampshire a special field investigation was made, with promising results. Requests for the investigation of the water supply of a number of cities and towns afflicted with typhoid epidemics were received and complied with as far as possible.

During 1904 manuscripts, including a bibliographic review and index of all publications of the United States Geological Survey relating to underground waters, a bibliography of underground waters of the United States for 1904, and tables relating to the computation of head, flow, etc., of artesian wells were begun by Mr. Fuller. Dr. Cleveland Abbe, jr., in addition to a large amount of editorial work on manuscripts, prepared a bibliographic review of the underground-water literature of New York State.

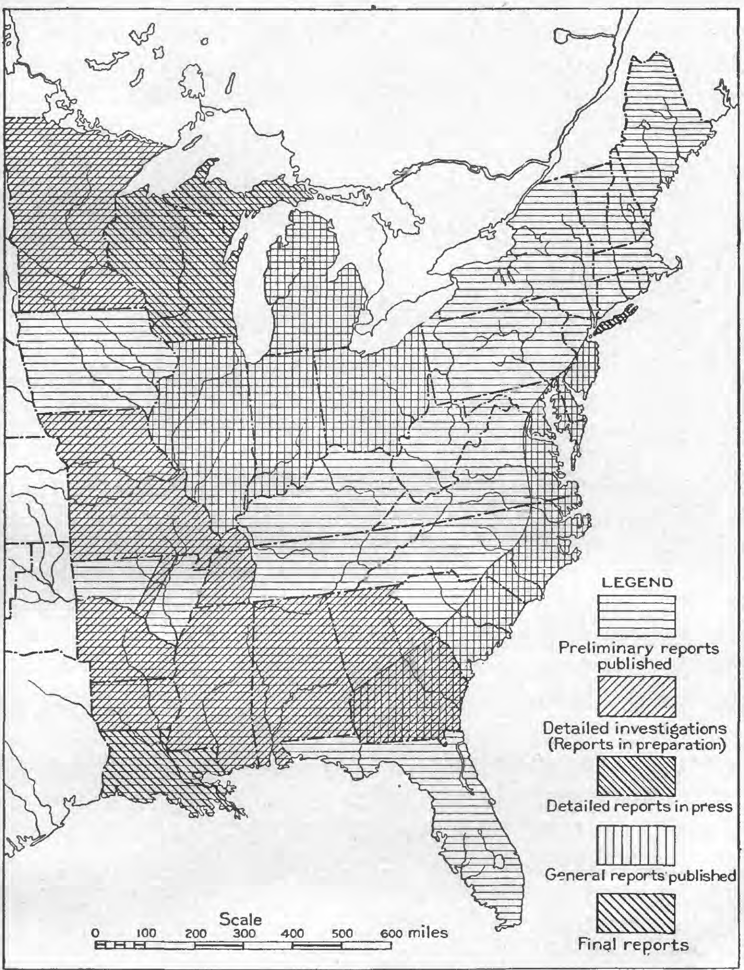

FIG. 1.—Index map showing extent of hydrologic work in eastern United States. Merely local investigations are omitted.

One of the most promising lines of work undertaken in the office is a system for collecting and preserving well records and samples from deep wells throughout the country. The plans for this work were drawn up by Mr. A. C. Veatch, who, with the assistance of Mr. E. F. Lines, inaugurated the work in July. Arrangements have been made for procuring the effective aid of drillers, and it is anticipated that a large amount of economic and stratigraphic data, much of which would otherwise soon be lost, will thus be preserved. It is proposed to publish the accumulated data promptly each year, making it quickly available to drillers and others interested in underground waters.

During 1904 a paper giving a summary of legal decisions on the various phases of underground waters was prepared by Mr. D. W. Johnson, setting forth the general principles on which legal decisions relating to water rights are based, and giving a general idea of the rights and obligations of well owners.

WORK BY STATES.

Maine.—The work in this State in 1904 consisted mainly of investigations relating to water-supply conditions along the shore of Penobscot Bay and near Augusta, and was conducted by Mr. G. O. Smith in connection with surveys for the geologic branch. A short report on the conditions at Augusta was prepared. Prof. W. S. Bayley also continued the collection of data by correspondence throughout the State.

New Hampshire.—The work in this State was continued under the direction of Mr. J. M. Boutwell, assistant geologist. In March Mr. Boutwell investigated the underground-water conditions in the vicinity of the Government forts at the mouth of Portsmouth Harbor, the work being done in response to a request received from the Quartermaster-General. Owing to the pressure of his regular mining work, Mr. Boutwell was unable to continue the work in New Hampshire, and the services of Mr. G. O. Smith, geologist, were obtained to complete the investigations at Portsmouth. Both Mr. Boutwell and Mr. Smith give favorable reports as to the possibility of obtaining underground supplies.

Massachusetts and Rhode Island.—The field work in these States consisted of investigations of the Pleistocene geology by Mr. M. L. Fuller. Cape Cod, Nantucket, Marthas Vineyard, and the Elizabeth Islands, Massachusetts, and Block Island, Rhode Island, were visited and a basis for the assignment of the glacial deposits to definite Pleistocene stages was established. The expense of this work was shared with the geologic branch.

A paper on the water supply of the delta type of sand plains, based on extensive observations and hundreds of borings at Clinton, Mass., was prepared by Prof. W. O. Crosby.

New York.—Mr. M. L. Fuller spent the month of June on Long, Gardiners, Plum, and Fishers islands, traversing the shore lines and investigating the Pleistocene stratigraphy. The result was to substantiate the subdivisions made in 1903 and to establish a basis of correlation between the New York and New England islands. It is now possible to recognize a series of deposits and erosion intervals agreeing with those of the Mississippi-Ohio Valley. Mr. Fuller was assisted by Mr. B. L. Johnson in his work on Long Island. Mr. A. C. Veatch spent a few days in May in search of Pleistocene fossils, which were found at two new localities.

Work on the springs was continued by Mr. F. B. Weeks, geologist, who completed the field work and is now preparing a report for publication. Mr. E. M. Kindle prepared a short report on the water resources of the Catatonk area. A report on the springs of the morainal-outwash deposits near Tully, N. Y., which represent a definite class of drift waters, was prepared by Mr. G. B. Hollister.

New Jersey.—Mr. G. N. Knapp, of the State Geological Survey, has been engaged during the year on office work connected with the preparation of a detailed report on the artesian waters.

Maryland.—Arrangements were made during the year with Prof. W. B. Clark, State geologist, for cooperation in the collection of well records and samples. The collecting is done from the Maryland office and duplicates of the records and samples furnished the United States Geological Survey. Brief reports on the Pawpaw and Hancock quadrangles were prepared by Mr. George W. Stose, geologist.

Virgina.—A plan of cooperation was arranged in November with Dr. T. L. Watson, State geologist, whereby the collection of well records and data relating to water resources and springs was begun. Reports by Messrs. M. L. Fuller and T. L. Watson will be prepared at an early date.

West Virginia.—Reports of the Pawpaw and Hancock quadrangles mentioned under Maryland, and on which reports were prepared by Mr. George W. Stose, are included in this State. Mr. I. C. White, State geologist, has cooperated in the collection of well records and samples.

Georgia.—Mr. S. W. McCallie, assistant State geologist, has continued to work in cooperation with the United States Geological Survey in the investigation of artesian waters of the Coastal Plain. The large number of fossils collected by Mr. McCallie have been identified by Dr. W. H. Dall and Mr. T. W. Vaughan, resulting in an increased knowledge of Coastal Plain stratigraphy. Mr. McCallie's report on the artesian waters is nearly completed. The division of hydro-economics has largely assisted in the investigation of the composition of waters.

Alabama.—Dr. E. A. Smith, State geologist, continued cooperation with the United States Geological Survey, completing the field work on artesian waters. His report was well under way at the end of the year. Doctor Smith has also cooperated in the collection of well records and samples.

Mississippi.—In conjunction with the geologic branch the eastern section of hydrology has continued the work on geology and underground waters. The field work, which has been in charge of Mr. E. C. Eckel, assisted by Mr. A. F. Crider, will be completed about the end of the year, and a report will be prepared at an early date, in which Mr. L. C. Johnson, who in past years has collected much data, is expected to participate.

Tennessee and Kentucky.—Mr. L. C. Glenn has continued work on a report on the artesian waters of the portion of the Mississippi embayment area included in these States, the field work on which was completed in 1903. In Kentucky Prof. C. J. Norwood, director of the State Survey, has cooperated in the collection of well records and samples.

Arkansas-Louisiana.—Mr. A. C. Veatch has been engaged during the latter part of the year in the preparation of a report on the artesian waters of southern Arkansas, northern Louisiana, and adjacent portions of Texas and Indian Territory. In the northeastern portion of the State investigations have been conducted by Prof. E. M. Shepard and Mr. M. L. Fuller on the artesian conditions of the New Madrid earthquake area. An account of the water resources of the Winslow quadrangle was prepared by Prof. A. H. Purdue.

Missouri.—In Missouri work was continued in charge of Prof. E. M. Shepard, who spent a portion of the summer in the study of the artesian waters of the State and in the investigation of the possible relation of artesian waters to certain phenomena of the New Madrid earthquake area noted under Arkansas. In this work he was accompanied part of the time by Mr. M. L. Fuller. A report on the water resources of the Joplin quadrangle was prepared by Mr. W. S. T. Smith, while notes on a number of large springs were submitted by Messrs. E. Johnson, H. F. Bain, and E. M. Shepard.

Iowa.—The work in Iowa was continued in charge of Prof. W. H. Norton, who, during the year, was consulted regarding artesian water by officials at Keokuk, Mount Pleasant, Waterloo, Fort Dodge, and Belle Plaine. A report on the artesian conditions at Waterloo was prepared. Professor Norton also assisted in the collection of well records and samples in Iowa.

Minnesota.—Prof. C. W. Hall continued work on his report on the artesian waters of the State and assisted in the collection of well records and samples.

Wisconsin.—A report on the artesian waters of Wisconsin, the field work for which was finished in 1903, was completed and submitted by Mr. A. R. Shultz early in the year. A short report on the water resources of the Mineral Point quadrangle was prepared by Prof. U. S. Grant.

Michigan.—The work in Michigan consisted of a detailed investigation of the water supply of the drift in charge of Mr. Frank Leverett, assisted by Messrs. C. A. Davis, W. M. Gregory, Isaiah Bowman, and Jon Andreas Udden. Mr. M. L. Fuller, chief of section, made a special investigation of the failure of wells in the Carleton district, southwest of Detroit, visited about twenty flowing-well areas in the western portion of the State, and spent some time in the field with the various parties. Reports on the Carleton and western Michigan artesian districts were prepared before the close of the year. Dr. A. C. Lane, State geologist, cooperated in the saving of samples and Mr. R. E. Horton prepared a report of the drainage of wells into swamps.

SUMMARY OF REPORT.

In the following paragraphs the aim has been to present a concise summary of the various short papers embodied in the present report and to call attention to those features deemed of special interest or importance.

Drainage of Ponds into Drilled Wells, by Robert E. Horton.

In the deeply drift-covered regions of Michigan and adjoining States the surface is characterized by numerous ponds held in the basin-like depressions known as "kettles." These are often shallow, and if drained would leave in some cases many areas of rich farming lands. Their situation in depressions is such that they can seldom be drained by ditches, but attempts to draw off the water by wells have been more successful. The average cost of a 3-inch well, including casing, should not exceed $1 a foot, and in most cases a depth of 100 feet will be sufficient. The wells are sunk with the mouths below water level and on completion are provided with a bell mouth and surrounded by screens. The effectiveness of the wells depend upon the height to which the underground water will rise being less than that of the pond. Under such conditions the water enters the well mouth and passes down the pipe and out into the porous sand, gravel, sandstone, etc., at the bottom, or into fissures where the well ends in compact rock. The construction of the wells, their capacity for drainage, etc., are described in detail in the paper. A considerable number of wells which have been successful in the reclamation of lands formerly covered by ponds are cited.

Two Unusual Types of Artesian Flow, by Myron L. Fuller.

The first of the two unusual types of flow described is from practically uniform sand, the impervious confining cover usually assumed to be essential to flows being absent. It appears, from observations on Long Island, New York, and in Michigan, that while any layer slightly finer than the water bed may, even though permeable, serve as a confining bed, such a layer is not necessary, an overlapping arrangement of slightly elongated grains in a uniform sand being apparently sufficient to produce the resistance to upward movement essential to artesian flows. The second unusual type of flow described is from the jointed upper portion of limestone and other rocks in southeastern Michigan. Although the waters are rock waters in composition, their origin and head are shown to depend on drift deposits, which likewise serve as the confining stratum. In fact, in all essentials they are drift waters, the rock simply serving as a carrier in place of the layer of stratified sand or gravel commonly present. The mineral matter is dissolved from the rock during the passage of the water through it.

Construction of the so-called Fountain and Geyser Springs, by Myron L. Fuller.

The term "fountain spring" is used to designate a spring whose water is made to rise to a point above the surface of the ground at the spring, while by a "geyser spring" is meant one so piped that a jet is intermittently thrown to a greater or less height. The classes of natural springs, the conditions under which they may be converted into one or the other of the artificial types mentioned, and the simple methods of construction employed are described and illustrated.

A Convenient Gage for Determining Low Artesian Heads, by Myron L. Fuller.

In this paper the difficulties in determining flows with the ordinary cumbersome gages, requiring considerable material, much time, and some skill, are pointed out, and attention is called to the necessity of a more convenient form for rapid work. The requirements were finally filled by a 2-inch nickel-plated gage, which can readily be carried in the vest pocket and which can be used for all pressures up to 50 pounds. By means of a rubber tube opening out into a flange, which is held firmly against the discharge pipe of the well, the pressure can be instantly obtained.

Water Resources of the Catatonk area, New York, by E. M. Kindle.

The Catatonk area lies in the hilly region northwest of Binghamton, between that city and the Finger Lakes region. The rocks are Devonian in age and are nearly flat, though showing very low swells, extending in an east-west direction. The whole region is more or less covered with glacial drift. As a whole the rocks are compact and carry little water, although they afford numerous small springs. Flows, however, are yielded by the sands and gravels at

Ithaca, near Slaterville Springs, west of Brookton, at Newark Valley, and just north of Tioga Center. Some of the water is high in mineral matter and possesses medicinal properties, which at Slaterville Springs have led to the development of a resort. Of the mineral springs may be mentioned the Dryden, Speedsville, Nanticoke, Spencer, Halsey, Valley, Glen Cairn, and springs south of Owego. The waters are commonly of the sulphur type, in which instances they probably come from the rock, and are sometimes of medicinal value. At several of the springs sulphur is deposited by the water. A number of summer hotels have been built. The streams are ordinarily fairly pure, one having long afforded the water supply for Ithaca, while Fall Creek supplies power for three or four mills and factories at Ithaca and the hydraulic laboratory, etc., of Cornell University.

Water Resources of the Pawpaw and Hancock Quadrangles, West Virginia, Maryland, and Pennsylvania, by George W. Stose and George C. Martin.

The area treated in this paper lies at the northernmost bend of the Potomac and is a moderately hilly region, with occasional high northeast-southwest ridges, rising to 2,260 feet in Cacapon Mountain. The rocks consist of quartzite, sandstone, shale, and limestone, from Ordovician to Carboniferous in age. A number of streams besides the Potomac have considerable volume and fall and afford present or prospective water powers. Springs are numerous, among the most important of which are those at Berkeley Springs, W. Va., the site of a fashionable resort. The water issues from steeply inclined sandstone at a number of points, has a temperature of 73° F., and yields about 1,500 gallons per minute. The water carries the small amount of 13 grains of mineral matter per gallon, mainly carbonate of lime.

Water Resources of the Nicholas Quadrangle, West Virginia, by George H. Ashley.

The area treated includes about 1,000 square miles in central West Virginia, a little east of New and Kanawha rivers. The region is extremely hilly, the crests often standing 500 to 1,000 feet above the adjacent streams and reaching a maximum height of nearly 4,400 feet. The tributaries from the north entering Gauley River (which crosses the area from east to west near the center) occupy broad, flat valleys separated from each other by irregular divides. There is some farming along the bottoms of these tributaries, but over the remainder of the area the valleys are sharp and steep and unsuited for cultivation. The rocks are mainly sandstones and sandy shales of the Pottsville group, and include some valuable coals and clays. The dip averages from 100 to 200 feet per mile to the northwest. The domestic water supply of the uplands is usually obtained from shallow wells, which often go dry in time of drought, necessitating recourse to the springs issuing along the coals, etc., at points lower down in the valleys. Wells in the valley bottoms generally obtain better supplies, the town supplies of Summersville and Richwood being from such wells. The water throughout the area is of the soft "freestone" type. The geologic structure would seem to afford unusually favorable conditions for artesian waters. The region is forested, giving flows to the streams throughout the year, and, owing to the character of the valleys, the opportunities for the construction of dams for power purposes are unusually good.

Water Resources of the Mineral Point Quadrangle, Wisconsin, by U. S. Grant.

This quadrangle is situated mainly in southwestern Wisconsin, the Illinois State line barely falling within its limits. Although a rich agricultural country, it is situated in the heart of the upper Mississippi Valley lead and zinc region and produces much ore. The topography is that of a low plateau, above which rise a few isolated elevations and below which are the wide flat-bottomed valleys occupied by the streams. The rocks consist of Paleozoic limestone shales and sandstones. The lead and zinc deposits occur at the base of the Trenton and at the top of the underlying Platteville limestone. Springs are numerous in the area, occurring mainly at the bottoms of the Galena and Platteville limestones and the St. Peter sandstone. They are often used for domestic and dairy purposes. The streams were formerly a source of many small water powers, but are now rarely utilized. Wells are commonly of the drilled type and generally vary from a depth of 10 feet in the valleys to 100 feet in the uplands. The largest supplies are from the St. Peter sandstone, but the Galena furnishes much water of good quality for domestic purposes. Deep wells are sunk to the St. Peter, when it is below the surface, and to the Potsdam, from both of which abundant supplies are generally obtained by pumping, although neither furnishes a flow. The Potsdam water is more highly mineralized than that from the higher horizons.

Water Resources of the Joplin District, Missouri-Kansas, by W. S. Tangier Smith.

This district lies at the intersection of the boundary lines of Missouri, Indian Territory, and Kansas, and includes the famous Joplin lead and zinc region. Topographically it lies on the western outskirts of the Ozark region and consists of level plains cut by valleys to a maximum depth of 200 feet. The drainage is southward into Arkansas River. The surface rocks are mainly limestones of the cherty lead- and zinc-bearing formation known as the Boone, but some shales and sandstones of the Cherokee formation occur. The dip is low to the northwest. The rocks are characterized by open folding, with considerable faulting in the vicinity of the ore deposits. The streams, which are all spring fed, afford power at a number of points, and Spring River and Center and Shoal creeks furnish water supplies for most of the cities in the district, including Joplin, Webb City, Carthage, and Galena. Other streams, formerly yielding good water, are now polluted by mine waters. Springs are common, sometimes of large volume, and are used for domestic or mine supplies. A part of the waters are high in mineral matter, sometimes carrying an appreciable quantity of zinc, and give rise to soft white, cream-colored, or reddish deposits. The wells in the region are usually shallow, but in the mining district there are several thousands of deep test borings sunk in search of ore, some of which are used as wells. No flows have been obtained, although supplies ranging up to 12,500 gallons per hour are obtained by pumping or air lift. A considerable number of analyses of waters from streams, springs, and wells, some of which are in considerable detail, are given.

Water Resources of the Winslow Quadrangle, Arkansas, by A. H. Purdue.

This quadrangle lies mainly in western Arkansas, a little north of Arkansas River, but includes a few square miles of Indian Territory. The topography is that of a plateau deeply cut by streams until it presents a mountainous landscape, forming a part of what is known as the "Boston Mountains." The rocks consist of limestones, shales, and sandstones of Carboniferous age, four of which—the Boone chert (largely limestone), Pitkin limestone, and the sandstones of the Hale and Winslow formations—are important water-bearing formations, yielding abundant water to wells or springs. The water varies from soft in the case of the Winslow formation to medium in the Boone chert and Hale formation and hard in the Pitkin limestone. Some of the springs yield water highly mineralized, and in one or two cases are utilized for medicinal purposes, or as resorts. Some of the water could be used to advantage for power or irrigation purposes.

Water Resources of the Contact Region between the Paleozoic and Mississippi Embayment Deposits in Northern Arkansas, by A. H. Purdue.

This paper treats of the geology and water resources of a belt from 12 to 15 miles wide, extending along the western edge of the Mississippi embayment deposits from Arkansas River northward to the Missouri line. The geology of both the Paleozoic and embayment areas, including a description of the beds and their history, are considered in some detail, and a geologic map showing the boundary with greater accuracy than any previously published map is given. The meaning of ground water, the relative amounts of run-off and ground water, the character of the water table, and the essential characteristics of a water-bearing formation are discussed, and the water-bearing beds, including the Ordovician limestone, Boone chert, Batesville sandstone, Pitkin limestone, Coal Measures, and the soft embayment deposits are described. Other subjects considered are the source of water from rainfall and leakage from streams and Paleozoic rocks, the amount, composition, and uses of the water, the prospects for flowing wells, and the problems of type, location, depth, and construction of wells from the sanitary standpoint. The practical discussions of these questions of general interest should prove of substantial benefit to the residents of the Arkansas lowlands.

Water Resources of the Portsmouth-York Region, New Hampshire and Maine, by George Otis Smith.

The examination of the water resources in the vicinity of Portsmouth was undertaken at the request of the War Department, with a view of determining the available supplies for the several forts at the mouth of the harbor. The conditions proved to be typical of those existing in districts of similar rocks at points along the Maine coast, where the problem of obtaining deep-well waters for the use of summer residents, especially those living on small islands, is one of great importance. The city supply of Portsmouth is from shallow wells in loose surface deposits, from which the farm supplies in the region are also generally obtained. Another source, utilized at the navy-yard, is the ponds on the slope of Mount Agamenticus, while a third source is the deep-rock wells. These rock wells, which supply a number of hotels and summer residences, have in numerous instances been successful in obtaining good supplies, the waters sometimes even flowing at the surface, demonstrating the existence of artesian storage of a type quite different from that usually described. The rocks consist mainly of schists, slates, and quartzites, which are compact, upturned, and characterized by numerous joints. Some dikes of igneous rocks occur. The water is contained in bedding planes, joint openings, etc., through which it circulates slowly, its escape to the surface being prevented by the closing of the joints by mineral deposits near the top. The water is to be regarded as coming from distant rather than adjacent areas. In many cases abundant supplies are obtained at less than 100 feet, while wells of 300 feet are nearly always successful, although, owing to the lack of regularity in the occurrence of joints, an occasional failure results. The schist appears to be the most promising rock.

A Ground-Water Problem in Southeastern Michigan, by Myron L. Fuller.

The spring and summer of 1904 were marked by a pronounced shortage of water in certain areas in southeastern Michigan, the failure of the wells being commonly attributed to underdrainage of a powerful flowing well on Grosse Isle, a few miles away. Investigation showed the loss of water to be due not to the big flowing well, nor to the deep quarry at Newport, but to certain general causes applicable to many other regions throughout the country. Of these causes deforesting seems to have been one of the most important factors in the decrease of supplies in the past, but had little immediate connection with the present shortage, which seemed to be due (1) to the extensive ditching that the region has undergone, which has lessened the amount of water absorbed by the ground; (2) to the early frost of 1903, which prevented the autumn and winter rains from entering the ground, and (3) to the drought during the spring and summer of 1904, during which little or no rain fell for long periods. The water will probably return only after one or more wet years, and may possibly never return in its original amount, but a deepening of the wells will probably result in securing supplies adequate for the ordinary needs of the inhabitants. The condition of the wells during 1904 is described at some length, and the application to other regions of the conclusions regarding the shortage is discussed.

Water Supplies at Waterloo, Iowa, by W. H. Norton.

The investigation of the conditions at Waterloo was undertaken in response to requests from city officials with a view of determining the availability of artesian waters to replace the surface supply from Cedar River, which had become dangerously polluted, giving rise to a severe typhoid epidemic. The investigation showed that shallow ground water was slight in amount, owing to its ready drainage into Cedar River and its extensive absorption by the underlying rock. There are, however, strong springs issuing from the limestone 5 or 6 miles up the valley, and artesian water could probably be found in the St. Peter sandstone at about 850 feet, the Jordan sandstone at about 1,300 feet, and the basal (Potsdam) sandstone at 1,800 feet or more. Such deep-seated water would be perfectly healthy, but would probably give more or less trouble in boilers on account of scale-forming minerals in solution. Two or more wells would be necessary to furnish the 3,000,000 gallons daily which the city requires. The necessity of test wells, the question of supplementary supplies, the head of the artesian waters, and the question of permanency of flow are all discussed.

Water Supply from Glacial Gravels near Augusta, Me., by George Otis Smith.

The region treated in this paper includes the Silver Lake system of ponds, about 5½ miles northwest of Augusta, which it was proposed to utilize, in connection with a series of springs at the head of Spring Brook, as a source of a water supply for that city. There are 13 ponds, with an aggregate area of 215 acres, connected in part by sluggish streams, but without any outlet stream. The springs mentioned are half a mile south of the southernmost pond. A study of the area shows that the gravels probably occupy a sort of basin, bounded beneath the surface, both on the east and west, by rock or impervious till. The drainage basin is divided on the surface by a winding ridge which separates the ponds into two chains. The water level in the ponds in general shows a regular decrease to the south, but the rate differs in the two chains, making it apparent that the water level of the ponds depends on the height of the ground-water tables, of which there are two—one on each side of the medial ridge. The movement of the water is manifestly to the south, its point of issue being in the springs at the head of Spring Brook, the flow of which is supplied from the same ground-water sheet as that which supplies the ponds, which are merely the visible portions of the ground-water lake. Since the ground-water body occupies a confined basin, any water taken from the ponds diminishes by so much the total amount, involving a corresponding decrease in the yield of the springs, which constitute practically the only source of outflow from the basin. Hence, the city supply would not be increased by drawing from the ponds.

Water Supply from the Delta Type of Sand Plain, by W. O. Crosby.

During the construction of the water system for Boston and the metropolitan district of Massachusetts the structure and waters of the sand plains near Clinton were thoroughly investigated by means of many hundred borings, and a summary of the results is presented in the present paper as an example of a type of water supplies of importance throughout New England. The plains, of which there are several, were deposited as deltas in a glacial lake caused by the obstruction of the northward-flowing Nashua River by the retreating ice sheet of the last Glacial epoch. The deposits known as the North Dike Plain are particularly considered, and their topography, composition, structure, origin, and water supplies are described, together with the crests and valleys of the buried rock surface upon which they lie. The form of the water table and the phenomena of "lost water" (water passing off into the sands at points below the water table), as well as the occurrence of "springs" or water seams under artesian head, are discussed. The deposition of iron and the cementing of the materials in certain of the beds and the oxidation of the drift, both of which features are dependent on the circulating waters, are also described and explained. A summary of the conditions and their application to other localities concludes the paper.

Waters of a Gravel-Filled Valley near Tully, N. Y., by George B. Hollister.

In a valley near Tully, N. Y., there is a thick accumulation of sands and gravels, representing the accumulations taking place at the termination of a tongue of glacial ice which occupied the valley during a late geological period. The deposits are similar to those at many other points in New York and New England, and the water-supply conditions represent a type of importance in these regions. The paper describes the character of materials, the volume of the springs issuing from them, the deposits of tufa formed by the spring waters, the waters of the lakes occurring in depressions in the gravels, and the composition of the spring and lake waters. A considerable number of analyses are given.

Notes on Certain Hot Springs of the Southern United States, by Walter Harvey Weed.

Although the economic importance of the hot springs of our country as resorts is immense there is a dearth of reliable information as to their occurrence. In this paper descriptions of two of the more important localities, the Warm Springs of Georgia and the Hot Springs of Arkansas, are described in some detail. The former issue from a fracture near the base of Pine Mountain, a sandstone ridge rising from the Piedmont Plateau, about 85 miles south-southwest of Atlanta. The waters, which, judging from their temperature of 87°, come from a depth of about 1,600 feet, are very pure, agreeing in this respect with the water of the Hot Springs of Arkansas. These latter springs issue from vents in old tufa or hot-spring deposits in a valley in a somewhat mountainous region of strongly folded Carboniferous and lower Silurian rocks about 50 miles west of Little Rock. The springs are Government property, and about them have been developed parks, numerous bathing establishments, and hotels, making the most important hot-spring resort in America and one comparable with the great European spas. The paper gives an account of the history, topography, geology, flow, temperature, and composition, including many analyses, of the springs. The discharge varies from about 500 gallons per twenty-four hours in the smallest spring to 201,000 gallons in the largest, and the temperature from 46° to 147°. The waters contain some carbon dioxid, nitrogen, and oxygen, the latter two resulting from the absorption of air, and in general correspond closely to the ordinary mountain springs, except in the element of heat, which is supposed to be derived from heated vapors rising from deep-seated igneous intrusions. There seems to have been little, if any, decrease in temperature or volume since about 1850, when the springs were first carefully studied.

Notes on Certain Large Springs of the Ozark Region, Missouri and Arkansas, compiled by Myron L. Fuller.

In this paper are put on record data relating to some of the immense springs of the Ozark Mountains which have recently been investigated by members of the Geological Survey with the object of determining their availability for water power. Those discussed are Greer, Van Buren, Fanchon, Alley, Blue, Mesamer, and Boiling springs in Missouri, and Mammoth Spring in Arkansas. All occur in limestone rocks, and several represent the outlets of subterranean rivers, while one, the Blue Spring, issues from a natural well nearly 50 feet in depth. The waters, though sometimes somewhat roily after storms, are usually entirely clear, of a bluish tinge, and pure except for the dissolved lime and magnesia. The summer temperatures average about 56°. Measurements in 1904, when the springs appear to have been very low, as compared with some past years, showed the flow to range from 23 cubic feet per second at Blue Spring up to 265 second-feet at Greer Spring. In nearly every instance the springs either furnished power or could be made to do so. Some of the springs show an intermittent flow, as, for instance, one near the junction of Jacks Fork and Current River, Shannon County, Mo., which has a rhythmic discharge with maxima about forty minutes apart, with intervening minima, when the flow nearly ceases. Sink holes are numerous, and in places are thought to mark the position of the underground streams feeding the springs.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

The results of the work of the Survey on underground waters and springs are published in a number of different forms, briefly described below. Complete lists of Survey publications, with prices of such of them as are for sale, can be obtained on application to the Director.

1. Papers and reports accompanying the Annual Report of the Director: Prior to 1902 many reports relating to underground waters were published in the royal octavo cloth-bound volumes, which accompanied the annual reports of the Director. This form of publication for scientific papers has been discontinued and a new series, known as Professional Papers, has been substituted.

2. Bulletins: The bulletins of the Survey comprise a series of paper-covered octavo volumes which in general contain a single report or paper. These bulletins formerly sold at nominal prices, but are now distributed free of charge to those interested in the special subject discussed. This form of publication is used for presenting information relating to underground waters when the hydrologic descriptions are accompanied by extended topographic or geologic discussions. Before the inauguration of the Water-Supply and Irrigation series of papers the bulletins were the form of publication for all shorter papers related to water supplies. Their small size precludes the use of large maps or plates, and reports requiring large illustrations are therefore issued in the series of Professional Papers.

3. Professional Papers: This series, paper covered, but quarto in size, is intended to include such papers as require large maps or other illustrations. Their publication was begun in 1902, and they are distributed in the same manner as the bulletins.

4. Monographs: This series consists of cloth-bound quarto volumes, and is designed to include exhaustive treatises on any subject coming within the province of the Survey. As yet no paper relating to water supply in any of its forms has been published as a monograph. The volumes of this series are sold at cost of publication.

5. Geologic Folios: Under the plan adopted for the preparation of a geologic map of the United States the entire area is divided into small quadrangles, bounded by certain meridians and parallels, and these quadrangles, which number several thousand, are separately surveyed and mapped. The description of each quadrangle is issued in the form of a folio as the survey is finished. When the series is complete the folios will constitute a Geologic Atlas of the United States. Copies of the folios, like the preceding publications, are sent to a large number of public institutions and libraries. Those remaining are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Many of the folios contain special descriptions and elaborate maps showing the occurrence of underground waters.

7. Reports on Mineral Resources: The reports of this series are cloth-bound octavo volumes, published annually, giving statistical summaries of the output of the various mineral products, including mineral waters and brines. They were issued as a distinct series from 1882 to 1893. They were then made a part of the Annual Report until 1900, when their separate publication was resumed. The volumes of the earlier series were generally sold at about 50 cents, but the later ones are for free distribution.

8. Water-Supply and Irrigation Papers: These are of octavo size, and are published in red paper covers. They are distributed gratuitously. As the name indicates, only papers relating to investigations and problems of water supplies in their various forms are published in this series. In common with the professional papers and bulletins the water-supply papers are divided into a number of series, as follows:

(I) Irrigation.
(J) Water storage.
(K) Pumping water.
(L) Quality of water.
(M) General hydrographic investigations.
(N) Water power.
(O) Underground waters.
(P) Hydrographic progress reports.

9. Reclamation Service Reports: These reports are octavo volumes, bound in light olive-green cloth, and issued annually. They cover the engineering and construction work relating to projects for reclaiming the arid public lands. In the three reports issued so far nothing relating to underground waters is given.

In addition to the various series of reports mentioned, the Survey issues a large number of topographic and other maps, on some of which springs are shown, as well as sinks resulting from subterranean drainage. Lists of the maps may be had on application.

The following detailed lists contain all papers on underground waters and springs issued by the Survey: [a]

PAPERS IN ANNUAL REPORTS.

The requisite and qualifying conditions of artesian wells, by T. C. Chamberlin: Fifth Ann. Rept., 1883–84, pp. 125–173, 1 pl.

Formation of travertine and siliceous sinter by the vegetation of hot springs, by W. H. Weed: Ninth Ann. Rept., 1887–88, pp. 613–676, 10 pls.

The potable waters of eastern United States, by W J McGee: Fourteenth Ann. Rept., 1892–93, pt. 2, pp. 1–47.

Natural mineral waters of the United States, by A. C. Peale: Fourteenth Ann. Rept., 1892–93, pt. 2, pp. 49–88.

Water resources of a portion of the Great Plains, by Robert Hay: Sixteenth Ann. Rept., 1894–95, pt. 2, pp. 535–588, 3 pls.

The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert: Seventeenth Ann. Rept., 1895–96, pt. 2, pp. 551–601, 15 pls.

Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton: Seventeenth Ann. Rept., 1895–96, pt. 2, pp. 603–694, 39 pls.

The water resources of Illinois, by Frank Leverett: Seventeenth Ann. Rept., 1895–96, pt. 2, pp. 695–849, 11 pls.

Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex., with reference to the occurrence of underground waters, by R. T. Hill and T. W. Vaughan: Eighteenth Ann. Rept., 1896–97, pt. 2, pp. 193–321, 44 pls.

Water resources of Indiana and Ohio, by Frank Leverett: Eighteenth Ann. Rept., 1896–97, pt. 4, pp. 419–559, 5 pls.

New developments in well boring and irrigation in eastern South Dakota, 1896, by N. H. Darton: Eighteenth Ann. Rept., 1896–97, pt. 4, pp. 561–615, 10 pls.

Principles and conditions of the movements of ground water, by F. H. King: Nineteenth Ann. Rept., 1897–98, pt. 2, pp. 59–294, 11 pls.

Theoretical investigation of the motion of ground waters, by C. S. Slichter: Nineteenth Ann. Rept., 1897–98, pt. 2, pp. 295–384, 1 pl.

The rock waters of Ohio, by Edward Orton: Nineteenth Ann. Rept., 1897–98, pt. 4, pp. 633–717, 3 pls.

Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton: Nineteenth Ann. Rept., 1897–98, pt. 4, pp. 719–785, 45 pls.

[a] For publications appearing since this text was prepared, see outside of back cover.

Preliminary description of the geology and water resources of the southern half of the Black Hills and the adjoining regions in South Dakota and Wyoming, by N. H. Darton: Twenty-first Ann. Rept., 1899–1900, pt. 4, pp. 489–599, 55 pls.

The High Plains and their utilization, by W. D. Johnson: Twenty-first Ann. Rept., 1899–1900, pt. 4, pp. 601–741, 44 pls., and Twenty-second Ann. Rept., 1901–2, pt. 4, pp. 631–669, 15 pls.

Geography and geology of the Black and Grand prairies, Texas, with detailed descriptions of the Cretaceous formations and special reference to artesian waters, by R. T. Hill: Twenty-first Ann. Rept., 1899–1900, pt. 7, 666 pp., 71 pls.

Mineral waters, by A. C. Peale: Sixteenth Ann. Rept., 1894–95, pt. 4, pp. 707–721; Seventeenth Ann. Rept., 1895–96, pt. 3 (continued), pp. 1025–1044; Eighteenth Ann. Rept., 1896–97, pt. 5 (continued), pp. 1369–1389; Nineteenth Ann. Rept., 1897–98, pt. 6 (continued), pp. 659–680; Twentieth Ann. Rept., 1898–99, pt. 6 (continued), pp. 747–769; Twenty-first Ann. Rept., 1899–1900, pt. 6 (continued), pp. 597–622.

BULLETINS.

32. Lists and analyses of the mineral springs of the United States; a preliminary study, by A. C. Peale. 1886. 235 pp.
47. Analyses of waters of the Yellowstone National Park, with an account of the methods of analysis employed, by F. A. Gooch and J. E. Whitfield. 1888. 84 pp.
131. Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell. 1895. 126 pp.
138. Artesian-well prospects of the Atlantic Coastal Plain region, by N. H. Darton. 1896. 232 pp., 19 pls.
199. Geology and water resources of the Snake River Plain of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

PROFESSIONAL PAPERS.

17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.
32. Geology and underground water resources of the Central Great Plains, by N. H. Darton. 1904.

REPORTS ON MINERAL RESOURCES OF THE UNITED STATES.

Mineral waters, by A. C. Peale: Mineral Resources of the United States, 1883–84, pp. 978–987; 1885, pp. 536–543; 1886, pp. 715–721; 1887, pp. 680–687; 1888, pp. 623–630; 1889–90, pp. 521–535; 1891, pp. 601–610; 1892, pp. 823–834; 1893, pp. 772–794; 1900, pp. 899–905; 1901, pp. 961–966; 1902, pp. 993–1002; 1903, pp. 1137–1162.

WATER-SUPPLY AND IRRIGATION PAPERS.

4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls.
6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls.
7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls.
12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898 56 pp., 21 pls.
21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls.
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp.
30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.
31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls.
34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
53. Geology and water resources of Nez Perces County, Idaho, pt. 1, by I. C. Russell. 1901. 86 pp., 10 pls.
54. Geology and water resources of Nez Perces County, Idaho, pt. 2, by I. C. Russell. 1901. 87–141 pp.
55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 63 pp., 7 pls.
57. Preliminary list of deep borings in United States, pt. 1, by N. H. Darton. 1902. 60 pp.
59. Development and application of water in southern California, pt. 1, by J. B. Lippincott. 1902. 95 pp., 11 pls.
60. Development and application of water in southern California, pt. 2, by J. B. Lippincott. 1902. pp. 96–140.
61. Preliminary list of deep borings in United States, pt. 2, by N. H. Darton. 1902. 67 pp.
67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls.
77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.
78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.
90. Geology and water resources of part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.
101. Underground waters of southern Louisiana, by G. D. Harris; with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.
102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.
104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.
106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.
110. Contributions to hydrology of eastern United States, 1904, M. L. Fuller, geologist in charge. 1905. 211 pp., 5 pls.
111. Preliminary report on underground waters of Washington, by Henry Landes. 1905. 85 pp., 1 pl.

112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1905. 55 pp., 7 pls.
114. Underground waters of eastern United States, M. L. Fuller, geologist in charge. 1905. 285 pp., 18 pls.

GEOLOGIC FOLIOS.

13. Fredericksburg folio, Maryland-Virginia, by N. H. Darton.
23. Nomini folio, Maryland-Virginia, by N. H. Darton.
36. Pueblo folio, Colorado, by G. K. Gilbert.
42. Nueces folio, Texas, by R. T. Hill and T. W. Vaughan.
67. Danville folio, Illinois-Indiana, by M. R. Campbell and Frank Leverett.
68. Walsenburg folio, Colorado, by R. C. Hills.
70. Washington folio, District of Columbia-Virginia-Maryland, by N. H. Darton and Arthur Keith.
71. Spanish Peaks folio, Colorado, by R. C. Hills.
80. Norfolk folio, Virginia-North Carolina, by N. H. Darton.
81. Chicago folio, Illinois-Indiana, by W. C. Alden.
85. Oelrichs folio, South Dakota-Nebraska, by N. H. Darton.
86. Ellensburg folio, Washington, by G. O. Smith.
96. Olivet folio, South Dakota, by J. E. Todd.
97. Parker folio, South Dakota, by J. E. Todd.
99. Mitchell folio, South Dakota, by J. E. Todd.
100. Alexandria folio, South Dakota, by J. E. Todd and C. M. Hall.
104. Silver City folio, Idaho, by Waldemar Lindgren and N. F. Drake.
105. Patoka folio, Indiana-Illinois, by M. L. Fuller and F. G. Clapp.
107. Newcastle folio, Wyoming-South Dakota, by N. H. Darton.
108. Edgemont folio, South Dakota-Nebraska, by N. H. Darton and W. S. Tangier Smith.
113. Huron folio, South Dakota, by J. E. Todd.

THE DRAINAGE OF PONDS INTO DRILLED WELLS.

By Robert E. Horton.

GENERAL CONDITIONS.

The extensive ice action of the Glacial epoch left portions of Michigan, Indiana, Wisconsin, and Minnesota covered with glacial drift to a great depth. Sand, gravel, and clay alternate in patches, but the soil is, as a very general rule, loamy and permeable in the lake-besprinkled regions. The rainfall is usually from 30 to 40 inches per annum, of which from 8 to 16 inches reach the streams as run-off, largely through springs and seepage.

PONDS.

On large districts the surface topography is moderately rolling, and, while sloping in a general way toward the larger water courses, contains innumerable slight hollows without outlets. These undrained depressions vary in character from very small sink holes, generally tillable, in which standing water is found only after heavy rains or in early spring, to lakes, the vast majority of which are less than 1 square mile in area and which drain sloping margin lands from five to fifty times their own extent.

In the region in which these kettle holes and ponds are common no direct surface run-off to the streams takes place over a considerable percentage of the area nominally tributary to the rivers. Data regarding water-surface evaporation in this region is very meager, but it may be said, in a general way, that the annual evaporation from the lakes about equals the rainfall, the evaporation being greater or less than the precipitation according as the season is wet or dry. For these ponds to persist at a nearly uniform level requires that the inflow plus the rainfall on the surface shall equal the annual losses by evaporation and percolation.

DRAINAGE OF PONDS.

Ponds of this character disfigure valuable farms, and, if drained, the rich, mucky soil reclaimed would in many cases be of great value. Special attention was called to the desirability of their drainage by the excessive high water which followed the melting of the unusually large snow accumulation of the winter of 1903–4.

One of these ponds, which has an area of 4 or 5 acres when full and directly drains perhaps 60 acres of rather steep and permeable land surface, and which has been observed in a general way through many years, has shown a variation in its high-water level of 3 to 4 feet. It is filled with grass, promoting evaporation, and in a dry season goes entirely dry for a few weeks. The soil beneath is probably impervious or nearly so, and there are no marshes nor visible springs which feed it.

SUBSOIL DRAINS.

An unsuccessful effort was made twenty-five years ago to drain the above pond by digging through the hardpan bottom and inserting a stone-filled curb. This method of draining into a porous subsoil is considerably used in France and elsewhere,[a] but was entirely without success in this case.

DEEP-WELL DRAINS.

Surface drainage being unfeasible, drainage into deep-drilled wells has been successfully tried in a number of cases in Jackson County, Mich., and vicinity. An ordinary well-driller's outfit may be used.

In drilling the well on Fred Watkins's place, in Parma Township, after the first water bed had been reached at a depth of about 90 feet, the pipe was allowed to project upward in the pond near the surface, and was not protected in any way. The rate at which the water from the pond flowed down the drainpipe, rapid at first, decreased greatly during the first week and afterwards more gradually, so that after two months the pond, though visibly lowered as compared with adjacent undrained ponds, yet was not dry.

The well was then drilled out to a depth of 170 feet and the intake protected, with the result that the water was sucked down the pipe very rapidly and the pond completely drained. This well drains an area of about 35 acres of sloping tilled land, the soil being a permeable gravelly loam. The pond area was $2\frac{1}{2}$ acres, and the pond seldom or never dried up. In the valley of Kalamazoo River, 4 miles distant, prolific artesian waters are obtained from a water horizon which has very nearly the elevation of the bottom of this

[a] Charpentier de Cassigny, J., Hydraulique Agricole.

drain well, and from which the water rises to an altitude about the same as the static head in the drain well.

Decrease of draining power of wells.—Several theories have been advanced for the rapid decrease in flow sometimes noticed, as in this case, after the opening of such wells. First, it has been suggested that an unsaturated pocket has been entered, but this appears doubtful from the rather permeable character of nearly all the material penetrated, and also from the fact that abundant water supply is always found in wells drilled to about the same depth in the surrounding region. Second, it appears possible that the percolating chamber below the bottom of the well casing may have filled by caving, reducing the percolating surface. This is not improbable, as a similar adjacent well, drilled for water supply in 1888 in the same siliceous material, caved frequently at first and still continues to do so at intervals, rendering the water very turbid. The effect of such caving in a drain well would probably be deleterious. The use of a perforated strainer point, as in driven wells, might be advantageous. A third possible cause of decreased flow is vegetable fibers and silt carried down the pipe owing to lack of screens. At the start the pond was full of vegetable matter resulting from the decomposition of pond lily and other aquatic plants, and long fibers could be seen entering the pipe. These would obviously collect on the percolating surface of the well and there form a matrix.

Efficiency of wells for draining.—The efficiency of such drain wells lies in their ability to draw down the accumulated waters resulting from melting of the snow, which usually takes place in March, sufficiently early to permit tillage at some time between about the first and the middle of May. The annual spring filling of the pond once removed, further filling will only result from excessive rains during the growing season, a contingency which can only be provided against by the use of a well of such capacity that the standing water will not ruin the growing crop before the well can draw it down. Such summer freshets will, however, occur at intervals only.

The pond being disposed of, tile drains may be needed to sufficiently dry the subsoil for tillage, and this requires that the inlet to the well shall be placed sufficiently below the bottom of the pond to receive their effluent.

Cost of drain wells.—The cost of a drain well increases with increased diameter; the price charged for a 3-inch uncased well is 70 cents and for a 4-inch one 90 cents a foot; casing costs in addition 25 cents and upward for each foot.

Capacity of drain wells.—The capacity of the drain pipe increases rapidly with increased diameter, first, because its area of section is proportionate to the square of its diameter, and, second, because the loss of head and velocity due to friction are less in a large than in a small pipe with a given velocity. A drain well can take care of no more water than can flow out into the water-bearing material at the bottom, and the effect of an increase in size of drain well depends largely on conditions at the bottom of the pipe, as will be explained. Rapid drawing off of the water in spring is the most essential requisite, and this requires that the efficiency or capacity of the drain well shall be as great as possible.

There are some matters connected with the attainment of this end that are not well understood by the drillers of such wells where the writer has observed them and that offer an interesting problem in hydraulics.

Underground conditions.—(*a*) The drain well may penetrate an open fissure in which flows a free stream of water. This may occur, for example, in limestone formations. It is to be regarded, however, as accidental, and is not—as some are led to believe from the great water-taking capacity of some drain wells—either a common or a necessary condition in such wells. For such a well the capacity of the drain up to the limit of the capacity of the fissure would be almost directly proportional to the capacity of the drainpipe, the condition being that of flow through a pipe with free outlet. (*b*) The drain outlet may be in porous rock, as sandstone. The water-carrying capacity of sandstone is not always fully appreciated; the porosity, or percentage of voids, commonly ranges from 5 to 20 per cent, 15 per cent being perhaps a fair average. The water-taking capacity of the sandstone will differ from that of a loose sand of the same material only as a result of their different degrees of compactness. (*c*) The drain well may enter a porous stratum of sand, gravel, or other earth.

The wells described in southern Michigan apparently penetrate porous layers of glacial drift or sandstone. The outward flow is obviously the inverse of that which takes place when a well in the same water-bearing material is drawn upon by pumping. The laws that control such flow from wells where the head is known have been fully worked out elsewhere.[a]

Such calculations, together with the known yield of artesian and pumped wells in the same or similar formations, abundantly prove that the water-bearing material encountered in the drain wells of southern Michigan is capable of caring for the apparently large inflow observed.

In fig. 2 the conditions which may occur in such a well are illustrated. The water is disposed of by flowing outward through

[a] Turneaure and Russell, Public Water Supplies, pp. 267–275.

the pores in the material forming the walls of the chamber at the bottom, and the rate of such outward flow is determined by the pressure head, the surface area of the chamber at the bottom of the well, and the size of the pores.

Assuming that the water would rise in the well to the level A (static level) if there were no inflow, but that the inflow at the top

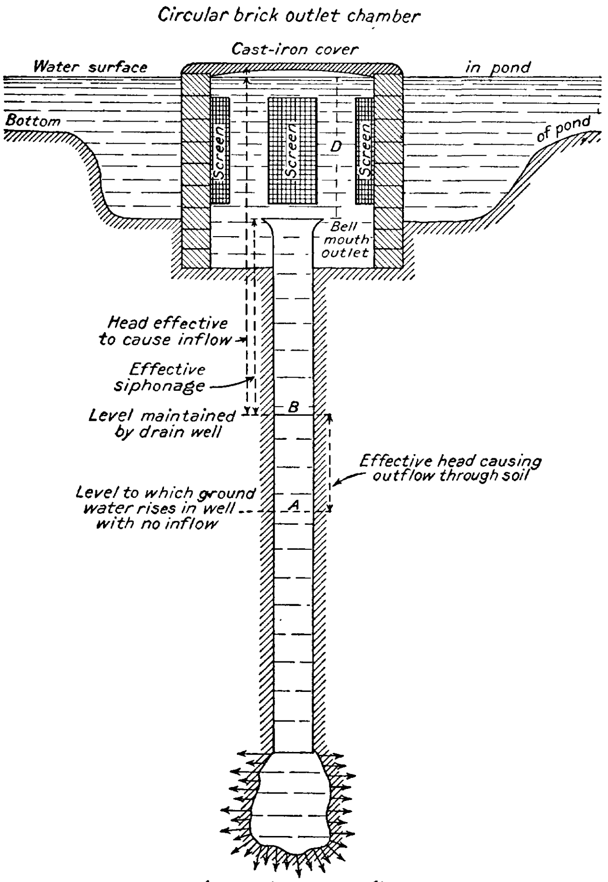

FIG. 2.—Diagram illustrating conditions in drainage wells.

of the pipe raises the water level to B, then AB is the effective head which causes discharge at the bottom. Later we shall consider siphon or draft-tube action in the pipe. Assuming for the present that water flows into the pipe as through an orifice, then the inflow to the mouth of the pipe will be proportional to the square root of the depth D of water above its mouth, indicating that in this case the intake should be placed low.

The mode of flow down a pipe, as commonly constructed by the drillers, is shown in fig. 3. This forms what is called a "Borda mouthpiece" and has a very low capacity. Only from 50 to 75 per cent of the pipe is effective, owing to contraction. If, however, a bell mouth be added to the pipe, having the form of the vena contracta, as shown in fig. 4, the full area of section will be effective, and the water will flow down the pipe with a velocity equal to about 96 per cent of that due to the head D.

Thus, a well fitted with a bell mouth may take 1.8 times as much water as one without. If the static level A is some distance below ground, the well will adjust itself to taking care of the increased supply of water provided by the bell mouth by increasing the head AB in about the same proportion that the inflow is increased, barring friction loss in the well pipe, a factor yet to be considered.

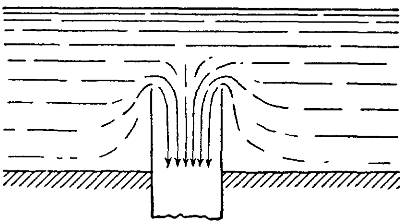

FIG. 3.—Diagram showing entrance of water into drainage pipe.

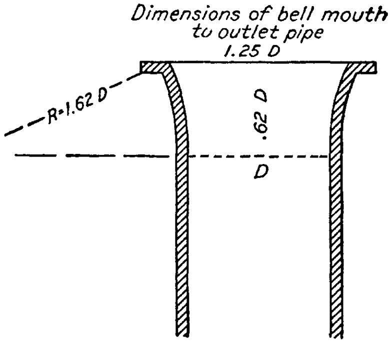

FIG. 4.—Diagram of mouth of drainage pipe.

In a well having tight casing and a proper entrance the inflow will be augmented by siphonage or draft-tube action, the water being forced down by atmospheric pressure in a manner the inverse of the action of a lift pump. If there be free discharge at the bottom and if the well be over 33 feet deep, then the maximum possible draft-tube head of 32.8 feet may be available.

Unless the ground-water horizon is at exceptionally great depth, however, it will probably happen, as has been observed in practice, that the discharge head h, required to take care of this large inflow of water, will cause the water level B to rise within much less than 32.8 feet of the surface, limiting the siphon head and dividing the total static head from A to the water surface of the pond in such a manner that the inflow head will just supply such a quantity of water as can be forced out of the bottom of the well by the remaining or discharge head. In any event the gain in capacity and rate of drainage which will result from siphonage will be very great; for example, with a pressure head D of 1 foot over the inlet, the discharge would be nearly doubled by the addition of 3 feet of effective siphonage and nearly trebled by the addition of 8 feet of effective siphonage.

Expressing the above relations mathematically,

$$Q=CA\sqrt{2g\left[H+(h-h_f)-K\frac{V^2}{2g}\right]}$$

Where Q=Discharge in cubic feet per second.
A=Area of cross section of pipe in square feet.
H=Depth of water above top of pipe.
h =Effective suction head.
h_f=Friction loss in pipe.
V=Mean velocity in pipe.
K=A coefficient, such that $K\frac{V^2}{2g}$ equals the combined entry head and head required to produce velocity. In general, V is unknown, and this factor being small, may be neglected.

The friction head h_f for various sizes of pipe, together with the entry and velocity head for various velocities, may be found in books on hydraulics.[a]

Velocity of flow.—The velocity of flow in the drainpipe may be measured by means of a simple Pitot tube of glass inserted vertically in the top of the pipe, the short end projecting upward and having its mouth near the outer end of the drainpipe and a few inches below the top of the pipe. If h is the height in inches to which the water rises in the long leg above the pond surface, then the velocity of downward flow in the pipe will be very nearly

$$V=\sqrt{\frac{64.32h}{12}}=2.32\sqrt{h}$$

The flow in cubic feet per second will be

$$Q=0.0055\ d^2\ V=\frac{d^2\sqrt{h}}{80}\text{ nearly,}$$

d being the inside diameter of the pipe in inches.

The quantity Q should be somewhat reduced by the use of a correction coefficient depending on the form of inlet to the pipe. With good siphonage this coefficient will be near unity.

The theory of flow from wells rests upon the assumption that the ground-water horizon is sensibly affected only within a certain mean radius of influence. There is no method of accurately determining

[a] Weston, Friction of Water in Pipes; Coffin, Graphical Solution of Hydraulic Problems, etc.

this radius in the case of a drain well, but as large variations in its value affect the result but little it may be assumed, and if the other necessary factors are known the discharge may be calculated.

WATKINS'S DRAIN WELL.

Without entering into details, the following example may be given to illustrate what takes place in a 3-inch drain well 170 feet deep, in which the water rises statically to within 25 feet of the top of the pipe and to within 27 feet of the pond surface, assuming that the outflow is into a sandstone stratum 100 feet deep, having a porosity of 15 per cent, and an effective mean-grain diameter of 0.15 millimeter. These conditions are practically those in Watkins's drain well, Parma Township. (See fig. 3.) From Turneaure and Russell's Water Supplies and Weston's Tables[a] it is found that the drain would carry down 165,000 gallons per day, or one-fourth cubic foot per second, and that the total available head of 27 feet would be utilized about as follows:

Utilization of head in Watkins's drain well.

	Feet.
Overcoming friction in pipe	6.0
Velocity head	.45
Entry head	.2
Head causing outflow at bottom of pipe	20.0
Total	26.65

A well drawing 1 cubic foot per second will lower a pond of 1 acre area about 2 feet per day, providing there is no inflow. It will lower a 2-acre pond 12 inches per day, and so on. The well in the above example should lower a pond of 2.5 acres area about $2\frac{1}{2}$ inches per day. If the pond were filled to an average depth of 2 feet at the end of March, the water should be drawn off and the subsoil sufficiently drained to permit tillage early in May. Early in 1905 the Watkins pond, which is fed by two lines of drain pipe, was well filled by the rains and melting snows, but was drained completely by the latter part of May. At the same time adjacent undrained wells remained nearly full.

SUMMARY.

Owing to low water at the time when visited, the writer had no opportunity to measure the actual rate at which any of the Jackson County drain wells take water. Such measurements would be of value in estimating the required size and probable efficiency of other wells.

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[a] Loc. cit.

In conclusion, the importance of a capacious percolation chamber at the bottom of the well, and of suitable screens to protect the inlet, may be emphasized. A screen over the mouth of the pipe should not be used, as it will reduce the inflow head, but an ample catch basin of brick or large tile surrounding the well is very desirable. This should have ample openings covered by screens—preferably by double screens. A suggestion for a suitable intake is shown in fig. 4.

Experience has shown that in any locality success by this mode of drainage can not be assured beforehand. In some cases failure has probably been due to improper methods.

The effect of this manner of drainage is to forcibly inject the waters of the pond into the ground-water bed. If the drainage waters are impure the pollution may be detectable in surrounding wells which penetrate the same water horizon.

STATISTICS OF DRAIN WELLS IN SOUTHERN MICHIGAN.

The following details regarding drainage and other wells in southern Michigan have been compiled chiefly from data furnished by Mr. Charles Winchester, well driller, of Jackson, Mich., and by Mr. Carl Horton. A number of artesian wells are included which have been drilled for drainage purposes, or in places adjacent to drain wells.

(1) Miran Clark, Jackson County, Mich.; 3-inch drilled well, total depth 75 feet. At this depth an artesian stratum was entered raising water 6 inches above the surface.

(2) Henry Sussex, near Jackson City, Jackson County, Mich.; 3-inch well drilled to 100 feet depth. At this depth an artesian basin was entered which raises water 7 feet above the ground surface.

(3) Truman Eggleston, near Parma, Jackson County, Mich.; 3-inch well drilled to 47 feet depth. Drains a pond 2 to 3 acres in extent. The reclaimed land is used for wheat growing.

(4) George Eggleston, near Parma, Jackson County, Mich.; 3-inch well drilled to 42 feet depth. At this depth an artesian basin was entered which raises water 6 inches above the ground surface, rendering the well useless for drainage purposes; further drilling is contemplated.

(5) Edward Burt, Jackson County, Mich.; two 3-inch wells, the first to a total depth of 32 feet, of which 19 feet are in rock; the second to a total depth of 46 feet, of which 22 feet are in rock. The two wells are 15 rods apart; the second affords a successful drain.

(6) Arthur Morrell, near Jackson City, Jackson County, Mich.; 3-inch well drilled to 147 feet depth. It yields an artesian stream rising 6 feet above the ground surface.

(7) Bullen Brothers, Parma County, Mich.; 3-inch well drilled to 34 feet depth. It yields an artesian flow raising water 12 to 18 inches above the ground surface. This is distant but a few miles from several successful drain wells. It is apparently an artesian well in stratified glacial drift.

(8) Charles I. Moe, Jackson County, Mich.; 3-inch well, at first drilled 116 feet without success. Afterwards it was drilled 32 feet farther, making the total depth 138 feet, and giving a successful drain, which reclaims about 10 acres.

(9) Fred Watkins, Parma Township, Jackson County, Mich.; 3-inch well, with a total depth of 170 feet, 48 feet at surface through sand and clay and 122 feet through apparently soft stratified rock. Water rises in well within 25 feet of the surface. The pond had an area of 2½ acres and seldom or never dried up. Soil muck, with clay underneath. Two lines of draintile 5 feet in depth have been used to drain the soil. Tributary area to pond, about 35 acres of tilled land.

(10) Ebb Burch, near Concord, Jackson County, Mich.; stated to have three successful drain wells.

(11) Frank Roe, near Bath Mills, Jackson County, Mich.; stated to have had 3-inch drain well in use for eighteen years, reclaiming a marsh; depth, probably 75 feet.

(12) V. R. Horton, Parma Township, Jackson County, Mich.; 4-inch well drilled 70 feet through stratified drift, followed by 143 feet in shales and sandstone; total depth, 213 feet, of which 75 feet was cased with 4-inch pipe. Well located in pond of 4 to 6 acres area, which became dry in some seasons. Shallow muck bottom covered with grass; drains about 60 acres steeply sloping tilled land. This well began to take water when about 170 feet deep. It drained very rapidly for a time, but gradually decreased in capacity, apparently as a result of caving or clogging of the pores in the discharge chamber. A measurement of the rate of flow by Pitot tube was made March 28, 1905, by Mr. Carl Horton. The well was then taking about 6 cubic feet per minute.

(13) W. H. Hartwell, Albion, Calhoun County, Mich.; 4-inch drilled well 37 feet depth, probably in glacial drift. Successfully drained pond of 1 acre area in a deep glacial depression 1 mile from Kalamazoo River and at a considerably greater elevation. Land area tributary to pond, perhaps 40 acres.

(14) ———, Ingham County, Mich.; 2 or 3 inch pipe; total depth, 138 feet—90 feet through sand and gravel, 48 feet in sandstone. Well afforded successful drain of surrounding marsh land, but has been closed to avoid possible pollution of ground water.

TWO UNUSUAL TYPES OF ARTESIAN FLOW.

By Myron L. Fuller.

INTRODUCTION.

As work on underground water progresses many variations and peculiarities in the conditions giving rise to flowing wells are brought to light. In another paper in the present report Dr. G. O. Smith has described certain flowing wells in crystalline rocks of Maine and New Hampshire and has explained the conditions governing their occurrence. It is the purpose to give in the present paper brief descriptions of two unusual types of flow.

In the first of the two types the flow takes place from essentially uniform sand, there being nothing which in any sense forms an impervious cover. In the second the flow is of rock water from the rock, although the confinement is not due to rock structure nor the head dependent upon the rock outcrop, but rather upon overlying deposits of drift.

FLOWS FROM UNCONFINED HORIZONTAL SANDY STRATA.

This peculiar type of artesian flow, which is sometimes encountered by engineers and others in their investigations of the water resources of regions of prevailingly sandy materials, apparently defies the commonly recognized requisites of artesian wells, presenting a problem of unusual interest and one which at first sight appears difficult of solution.

The essentials for artesian flows, as defined by Prof. T. C. Chamberlin in his treatise on artesian waters,[a] are a pervious bed lying between two impervious beds and having its outcrop at a height greater than that of the surface at the well—adequate rainfall, suitable outcrop, and absence of leakage being assumed.

The requisites as defined by Professor Chamberlin, the most essential features of which are the impervious confining beds and the inclination of the strata, have been almost universally accepted by writers on the subject, but recent investigations, some of the results of which

[a] Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 134–135.

are here represented, have shown that true artesian flows may take place where both of these conditions, supposedly indispensable to flows, are absent. In fact sands which are pervious throughout and which are horizontal will often, when penetrated, yield flowing wells. The principal governing such flows was, to a certain extent, recognized by Chamberlin, who states in the report cited (p. 138) that the water itself may act as a confining agent, but in his descriptions and illustrations two confining beds are always recognized, the water through its pressure acting simply as an adjunct to the upper confining layer in preventing leakage or increasing the head. The possibility of flows from uniform materials does not seem to be recognized.

EXAMPLES ON LONG ISLAND, NEW YORK.

In an investigation of the water resources of Long Island, New York, conducted by the Survey in cooperation with the commission on additional water supply for Greater New York, a study was made of the ground water near the base of certain high bluffs bordering the deep, narrow depressions constituting the bays of the north shore.

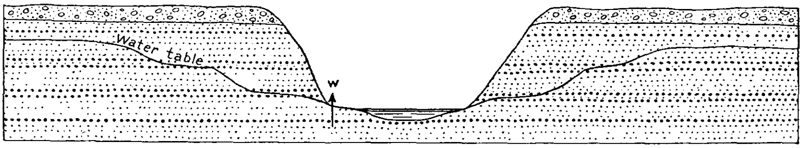


FIG. 5.—Diagrammatic east-west section across the bays on the north shore of Long Island, New York, showing horizontal stratification of beds, form of water table, and position of flowing wells.

The materials in which the bays are cut consist of gravels and sands, largely the latter, with no clays or other impervious materials. They are essentially horizontal and form an imperfect terrace about 200 feet above sea level, as shown in the accompanying profile (fig. 5).

The sands, even of the finer varieties, were invariably pervious, and the water table appeared to exhibit in the main the regular curve characteristic of uniform materials, although irregularities, due to varying coarseness, doubtless exist. Notwithstanding this, wells penetrating below the water table at points near the base of the bluffs (W, fig. 5) obtained flowing water. Mr. A. C. Veatch, who investigated the problem for the Survey, decided that the occurrence of flows depended upon slight differences in the degree of porosity of the sands, which, however, were in all cases pervious throughout. Beyond the determination that a slight difference in porosity was sufficient to determine an artesian horizon,[a] however, nothing definite was discovered as to the exact differences in texture necessary to give rise to flows. In a way the conditions are in harmony with a part of

[a] Science, n. s., vol. 19, 1904, pp. 795–796.

those outlined by Chamberlin, the finer materials, though entirely pervious, opposing the passage of water to a greater extent than the coarser material. Pressure, however, is readily communicated through the sand, even where there is much resistance to the movement of the water, and as the well pipe affords a less resistance to the upward passage of the latter as compared to that presented by the finer sands, flows take place.

EXAMPLES IN MICHIGAN.

Character of flows.—During the summer of 1904 an investigation of the waters of the Michigan drift was undertaken by the Geological Survey, during which 300 or more flowing-well areas deriving their supplies from the glacial drift were studied. One of the most interesting features brought out was the occurrence, as on Long Island, of flows from wells sunk wholly in sand. The topographic conditions are similar to those in the locality previously described, the wells being located on broad valley deposits, or terraces or plains of sand, above which rise higher moraines or other glacial deposits. The wells are almost invariably located at the base of the slopes of the latter, where they merge into the lower plains, etc. Commonly they meet with more or less clay, but numerous cases were reported where only sand was encountered. It is the flows from the latter which are of special interest.

In many instances it is probable that, as on Long Island, more or less marked differences in texture exist in the sands of the wells, giving rise to the flows, but in other cases it was established that flows could be obtained where the sand was of so uniform a texture as to present no recognizable difference in the size of the grains. It was further found that such occurrences were not isolated, but of widespread distribution, the flows apparently resulting from some cause other than difference in texture, and depending on a seldom recognized but widely prevalent type of artesian conditions.

Cause of flows.—The cause of these flows is probably to be found in the arrangement and shape of grains. All the materials from which the flows of the nature described are obtained are stratified; in other words, were deposited as layers, which, though composed of material of uniform grain, were nevertheless laid down successively one over another as horizontal laminæ. It is characteristic of this process to develop conditions more favorable to the transmission of water along the laminæ than across them, this being due in part simply to the lamellar arrangement.[a] There is, however, another factor present—

[a] This overlapping of grains has been described by W. O. Crosby in his discussions of "hard packed" sand in glacial deposits at Clinton, Mass. (Techn. Quart., vol. 17, 1904, pp. 61–62 and 67–70). Although such sand is so deposited or "packed" that it strongly resists the advance of the drill it nevertheless absorbs large quantities of water.

namely, the irregularity of the shape of grains—which has probably considerable influence in regulating the flow of water through the sand. In sediments, such as gravel and sand, the particles, no matter how uniform their size, are not symmetrical in shape. One axis is almost sure to be longer than the other (fig. 6), and when deposition takes place there is a strong tendency of the grains to arrange themselves with the longer axis horizontal and with the grains overlapping each other to a greater or less extent, like the shingles of a house, though, of course, far less perfectly (fig. 7). Under such conditions it is clear that, although the material is perfectly pervious and may hold large amounts of water, the passage of water across the stratification will be difficult, at least as compared with its passage along the lines of bedding. When a well enters such material it affords an easy upward path for the water, as compared with the passage through stratified material of the character described, and a flow will often result.

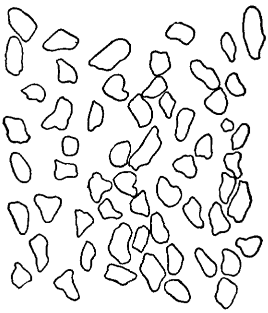


FIG. 6.—Shape of grains of a coarse sand; natural size. Drawn from photograph. (After King.)

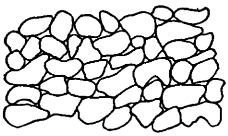


FIG. 7.—Overlapping sand grains, selected from those shown in fig. 6, and from other similar materials, when arranged with larger axes approximately parallel with one another; normal size.

Importance of principle.—The bearing of this particular type of flow on the water-supply problems of individuals or of small towns in the deeply gravel- or sand-covered regions of Michigan, Wisconsin, and other of the Northern States is important. It is no longer to be assumed that impervious confining beds are necessary to the flows which are so highly prized in many regions, but if the topographic conditions are such as to give the necessary head, flows may even be obtained in uniform sands. In the States mentioned it is rare that a well located at the base of any high elevation of sand or gravel or clayey materials fails to obtain flowing water (the exceptions being generally those wells penetrating nothing but clays), and pure ground-water supplies are awaiting development in hundreds of small villages in these regions. Most wells obtain flows at a depth of 100 feet or less, while wells over 200 feet deep are relatively rare. The flows are commonly confined to a strip along the base of the bluffs or slopes about one-fourth or one-half mile in width, but occasionally artesian wells are found at considerably greater distances from the highlands.

PECULIAR ROCK FLOWS.

In one of the regions in southeastern Michigan visited by the writer in 1904 there were several flowing-well areas in which waters partaking of the character of rock waters rose under artesian pressure from the fissured surficial portion of the rock just beneath the surface clays.

The locality visited is in southern Wayne and northern Monroe counties and lies along the lower course of Huron River. The region is characteristically flat, the surface materials consisting in general of stiff, sometimes pebbly clays, covering to a thickness of from 20 to 60 feet a slightly irregular rock surface mainly of limestone or sandstone. The general conditions are shown in fig. 8.

From the figure it will be seen that the rocks, though dipping west at a rate of about 25 feet per mile, have been so eroded that their

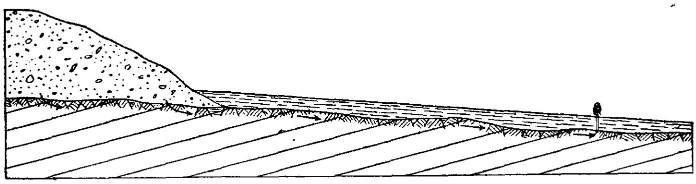


FIG. 8.—Type of artesian conditions in southeastern Michigan.

surface slopes not to the west, but to the east. The westward dip of the rock layers continues halfway across the State, after which the beds rise again, but they do not reach the surface anywhere in Michigan. Considering the general impervious character of the rocks, the remoteness of their western outcrop, and the fact that the elevation of the latter is nowhere sufficient to give the observed head at a point so far away, it is certain that the water can not come up the dip from remote sources. On the contrary, a careful study of the wells showed that the water simply occupied the fissured upper portion of the rock and moved eastward entirely independently of the character of the rocks or their dip. Following the wells westward, it was found that the source of the water was in the drift hills resting on the rock a few miles to the westward, against which the clays, serving as an impervious cap to the rock, terminate at a level higher than that of the flowing wells.

The fissures in the rock appear to be largely of the nature of joint and similar cracks, and were probably opened under the influence of the weather when the rock was exposed at the surface before its burial by the drift. Solution crevices dissolved in the limestone by the percolating waters also form a part of the fissure system. In general the crevices are most numerous near the surface, the water being commonly found within a few feet of the top. It is probable, however, that some of the fissures reach considerable depths and will yield water to deep wells. The water in its passage through the rock dissolves from it more or less mineral matter, so that when it issues once more from the wells it possesses the characteristics of a rock water. In certain of the limestone areas it is high in sulphur, while at other points it is low in sulphur, but high in iron, etc.

Summarizing, it may be said that the district presents the anomalous condition of furnishing flowing rock waters, which, nevertheless, are not originally derived from the rock, but from the drift, are confined by drift, and depend upon the drift rather than the rock for their head. In fact, in all essentials they are drift waters, the rock simply serving as a carrier in place of the layer of stratified sand or gravel commonly present.

The conditions described are duplicated at a considerable number of points in southeastern Michigan, and the same explanation of the flows may apply to other artesian districts in the clayey flat lands bordering the lakes in Michigan and adjacent States. The part played by the surface clay as a retaining layer of rock waters suggests a possible explanation of the confinement in crystalline or jointed rocks that results in artesian flows.

CONSTRUCTION OF SO-CALLED FOUNTAIN AND GEYSER SPRINGS.

By Myron L. Fuller.

IMPROVEMENT OF SPRINGS.

Where springs issue in transparent pools or as streams of clear water from the rock little can be added to their attractiveness by artificial means. In many places, however, the water of the springs seeps out slowly through the soil, the place of emergence being marked simply by a wet, grassy, or boggy spot. In such cases the springs may often be transformed by the construction of artistic basins, rocky arbors, rustic spring houses, and other similar means. One of the most useful methods of treatment is the construction of a so-called " fountain spring," while the most interesting in many ways, and the most puzzling to many, is the " geyser spring." Both are of simple construction and inexpensive, and the results under favorable conditions are quite striking.

CLASSES OF SPRINGS.

In the present discussion springs are, for convenience, grouped into two classes: (1) Hillside springs and (2) springs on flat or level lands. In either the water may or may not be under pressure or head. In those cases where there is no head the water can not be made to rise naturally above its point of emergence, but when under pressure it will, if confined, rise to a greater or less height above the point at which it issues.

Fig. 9 represents a hillside spring unconfined and without head, while fig. 10 shows a similar spring fed from waters confined between two impervious layers and under more or less pressure; only in the latter case will the water rise if confined. From either, however, a fountain or a geyser spring can be constructed if sufficient fall can be had close at hand.

Springs occurring on level land can also be classified according to the amount of head which their waters possess, which will vary in amount from just sufficient to bring the water to the surface to enough to make it boil strongly from the ground.

To test the amount of head of the water of a spring it is necessary to confine the flow. When this is low it can often be determined by inserting a bottomless barrel about the spring. If the water rises to a height considerably above the surface of the ground, and especially if the half-sunk barrel fills and overflows, it may be presumed that the water would under more favorable conditions rise still higher, and possibly the spring could be made into a "fountain spring."

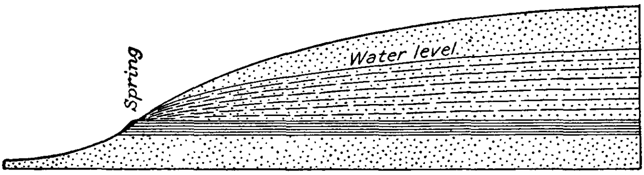


FIG. 9.—Hillside spring from unconfined water bed without head.

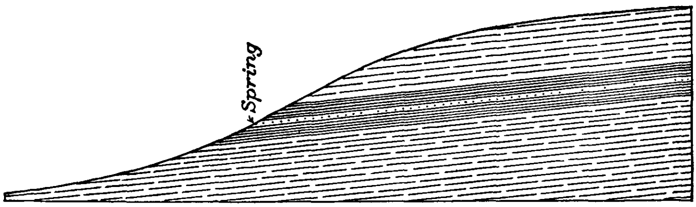


FIG. 10.—Hillside spring from confined water bed under more or less head.

CONSTRUCTION OF FOUNTAIN SPRINGS.

Definition.—The term "fountain spring" is here used to designate a spring the water of which is made to rise through a pipe to a point above the surface of the ground at the spring. It may flow gently from a pipe into a trough by the roadside or in the barnyard, into the sink in the kitchen, or it may, if the head is considerable, be made to throw a jet into the air as in an ornamental fountain.

Construction.—The aim in the construction of "fountain springs" is to confine the water and force it to rise, instead of flowing out uselessly upon the ground as in the undeveloped spring. To do this a circular excavation about 3 feet in diameter should be made about the spring, the earth being removed to a depth of 3 to 5 feet, or until a layer of clay or clayey sand is encountered. The excavation when completed should have the outline indicated by $e\ e^1\ e^2\ e^3$ in fig. 11.

A bottomless barrel (b b^1 b^2 b^3) may then be inserted and an upright pipe placed in the center with its bottom nearly level with the lower edge of the barrel. Around the pipe inside the barrel are packed rounded stones (G) 3 or 4 inches in diameter at the bottom, but gradually decreasing in size until a height of 2 feet is reached. About 6 inches of sand (S) should then be inserted, covered with an equal thickness of clay, or of as clayey sand or loam as can be found (C). This should somewhat more than fill the remainder of the barrel, and should be worked in around the edges on the outside until all avenue of escape of the water, except through the projecting pipe is cut off. The ground should then be leveled over and thoroughly tamped down. An auger hole bored through the clay at the point where the water rises (Sp) will sometimes improve the flow. In more elaborate constructions cement can be used to advantage in place of clay.

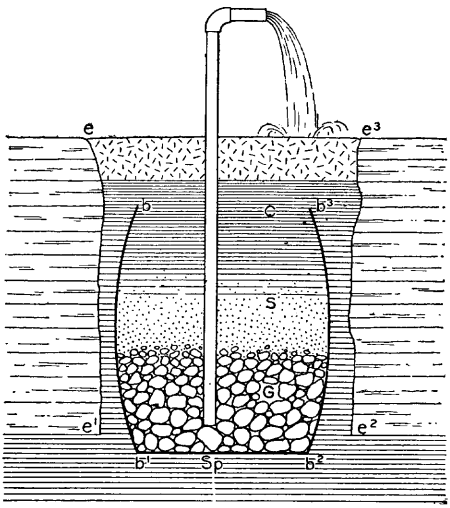


FIG. 11.—Diagram showing method of constructing a "fountain spring." Sp, point of emergence of spring; G, gravel; S, sand; C, clay; b b^1 b^2 b^3, sunken barrel; c c^1 c^2 c^3, outline of original excavation.

The result of this treatment is that the water of the spring, deprived of its ordinary outlet, is forced to rise through the pipe. The height to which it will rise and the force with which it will flow depends upon its head, which is in turn dependent upon the elevation of its source. There are many instances where the water is raised into roadside troughs, and its possibilities in connection with farm and household supplies are considerable. A few owners of important springs, as at the Nochemo Springs, Reed City, Mich., have by this or similar processes succeeded in obtaining streams which throw jets several feet into the air, making fountains of considerable beauty.

Unfortunately, not all springs can be converted into "fountain springs," but testing by means of the treatment outlined above is inexpensive and requires but a few hours of labor to complete. Something of the height to which the water will rise may sometimes be judged from the force with which it boils up in the bottom of the pools so frequently associated with the springs.

CONSTRUCTION OF GEYSER SPRINGS.

Definition.—By a geyser spring is meant one so piped that it will throw, at fixed intervals, a jet of water to a greater or less height into the air, after which the flow subsides and ceases until the lapse of another interval of time, when it again flows.

Necessary conditions.—To successfully construct a geyser spring it is necessary to find a spring at some elevation above the point at which the flow is desired and but a short distance away. A spring on a steep hillside, not more than 100 feet away from the desired point

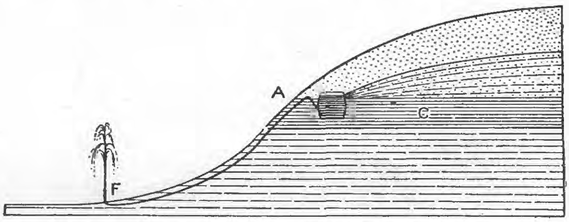


FIG. 12.—Diagram showing method of construction of "geyser spring." *A*, Normal point of emergence of springs; *C*, impervious stratum; *F*, geyser spring.

of flow and 15 to 20 feet higher, presents the most favorable condition. It does not matter in this instance whether or not the water is under pressure.

Construction.—The spring will nearly always emerge just above an impervious layer as at A in fig. 12. A little back from this point a small pit several feet deep should be dug and a barrel inserted with its upper edge about 6 inches above the top of the impervious layer. Holes should be bored in the sides to admit the water just above the clay, this part of the barrel being surrounded by fine gravel to keep the holes from clogging and to prevent clay and sand from entering. The barrel may be covered and the earth tamped down if desired. A pipe should finally be connected with the bottom of the barrel by a tight joint, and should lead upward sharply until about 6 inches below the top of the clay or a foot below the top of the barrel, when it should be bent gradually and carried downward below the surface at a depth just sufficient to prevent freezing, to the fountain, when it should be bent again into a vertical position and brought to the surface. The pipe is in fact a simple siphon.

Operation.—The water gradually accumulates in the barrel until it reaches a height equal to that of the upper bend of the siphon, at which moment a flow is inaugurated, issuing at the fountain at F. The flow will continue until the water is exhausted from the barrel, when it will stop, only to commence again when the level of the top of the siphon is again reached. One precaution, however, is to be observed in regard to the working of the siphon, namely, the capacity of the pipe should be greater than the capacity of the spring, otherwise the flow once inaugurated will be continuous.

The height to which the water will be thrown depends primarily upon the altitude of the spring above the fountain—the higher the spring the higher the jet. A decrease in the size of the jet will also within certain limits increase the height to which it will rise.

A CONVENIENT GAGE FOR DETERMINING LOW ARTESIAN HEADS.

By Myron L. Fuller.

One of the most important items in the investigation of artesian wells is the head, or height, to which the water will rise. Although the volume and velocity of discharge afford general indications of the head, other factors, especially the size of the pores of the rock through which the water passes, have an important modifying action upon the flow. The head which in a porous material will give a large discharge under considerable velocity may give only a small drizzle in a very fine-grained material, owing to the resistance of the latter to the passage of water. In most cases the exact character of the water-bearing horizon is not known, and even where known the flow may be dependent, not on the nature of the material in the immediate vicinity of the well, but on the average character of the material which the water has penetrated in its passage from its source to the point of emergence. This is known even more rarely than the character of the water bed at the well.

It being, therefore, commonly impossible to calculate the head from the volume or velocity of flow, it becomes necessary to apply some form of pressure gage to the well. This has often been done in the case of wells of high head in the more important artesian districts, but, because of the cumbersome character of ordinary gages and the difficulty of connecting them with the wells, they have been rarely used on small wells of low head, such as those which occur at many points in the drift-covered areas throughout Michigan, Wisconsin, and Minnesota.

The ordinary steam gage is about 5 inches in diameter and several inches thick, and its use has commonly necessitated considerable plumbing work in piping it on to the well. For some time the writer has sought for a gage of small size, capable of being quickly applied, and has at last found one of low price which will measure heads up to 50 pounds, or about 100 feet, can be carried in the vest pocket, and can be applied to ordinary pipes and read in a second's time. It is described in the following paragraphs.

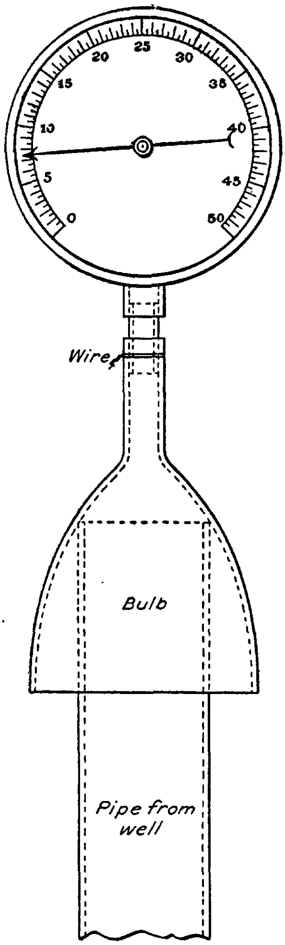


FIG. 13.—Convenient form of pressure gage and its application.

The gage adopted for the measurement of low pressures is 2 inches in diameter and 1 inch in thickness. The type commonly used is nickel plated, though it can be obtained plain, and the face is protected by a thick beveled crystal. The dial is graduated in pounds and reads up to 50, each fifth pound being marked by figures (fig. 13).

Into the stem of the gage a small three-eighths inch metal tube, about an inch in length, is screwed, over which is stretched and wired a rubber tube which opens out into a broad flange 2 inches or more in diameter (fig. 13). This peculiar tube, though appearing at first sight of a character difficult to obtain, may nevertheless be secured at any drug store, and is made by simply cutting through the middle of the bulb of a large-sized syringe.

In the case of small wells, such as those for which the apparatus was devised, the diameter of the pipe from which the flow issues is commonly from one-half to 1 inch, and will rarely exceed 2 inches. In applying the apparatus take the gage in the right hand and at the same time slip the open half of the rubber bulb over the end of the pipe, holding it firmly so that no leakage takes place. With discharge pipes up to 1 inch in diameter and with heads within the limits of the gage this can be done without difficulty, and the pressure read immediately from the dial. With 2-inch pipes the gage can not be used satisfactorily for pressures much greater than 25 pounds per square inch.

WATER RESOURCES OF THE CATATONK AREA, NEW YORK.

By E. M. Kindle.

LOCATION.

The area here considered lies to the southeast of the Finger Lakes region of New York and has for its southern boundary the New York-Pennsylvania State line. It is about midway between the east and west boundaries of the State. Four 15-minute quadrangles, known as the "Dryden," "Harford," "Owego," and "Apalachin," comprise the area. The city of Ithaca lies near the northwest corner of this area, but only partly within it. Binghamton lies near the southeast corner, but just outside the area.

TOPOGRAPHY AND GEOLOGY.

The region is one of strong topographic relief, the hills reaching a maximum elevation of 2,000 feet, with an average elevation of, perhaps, 1,500 feet. The drainage is principally to the Susquehanna River, which crosses the southern part of the area from east to west. The drainage of the northwestern part of the area, including most of the northern half of the Dryden quadrangle, discharges into Lake Cayuga. All of the principal valleys lie between the 800- and 1,200-foot contours except Cayuga Valley, which just enters the region on the northwest and has an elevation of between 380 and 400 feet at Ithaca. Shales and sandstones of upper Devonian age comprise the surface rocks of these quadrangles. The rocks lie approximately horizontal, with a general but small southerly inclination, interrupted over a part of the area by very low folds with east-west trend. Glacial deposits of clay, sand, and gravel cover the whole of the region.

WATER RESOURCES.

WELLS.

The sandstones and shales which constitute the consolidated rocks of the region are comparatively impervious to water, and relatively few wells or springs derive their supply from them. The glacial till, with its interbedded sands and gravels, acts throughout the whole region as a reservoir, from which wells from 10 to 40 feet deep usually obtain a satisfactory supply of water for domestic pusposes. Springs are common on the hill slopes and supply flowing water to a large number of farms.

The wider and deeper valleys of the region have very generally been deeply filled by drift. The complicated structure of this filling, which frequently includes alternating beds of clay, gravel, and sand, affords in some localities artesian-water conditions. It probably includes in all cases sand or gravel beds between more or less impervious beds of clay. These coarse beds are doubtless connected by more or less continuous deposits of water-bearing materials reaching diagonally across or rising between the impervious beds and connecting with the alluvial fans in front of the mouths of streams descending to the valleys from the hills. A continuous waterway is thus formed from the gravel fans, which absorbs all of the water at the mouths of many small streams, except in times of flood, to the buried sheets of sand and gravel.

Ithaca wells.—The most important of these artesian-water areas is that of the Ithaca delta at Ithaca, which is partly in the Dryden and partly in the Ithaca quadrangle. Well records show the maximum thickness of the drift filling here to be 400 feet. A large number of wells at Ithaca have secured artesian water at depths of from 70 to 100 feet. The wells which afford large flows, however, all go deeper than this.

More than a dozen wells, a majority of which have been successful, have been sunk just south of the city of Ithaca for the purpose of securing artesian water for the city, which it is purposed to supply entirely from this source. The first of the series was estimated to yield a daily flow of about 300,000 gallons. The records of these wells[a] show, first, a bed of fine-grained massive clay 40 to 60 feet thick. Coarse water-bearing beds of sand and gravel follow the clay to a depth of 60 to 120 feet. These are underlain by a second clay series extending to a depth of from 200 to 280 feet. Below these in every well are found coarse-textured beds, including some sand and gravel. These are the principal water-bearing beds and vary in texture from coarse gravels to fine "quicksand," which last is sometimes forced by the water under pressure into the pipes in sufficient quantity to stop the flow. The largest flow is obtained from the coarse gravels.

According to Professor Tarr, the origin of the artesian water at Ithaca is, in the case of the upper water-bearing horizon, "the alluvial fans opposite the mouths of the streams that descend to the Ithaca delta."[b] The water found in the deeper sands and gravel is

[a] Jour. Geol., vol. 12, 1904, pp. 69–82.

[b] Id., p. 81.

believed to originate in "the moraine which occupies the Cayuga Valley from the divide nearly to the well sites, a distance of over 11 miles."[a]

Slaterville Springs wells.—A number of flowing wells are located in the broad valley of Sixmile Creek, in the vicinity of Slaterville Springs. These usually reach the artesian-water horizon in a bed of sand or gravel at from 44 to 74 feet below the surface. The flow is small, usually not exceeding 5 gallons per minute. Much of the water is mildly chalybeate in character and carries small quantities of calcium carbonate, magnesium, sodium, and potassium. It is considered to have medicinal value, and the village has become a popular summer resort on account of it. A successful attempt was made at the creamery to secure water free from the mineral properties characterizing many of the wells. Two wells, respectively 110 feet and 76 feet deep, secured flowing water in sand free from mineral constituents.

Other artesian wells.—Other localities at which flowing wells occur in this region are as follows: One mile west of Brookton on the land of D. C. Hanford, at Newark Valley on the property of Jabez Smith, and just north of Tioga Center.

MINERAL SPRINGS.

Several springs whose waters contain sulphur or other minerals occur within this region. The following list includes those which have been visited by the writer, but is probably incomplete:

Dryden.—West of Dryden one-half mile a chalybeate and a sulphur spring are located within a few feet of each other. A summer hotel has been located near the springs for many years. The sulphur spring has a strong sulphurous taste and is favorably known for its medicinal properties.

Speedsville.—A sulphur spring is located about 1 mile northeast of Speedsville on the east side of Owego Creek Valley. The water is used for stock.

Nanticoke.—Nanticoke spring is located 1 mile south of the village of Nanticoke in a small valley running northwest from Nanticoke Creek. The spring apparently rises through the drift, but the proximity of bed rock is shown by an outcrop of sandstone and shale a few yards away. The water tastes rather strongly of sulphur and coats the sides of the spring with a white deposit of that substance. The water is used for domestic purposes.

Spencer.—Two springs known as Spencer Springs are located in a small valley 3 miles northeast of Spencer. They occur in a seepage

[a] Jour. Geol., vol. 12, 1904, p. 82.

area of 60 or 70 square yards in the bottom of the valley. Three separate springs have been developed and inclosed in this seepage zone, two of which furnish strong sulphur water, which coats the channel leading from them with white sulphur; the third has a very mild mineral taste, with little or no sulphur. The place was formerly the site of a summer hotel, which was burned a few years ago.

Halsey Valley.—A sulphur spring is located 3 miles southeast of Halsey Valley on the west fork of Pipe Creek, issuing from the slope of a steep hill about 100 feet above the valley. There is a considerable flow of water, which is used for stock. This is the only mineral spring in the region that is located considerably above the bottom of the valley in which it is found.

Glen Cairn.—South of Glen Cairn 1¼ miles and about 4½ miles northeast of Waverly a sulphur spring occurs in a small branch of Ellis Creek Valley. The spring is located very near an outcrop of bed rock, from which it is probably derived. The flow is larger than that of most of the mineral springs, and contains considerable sulphur, which coats the sides of the spring. It is used for stock and domestic purposes.

Owego Creek.—Three miles south of the mouth of Owego Creek and near the head of Smith Creek there is a sulphur spring, which has a mildly sulphurous taste. The small flow is used for stock.

Source of the springs.—None of the mineral springs afford a large volume of water, the flow probably in no case exceeding 5 gallons per minute. All reach the surface through glacial deposits, but it appears probable that the sulphur springs derive their waters from the consolidated rock below the drift, possibly the Genesee. This opinion is based upon the following considerations: (1) Sulphur waters are derived from the decomposition of mineral sulphides, very frequently from pyrites; (2) there is a comparatively small amount of such minerals in the drift and a relative abundance of them in the Genesee and other upper Devonian rocks; (3) the Genesee and Portage are cut by well-developed systems of joints, which permit surface waters to penetrate and traverse them; (4) the general southerly inclination of the bed rock would cause waters traversing them to rise to the surface when the joint conditions were favorable; (5) just north of this region strong sulphur springs escape from the joints in the Genesee at points where the formation is exposed in post-Glacial gorges.

STREAMS.

The streams of this region derive their waters throughout the greater part of the year principally from seepage and from the springs in the assorted glacial material and till. A fairly uniform supply is maintained, therefore, during the months of least rainfall, of water of excellent quality and purity when protected from barnyard contamination.

The streams furnish the principal source of water supply for the villages and cities within the area. The water supply for the Cornell University campus is derived from Fall Creek. The city of Ithaca derives the greater part of its water supply from Sixmile Creek.

A number of streams with moderate gradient have been utilized to furnish water power for sawmills and gristmills. Water power is thus used at Brookton, Marathon, Newark Valley, Owego, Candor, and other points. Streams possessing both a very high gradient and a considerable volume of water are confined to the northwest corner of the region and are two in number—Cascadilla and Fall creeks. Both streams have a fall of about 400 feet in 1 mile at Ithaca, but the latter is the larger and more important stream. It supplies power for three or four mills and factories and for the Sibley shops and hydraulic laboratory of Cornell University.

WATER RESOURCES OF THE PAWPAW AND HANCOCK QUADRANGLES, WEST VIRGINIA, MARYLAND, AND PENNSYLVANIA.

By George W. Stose and George C. Martin.

GENERAL CONDITIONS.

Potomac River divides the Pawpaw and Hancock quadrangles into two almost equal parts, the portion north of the river lying in Maryland and Pennsylvania and that south of it in West Virginia. The river here is about a quarter of a mile wide, and in most places is too deep to be forded. The only wagon bridge within the area is at Hancock, Md., and the only existing railroad bridges at Cherry Run, but the Western Maryland Railroad is now constructing four bridges for its new extension to Cumberland in the vicinity of Pawpaw. The only ferry within the area is at Cherry Run. At Great Cacapon, W. Va., the river is dammed to a height of about 15 feet to furnish water for a feeder to the Chesapeake and Ohio Canal on the Maryland side. A gristmill at Great Cacapon formerly obtained power from the same source. Pollution of the river is not excessive in this area, as there are few large towns or factories along the banks.

TOPOGRAPHY.

The area is essentially a hilly region, crossed by prominent ridges and mountains having a northeast trend, which are part of the Appalachian Valley system. The maximum elevation attained is 2,260 feet, in Cacapon Mountain. Sideling Hill, Town Hill, Sleepy Creek Mountain, and Third Hill Mountain are other prominent ridges, from 1,700 to 2,000 feet in altitude. The intervening areas are of a plateau character, deeply dissected by numerous streams. The valleys are narrow and steep and in general have a northeast-southwest course. The remnants of the plateau, the surface of which ranges in elevation from 700 to 1,000 feet, form narrow, flat-topped ridges, parallel to the longitudinal streams.

GEOLOGY.

The rocks are all sedimentary, and range in age from Ordovician to Carboniferous. They are closely folded in a northwest-southeast direction, and the truncated, steeply inclined beds, trending northeast and southwest, cross the entire quadrangle and control the development of mountains and valleys in this direction. Cacapon Mountain is composed of Silurian (Medina) quartzite, brought up by a bold anticline, while Sideling Hill, Town Hill, Sleepy Creek Mountain, and Third Hill Mountain are composed of Carboniferous sandstones infolded in synclines. The minor ridges are mostly monoclinal, composed of thinner siliceous formations in the Silurian and Devonian shales and limestones, on the upturned edges of which the plateau has been carved.

WATER RESOURCES.

STREAMS.

The chief tributary streams are Great Cacapon River, Little Cacapon River, Sleepy Creek, and Back Creek, on the West Virginia side of the Potomac, and Licking, Tonoloway, Sideling Hill, and Fifteenmile creeks on the Maryland-Pennsylvania side. These streams have a large flow of water, and the fords are deep, even at low stage. The water is clear and in general unpolluted. Many of the smaller streams also have a considerable flow of clear water suitable for water supply or for power. The water power of these streams is undeveloped, with the exception of that utilized by a few gristmills. An electric power and light plant of considerable magnitude, however, is at present under construction near the mouth of Great Cacapon River. Although deeply incised in the topography, this river has, in places, a very sinuous course, and 1½ miles southeast of the town of Great Cacapon makes an unusually long detour of 1¾ miles, whereas the direct distance across the neck is less than one-fourth mile. A rock tunnel 14 feet wide, 10 feet high, and 234 feet long has been cut through this neck, and a dam 15 feet high and 12 feet base has been built at the entrance. A fall of 18 feet is thus obtained, and it is estimated by the company that there is sufficient water, even at low stage, to furnish 750 horsepower. A direct-acting turbine of 600-kilowatt capacity is being installed. Wires have been strung to the towns of Great Cacapon and Berkeley Springs, which are to be lighted by electricity, and in time power and light will be furnished to all surrounding villages as far as Hancock. The plant is to be in operation early in 1905. The power thus made available at small cost will no doubt attract new industries to this sparsely settled portion of West Virginia.

SPRINGS.

MISCELLANEOUS SPRINGS.

Small springs are frequent where sandy strata or limestone are exposed, but large springs are not common in this area. One spring worthy of note is at Ziler Ford, W. Va., near the southern end of the Pawpaw quadrangle. A stream of such size issues from beneath a ledge of upturned limestone that it was formerly used to run a gristmill. It is now abandoned, however, and the mill has fallen into decay. Another important spring is at Indian Springs, Md., in the eastern part of the Hancock quadrangle, where a small but attractive hotel entertains many summer guests.

BERKELEY SPRINGS.

The most noted springs in the region are at Berkeley Springs, W. Va., formerly called Bath, in the western part of the Hancock quadrangle. They issue from the foot of a monoclinal ridge of steeply inclined sandstone (Oriskany), at the contact with overlying impervious shale (Marcellus).

History.—These springs have been resorted to for their health-giving properties for many years, and the names of Washington, Fairfax, and others dating back into the eighteenth century are closely associated with them. The road leading from Washington to the springs is known throughout this part of the country as the Warm Spring or Sir John Road. The following is an extract from Burke's Virginia Mineral Springs, 1853:

These springs were the first known, as, assuredly, they are among the most important of the mineral waters of Virginia. They were frequented before the Revolution and visited by Washington and other distinguished personages, who had cottages erected for their own accommodation. The property of these springs was originally vested in Thomas Lord Fairfax, who made a grant of a few acres of land and the water privileges to the State, reserving to his own use one spring, still known as "Lord Fairfax's Spring," and thereon obtained a charter for laying off 50 acres as the site of a town, which was accordingly laid off and partially built upon. The State grounds and water privileges were vested in a body of trustees, whose successors continue to govern and control them.

The setting aside of this park as a State reservation is described by J. J. Moorman[a] as follows:

The importance of this property was appreciated by the country at a very early period, for in October, 1776, in the first year of the Commonwealth, we find the following in the statute book of Virginia:

"Whereas it hath been represented to the general assembly that the laying off

[a] The Virginia Springs, 1859.

of 50 acres of land in lots and streets for a town at the Warm Springs, in the county of Berkeley, will be of great utility, by encouraging the purchasers thereof to build convenient houses for accommodating numbers of infirm persons who frequent those springs yearly for the recovery of their health:

"Be it therefore enacted by the general assembly of the Commonwealth of Virginia that 50 acres of land adjoining the said springs, being part of a larger tract of land, the property of the Right Hon. Thomas Lord Fairfax, or other person or persons holding the same by a grant or conveyance from him, be, and the same is hereby, invested in Bryan Fairfax, Thomas Bryan Mastin, Warner Washington, Rev. Charles M. Thurston, Robert Rutherford, Thomas Rutherford, Alexander White, Philip Pendleton, Samuel Washington, William Ellzey, Van Swearengen, Thomas Hite, James Edmunson, James Nourse, gentlemen trustees, to be by them, or any seven of them, laid out in lots of one-quarter of an acre each, with convenient streets, which shall be, and the same are hereby, established a town by the name of Bath," etc. (Hening's Statutes at Large.)

The town was consequently laid off into lots in August, 1777. Among the purchasers were Charles Carroll of Carrollton, Horatio Gates, Gen. George Washington, and many others of note and distinction.

Berkeley Springs is now a fashionable watering place, and many of the best families in the East have handsome summer residences there. A beautiful park of several acres surrounds the springs, in which are located the bath houses and offices of the company controlling the property. Formerly a spacious hotel faced this plaza, but it was burned down, and another has had a similar fate, so there remains but one hotel, too small to accommodate the health and rest seekers during the summer season. Another large hotel adjoining the park is much needed to restore this resort to the place it formerly held as one of the leading watering places in the East.

Character of Berkeley Springs.—The Warm Spring ridge is composed of white porous sandstone, which crops conspicuously on its eastern face, dipping down the slope at about 50°. The black shale overlying the sandstone is exposed on the flanks of the ridge at many places. At the springs, however, the steep sandstone slope descends to the valley bottom so that the shale does not appear. The principal springs are four in number, but in reality the water seeps out continuously over a space of 100 yards. These four springs have been inclosed by stone walls, within which the sparkling water bubbles up through the white sand and gravel at the bottom. From these inclosures the water is piped into the bath houses. There are two large swimming pools, through which the water flows constantly at its natural temperature, and although these pools are 4½ feet deep, the remarkable purity of the water makes them appear very shallow. A newcomer always hesitates to dive into the pool for fear of striking the cement bottom. There are also a large number of tubs and small pool baths 3 feet by 6 feet in cross section and 4 to 5 feet deep, where the water is heated to any desired temperature by the injection of steam.

An analysis of the water, made for the company by J. H. Dickson, chemist, Pittsburg, Pa., and published in an advertising leaflet, is as follows:

Analysis of water at Berkeley Springs, W. Va.

	Grains per gallon.
Iron	0.506
Carbonate of lime	9.577
Carbonate of magnesia	1.951
Sulphate of lime	1.098
Chloride of sodium	.244
Silicic acid	.122
Total residue	13.498

Since the United States gallon contains 58,372 grains, the percentage of mineral matter in the water is small. The gas occurring in the spring water has been determined by W. B. Rogers[a] to be chiefly nitrogen, with a small amount of oxygen and carbonic acid. The water is regarded as beneficial, both as a beverage and for bathing, being especially recommended for rheumatism and gout. Its temperature of 73° F. makes it very comfortable for summer bathing, although in the swimming pools it loses some of its heat by radiation. On account of its temperature it is somewhat insipid as a beverage when taken direct from the spring, and some prefer to let it cool or use ice; but one soon becomes accustomed to drinking it and relishes it for its purity and sparkle. The mineral contents are not sufficient to give it a taste, and unless taken in large quantities it can hardly be classed as a mineral water. Some patients drink as many as thirty glasses a day.

Flow of Berkeley Springs.—It is difficult to determine the amount of flow from the springs, since the water is diverted to many channels, some being supplied direct to an electric-light plant and some piped into the town. A rough estimate was obtained by measuring the stream which flows away from the springs and calculating what is otherwise consumed. The flow for the combined springs as thus determined is 1,560 gallons per minute. In William Burke's report, referred to above, the flow is stated to be between 1,000 and 1,500 gallons per minute. This copious supply of crystal pure water is largely unconsumed and, except in the process of washing glass sand in the factories below the town, is unused, whereas millions of gallons could be bottled for domestic purposes and shipped to eastern cities at small cost.

Origin of Berkeley Springs.—The springs undoubtedly come from the sandstone forming the Warm Spring ridge. This is an unusually pure sandstone, quarried for glass sand at many points; yet it prob-

[a] Geology of the Virginias, p. 582.

ably furnishes the small quantity of minerals, chiefly carbonates of lime and magnesia, contained in the water. Since there is no indication of the volcanic or chemical origin of the heat, it is assumed that the waters have risen from a considerable depth, where the internal heat of the earth is sufficient to produce the temperature. At the rate of increase of 1° for each 50 or 60 feet of depth within the earth, which is the generally accepted average determined from deep mines and bore holes, the depth necessary to heat the water from 52°, the average temperature of the region, to 73° would be between 1,000 and 1,300 feet. It is considered, therefore, that the waters circulating through the sandstone at approximately this depth, unable to rise through the overlying impervious shale, find at this place some condition in the sandstone just beneath the shale favorable to their escape.

WATER RESOURCES OF THE NICHOLAS QUADRANGLE, WEST VIRGINIA.

By George H. Ashley.

LOCATION AND GENERAL FEATURES.

The Nicholas quadrangle is a 30-minute quadrangle with an area of nearly 1,000 square miles, located near the center of West Virginia, a little to the east of New and Kanawha rivers. It is within the area of the Allegheny plateaus, though no remnants of those are to be recognized within its boundaries. The elevations range from just above 800 feet on Buffalo Creek to nearly 4,400 feet in the southeast corner. The region, as a whole, is deeply incised, the hills rising from 500 to 1,000 feet or more above the adjacent streams. There are two rather distinct types of topography found here. The first occurs in two areas, one south of Gauley River and the other north of the divide between Gauley and Elk rivers. In these areas the streams occupy relatively narrow valleys between steep banks, rising to rounded divides. As a rule, the valleys are too narrow to pay for cultivation, and nearly all of the farming is upon the tops or upper slopes of the ridges, so that the roads usually follow the divides and cross, but do not follow, the valleys. The second type of topography is found between Gauley River and the divide to the waters of Elk River. Within this area the valleys are generally flat and broad with low gradients, separated by divides that are usually narrow and irregular. Here farming is almost entirely confined to the broad, flat valleys. The difference in the two types of topography is due to the positions of certain sandstone strata and the accompanying shale beds.

CULTIVATION.

At present the quadrangle is lacking in railway facilities. As a result there exist within it large tracts of fine timber, which are very sparsely inhabited, only a small portion, confined almost entirely to the ridges in the southern half and the northeast corner, being at present under cultivation. In the area immediately north of Gauley River the farms are in the valleys or on the broad benches. At the present time a branch of the Baltimore and Ohio Railroad extends into the area to Richwood, and there are prospects that in the near future other railroads will be built for the exploitation primarily of the timber and later of the coal.

DRAINAGE.

Gauley River crosses the quadrangle in almost an east-west direction near its center and drains most of it. The drainage of the north edge is to Elk River, mainly through Birch River and Buffalo Creek. Meadow River is the main tributary of the Gauley from the south in the western part, while the Cherry and the Cranberry are the principal tributaries in the eastern part of the area. The extreme southwest corner drains to New River. As a rule, the streams have a rapid fall and during much of the year are clear, and at the present time (before extensive lumbering has been undertaken) are among the most attractive streams in the Appalachian Mountains. As the water comes entirely from sandstone and shale, it is what is commonly known as freestone, or soft water.

GEOLOGY.

The rocks of this quadrangle belong almost entirely to the Pottsville group of the Pennsylvanian series of the Carboniferous. The rocks are predominantly sandstones or sandy shales, accompanied by valuable beds of coal and clay. The dip is nearly uniform from southeast to northwest, ranging from almost nothing to 300 or 400 feet to the mile, with an average of from 100 to 200 feet.

WATER RESOURCES.

Water for domestic purposes.—At present wells are mainly depended upon for drinking water and other domestic purposes. Over a large part of the area the houses upon the ridges depend upon wells rather than upon springs because of the necessary distance down to the latter. Such wells are usually not deep and get but a variable supply. In very dry weather they tend to give out, and recourse is had to the springs down the slopes of the hills. In the flat valleys and on the broad benches north of Gauley River wells are also depended upon. Summersville, the county seat of Nicholas County, and until a few years ago the largest village within the area, depends entirely upon wells. Richwood, which has recently sprung up on the branch of the Baltimore and Ohio Railroad, is supplied from several deep driven wells and has a waterworks system. Farms which are on the slopes of the hills or in the narrow valleys south of the Gauley usually depend upon springs. No large springs were noted in this area, but small springs are abundant, especially at the horizons of certain of the coals. One coal, known as the "Gauley," which is found at or near the horizon of the well-known Sewell coal on New River, is a notable spring horizon. From the almost uniform dip of the rocks it would seem that this area offers unusual opportunity for developing artesian wells.

Water power.—The large percentage of the ground that is covered with standing timber tends to render the streams fairly constant in volume. Most of them have a small flow all through the summer, even in extremely dry weather. On account of the narrowness of most of the valleys the latter are of very limited value for farming purposes, and the dip of the rocks carries many hard cliff-making sandstones down to water level along many of these valleys, rendering possible the construction of large power dams at relatively small cost. Probably a large percentage of the streams could be dammed at some point so as to yield a fair amount of power, which could be transmitted electrically to some manufacturing center.

In many cases where the streams cross the sandstones falls or rapids are produced, among which may be mentioned the falls of Hominy and Grassy creeks, each of which is about 20 feet high. North of Gauley River the streams cross a sandstone which lies just below the level of the flat bottom lands and then cut through a comparatively deep gorge to the Gauley. Most of these streams present opportunities for water storage and power.

WATER RESOURCES OF THE MINERAL POINT QUADRANGLE, WISCONSIN.

By U. S. Grant.

LOCATION AND GENERAL RESOURCES.

The Mineral Point quadrangle is situated in the southwestern part of Wisconsin, with its southern edge extending less than one-half mile into Illinois. It comprises considerable parts of Iowa and Lafayette counties and the eastern portion of Grant County, in Wisconsin, also a narrow strip along the northern border of Jo Daviess County, Ill. The quadrangle is bounded by west longitude 90° and 90° 30′ and by north latitude 42° 30′ and 43°, and contains, approximately, 878 square miles.

The district is one which was settled early in the history of Wisconsin, and is a rich agricultural region. The chief farm products are hay, corn, oats, cattle, butter, and cheese. There are small manufacturing establishments at a number of points, and at the town of Mineral Point large quantities of sulphuric acid and zinc oxide are produced.

The district is in the heart of the upper Mississippi Valley lead and zinc region, and has for seventy-five years been known as a producer of lead and zinc ores. During recent years this production has decreased, but in the past two or three years the production of zinc ore has advanced markedly. This is due to the mining of bodies of zinc sulphide which exist below the level of ground water, a horizon below which much of the early mining did not extend. The prospects are that the future will see a more extensive development of this mining industry and that the district will continue to be an important area for both metals.

The principal towns are Platteville, Mineral Point, Dodgeville, Darlington, and Shullsburg. The district is reached by branch lines of the Chicago and Northwestern Railway, the Chicago, Milwaukee and St. Paul Railway, and the Illinois Central Railway.

TOPOGRAPHY.

The Mineral Point quadrangle is situated within the driftless area of upper Mississippi Valley, a region which was not crossed by the invasions of the Pleistocene ice sheets, and consequently lacks those peculiar details of topography which are so common in the surrounding glaciated areas. Thus there are none of the minor irregularities due to drift deposits, nor are there lakes or swampy areas except locally along the flood plains of some of the larger streams, and the drainage features are well developed and systematized. In fact, the whole topography is that produced by subaerial erosion acting on strata nearly horizontal in position and of rather uniform degrees of resistance.

The most noticeable topographic feature of the district is the flatness of the uplands, for from any of the stream divides in the district the eye passes over an apparently even stretch of land. In this plain the streams have cut marked valleys, the main ones of which lie 200 feet or more below the main level. These valleys are wide and flat-bottomed, even when very small, and the district is topographically mature. It has been estimated that about one-half of the cubic contents of the land for 300 feet below the surface of the plain has been carried away by stream erosion. Above this level, which is of the nature of a peneplain formed probably in Tertiary time, rise two groups of isolated mounds or monadnocks, one group (the Platte mounds) lying 5 miles northeast of Platteville and the other south of Shullsburg.

Aside from the mounds, the highest of which rises 1,430 feet above the sea, the most elevated points of the plain are near the north side of the quadrangle along what is known as the Military Ridge, where the altitude averages close to 1,200 feet above sea level. To the north of this ridge the streams descend rapidly, and the land less rapidly, to Wisconsin River, which is outside of the boundary of the quadrangle. To the south the plain slopes gradually toward the south-southwest, the lowest point being near the southwest corner of the quadrangle, or about 950 feet above sea level. The lowest point in the valleys—660 feet above tide—is along Fever River, where it crosses the southern boundary of the quadrangle. The difference between the extremes in elevation in the quadrangle is 770 feet.

GEOLOGY.

The district is underlain by rocks of early Paleozoic age, which dip at very low angles toward the south-southwest, but in some places have been thrown into gentle folds whose axes have a general east-west direction and whose south limbs are long and gently sloping, while their north limbs are short and steeper. The formations represented in the district are shown in the following table, in which the approximate average thickness of each is given:

Ideal section in Mineral Point quadrangle.

		Feet.
Quaternary	Loess and soil	7
Silurian	Niagara limestone	50
Ordovician	Maquoketa shale	160
	Galena limestone	230
	Platteville limestone	55
	St. Peter sandstone	70
	Lower Magnesian limestone	200
Cambrian	Potsdam sandstone	700

The Potsdam sandstone does not outcrop within the area of the quadrangle, but is regarded as present beneath the Lower Magnesian limestone over the entire district. The Lower Magnesian limestone consists of a lower main body of massive dolomite, above which is a sandstone layer which is usually overlain by another dolomite. The outcrops of the Lower Magnesian in this quadrangle are confined to the bottoms of some of the valleys, where it emerges irregularly from beneath the overlying St. Peter sandstone. The St. Peter sandstone is usually a poorly cemented, comparatively pure quartz sandstone. It varies considerably in thickness and its outcrops are confined to the valleys. The Platteville (or Trenton) limestone is, except for its lower part (which is magnesian), a true limestone, which, for this reason and also because it commonly occurs in beds of only a few inches in thickness, is readily distinguished from the other limestone formations of the district. It outcrops along the sides of many of the valleys. The Galena limestone is a massive, rough-weathering, frequently flinty dolomite, which forms the surface rock over the main part of the quadrangle. Outcrops are frequent. In this formation and in the upper part of the next lower are the lead and zinc deposits of the district. The Maquoketa shales (frequently called in this district the "Hudson River" shales) consist of blue to green shales and clays, with some thin bands of earthy limestone. This formation, because of its soft nature, is rarely seen in outcrop. It is confined chiefly to the base of the mounds and to some of the higher ground surrounding the mounds. The Niagara limestone is a dolomite, frequently carrying large amounts of flint, and is confined to the summits of the higher mounds; its total thickness is not seen in the Mineral Point quadrangle, the figures above given referring only to the formation as here represented. This hard dolomite at times forms bold outcrops near the summits of the mounds.

The soils of the district, except the valley alluvium, are residual—that is, are formed from the decay of the immediately underlying rock. Spread over much of the district is a very thin mantle of loess, which becomes thinner and even entirely lacking in the eastern portion of the quadrangle. It is more noticeable on the west and southwest, but even here it rarely exceeds 4 feet in thickness and does not average more than half of that amount.

These indurated formations represent one long period of early Paleozoic sedimentation twice interrupted—once probably in Potsdam time and again at the end of Lower Magnesian time—the St. Peter sandstone being unconformable upon this limestone formation. There are no evidences in this quadrangle that formations later than the Niagara were deposited here. There is, though, in the peneplain already mentioned, direct evidence that the district was reduced by subaerial erosion to a low-lying, rather level surface, probably in Tertiary time. Later the peneplain was elevated and erosion has continued uninterruptedly to the present day.

WATER RESOURCES.

SPRINGS.

Among the important water resources of this quadrangle are springs, which are numerous, and which are in the main confined to three geologic horizons—the base of the Galena limestone, the base of the Platteville limestone, and the base of the St. Peter sandstone. A few springs issue at other horizons, as on shaly layers in the Galena, but these are not large and do not occur uniformly.

At the base of the Galena is a stratum, from a few inches to 4 feet in thickness, of a black to brown carbonaceous shale, which is known locally as the oil rock. This is commonly underlain by one or more thin strata of blue to white clay or shale. All these strata are practically impervious and turn much of the water which soaks down through the porous Galena dolomite above. Springs from this horizon are less common in the eastern portion of the quadrangle than elsewhere, although they do occur here, while they are common wherever streams have cut down into the Platteville limestone in the vicinity of Platteville.

Immediately overlying the St. Peter sandstone is a bed of blue shale, sometimes sandy, which is from 2 inches to 3 feet in thickness. This very commonly turns the water, and there results the rather unusual phenomenon of a marked line of springs above a porous sandstone formation. This is a very constant spring horizon throughout the parts of the district in which the St. Peter sandstone outcrops.

The Lower Magnesian limestone appears irregularly beneath the St. Peter sandstone in some of the deeper valleys. Close to the top of this limestone formation at times are beds of very compact limestone or of shale and clay. The springs at this horizon are not so numerous nor so constant in occurrence as at either of the two other horizons.

These springs frequently form the starting points of permanent streams, and they are of local importance to the farmers, as they furnish fine supplies of water for domestic and dairy uses, thus frequently determining the location of the farm houses.

STREAMS AND WATER POWERS.

The rainfall of the district is approximately 35 inches a year, the streams are numerous, and irrigation is not necessary. The smaller streams of the quadrangle descend quite rapidly, at times as much as 60 feet per mile, while the larger streams have in their lower parts an average descent of not to exceed 10 feet in a mile. There are no waterfalls in the quadrangle, except those altogether too small to be utilized as water powers. The main streams are Pecatonica River in the eastern and Fever River in the southwestern part. Both streams head within the quadrangle. The former is the larger, but both are capable of furnishing water power for local use, though at present they are not utilized except at two points—at Darlington, on Pecatonica River, and near Benton, on Fever River, where small dams have been erected. Many of the streams of the district having a fall of from 10 to 40 feet per mile possess enough volume to furnish water powers sufficient for small flour and grist mills. Abandoned mills and millraces testify to the use of these water powers before the building up of the large milling centers in the Northwest.

WELLS TO GROUND WATER.

The distance from the surface to the level of ground water in this area varies from less than 10 feet in the valleys to 100 feet or more on some of the high interstream areas. No figures are available as to the average depth to the ground-water level, but this is far enough below the surface to make it usually inexpedient to excavate open dug wells. Wells sunk by churn drill are common, especially in the broad upland parts of the district. The Galena limestone, which is the rock immediately underlying the surface in the greater part of the quadrangle, is sufficiently porous to furnish reasonable supplies for domestic purposes in wells sunk a few feet below ground-water level. The water of such wells is somewhat hard (although no accurate determinations are at hand), but of excellent quality for domestic use. Where wells are sunk to ground-water level in areas underlain by the St. Peter sandstone the supplies of water are large.

DEEP WELLS.

For deep wells there are two important water-bearing horizons, the Potsdam and the St. Peter sandstones, one or both of which can be found under all the quadrangle. Little can be said concerning water supply from the sandstone in the upper part of the Lower Magnesian limestone, for it is not yet known whether it extends under all the quadrangle, and in some places it is not separated from the St. Peter by marked limestone strata.

St. Peter sandstone.—The St. Peter is a poorly cemented homogeneous sandstone of medium grain, composed sometimes of 99 per cent of rounded quartz grains. It is an ideal water-bearing stratum. Near the northeast corner of the quadrangle its upper surface is 1,050 feet and at the southwest corner about 600 feet above sea level. It may be regarded as descending uniformly from the former to the latter altitude, except for two areas, where it is 50 to 150 feet higher than normal. These areas are along gentle anticlinal folds whose axes run east and west; the axis of one fold lies south of Mineral Point and north of Platteville, and that of the other runs from Redrock on the east to Cuba on the west. In the general upland level (the old peneplain surface) of the quadrangle, where the Galena is the surface rock, the St. Peter can be reached in from 100 to 300 feet, while in areas immediately underlain by Maquoketa shales (as about the Platte mounds, near Hazel Green, and south of Shullsburg) it is farther from the surface. Wells sunk into the upper part of this sandstone will at times furnish good supplies of water, while an abundant supply can be counted on, except near some of the Lower Magnesian outcrops, in wells sunk to the base of the St. Peter. The water from this sandstone is less liable to hold considerable quantities of mineral substances than is water from lower horizons.

The inclination of the strata is toward the south-southwest, the dip being greater than the surface slope. Thus favorable conditions for artesian flows from the St. Peter sandstone would exist in the southern part of the quadrangle were it not that toward the south (at La Salle and Oregon, Ill.) and the west (near Dubuque) this sandstone outcrops at lower levels than it holds within the quadrangle. So artesian flows are not to be expected from this water-bearing stratum, though in some wells the water will rise for a short distance above the top of the sandstone.

Potsdam sandstone.—The Potsdam sandstone is in large part as uncemented as the St. Peter, and so is a good water-bearing formation. It has, however, commonly more calcareous and argillaceous impurities, which at times form distinct limestone and shale beds, and thus furnishes more than one water-bearing horizon. The Potsdam undoubtedly underlies the whole quadrangle at a depth of from 230 to 350 feet below the top of the St. Peter. It can be relied upon as a strong water-bearing formation, and is even more important than the St. Peter. Water from the Potsdam will rise above the top of that horizon, but can not be commonly expected to furnish flowing wells. It is, however, possible that flowing wells from this horizon may be obtained in some of the valley bottoms.

WATER RESOURCES OF THE JOPLIN DISTRICT, MISSOURI-KANSAS.

By W. S. Tangier Smith.

TOPOGRAPHIC AND GEOLOGIC CONDITIONS.

LOCATION.

The Joplin district is located at the intersection of the boundary lines of Missouri, Kansas, and Indian Territory. It embraces an area of 476 square miles, lying between 94° 15′ and 94° 45′ west longitude and 37° and 37° 15′ north latitude. About three-fourths of the district lies in Missouri, and includes among its larger towns Joplin, Webb City, and Carthage; the remaining fourth (except for a fraction of a square mile falling in Indian Territory) is in Kansas, and its largest towns are Galena, Empire, and Baxter Springs. It is essentially a lead- and zinc-mining region, and most of the settlements of the district are dependent on these interests. Next to mining, agriculture is the most important industry.

TOPOGRAPHY.

The Joplin district lies near the western margin of the Ozark uplift, a flat, asymmetric dome comprising most of the southern half of Missouri and the northern half of Arkansas. The upland surface of the district is almost flat, with a very low general slope to the northwest. These nearly level uplands—on which most of the cities and towns are located—are cut by numerous stream valleys, for the most part open and rather shallow. The valleys grow deeper toward the southern and western parts of the quadrangle, reaching a maximum depth of about 200 feet below the adjacent uplands, and bordered here and there, especially along Shoal Creek, by abrupt cliffs. The drainage of the district as a whole is toward the southwest.

DRAINAGE.

The most important drainage lines of the district are Spring River and its tributaries, Shoal, Center, Turkey, Cow, Shawnee, and Short creeks and Buck Branch, together with several of the tributaries of Center Creek. These, with about two dozen minor streams, comprise all the perennially flowing streams of the district. The minor drainage lines run for the most part roughly at right angles to the valleys to which they are tributary, and are characteristically short, seldom exceeding a length of 3 or 4 miles. None of the streams are navigable. Even the largest, Spring River and Shoal Creek, though comparatively broad—the former having a width of 150 feet or more in places along its lower stretches—are at many points shallow enough to be forded.

The streams are all spring fed (except for a few small ones formed by water pumped from the mines), and those which rise outside the district receive important additions from springs in their course across it.

GEOLOGY.

The rocks of the district are wholly sedimentary, and the surface exposures are all of Carboniferous age, both the upper and lower being represented. The lower Carboniferous (Mississippian) rocks consist of about 350 feet of normally nonmagnesian limestones and cherts in varying proportion, constituting the Boone formation. Not far from the top of this formation is a thin but persistent bed of oolite, outcrops of which occur in all parts of the district. About 100 feet below this is a heavy bed of chert, averaging about 40 feet in thickness and known as the Grand Falls chert.

The exposures of the Mississippian rocks cover the greater part of the Joplin district. Above these lie the upper Carboniferous (Pennsylvanian) shales and sandstones, constituting the Cherokee formation. There is a considerable area of these shales and sandstones along the western margin of the quadrangle west of Spring River, in addition to which scattered areas and patches of them dot the entire district.

As shown by exposures outside the district and by deep drill holes, there is beneath the Mississippian rocks a very thin body of Devono-Carboniferous deposits, succeeded in depth by 1,300 or 1,400 feet of Cambro-Silurian rocks, consisting of a series of dolomites, magnesian limestones, and sandstones, chiefly the first. These overlie the pre-Cambrian crystalline rocks.

The rocks of the district have a low general dip to the northwest, at an angle somewhat greater than the general inclination of the surface. Open folding is common on both a large and a small scale. Noticeable faulting is uncommon over the quadrangle as a whole, but in those parts where the lead and zinc deposits occur both faulting and folding are of more importance. The faulting has often given rise to brecciation of the rocks adjacent to the fault planes, especially in the more cherty portions of the Boone formation. The underground waters of the district, as seen in springs and deep wells and in the mines, circulate chiefly along the bedding planes of the rocks and along the fault planes—at least within the Boone formation—the chert breccias forming unusually favorable channels for underground circulation.

WATER RESOURCES.

The economic water supply of the district is drawn from the streams, springs, wells, and rainfall, the last being sufficient in general for agricultural purposes.

STREAMS.

General character.—The streams of the district are used both as a source of water supply and for power. Of those available for power Shoal Creek has an average fall of 7 feet to the mile for the 17 miles of its course through the district. Center Creek has an average fall of 6.3 feet per mile for its 27 miles, while the average fall of Spring River for the 28 miles of its course included in the western part of the district is only 2.1 feet to the mile, and for its entire length within the district about 3.6 feet per mile. The grade of these streams is somewhat variable, so that locally the fall is considerably greater than the figures given. At Lowell the course of Spring River is broken by rapids, while along Shoal Creek between Lowell and Reddings Mill rapids are found at a number of points. The only falls on these streams are those at Grand Falls, on Shoal Creek.

Power.—Shoal Creek has been dammed at Reddings Mill and at Grand Falls, furnishing power at the former for a mill on the south bank of the stream and at Grand Falls for the Joplin electric-light plant. At Lowell, which is situated at the mouth of Shoal Creek, both this stream and Spring River are dammed, the former stream furnishing power for a gristmill which has not been run for two years or more. The water of Spring River is used here for a large gristmill on the west side of the river and for a small corn and feed mill on the east side. On account of the low grade of the stream the dam across Spring River here backs the water for about 2 miles up the river. Below Lowell and east of Baxter Springs Spring River is dammed again to furnish the power for a large mill.

Up Spring River from Lowell there was formerly a mill using water power, at the old Boston Mill Bridge across Spring Creek north of the mouth of Center Creek. South of Waco, on Spring River, there is a small mill, which has lately been repaired and put in running order. In addition to these, there is a mill obtaining power from Spring River 1 mile west of the eastern margin of the district. A short distance south of Spring River, in Carthage, a large mill, which was burned down not long since, had a canal more than three-fourths mile long cut to it from the river. A flour mill near Spring River, west of Alba, also obtains water power from the river through a canal, in this case nearly one-half mile long.

Domestic supply.—Spring River and Center and Shoal creeks furnish the water supply of most of the cities of the district. The Carthage pumping plant is on Spring River just north of the city. The pumping station of the Webb City waterworks is on Center Creek about a mile east of Oronogo. That for the Galena waterworks is on Shoal Creek about 1½ miles south of the city. The Joplin city water is taken from Shoal Creek at a point about 3 miles a little west of south of the city, and about 6 miles east of and above the source of the Galena supply. It is pumped to a settling basin in Blendeville in the southern part of the city, where it is filtered before being pumped into the city mains.

A number of the streams of the district, most of them otherwise potable, have been polluted to a greater or less extent by water pumped from the mines. These waters contain zinc sulphate and other impurities, which, if sufficient in amount, render the streams unfit for domestic uses and sometimes for other purposes as well. Pollution from this source is greatest, of course, immediately in the neighborhood of the mining camps, and it affects chiefly the smaller streams. Rarely the zinc content of the waters is sufficient, as in the case of Turkey Creek, to destroy the fish once found in the stream. Of the larger streams those principally affected are Turkey and Short creeks and, to a much less extent, Center Creek below Carterville and Oronogo. Comparatively few mines contribute water directly to Spring River and Shoal Creek. For this reason and on account of the large volume of these streams, their zinc content is small. In the Joplin city water, taken from Shoal Creek, the amount of metallic zinc, as determined at different times by Mr. W. George Waring, ranges from a trace to 4.2 parts per million.

It is probable that the Galena city water has a somewhat larger proportion of zinc than the Joplin water (though not a dangerous amount), on account of the zinciferous springs and the mines of Gordon Hollow and its neighborhood, which are located just north of Shoal Creek and several miles above the point of intake of Galena's water supply, and on account of the waters from the mines south of Blendsville, which empty into Shoal Creek just below the source of Joplin's city supply. In addition to this there is the danger of sewage pollution from these mining camps. In the case of the Joplin city water any such danger appears to be slight, and it is doubtless reduced to a minimum by the filtration to which the water is subjected.

The water of Shoal Creek is only slightly turbid, is without odor or appreciable taste, and appears, from partial analyses made by Mr. Waring, to have a low content of mineral matter. The water of Center Creek, as shown by the accompanying analysis, contains a moderate amount of mineral matter, the comparatively large proportion of silica and alumina being due to suspended clays.

Mineral analysis of water from tap in Webb City waterworks office.

[Parts per million.]

Silica	66.4
Alumina	16.9
Sodium chloride	9.6
Sodium sulphate	68.4
Magnesium sulphate	33.3
Ferrous sulphate	10.5
Calcium sulphate	111.5
Calcium bicarbonate	240.9
	557.5

Cleveland and Millar Analytical Laboratory, analyst.

While this water is not known to be contaminated by sewage, the location of Lakeside Park, between 2 and 3 miles above the source of the Webb City supply, suggests a possibility of danger from this source.

The Carthage city water is undoubtedly as free as any of the waters derived from the streams of the district from contamination from any source.

SPRINGS.

Occurrence.—Springs are common throughout the district, especially along Shoal Creek and its tributary valleys. They are found for the most part along the margins of the valleys, though one issues on the upland west of Joplin, the water here rising to the surface along a fault plane. These waters come from different horizons in the Boone formation. The Grand Falls chert appears to be especially favorable to underground flow, and many of the springs along Shoal Creek (almost the only part of the district where this member of the Boone formation is exposed) emerge at either its upper or lower surface. The springs are often of considerable volume, but the amount of flow has not been definitely determined in any instance. The largest one known to the writer in the district—on the eastern margin of Grove Creek valley, about one-half mile west of north of Scotland—gives rise to a stream 12 feet wide and 6 or 8 inches deep.

Character.—The water from all the springs is cold, no thermal springs being known in the district. Most of the spring waters are clear, colorless, without sediment, and are potable, containing only a comparatively small amount of mineral matter in solution, chiefly calcium bicarbonate. Analysis No. 1 of the accompanying table is probably typical of these springs. Where favorably situated these springs are used as a source of water supply for household and other purposes, but not for irrigation, so far as known. The water from the spring on the upland west of Joplin is not only used by the people of the vicinity, but is also piped to a neighboring mine.

Of the comparatively few spring waters of the district which differ from those just referred to, one (see analysis No. 2) contains sodium sulphate (which, next to calcium bicarbonate, is its principal constituent) in sufficient amount to be somewhat medicinal, thus classing it as a mineral water. The chalybeate springs at Baxter Springs—used commercially and as a resort—contain chiefly calcium and iron bicarbonate (analysis No. 3). These waters have only a slight taste and show a slight reddish, flocculent precipitate.

A few of the springs of the district contain, in addition to the constituents usually found in such waters, more or less zinc derived from the oxidation of neighboring deposits of zinc ore. Springs apparently normal in other respects are thus rendered unfit for use. This applies particularly to the springs in and near Jackson, Roaring Spring, and Gordon hollows, most of which form more or less of a cream-colored to nearly white, flocculent deposit. All the waters showing these deposits probably contain zinc, which is known to occur in four of the springs. One near the head of Roaring Spring Hollow, according to an analysis by Mr. W. George Waring, contains 102.8 parts per million, while two springs nearly a mile south of east of the mouth of Gordon Hollow, and just north of Shoal Creek (see analyses Nos. 4 and 5), contain, respectively, 120.5 and 132.4 parts per million of zinc. The deposits of these springs, as shown by qualitative analyses, differ somewhat in character from each other, though in most cases they appear to consist chiefly of alumina and aluminum sulphate, together with more or less silica. Some of the deposits contain zinc, but others do not, even where it is present in the water itself, as in that analyzed by Mr. Waring. The waters analyzed by Doctor Hillebrand were considered by him unique in having zinc sulphate as their chief constituent. These waters have a more or less astringent taste, only slightly so in some cases. Near the mouth of Gordon Hollow is a spring the water of which is clear, the only deposit formed being an ocher-yellow film on rock surfaces over which it flows. This water has an astringent, alum-like taste, and gives an acid reaction with litmus. Other springs containing zinc are the Great Western, nearly 3 miles north of east of Joplin, and the Green spring, east of Empire, which are shown by analyses to contain, respectively, 35 parts per million and 12.6 parts per million of metallic zinc.

Analyses of spring waters.

[Parts per million.]

	1.	2.	3.	4.	5.
Lead sulphate	None.			Trace.	
Copper sulphate	Trace.			0.5	
Cadmium sulphate				.9	
Zinc sulphate	None.			297.7	327
Ferrous sulphate		1.3		1.6	1.6
Manganese sulphate				6.3	6.6
Aluminum sulphate				2.5	3.2
Barium sulphate	None.				
Calcium sulphate		49	66.2	109.9	85.8
Magnesium sulphate	0.4	11	11.7	19	21
Sodium sulphate	4	204.4		5.9	6.8
Potassium sulphate	2.2			5.6	5.6
Sodium chloride	2.8	13.3	3.4	4.3	4.3
Potassium chloride			1.9		
Ferrous carbonate			92.1		
Ferrous bicarbonate	Trace.				
Calcium carbonate			152.5	72	94.7
Calcium bicarbonate	172.7	369.4			
Magnesium carbonate			2		
Magnesium bicarbonate	14.6				
Lithium carbonate			6.9		
Carbon dioxide (free)	1.3		([a])		
Silica	15	13.7	39.4	13.7	15.7
Alumina	Trace.	2			
Organic matter, volatile, and loss			29.2		
	213	664.1	405.3	539.9	579.3

[a] 38 cubic inches.

1. Water from spring, eastern margin of Shoal Creek valley, about 3 1/16 miles southeasterly from Thurman. Analyst, H. N. Stokes, U. S. Geological Survey Laboratory. Combination of substances by W. S. T. Smith.
2. Water from spring near Webb City. Analyst, Cleveland and Millar Analytical Laboratory, Joplin.
3. Water from Baxter Springs. Analyst, A. Merrill (1882). Reference: Bull. No. 32, U. S. Geol. Survey, p. 173.
4. East Spring, and 5, West Spring, from group of springs on the road from Joplin to Seneca, about 4½ miles southwest of Joplin, at the base of a low bluff of Grand Falls chert. Analyst, W. F. Hillebrand, U. S. Geol. Survey laboratory. Reference: Am. Jour. Sci., 3d ser., vol. 43, p. 419.

WELLS.

General character.—Shallow dug wells are, outside the cities, the most common source of water supply throughout the district, and are to be found on the outskirts of even some of the larger cities. Such wells range in depth from about 15 to about 65 feet. Some of the deeper wells of the district are also partly dug, only their lower portions being bored. Occasionally water in old prospect or mine shafts is utilized as a source of local supply, when it is not contaminated by oxidation products from the ore deposits.

Deep wells.—There are in the district several thousand drill holes, nearly all sunk in search of ore, and ranging from slight depths to 600 feet or more, very few, however, exceeding 250 feet. Although for the most part concentrated in the mining camps, scattered holes are to be found in all parts of the district, and in some instances, outside the mining camps, they have been utilized as deep wells. In the vicinity of the mines, however, they are not in general available for this purpose, on account of the lowering of the water level by pumping at the mines, and also because of the frequent contamination of the waters by oxidation products from the ores. Probably none of the holes which are less than 300 feet deep extend below the base of the Boone formation. In addition to these, between twenty and thirty deep drill holes have been put down primarily for water to depths ranging from about 500 to 2,005 feet. They are, with one exception, the result of private enterprise, and a considerable proportion of them have been sunk chiefly to obtain water for use in boilers. Besides this use, the water from the wells is employed for making ice and for other commercial purposes, as well as for domestic use. In Joplin and Webb City, although both have a regular water supply, water from deep wells is carried about in water carts and sold for drinking. Empire is the only town depending on a deep well for its water supply.

There are no flowing wells, the water standing at depths ranging from 15 to 200 feet below the surface. Both lift pumps and compressed air are used for raising the water. The full capacity of most of the wells is not known. The Missouri Lead and Zinc Company's well at Joplin has a capacity of about 4,000 gallons per hour (68 gallons per minute). In other instances water has been pumped in amounts ranging from 2,000 to 12,500 gallons per hour without affecting the level. Except close to the surface the ground is, in general, firm enough to stand without caving. A part of the wells, at least, are cased, the casing in several known instances extending to a depth of 400 feet. The water in the wells is, in general, derived from the Cambro-Silurian rocks, although there do not appear to be in these rocks any definite water-yielding beds which are continuous throughout the district. In some instances, as the Redell well in Joplin, there is but one flow of water, in this case at a depth of 1,350 feet; in others there are several flows. At the Freeman Foundry well, less than three-fourths mile south of the Redell well, water was struck at depths of 815, 860, 875, and 900 feet, the chief flow being from the uppermost horizon.

The catchment area for these deep wells is to the southeast, where the northwesterly dip of the rocks brings the deeper formations of the district successively to the surface. It extends at least as far east as the crest of the Ozark uplift, and probably some distance beyond it.

Chemical content.—The water from these wells is moderately cold, temperature determinations in three cases ranging from 63° to 66½° F. The water in three of the Joplin deep wells has a slight though distinct odor of hydrogen sulphide as it issues from the well, and this is probably true also of some of the others of the district. This odor disappears after the water has stood for a while, and it is not enough to give the water any taste. Chemically the well waters which have been analyzed show considerable uniformity. As shown by the following table, the total content of mineral matter is low, consisting chiefly of calcium and magnesium bicarbonates, with smaller amounts of sodium and potassium salts and silica.

Analyses of deep-well waters, Joplin district.

	1.	2.	3.	4.	5.	6.
Copper sulphate	Trace.					
Calcium sulphate					6.8	
Magnesium sulphate	13.8					
Sodium sulphate	11.1	51.4	20.6	21.3		1.8
Potassium sulphate	12.5					
Sodium chloride	15.3	11.7	16.6	19.9	9.9	8.2
Potassium chloride		Trace.				
Lithium chloride	Trace.					
Ferrous bicarbonate	1.3	.9	2.6	2.9		.2
Calcium bicarbonate	162.9	214	178.5	150	202.5	215.5
Magnesium bicarbonate	60.1	98.6	131.3	103.7	108.8	43.8
Sodium bicarbonate		14.5	35.6	30.9		74.1
Silica	47.7	7.2	14.2	10		10.8
Silica and insoluble residue					12.5	
Alumina	Trace.			.9		.2
Undetermined					7.7	
	324.7	398.3	399.4	339.6	348.2	354.6

1. Redell well, Joplin. Analyst, H. N. Stokes, U. S. Geol. Survey laboratory; combination of substances by W. S. T. Smith.
2. Freeman Foundry well, Joplin. Analyst, Cleveland and Millar Analytical Laboratory, Joplin.
3. Well on Missouri Lead and Zinc Company's land, Joplin, taken when well was 940 feet deep. Analyst, Cleveland and Millar Analytical Laboratory.
4. Well on Missouri Lead and Zinc Company's land, Joplin, taken when well was 1,387 feet deep. Analyst, Cleveland and Millar Analytical Laboratory.
5. Well on Missouri Zinc Fields Company's land, Webb City. Analyst, W. Geo. Waring, Webb City.
6. Well on American Zinc, Lead and Smelting Company's land, Carterville. Reference: Water-Supply and Irrigation Paper No. 102, U. S. Geol. Survey, 1904, p. 405.

Location.—The locations of the deep wells in the district are as follows:

Carthage: Well at Harrington dairy, just east of the city (2,005 feet in depth, the deepest in the district); Independent Powder Works well (746 feet deep), 3 miles southwest of Carthage.

Webb City: Wells at the ice plant, at the power house of the Southwest Missouri Electric Railroad Company (826 feet deep), and at Harrod Brothers' meat market (825 feet deep).

Wells on mining tracts southeast of Webb City: Center Creek Mining Company (827 feet), Missouri Zinc Fields Company (854 feet), Homestead Lead and Zinc Company (650 feet), American Lead, Zinc and Smelting Company (799 feet), Eleventh Hour Mining Company (1,000 feet), Troup Mining Company (998 feet), and Ten O'Clock Mining Company (537 feet).

Carterville: Well at Bryant's Iron Foundry (643 feet deep).

Duenweg: Boston-Duenweg Zinc Company's land (475 feet deep).

Joplin: Keystone Hotel, G. H. Redell's brewery (1,379 feet), ice plant, Freeman Foundry and Machine Works (908 feet), Missouri Lead and Zinc Company's land (1,387 feet).

Chitwood: United Zinc Companies' land (800 feet).

Galena: Ice plant (972 feet); a second well not used.

Empire: City well (1,002 feet deep) furnishes water for town supply.

WATER RESOURCES OF THE WINSLOW QUADRANGLE, ARKANSAS.

By A. H. Purdue.

LOCATION AND AREA.

The area included within the Winslow quadrangle lies mainly in the western part of Arkansas. Its southern border is but a short distance north of Arkansas River, and its northern border is 4 miles south of the city of Fayetteville. Its boundaries are the parallels 35° 30′ and 36° north latitude and the meridians 94° and 94° 30′ west longitude. It is about 28 miles wide from east to west and 34 miles long, covering an area of about 968 square miles. Of this something like 22 square miles is in Indian Territory.

TOPOGRAPHY OF THE AREA.

In the north-south direction the area extends entirely across the highlands known in Arkansas as the Boston Mountains, and includes some of the highest points of that elevation. The northern three-fourths of the area is essentially a plateau with a slightly curved surface, the highest part extending east and west in about the latitude of the town of Winslow. This plateau is deeply cut into by numerous valleys, the main ones of which run north and south. These, with their tributary side ravines, cut the region up into steep-sided hills with tops from 500 to 1,000 feet above the streams below, from which the adjacent hills and valleys present imposing landscapes. The highest of these hills—the one on which the village of Sunset is located—is near the eastern border of the area and is somewhat more than 2,250 feet above sea level.

From the highest part of the region the surface falls off gradually to the south, so that while the southern part is rugged, the maximum elevation along this border is only about 800 feet above sea level.

DRAINAGE.

About one-sixth of the area, located in the northeastern part of the quadrangle, drains northward into White River; the remainder drains into the Arkansas. The water divide extends from the eastern border of the quadrangle through the town of Winslow, and then runs northward a few miles west of and roughly parallel with the St. Louis and San Francisco Railroad to the north border of the quadrangle.

While the rainfall is considerable, the short distance on either side of the divide to the borders of the area prevents the occurrence of large streams, though there are many that have a constant supply of water, which, when the streams are at low stage, is very clear from filtering from pocket to pocket through the gravel of the stream beds.

The drainage into White River passes northward through Middle Fork and West Fork of White River; that into the Arkansas passes northward and westward through the Illinois and its tributaries, and southward through Lee Creek, Frog Bayou, Mulberry River, and their tributaries.

GEOLOGY.

The rocks of the region are of Carboniferous age, and consist of limestones, sandstones, and shales. The limestones are confined to the northern two-thirds of the area. They outcrop on the hillsides of the north slope of the Boston Mountains, and are exposed in the deepest ravines of the south slope as far south as the latitude of Porter, on the St. Louis and San Francisco Railroad.

An idea of the stratigraphy and structure of the region can be had from fig. 14. The rocks dip gradually to the south, except in the latitude of Porter, where there is a marked east-west monocline with a south dip, causing all the rocks that lie below the Winslow to pass out of sight below that formation.

North of the monocline is a series of east-west faults, which are pronounced in the west half of the quadrangle. The downthrow of these faults, one of which is shown in the section, is on the north side. Also, there is a fault several miles long, with the downthrow on the east side, following the valley of Cove Creek.

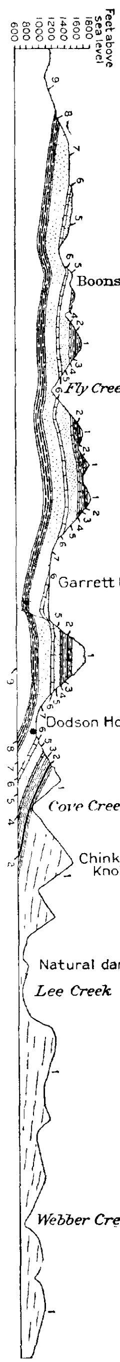


FIG. 14.—North-south geologic section through Boonsboro and Chinkapin Knob, Arkansas. 1, Winslow formation; 2, Kessler limestone; 3, coal-bearing shale; 4, Brentwood limestone; 5, Hale sandstone and limestone; 6, Pitkin limestone; 7, Wedington shale and sandstone; 8, Fayetteville shale; 9, Boone chert.

The following rock formations, named from above downward, occur in the region: Winslow formation, Kessler limestone lentil, coal-bearing shale, Brentwood limestone, Hale sandstone member, Pitkin limestone, Wedington sandstone, Fayetteville shale, Boone chert.

WATER RESOURCES.

Springs and wells.—Of the above formations, four—the Boone, the Pitkin, the Hale, and the Winslow—are important water producers.

The Boone consists largely of gray limestone, containing a large amount of chert in thin lenses parallel with the beds. This is the surface rock about Prairie Grove and Summers and north of Morrow, in the valley of Prairie Fork of Illinois River. Its presence beneath can usually be determined by the occurrence of loose chert fragments on the surface. Both the chert and the limestone of this formation are much fractured and jointed, making it an easy matter for water to gain access to and pass through it. As a result this formation contains a large amount of excellent water; but because of the level character of the region over which it is the surface rock, only a few springs emerge from it, and in order to secure water it is necessary to sink wells. In the town of Prairie Grove is an excellent spring from this formation, and there is another 1½ miles east of the town.

The Pitkin is a gray, compact limestone from 15 to 40 feet thick, resting upon a bed of shale. It outcrops all along the north slope of the Boston Mountains and in the deepest valleys of the south slope in the western half of the area. The shale beneath holds the ground water up in the limestone, through which it moves along the joints as small, underground streams, and issues here and there in strong, beautiful springs. The springs at Boonsboro come from this limestone, and there are numerous others along its northern outcrop. Likewise there are many springs flowing from this horizon on the south slope where it is exposed in the ravines, such as Cove Creek, Low Hollow, Garrett Hollow, Whitzen Hollow, and Mountain Fork.

The Hale sandstone consists of about 100 feet of calcareous sandstone interbedded with limestone. The sandstone usually contains a great many cavities the size of hen's eggs and smaller. Like the Pitkin, this formation outcrops all along the north slope of the Boston Mountains and in the deep ravines of the south slope. Being thick and of an open, porous nature, it forms an excellent water reservoir, from which a large number of fine springs issue at frequent intervals along its outcrop.

The Winslow formation, which occupies the tops of the Boston Mountains, and is the surface rock over nearly all the south half of the quadrangle, consists of several hundred feet of alternating beds of sandstone and shale. Springs occur on the hillsides of the north slope, but they are of minor importance, both in size and number.

However, the Winslow sandstone furnishes water in abundance from wells of moderate depth, even on the summits of the highest hills. Over the area where this is the surface rock wells are relied on almost wholly for culinary and drinking purposes. In the ravines of the south slope occasional springs issue from sandstone, which owe their existence to the general south dip of the rocks. Of such are Dripping Springs, at Stattler; Oliver Spring, 2 miles west of Rudy; the spring at Dean Spring; Fine Springs in sec. 18 and a spring in sec. 8, both of T. 10 N., R. 30 W.; springs in secs. 17 and 33, T. 12 N., R. 29 W.; springs in secs. 2, 13, 14, and 15, T. 11 N., R. 29 W.; a spring in sec. 33, T. 12 N., R. 31 W.; and one in sec. 11, T. 10 N., R. 31 W.

Nature of the water.—All the water from the limestone beds is clear, cold, and sparkling, and is unsurpassed in purity among natural waters. As would be expected, that issuing from the Pitkin limestone is hard, being heavily charged with lime. That from the Boone chert and the Hale formations, while hard, does not contain as much lime as that from the Pitkin, owing to the large amount of silica in these formations, in the one case as chert and in the other as sandstone. The water in the Winslow formation is soft, coming as it does from sandstone.

Mineral springs.—In sec. 32, T. 11 N., R. 32 W., 1½ miles northeast of Uniontown, is a spring strong in sulphur, which has been inclosed and is locally used for medicinal purposes. It issues from the Winslow. At Sulphur City, in the northeastern part of the quadrangle, a spring of similar nature issues from the Wedington formation and gives rise to a local resort. So far as the writer knows, no analysis of either of these springs has ever been made.

Uses of the water.—The city of Fayetteville receives its water supply from West Fork of White River, the water being pumped 2 miles into a reservoir on a hillside overlooking the place. Aside from this, practically no use is made of the water of the area except for domestic and stock purposes. The gradient of the streams is considerable, and in some places power might be secured to run small mills, but it is not so utilized, probably owing to the fact that it could not be relied upon during the low water.

The southern part of Frog Bayou valley is coming to be generally utilized for the culture of fruit and vegetables, and it appears wholly practicable for the water of that stream to be used for irrigation purposes, thus insuring the crops against droughts, which are not infrequent. Even during seasons of average rainfall, such use of the water would yield sufficient returns in the way of increased production and improved quality of fruit to justify the expenditure for irrigation ditches. The same could be said of the valley of Lee Creek, were it supplied with transportation facilities.

WATER RESOURCES OF THE CONTACT REGION BETWEEN THE PALEOZOIC AND MISSISSIPPI EMBAYMENT DEPOSITS IN NORTHERN ARKANSAS.

By A. H. PURDUE.

GENERAL STATEMENT.

The area treated in this paper consists of a belt of land from 12 to 15 miles wide lying along the western border of the lowlands north of Arkansas River and also of a narrow belt of the highlands adjacent.

The field work was done in August and the early part of September, 1903. The object was to map the contact between the highlands and the lowlands in that part of Arkansas north of Arkansas River, ascertain the stratigraphic relations between the rocks of the two areas, determine the water horizons and the sources of water in each, and solve such other economic questions as the depth, amount, permanency, and character of the water.

The work was less thorough than is to be desired, made so by the short time at command, the want of good maps, the uncertain location of the roads in the forest-covered portion, the sparse population of some parts, and the fact that much of the population consists of tenants who are unable to give the necessary land descriptions to enable one to map with accuracy. For these reasons future workers may change somewhat the mapping of the contact between the Paleozoic and Tertiary areas. However, such inaccuracies as may exist are but small ones, and the mapping herein presented can be taken as correct for all practical purposes.

GEOGRAPHIC FEATURES.

TOPOGRAPHY OF THE LOWLANDS.

The lowlands of Arkansas lie in the eastern and southern parts of the State and comprise about half its area. They are a part of a lowland area of vast extent lying within the Gulf States and reaching northward to a point a short distance beyond the junction of Ohio and Mississippi rivers. The region they cover is known to geologists as the "Embayment Area," and represents the extent of the Gulf of Mexico during Tertiary times.

An idea of the hypsometry of the lowlands may be obtained from the following table of elevations along the St. Louis, Iron Mountain and Southern Railway, beginning at the northern border of the State and extending southward to Arkansas River.[a] In the preparation of this table the railway line "was tied up and adjusted to the line of precise level brought up from the Gulf of Mexico by the United States Coast and Geodetic Survey."

Elevations along St. Louis, Iron Mountain and Southern Railway, Arkansas.

Station.	Elevation.	Station.	Elevation.
Moark	297.10	Grandglaise	223.10
Corning	289.10	Bradford	241.10
Colony Lake	282.60	Russell	233.10
Black River	288.10	Bald Knob	220.10
Knoble	280.10	Judsonia	217.10
Peach Orchard	285.10	Little Red River	217.10
Delaplaine	277.60	Kensett	224.10
O'Kean	270.60	Higginson	220.10
Murtha	270.60	Garner	220.60
Walnut Ridge	270.10	Beebe	244.60
Hoxie	268.10	Ward	238.10
Minturn	260.60	Austin	248.10
Alicia	253.60	Cabot	288.10
Swifton	248.00	Holland	255.10
Tuckerman	241.60	Jacksonville	282.10
Diaz	230.10	McAlmont	271.00
Newport	[a] 227.10	Baring Cross	260.10
White River bridge	232.70	Arkansas River bridge	267.10
Olyphant	220.10		

[a] The track has been raised at Newport, but it is not known how much. Levels from the United States bench mark on the river bank 400 feet north of the elevator make the top of the rail opposite the end of the passenger station 233.07.

It will be seen from an inspection of this table that the elevation of the surface is remarkably uniform. The average elevation of all the stations given is 261.18 feet; that of the highest, Moark, is 297.10 feet; that of the lowest, Judsonia, is 217.10 feet. Notwithstanding this close approach to a uniformity of level, this line, if taken alone, would give an exaggerated idea of the topography of the region, for,

[a] From Ann. Rept. Geol. Survey Arkansas, 1891, vol. 11, pp. 103–104.

running as it does near the contact of the lowlands with the highlands, it varies more from uniformity than would be the case along a north-south line farther eastward. Taken as a whole, there is a slight but gradual fall of the region from the north toward the south, and in the southern part of it from the west toward the east. The small irregularities of the surface that are usually met with are such as have resulted from the formation of natural levees along the overflowing streams and the meandering of such streams.

The only place within the region where there is any approach to marked topographic features is in the southern part, where there is

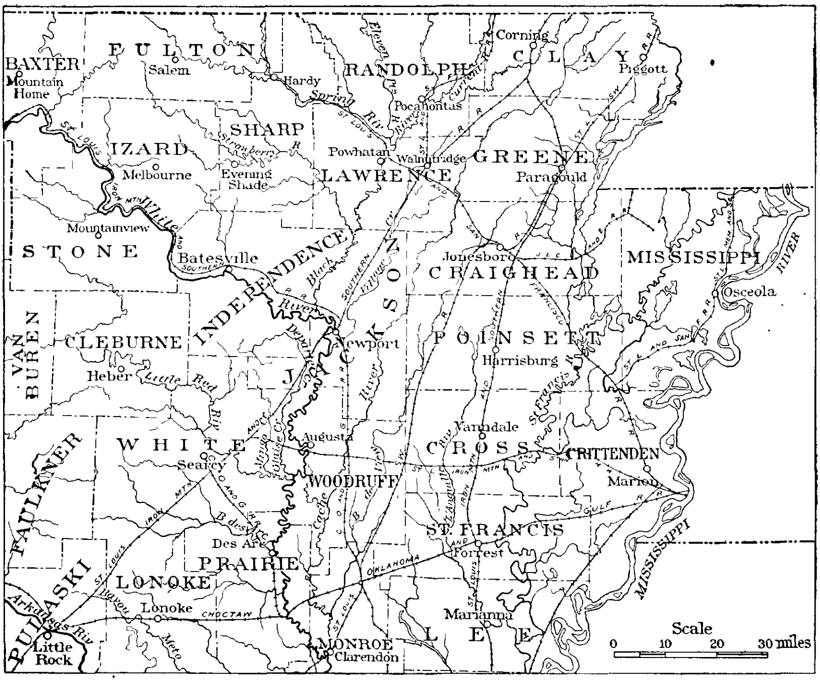
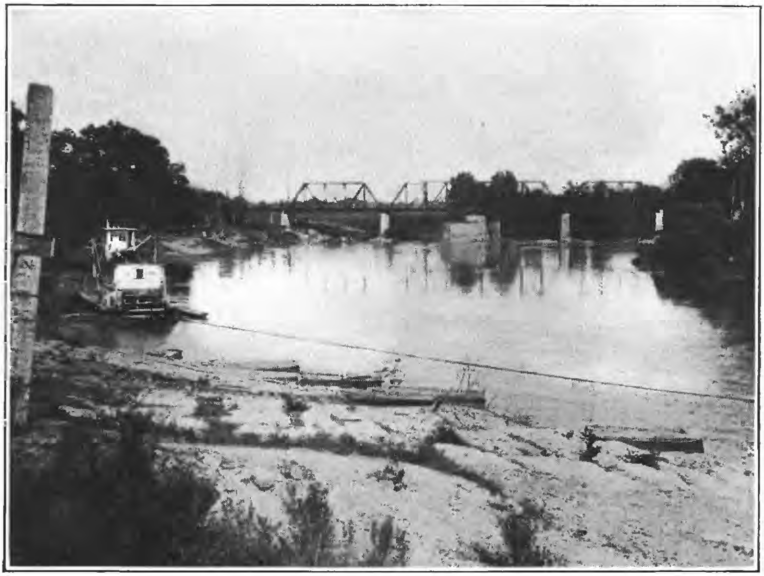


FIG. 15.—Drainage map of northeastern Arkansas.

a small area of irregular outline a mile east of Jacksonville. North of this, and separated from it by Bayou Two Prairie, is a larger area of the same sort, about 10 miles in length and averaging 2 in width, the northern end being just east of the town of Austin. Each of these elevations is about 350 feet above sea level, or 100 feet higher than the surrounding country.

TOPOGRAPHY OF THE HIGHLANDS.

In marked contrast to the monotonous level of the lowlands is the rugged topography of the adjacent highlands. For the purpose of description this will be considered in two parts—that north and that



A. BLACK RIVER AT BLACKROCK, ARK.

A typical stream of the Paleozoic highlands.

B. A TYPICAL STREAM OF THE LOWLANDS.

south of White River. The former is essentially a plain with a maximum elevation of about 400 feet within the area herein considered, dissected by Dota Creek, Bayou Curia, Strawberry River, Eleven Points Creek, Fourche de Mas River, and other small streams debouching upon the lowlands.

The southern part rises quite rapidly from White River to an elevation of about 800 feet above tide, south of Batesville, and then gradually falls off southward as a dissected, sloping plain, to near the latitude of Beebe, southward from which point the plain is succeeded by a series of east-west ridges, in height from 150 to 250 feet above the surrounding country. This region, like the one to the north, is dissected by numerous streams which flow in a general southeasterly direction and pass out upon the lowlands. Among these are Bull Creek, Bayou des Arc, Little Red River, Glaise Creek, Oats Creek, and Departe Creek.

Throughout the entire contact of the highlands with the lowlands, except in small portions of the southern part, the latter abut against an escarpment of the former, so that the line of contact is pronounced. Between the ridges of the southern part the lowlands pass so gradually into the highlands that it is not always an easy matter to determine where to map the contact of the two. But the ridges bounding the valleys are always truncated at the ends, standing up promontory-like, leaving no doubt as to the line of contact.

DRAINAGE OF THE AREA.

The principal stream of the region is White River, which receives from the west Bayou Meto, Bayou des Arc, Little Red River, Glaise Creek, and Departe Creek; from the north, Village Creek and Black River. The latter has two important tributaries—Spring River, emerging from the highland area, and Current River, which flows southward near the contact of the highlands and lowlands.

As would be expected from the low altitude of the lowlands, the valleys therein extend scarcely beyond the stream borders, and the height of the banks above the stream surface seldom exceeds 20 feet, even at low-water stage. (Pls. I, II, and III.)

GEOLOGY OF THE LOWLANDS.

HISTORY.

PRE-TERTIARY CONDITIONS.

The geologic history of the lowlands antedates the period when the Gulf of Mexico covered the Embayment Area. Previous to that time a great valley had been cut into the Paleozoic rocks by stream erosion, probably aided by faulting.[a] This valley was bounded on the west by the present highlands of Arkansas and Missouri and on the east by the similar highlands of Kentucky and Tennessee, and was several hundred feet deeper than the present surface of the Embayment Area. The edges of the Paleozoic rocks were exposed all around the borders of this old valley, just as their upper parts are now exposed above the lowlands.

Following the formation of the valley there came a subsidence of the area, permitting the waters of the Gulf to extend northward to a point a short distance beyond the present junction of Ohio and Mississippi rivers. This extension of the Gulf took place in late Cretaceous times. During this time material was carried by the streams from the surrounding land areas and spread out over the bottom of the Gulf. The deposits formed at this time are of late Cretaceous age, and now lie buried beneath the younger ones to be considered later.

The character of the Cretaceous deposits within the area herein considered can not be definitely stated, but they probably consist largely of sand, clay, and marl, such being their nature farther south in the Embayment Area.

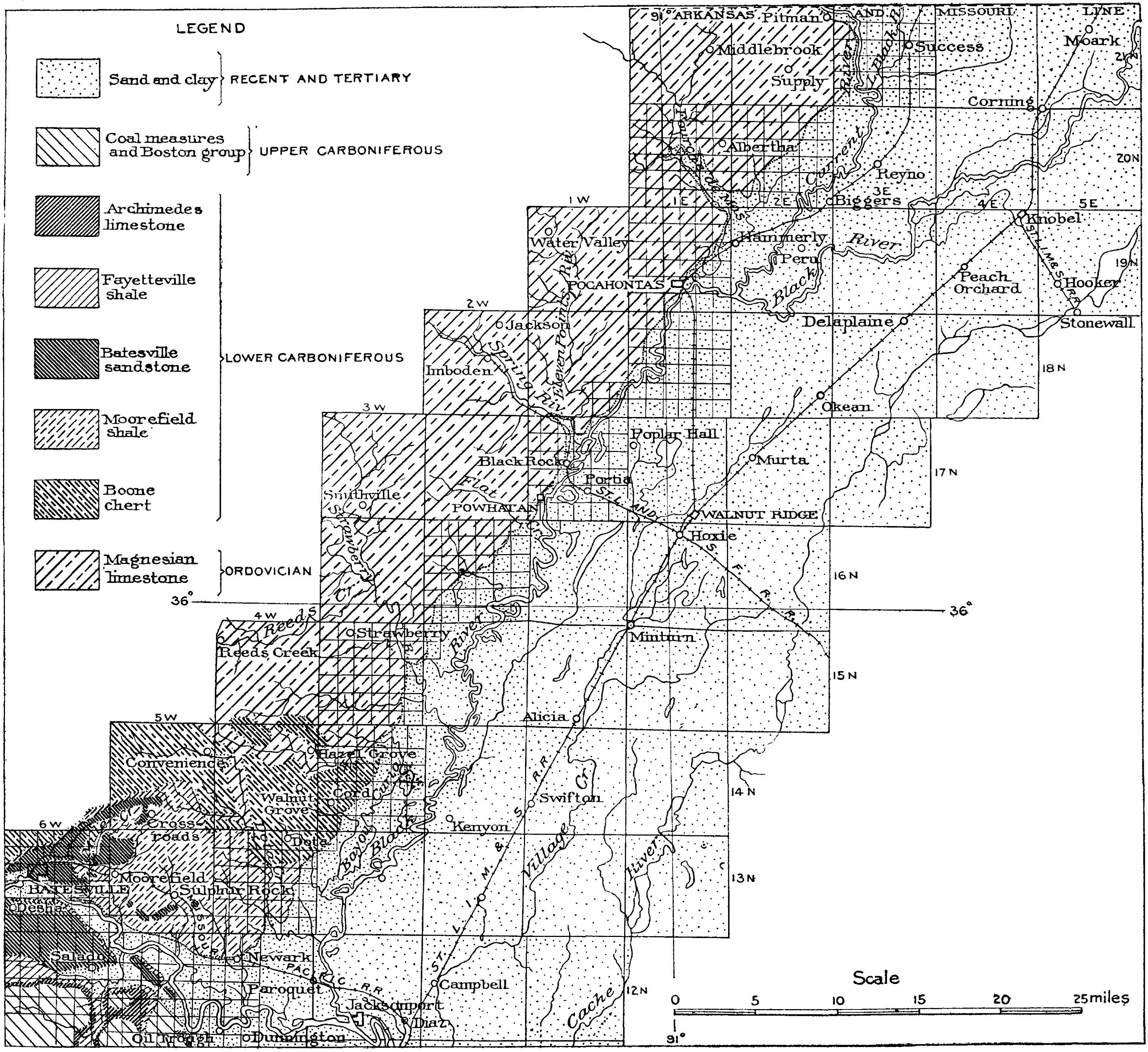
TERTIARY CONDITIONS.

Following the deposition of the Cretaceous strata, there came an increased subsidence of the area,[b] and as a result the borders of the Gulf were somewhat extended landward beyond those of late Cretaceous time. During this time material continued to be washed in large quantities from the land thereabouts and spread out over the Cretaceous deposits, resting against the edges of the old rocks around the border. This was during early Tertiary time, and the material deposited is of Tertiary age. As the region stood at a lower level during early Tertiary time than during late Cretaceous time, the Tertiary deposits therein lap farther over on the Paleozoic rocks than do the underlying Cretaceous.

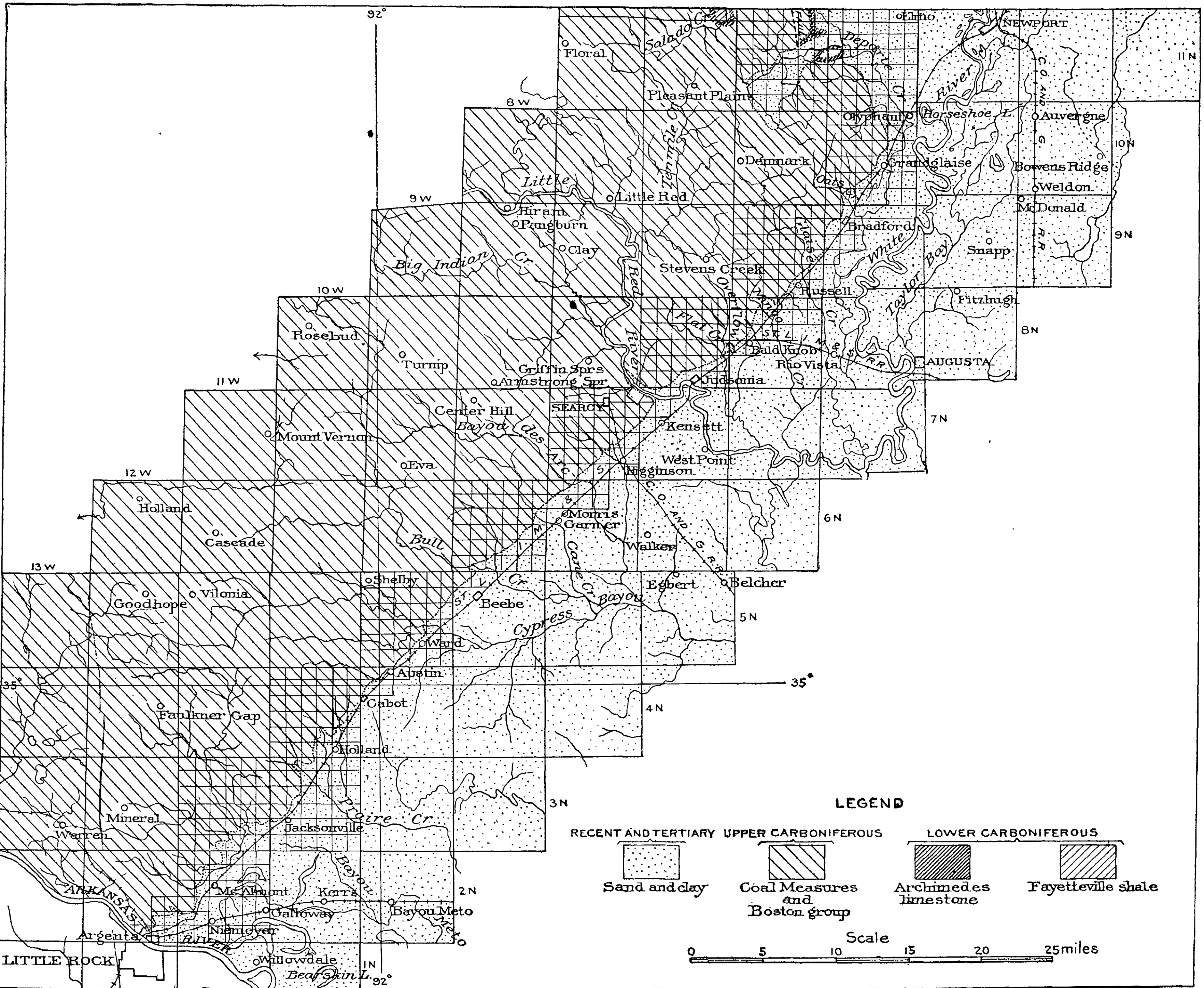
POST-TERTIARY CONDITIONS.

The period of embayment, and consequently of deposition, was brought to a close by the elevation of the region, causing the Gulf to retreat southward and Mississippi and Ohio rivers to extend themselves over the newly formed Tertiary deposits.

[a] Branner, J. C., Am. Jour. Sci., vol. 4, 1897, pp. 357–371.
[b] Harris, G. D., Geol. of Louisiana, 1902, p. 7.



GEOLOGIC MAP OF THE PALEOZOIC AND MISSISSIPPI EMBAYMENT CONTACT IN NORTHERN ARKANSAS (NORTH HALF).



GEOLOGIC MAP OF THE PALEOZOIC AND MISSISSIPPI EMBAYMENT CONTACT IN NORTHERN ARKANSAS (SOUTH HALF).

long to the deposits known as "Orange Sand," "La Fayette formation," or any of the terms employed to designate similar deposits within the Embayment Area, the writer is not prepared to say. But the large quantity and size of the cobblestones, the fact that so great a percentage of them has been derived from the Paleozoic rocks on which they rest, and their general distribution along the Paleozoic escarpment argue against a fluviatile and for a marine origin of them. Whatever may have been their origin, it is certain that these gravels have suffered great change since their original deposition in all places where streams could get hold of them. Fine examples of this may be seen along the streams that are crossed in driving from Sulphur Rock to Newark. The large deposit of gravel on which Newark stands is probably of this worked-over material.

ROCKS.

TERTIARY.

The recent deposits of the lowland area rest upon deposits of the Tertiary period, this being represented by the Eocene rocks, the lowest and oldest of its series. The lowest division of the Eocene is the Midway, with which Doctor Harris has classified the limestone at and about Grandglaise.[a] By referring to the section, fig. 17, p. 94, it will be seen that this limestone lies in a horizontal position, and at a higher level than the Recent deposits to the east. That it does not represent the base of the Tertiary is shown by the occurrence of lignitic beds at Newport, about 11 miles distant, beneath which no limestone has been reported.

CRETACEOUS.

The most northern point within the area from which Cretaceous rocks have been reported is at Beebe, where Doctor Harris notes fossils of this age, taken from beneath the Tertiary in a well.[b] But that Cretaceous rocks extend over the whole of the area appears certain from our present knowledge of its history, according to which there was a subsidence at the close of the Cretaceous,[c] permitting the deposits of that age to be covered by those of Tertiary age.

In the absence of fossils from the deep wells of the region, and because of the similarity of the lower part of the Tertiary and the upper part of the Cretaceous, we are unable to determine the thickness of the latter. One mile southwest of Newport, in sec. 10, T. 11 N., R. 3 W., there is a drilled well, 1,000 feet deep, the deepest in the area studied, in which the following section is reported:

[a] Op. cit.

[b] Geol. of Arkansas, 1892, vol. 2, pp. 10–11, 184.

[c] Harris, G. D., op. cit.; also, Geol. of Louisiana, 1902, p. 7.

ring in the wells at Walnut Ridge, Hoxie, and Alicia represents the lower limit of the Recent deposits, these deposits are about 50 feet thick at the first two places and about 60 feet thick at the third. The assumption that this gravel represents approximately the base of the Recent deposits is supported by the section at Augusta, in which there is reported 100 feet of sand and clay resting upon a thin bed of clay, which in turn rests upon a bed of gypsum. (Fig. 18.)

There can be no doubt but that in this case the 100 feet of sand and clay are of Recent age. The thickness of the Recent deposits is shown

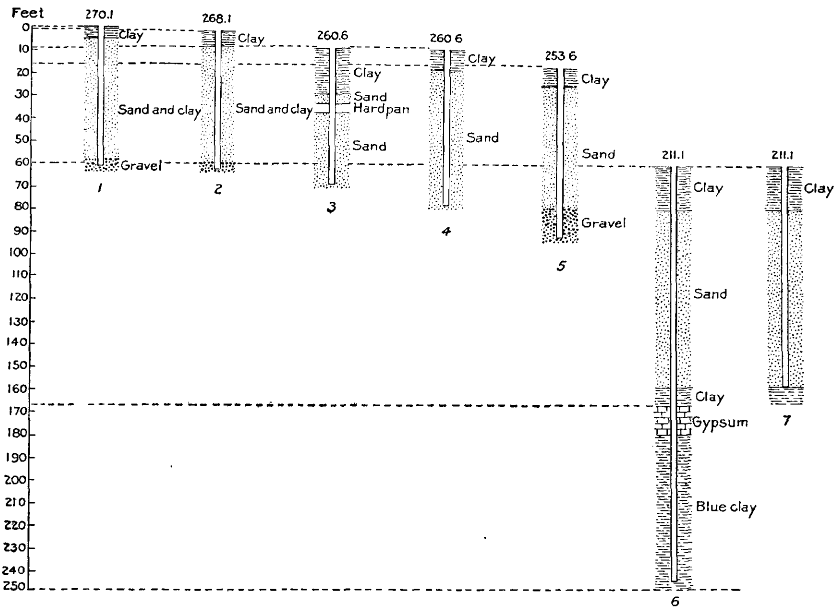


FIG. 18.—Well sections. 1, Well of Trumbull Wagon Co., Walnut Ridge; 2, well of the Iron Mountain Railway Co., Hoxie; 3, well of the Southern Cooperage Co., Minturn; 4, well of A. W. Shirrey, Minturn; 5, well of Iron Mountain Railway Co., Alicia; 6 and 7, wells of Campbell & Vinson, Augusta. Figures at top show the surface elevations of the near-by railway stations.

also in the section of the deep well at Newport, described later, where 105 feet of sand and clay, mainly sand, are reported as resting on "soapstone." The sand and clay in this case are of Recent age.

Gravels.—All along the Paleozoic border and lying upon the slopes of the escarpment above the Tertiary there are deposits of gravel and cobblestones of all sizes up to 6 inches or more in diameter. They are well rounded and have been derived largely, if not entirely, from the Paleozoic area adjacent to the Tertiary. In places they are cemented into conglomerate. The altitude of their upper limit is about 500 feet above sea level, or from 250 to 275 feet above the present level of the lowland area. As to whether these gravels are of Tertiary age or be-by Bayou Two Prairie. With the exception of a bed of thinly laminated sandstone near the top of the ridge, rarely exceeding a foot in thickness, the material of these elevations is unindurated. It is, however, of an open, clayey nature, and has the power of standing unsupported in vertical walls for years.

Grandglaise area.—Another erosion remnant of Tertiary rocks lying along the western border, extending from Coffeyville southward to Bradford, is herein designated the Grandglaise area. The rocks of this area consist of indurated material, varying in character from a rather sandy limestone to one of comparative purity, most of it being quite fossiliferous. The beds lie in a horizontal position against the old Paleozoic rocks and occupy the narrow strip between the Iron Mountain Railway and the highlands.

Their greatest height is about 100 feet above the lowlands to the east. This limestone is mentioned by Dr. G. D. Harris,[a] and is classified by him as belonging to the Midway or lower stage of the Eocene Tertiary.

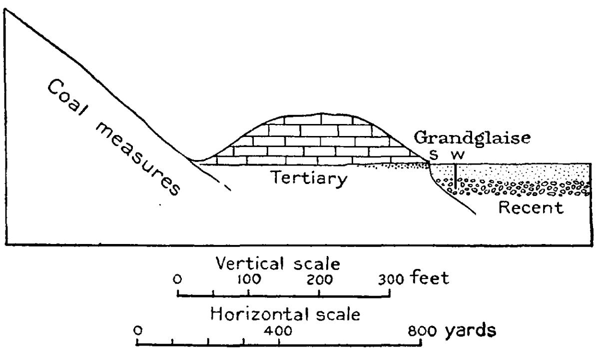


FIG. 17.—Section at Grandglaise, Ark. *w*, Well; *s*, spring.

DEPOSITS.

Sand and clay.—The lowland area, aside from the erosion remnants mentioned above, is covered with Recent river deposits consisting of sand and clay. Much the greater part is sand. Where clay is reported it is usually near the surface. In places there are as many as three thin beds within 40 feet of the surface. These beds are of uncertain extent, apparently occurring as lenses in the sand.

The number of deep-well sections is so limited as to make it impossible to ascertain the thickness of the Recent deposits over much of the area; but they of course vary with the topography of the old valleys before the filling began. On the supposition, yet remaining to be confirmed, that the gravel mentioned later in this paper as occur-

[a] Geol. Survey Arkansas, 1892, vol. 2, p. 24.

EROSION.

Crowleys Ridge.—At this time the Mississippi flowed to the west of what is now Crowleys Ridge and the Ohio to the east of that area. Each of these streams wore away the Tertiary deposits to considerable depths, cutting out a wide valley and leaving Crowleys Ridge[a] as a remnant of the bed which, before the erosion took place, extended westward to the Arkansas highlands and eastward to those of Kentucky and Tennessee. According to Professor Branner, the height of Crowleys Ridge in Arkansas is "about 350 feet above the present tide level, 120 feet above the lowlands to the east and west." According to Professor Marbut, as indicated by the topographic map accompanying his paper, it reaches in Missouri the height of 600 feet, or 280 feet above the lowlands.

The thickness of 120 feet in Arkansas and 280 feet in Missouri does not indicate the total amount of erosion, for while the valleys to the east and the west of the ridge were being formed the top of the ridge itself was suffering erosion. Just how much of it was removed

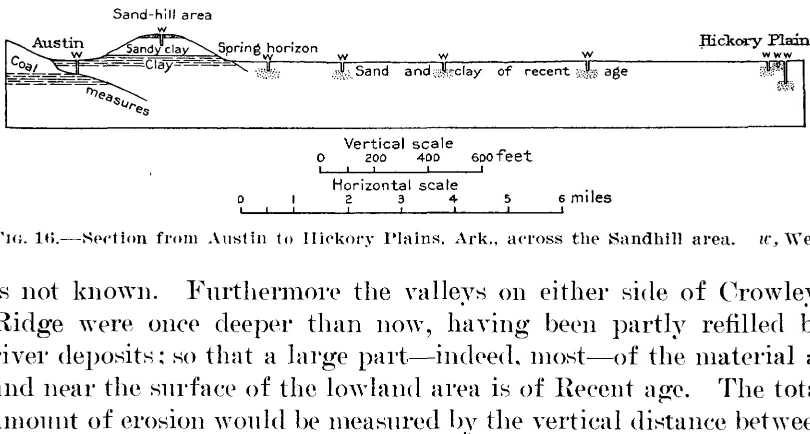


FIG. 16.—Section from Austin to Hickory Plains, Ark., across the Sandhill area. *w*, Well.

is not known. Furthermore the valleys on either side of Crowleys Ridge were once deeper than now, having been partly refilled by river deposits; so that a large part—indeed, most—of the material at and near the surface of the lowland area is of Recent age. The total amount of erosion would be measured by the vertical distance between the base of the Recent deposits and the original surface of the Tertiary.

Sandhill area.—As above stated, Crowleys Ridge is a remnant of the formerly widespread Tertiary rocks. The ridge mentioned under the head "Topography of the lowlands," extending southward from the town of Austin, is locally known as the Sandhill, a name adopted here for want of a better. This ridge also is an erosion remnant of Tertiary rocks, similar to Crowleys Ridge. As the name implies, the soil is sandy. The other small hill east of Jacksonville is of the same origin and character as this, having been cut off from it

[a] For the history of Crowleys Ridge see Branner, J. C., Geol. Survey Arkansas, 1889, vol. 2, preface, pp. xiii, xiv; also Marbut, C. F., The evolution of the northern part of the lowlands of southwestern Missouri: Univ. of Mo. Studies, vol. 1, No. 2, 1902.

Section of well near Newport, Ark.

	Feet.
Clay and sand	30
Sand	75
"Soapstone"	50
Quicksand	500
Rock of different kinds, ending in flint	345

The 105 feet of clay and sand at the top are of Recent age; the rocks from the base of the quicksand downward are supposedly Paleozoic. The 550 feet between the Recent and the Paleozoic may all be Cretaceous, though it is possible that the upper 50 feet, reported as "soapstone," is Tertiary.

PALEOZOIC.

The great mass of the substrata consists of Paleozoic rocks, in age passing from the Ordovician in the northern part to the upper Carboniferous in the southern part. The younger rocks lie unconformably upon these, resting against their truncated edges around the borders. (Figs. 16, 17, 21, 23, and 25.)

The Ordovician are the underlying rocks from the northern part of the area to about the latitude of Newport. South of there these rocks pass under those of Carboniferous age. (See fig. 8.) The kinds of rocks constituting the Ordovician, which would be penetrated in deep-well drilling north of Newport, after having gone through the unconsolidated Tertiary and Cretaceous beds, can be ascertained by referring to fig. 19. South of Newport shales, sandstones, limestones, and chert beds of Carboniferous age would be penetrated before reaching the rocks shown in fig. 19. The thickness of the Carboniferous rocks above the Ordovician would increase with the distance south from Newport.

GEOLOGY OF THE HIGHLANDS.

ROCKS.

As the rocks of the highland area lie in a practically horizontal position and the formations are of wide extent, the geology of the border can not well be discussed without at the same time including that of the entire highland area of the northern part of the State. The rocks of this area have long been known to be of Paleozoic age, the divisions represented being the Ordovician, Silurian, Devonian, and Carboniferous.

ORDOVICIAN.

The Ordovician rocks, which constitute most of the exposures north of White River within the area considered in this paper, consist mainly of magnesian limestone, though there are several beds of sandstone and some chert among them. Their lower limit is un-

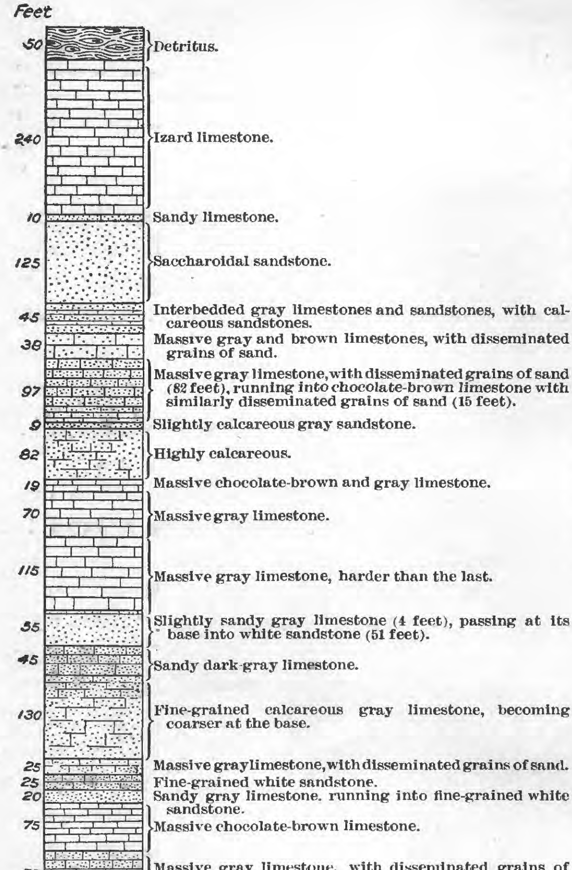


FIG. 19.—Section of deep well at Cushman, Ark.

known, but that it is very deep is disclosed by the section of a well at Cushman, heretofore published by the Geological Survey of Arkansas.[a] This well passes through 2,040 feet of Ordovician rocks without reaching their lower limit. As this section represents the most complete knowledge of the stratigraphy available, it is reproduced here.

SILURIAN.

St. Clair formation.—The Silurian is represented by the St. Clair formation. This is usually of a pinkish-gray color, and is generally highly crystalline. Where exposed it commonly shows in heavy layers which, as Doctor Hopkins observes, have probably been brought out by weathering, but sometimes it is massive. Its maximum thickness, as reported by Dr. T. C. Hopkins,[b] is 155 feet at Penters Bluff on White River. This

[a] Ann. Rept. Geol. Survey Arkansas, 1890, vol. 1, p. 118.
[b] Ann. Rept. Geol. Survey Arkansas, 1890, vol. 4, p. 214.

formation extends far to the westward from the longitude of Moorefield, but does not occur on the eastern border of the Paleozoic area.

DEVONIAN.

Sandstone lentil of Sylamore formation.—The sandstone lentil of the Sylamore formation, where observed by the present writer, varies greatly in character from a coarse-grained, saccharoidal sandstone, through a black, nodular, conglomerate-like rock, to black shale. When saccharoidal it is specked here and there by particles of limonite, which have resulted from the alteration of iron pyrite. Its thickness varies greatly within short distances, and in places it is entirely wanting. This formation is thought by Dr. H. S. Williams to belong to "the very close of the Devonian and the beginning of the Carboniferous." [a]

CARBONIFEROUS.

The rocks that belong to the Carboniferous and that enter into the hydrology of the eastern Paleozoic border are as follows, beginning with the lowermost: St. Joe limestone member of the Boone formation, Boone chert, Moorefield shale, Batesville sandstone, Fayetteville formation, Pitkin (Archimedes) limestone, Morrow formation (Boston group), and Coal Measures, or Pennsylvanian.

The first four of these belong to the Mississippian series. The position of the Pitkin limestone is yet doubtful, but the probability is that it also belongs to the Mississippian. The Boston group and the Coal Measures, which are mapped together, consist of 400 feet of sandstone and shale, containing at least one and probably two beds of limestone.

St. Joe limestone member, Boone formation.—The lowest member of the Carboniferous is the St. Joe marble, a more or less crystalline limestone, varying in color from gray to red, usually thin bedded, and from 25 to 50 feet thick. This formation has not been observed along the eastern border of the Paleozoic area.

Boone chert.—The Boone chert, which lies above the St. Joe member, is over 300 feet in thickness. It is essentially a bed of limestone, in places quite crystalline, containing a large amount of chert in lenses parallel with the bedding. The relative amounts of calcareous material and chert vary greatly, both horizontally and vertically. In places the formation is chiefly limestone, while in others the chert constitutes practically the entire mass. So abundant is the chert in all places where this formation is exposed that a large amount of detrital material occurs on the surface as a residual product left from the solution by underground water of the calcareous material with which it is associated. The calcareous beds are

[a] Ann. Rept. Geol. Survey Arkansas, 1892, vol. 5, p. 319.

penetrated by numerous joints, which in many places have been enlarged by solution into caverns, and the cherty portions are always profoundly fractured.

Moorefield shale.—Resting upon the Boone formation in the eastern part of the Paleozoic area is a bed of shale somewhat more than 100 feet thick. This formation is wedge-shaped, thinning out westward, and is wanting in the central and western parts of the State. It was mapped in the reports of the Arkansas Geological Survey as Fayetteville shale on the belief that it was in the same stratigraphic position occupied by that formation in the western part of the State, where it is typically represented. But while it closely resembles the Fayetteville shale it differs from it in that the laminæ are thicker, in having greater resistance to atmospheric action, and in being of a duller dark color. Hence the new name Moorefield shale has been adopted, it being typically developed at the town of Moorefield.

Batesville sandstone.—Above the Moorefield shale is the Batesville sandstone, which, on the south side of White River at Batesville, has a thickness of something more than 100 feet. It lies in beds which vary from a few inches to 3 or 4 feet in thickness, is of a brown color, and of considerable porosity. Quarries in this stone furnish beautiful slabs of almost any thickness and size desired. This formation gradually thins to the western part of the State, where it is usually only a few feet thick and in many places is entirely absent. This is the same sandstone that is known as the Wyman sandstone in the reports of the Arkansas Geological Survey.[a] As the Moorefield shale is absent in the central and western parts of the State, the Batesville sandstone, when present there, rests directly upon Boone chert. When the Batesville sandstone is absent the Fayetteville shale rests upon the Boone chert.

Fayetteville formation.—The Fayetteville shale is of wide extent, reaching from the eastern border of the Paleozoic area westward, far beyond the borders of the State. It is seldom less than 25 extent, reaching from the eastern border of the Paleozoic area westward, far beyond the borders of the State. It is seldom less than 25 feet thick and in many places exceeds 100 feet, especially along the eastern border of the Paleozoic area. It is of a lively dark color, very thinly laminated, easily broken down under atmospheric influences, is intersected by numerous clean-cut joints, and contains a great many concretions of large size. Though of wide east-west extent, it is of uniform nature throughout. Indeed, the uniform lithologic character of the different formations constituting the Paleozoic rocks of northern Arkansas is one of the features of the geology that most strongly impress themselves upon the observer in the field.

Pitkin (Archimedes) limestone.—The Pitkin limestone, which in the eastern and central parts of the Paleozoic area rests upon the

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[a] 1888, vol. 4, pp. 38–41.

Fayetteville shale, is usually from 10 to 20 feet thick. But in the eastern part of the region, between Salado Creek and Goodey Creek, it is 100 feet thick. As a rule, it is composed practically entirely of calcareous matter, but in places contains enough siliceous matter to give it the appearance of the Boone chert.

As above stated, there is, in the eastern part of the Paleozoic area above the Pitkin limestone, about 400 feet of sandstone and shale, including a small amount of limestone. This is mapped together as the Boston formation and the Coal Measures.

STRUCTURE OF THE HIGHLANDS.

The structure of the northern part of the region is on the whole quite simple, the beds dipping southward at a low angle, this dip being disturbed locally by faults of greater or less throw, and by small flexures. In the flexuring some of the more brittle rock, especially of the Ordovician area, suffered a great deal of fracturing, producing brecciated belts of greater or less width. The accompanying section through Batesville to the summit of the Boston Mountains (fig. 20) gives a general idea of the structure and stratigraphy of the region. That portion of the section south of Batesville represents the structure and stratigraphy as determined by the writer. That north is adapted from a section by Dr. R. A. F. Penrose, jr.[a]

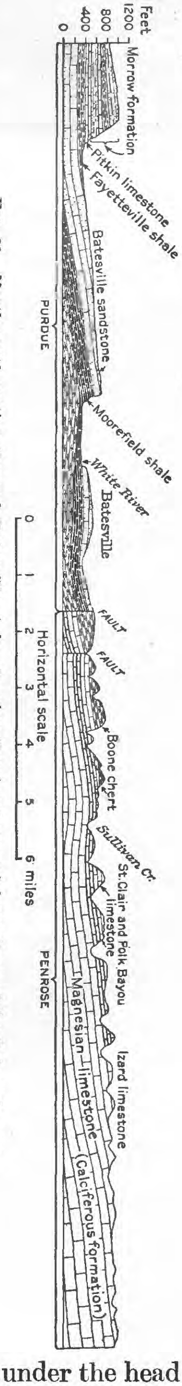


FIG. 20.—North-south section through Batesville, Ark., showing the structure and formations of the Paleozoic area.

South of the Boston Mountains, near the latitude of the town of Beebe, the usual south dip of the rocks is succeeded by east-west anticlinal and synclinal folds. These folds are the result of the northward-diminishing tangential force which, south of Arkansas River, is expressed in the Ouachita Mountains.

PALEOZOIC-TERTIARY CONTACT.

PALEOZOIC ESCARPMENT.

The Paleozoic escarpment along the line of the Paleozoic-Tertiary contact has already been alluded to under the head of "Topography of the highlands." This escarpment is of such

[a] Geol. Survey Arkansas, 1890, vol. 1, pocket map.

nature as to make it certain that during Tertiary time, when the waters of the Gulf of Mexico covered all of what is now the lowland area of the State, the plateau portion of the Paleozoic area terminated along the seashore in bold, high cliffs, while the east-west ridges of the region to the south projected into the sea as capes.

Fig. 21 shows the general relations of the rocks of the two different ages. It will be noticed by an inspection of this figure that the

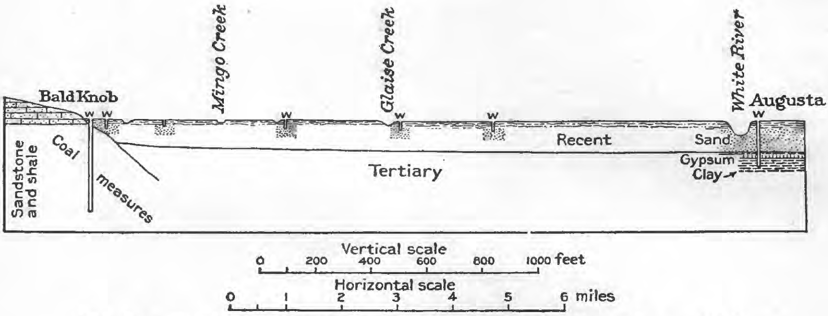


FIG. 21.—Section from Bald Knob eastward to Augusta, Ark. *w*. Well.

Paleozoic rocks pass at a high angle beneath those of later age. The same thing is shown by the section at Newark (fig. 25, p. 109), and many other similar sections might be produced.

OSCILLATIONS DURING TERTIARY TIME.

The above-mentioned sections, together with the steep nature of the Paleozoic escarpment in many places, indicate that the shore line

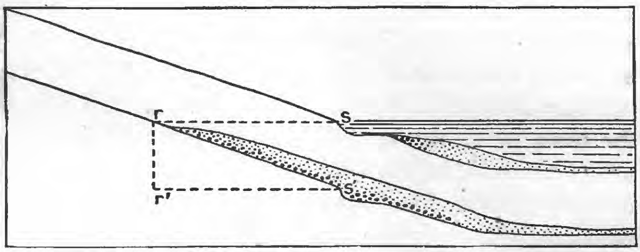


FIG. 22.—Diagram showing encroachment of the sea upon the land as a result of land subsidence. *s*, Position of the shore line before subsidence; *r*, position after subsidence; *rr'*, amount of subsidence; *sr*, the transgression of the sea upon the land as a result of the subsidence.

must have remained at about the present level of the lowlands for some time—long enough for the wave action to have worn away the Paleozoic rocks to their present form. On the other hand, the slope of the part of the Paleozoic escarpment above the line of contact, over which the plateau gravel is distributed, is so gradual as to permit wagon roads over it. At some time during the Tertiary period the Paleozoic region must have subsided to a point at least 500 feet lower than its present height, that being the height above sea level of the upper limit of the gravel. This will be understood by an inspection of fig. 22. If the shore line remains stationary for some time a terrace will be produced, as is shown at s; but if, after subsidence begins, it continues as a gradual movement, bringing about a constant shifting of the shore line landward, then at most but faint terracing will take place. The writer observed no terraces over the region of the plateau gravel, though it would not be surprising if more careful search should lead to their discovery. At any rate, the topography of the plateau gravel indicates that there was a gradual transgression of the Tertiary sea westward from about the present margin of the lowlands until the region sank 500 feet below its present level, after which it was reelevated. It is altogether reasonable to assume that at least a part if not all of the gravel was formed at the time of the upward impulse as a result of the rejuvenation of the streams.

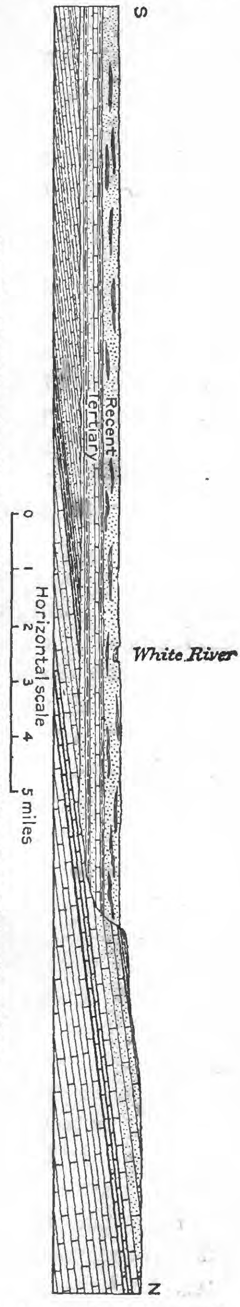


FIG. 23.—Generalized north-south section showing relations of Paleozoic and later formations.

STRUCTURAL RELATIONS OF THE PALEOZOIC AND LATER FORMATIONS.

The stratigraphic relations of the Paleozoic and younger formations may be seen by an inspection of figs. 21, 22, 23, and 25. The origin of these relations will be understood when it is recalled that the older rocks formerly extended eastward and joined onto the same rocks in the highlands beyond Mississippi River and were worn away by streams and wave action until their truncated edges occupied their present position, after which the younger formations were laid down upon them, abutting against their truncated edges. It will be noticed that in an east-west section the rocks of both ages are practically horizontal. It has already been stated that the general dip of the Paleozoic rocks is southward. This and the fact that the line of contact between the Paleozoic and the younger rocks is northeast-southwest brings the older rocks under the younger along the north-south line, as shown in fig. 23.

UNDERGROUND WATER RESOURCES.

GENERAL STATEMENT.

By underground water, or ground water, is meant the water in the rocks of the earth, whether those rocks consist of indurated or loose material. The source of all water of the land is the ocean, from which it is carried by the winds in the form of vapor and precipitated from the atmosphere as rain, snow, hail, and sleet. Falling upon the earth, a part of this water, which collectively is known as meteoric water, enters the ground, and in so doing becomes ground water. Another part flows off over the surface and is known as run-off. Whether a particle of water becomes ground water or run-off, it in either case at once seeks its way back toward the ocean. This is as true of the ground water as of the run-off, though the usual velocity of the former is much less than that of the latter. Indeed at times it may be nil.

The relative amounts of run-off and ground water depend upon a great many things, among which are the slope, the character of the surface material, the presence or absence of vegetation, and the time distribution of the rainfall.

A steep slope is conducive to a large run-off and a small amount of ground water; a flat slope, to a small run-off and a large amount of ground water. A thin soil is conducive to a large run-off and small amount of ground water; a thick soil, to a small run-off and large amount of ground water. Absence of vegetation is conducive to a large run-off and a small amount of ground water; the presence of vegetation, to a small run-off and a large amount of ground water. Compact rocks are conducive to a large run-off and a small amount of ground water; porous ones, to a small run-off and a large amount of ground water. Torrential rainfalls are conducive to a large run-off and a small amount of ground water; slow rains, to a small run-off and a large amount of ground water.

Favorable conditions for the occurrence of ground water are those in which porous rocks, as sandstone, are exposed at the surface and are underlain by close-textured rocks, as shale. An area of porous rocks so exposed is known as a catchment or collecting area.

The upper limit of saturation of the rocks is known as the water table; otherwise as the ground-water level, or the ground-water surface. All the rocks beneath the surface within a limited area may contain all the water they are capable of holding; the water table is then either at the ground surface or above it, in the latter case producing ponds. Or there may be a zone of rock in which there is but little water, this zone being bounded by the ground surface above and the water surface below; such a zone varies in thickness in different localities and in the same locality with the wet and dry seasons. Wells sunk into the ground below the water table fill up to it. Streams that have cut their valleys below the water table drain off the ground water, which issues as seeps and springs.

In a region like the lowland area of Arkansas, where the surface is level and the material constituting the sediments is loose and sandy, the water table is well defined and is practically parallel with the surface. But in a hilly region of consolidated rocks it is usually poorly defined and conforms to the surface only in a general way. Usually it is farther from the surface on the hills than in the valleys; so that, as a rule, wells on hills are of necessity deeper than those in adjacent valleys.

The amount of water that a formation contains depends upon a great many things, among which are its thickness, porosity, relation to other beds, and the amount and time distribution of the rainfall. It goes without saying that if all else is equal a thick formation is a better source of water than a thin one; also that a porous formation is a better water producer than a less porous one. Sandstones and pudding stones contain a great deal of water under favorable conditions; loose sand and gravel contain more; shale and clay, being close textured, neither hold much nor permit the passage of much through them.

Limestones are usually compact in hand specimens, but in the beds they are jointed, the joints frequently having been greatly enlarged by the solvent power of the water that finds its way through them. So that a formation of limestone resting upon a bed of shale is almost certain to be, as in the case of sandstone similarly situated, an important water producer.

UNDERGROUND WATER OF THE HIGHLANDS.

As already stated, the rocks ot the Paleozoic area consist of a great thickness of Ordovician limestone, upon which is superimposed, in the eastern part of the area, sandstones, shales, and limestones aggregating 1,100 feet or more in thickness. Among these rocks along the eastern border there are four important water horizons.

ORDOVICIAN.

The lowest of these in the geologic column is in the great deposit of Ordovician limestone which is spread over a considerable area in the northern part of the State. As the topography of this region is somewhat old, the former steep slopes having been worn off into more or less rounded ones, and as the rocks themselves are considerably fractured along lines of folding, permitting the water to enter, the conditions are such as to result in a considerable supply of ground water.

This water issues as springs along those courses where denudation has brought the stream valleys below the ground-water level. Wells are not uncommon, but, as the water table is frequently some distance from the surface on the divides between the streams, cisterns are frequently resorted to for water supply. An additional reason, however, for the use of cisterns is found in the fact that the water of this region, moving as it does almost entirely through limestone, is very hard.

The most common method of sinking wells in this horizon is by digging and blasting, but drilling is sometimes resorted to. It will be remembered that in the quest of water in limestone, success depends upon striking a water-producing fissure, the stone being so compact as to prohibit water from moving through it except along lines of fracture. In so far as the chances of striking a fissure are increased by increase of well diameter, blasting is the most promising method; but, on the other hand, the chances of striking a fissure are greater in a deep well than in a shallow one, and as the cost of drilling is much less than that of blasting, the former method is advisable in most cases. Especially is this true when the sanitary advantages of a carefully cased drilled well over an open one are taken into consideration.

CARBONIFEROUS.

Boone formation.—The next water-bearing stratum of importance in the eastern part of the Paleozoic area is in the Boone formation. The great thickness of this, together with the much-fractured character of its chert and the jointed structure of its limestone, combine to make it the most important water-bearing formation in the Paleozoic region of northern Arkansas. Where this is the surface rock, the limestone of the upper part has been removed by solution, but the insoluble chert is left as a residue upon the surface, in many places several inches thick. In such places this chert débris largely reduces the run-off and by so much adds to the ground water. The large number of joints in the limestone permit the water to descend, and the fractured nature of the chert lenses allows it to be freely transmitted horizontally.

Along the courses of the streams which have cut their channels into this chert below the water table issue many strong, beautiful springs, and, except on the high divides, an abundance of water can be secured from it by digging wells. As a large part of the formation is chert and practically insoluble, the water is not particularly hard.

Batesville sandstone.—The Batesville sandstone, lying between the Moorefield shale below and the Fayetteville formation above, is a water-bearing horizon of much importance. This formation at Batesville is about 100 feet thick. It is the surface rock over a considerable area, and being of a porous nature, collects a great deal of water which is retained because of the thick bed of impervious shale beneath. Within the area of the Batesville sandstone that formation furnishes practically all the water that is used. It was the source of the water supply at the city of Batesville before the water plant was installed there. Wells sunk almost anywhere in this rock furnish water, and springs emerge from it along the stream valleys. The water is soft and well adapted to domestic uses.

Pitkin (Archimedes) limestone.—The next water-producing stratum of importance is the Pitkin limestone. This formation lies at the top of the Fayetteville shale (fig. 20) and beneath several hundred feet of sandstone and shale. It is considerably jointed, and this fact together with its stratigraphic position makes it an important spring horizon. Its jointed nature permits it to receive the water that comes from above, which the impervious Fayetteville formation prevents from escaping below, so that springs are common at the base of this formation on the hillsides where it outcrops. As might be expected, the water is hard.

Morrow formation (Boston group) and Coal Measures.—Along the eastern border of the Paleozoic area there are 400 feet of sandstone and shale, with some limestone, above the Pitkin limestone. In this there are several water horizons of minor importance. Near the top of the Boston Mountains the sandstone becomes coarse grained, even approaching a conglomerate. This coarse character of the rock makes it a good water producer, and wells are common even on the highest parts.

UNDERGROUND WATER OF THE LOWLANDS.

ORIGIN OF THE WATER.

The ground water of the Arkansas lowlands has three sources: (1) That which sinks directly into the ground from the rainfall; (2) that which leaks from the streams flowing from the Paleozoic region; (3) that which leaks from the truncated edges of the Paleozoic rocks.

Rainfall.—Though no data is at hand by which the amount supplied from each of these sources can be approximated, there is hardly a doubt but that the principal source is the first one mentioned. The average annual rainfall, according to the records kept by the United States Weather Bureau at Newport, extending over several years, is about 48 inches. The extremely level surface, the open, sandy nature of the soil, and the large amount of sand in the recent deposits are all conducive to a small run-off and a large amount of ground water. While a large portion of the surface of the lowlands is of a clayey nature, it is sufficiently porous to permit the water to pass through it into the sandy beds below. That portion of the area from Newport northward and extending westward to Black River is very sandy. There is also a great deal of sand between Newport and Augusta east of White River. This surface sand serves as a collecting reservoir in which the rain water is held while it slowly sinks into the strata beneath.

Stream leakage.—The amount that is supplied by stream leakage, while problematical, is doubtless large. It is a matter of common observation by those who live near the principal streams that the wells rise and fall with the fluctuations of the streams. If the statements of the people can be relied upon, wells situated several miles from Black River and White River are thus affected. The

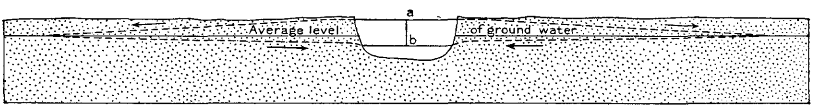


FIG. 24.—Diagram showing the infiltration of water from a stream into adjacent sandy beds.

reasons for this will be made apparent by reference to fig. 24. The unconsolidated and usually sandy nature of the material permits the free movement of the water either toward or away from the river, according to the slope of the water table. While the river is at the height *a*, and above the general level of the ground water, the movement will be from the river outward. During such times an enormous amount of water is contributed by streams to the region on either side. When the level of the stream is at *b*, below the general level of the ground water, the movement is toward the stream, which is then changed from a source of supply to a line of drainage; but as the surfaces of the main streams are seldom more than 20 feet below the country on either side, the zone which they can at any time drain is limited to a depth of only a few feet from the surface, represented by the line *ab*.

Leakage from the Paleozoic rocks.—The amount of water supplied by this source, while probably smaller than that from either of the others, must be considerable. The edges of the Paleozoic rocks are truncated to a considerable depth, and the loose deposits abut against the truncated edges. (See figs. 16, 17, 21, 23, and 25.) With this in mind, also remembering that the Tertiary-Paleozoic line of contact has a northeast-southwest course, and that the Paleozoic rocks dip south, it will be seen that the leakage from the old into the young rocks must be very great.

WATER HORIZONS.

There are but three areas within the region, all of limited extent, where well-defined water horizons have been made out above the Paleozoic rocks. These will be designated as the Newark, Grandglaise, and Sandhill horizons.

OCCURRENCE.

Newark horizon.—Attention has already been called to the gravel at Newark as a source of water. The considerable amount of this gravel, its unconsolidated nature, its stratigraphic situation on the Moorefield shale, and its location on the border of the highlands from

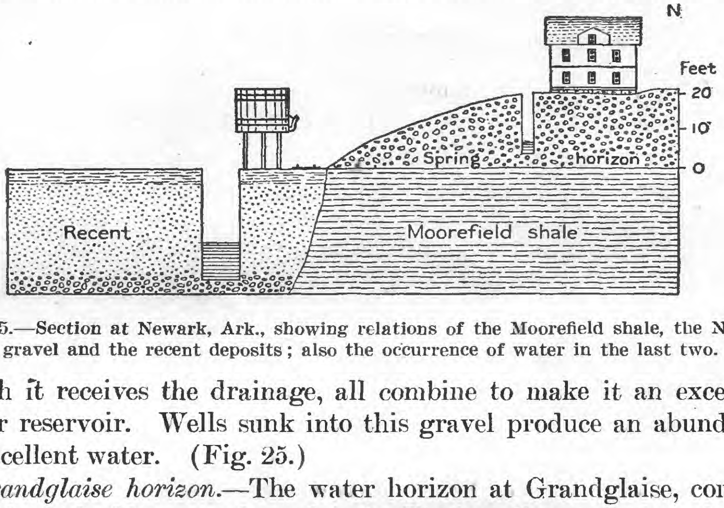


FIG. 25.—Section at Newark, Ark., showing relations of the Moorefield shale, the Newark gravel and the recent deposits; also the occurrence of water in the last two.

which it receives the drainage, all combine to make it an excellent water reservoir. Wells sunk into this gravel produce an abundance of excellent water. (Fig. 25.)

Grandglaise horizon.—The water horizon at Grandglaise, consisting of a bed of loose sand overlain by Tertiary limestone, has already had attention under the head of "Springs." It is probable that this sand is underlain by clay, though no exposure was observed where it could be seen.

Sandhill horizon.—In the Sandhill area there is a well-defined water horizon above the bed of clay which underlies the ridge. (Fig. 16.) This horizon is due to the sandy surface, which makes it a good collecting area, to the porous, sandy nature of the clay beneath the surface, and the impervious stratum below. It is from this horizon that the residents of the area obtain water. The sandy clay from which water is secured has the property of standing unsupported for many years. Wells that are said to have been dug before the civil war and left without walls, except a few feet next the surface, are still in an excellent state of preservation. Whether wells are dug or bored, they always furnish a copious supply of water.

Other horizons.—The gravel bed in which the wells at the Trumbull Wagon Company's plant at Walnut Ridge and that which supplies water for the Iron Mountain Railway tank at Hoxie are sunk probably represents an important local horizon from which it would be advisable to seek water. These wells are 60 and 62 feet deep, respectively. It would not be a difficult matter to drive wells into this gravel which would furnish an abundance of water for family, hotel, or stock purposes.

Unfortunately the number of deep wells is not sufficient to determine the extent of this gravel bed. The well which supplies the railroad tank at Alicia is said to be 75 feet deep and to extend into gravel for 14 feet. This is probably the same gravel that occurs at Walnut Ridge and Hoxie. At Newport there are two bored wells, belonging to the Newport Ice and Cold Storage Company, 97 and 102 feet deep, respectively, but from neither of these is gravel reported.

LACK OF DEFINITION OF HORIZONS.

Aside from the above-mentioned water horizons, none of more than local importance were determined. The whole ground is thoroughly saturated with water from within a few feet of the surface downward. Most of the material within 100 feet of the surface is sand, which allows the water to move freely through it when the conditions for movement are supplied. While this sand contains beds of clay, these are of local extent and occur at different levels, so that there is nothing to prevent the free commingling of all parts of the ground water, especially where a portion of the water from a considerable distance below the surface is removed, as is the case in pumping from deep wells. The removal of water in considerable amounts from wells causes a more or less rapid flow from above and about the point of removal. The deeper the well the greater the area drained and the more water involved in the movement. For these reasons no distinct horizon of any considerable extent from which the water is materially different from that above or below is to be expected.

The reason for want of definition of water horizons within the area will be better understood when the manner of deposition of most of the material in which wells are sunk is recalled. This is of Recent age (fig. 21, p. 102) and is stream deposit. It was built up by the overflow of streams and the consequent deposition. The difference that is found in the character of material beneath the surface at the same level is precisely like that in the surface of flood plains—sand here and clay there. As the streams shifted, now to one side and now to the other, the character of the material at all points changed, so that beds of sand and clay have come to alternate.

The great variation in the character of the deposits within short distances may be seen from figs. 26 and 27, which show sections at Tupelo and at Weldon and Auvergne.

CHEMICAL CHARACTER OF THE WATER.

In the absence of analyses, it is possible to give only the general character of the water. The water over the lowland region is in nearly all cases reported as hard. Only the comparatively small number of wells that are in superficial sand deposits produce soft water. The residue from evaporation around the valves of boilers frequently contains a great deal of common salt. Some of the wells between Bald Knob and Augusta contain so much salt as to render the water unfit for drinking purposes. Most of the water forms a scum of hydroxide of iron on the surface after standing a few

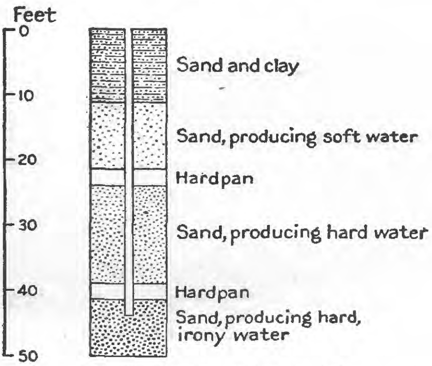


FIG. 26.—Section at Tupelo, Ark.

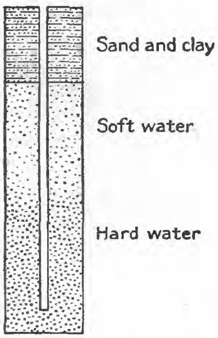


FIG. 27.—Representative section at Weldon and Auvergne, Ark.

hours, and a yellowish stain of the same material lines vessels in which water from almost any of the wells is used. The amount of organic matter contained in the water is great in many cases.

The character of the water varies greatly with depth. Also it often varies greatly in short horizontal distances. Frequently wells of a given depth furnish fairly good water, while those near by, either shallower or deeper or of the same depth, supply water which is unfit for use. The difference in the character of the water from different depths is explained by the vertical variation in the character of the beds. The difference in the character of water in wells which are close together and of the same depth is accounted for in the horizontal variation of the beds (fig. 28). It is a common thing for two wells to be situated near together, the water of one being good, while that of the other can scarcely be used on account of the large amount of iron and organic matter contained in it. This difference of the water within short distances is so well known to the residents that often when bad water is secured the pipe is "pulled" and driven in another place near by.

This great difference in the character of the water within short distances results from the manner of deposition of the material. A detailed map of the region would show hundreds of sloughs, which are abandoned channels of streams. The water in these sloughs is stagnant, and the borders are lined with aquatic plants which annually die, adding their material to the mud of the bottom. Besides the plants, these sloughs all contain a large amount of driftwood and are favorable places for the accumulation of iron ore in greater or less amounts. Hundreds of such sloughs have become buried by the flooding of adjacent streams, there being nothing left on the surface to indicate their presence beneath. The organic matter in these buried sloughs, absent from the atmosphere, reduces the insoluble iron compounds to soluble forms, which, together with the organic acids from the decay of the vegetable matter, are taken up by the water;

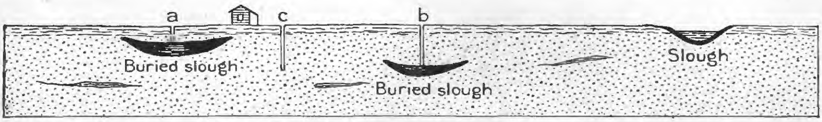


FIG. 28.—Diagram showing buried sloughs. Wells at *a* and *b* would furnish water containing iron and organic matter. The well at *c* would furnish comparatively pure water.

so that a well driven into one of these buried sloughs, as shown in fig. 28, would furnish water unfit for use, while another near by might furnish comparatively good water.

USES OF THE WATER.

The inhabitants of the region depend wholly upon the water that can be secured at their doors for domestic and stock purposes. The cities that have waterworks, such as Newport, Augusta, Argenta, and Jonesboro, get their water from wells. Batesville uses water from White River.

The lumber and other manufacturing industries of the region demand a large amount of water for boiler purposes. Unfortunately, all the water forms more or less scale in the boilers, and in some cases it is found advisable to resort to the use of boiler compounds to prevent this. The most troublesome scale is that formed from a combination of fine sediment and the calcium and magnesium precipitated from boiling.

At Lonoke experiments have been made in rice culture on a small scale, using water from wells for irrigation. Should the climatic and soil conditions be found favorable to this culture, no reason exists why it should not become an important industry, for there is an abundance of water for irrigation.

SPRINGS.

The number of springs within the lowland area is so limited that for all practical purposes they might be left out of consideration as water producers. There are but three localities within the lowlands where springs occur, viz, at Newark, Grandglaise, and the Sandhill area east of the towns of Austin and Cabot. The limited number of springs is due to the usually level surface of the region, the horizontal position of the beds, and the shallow stream valleys. The springs at the localities mentioned issue from erosion remnants, the edges of whose horizontal beds outcrop above the adjacent areas.

As previously stated, the town of Newark is situated upon a heavy deposit of gravel, probably of post-Tertiary age. This gravel is an excellent source of water, as it rests directly upon the Moorefield shale, which, because of its impervious nature, prevents the water from sinking (fig. 25, p. 109). In the eastern part of the town, at the base of the gravel and the top of the shale, there are several springs.

At Grandglaise a spring of considerable strength issues from a bed of loose sand beneath the Tertiary limestone and just above the level of the lowlands to the east. There is another spring at the same horizon, about half a mile south of Grandglaise station.

East of the towns of Austin and Cabot are several springs which issue from the slopes of the ridges on the east, north, and west sides. Among these are the Camp Grounds Spring, NW. ¼ sec. 22; Crab Tree Spring, sec. 9; and some four or five springs in sec. 16—all of them in T. 4 N., R. 9 W. As will be seen from fig. 16 (p. 93), the Sandhill area is underlain by a bed of clay near the base, which, being impervious, causes the water to flow out on the hillsides as springs.

WELLS.

CHARACTER OF WELLS.

While but few springs occur within the region, there is no limit to the possible number of wells. The ease with which water can be secured from wells anywhere within the region causes them to be resorted to for water even in the few localities where springs occur.

The deepest wells that have been sunk in the region are in the neighborhood of 100 feet. However, there are but few places where water can not be secured within 20 feet of the surface. Usually where wells have been sunk to a greater depth than 30 or 40 feet, it has been with the reasonable assumption that the quality of water improves with depth and not because there was an insufficient supply near the surface.

However, the advantage of a well which terminates in gravel over one that stops in sand within a few feet of the gravel is in the fact that its open nature permits a free flow of water to take the place of that pumped out—a flow sufficient to supply the demands for any purpose—and in that all possibility of sand entering the pipe is precluded. There is no reason to believe that the quality of water obtained from the gravel is any better than that from the sand immediately above, with the exception that the former is free from sediment, for the two contain the same bed of water. Water, of course, from near the surface is less suitable for domestic purposes than water from greater depths, but the difference between the water from the gravel and that from a few feet away is certainly very little.

METHODS OF SINKING WELLS.

Formerly the only means of securing water was by digging open wells. While a good many dug wells are still in use, that means of seeking water has been succeeded by driving and boring. Driving ordinarily necessitates but a few feet of iron pipe, a driving point, a pump, and a few hours' work. The pipe is sometimes of common iron, sometimes galvanized, and is usually $1\frac{1}{4}$ inches in diameter.

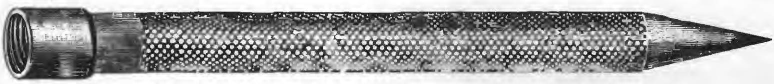


FIG. 29.—Style of drive-well point commonly used.

The point is made of perforated gas pipe, covered with brass wire cloth, usually 60, 80, or 100 mesh, and protected by a perforated brass jacket. The pump is usually of the style known as the "pitcher pump."

Bored wells are in most cases 8 inches in diameter, the water being raised by a windlass and cylinder bucket with a valve at the bottom.

A few windmills are in use, but water for domestic purposes is commonly raised by hand.

Whether boring or driving is resorted to seems to be a matter of local custom. In the southern part of the region, between Hickory Plains and West Point, nearly all the wells observed by the writer are bored, though there is no apparent reason why they should not as well have been driven. In the northern half of the region a bored well is seldom seen, except in those cases where a large amount of water is desired and where the wells are of considerable depth. In all parts dug wells are occasionally met with, but since the advent of the iron pipe and "pitcher pump" the relative number of these is constantly decreasing.

An ingenious method of sinking deep wells is employed by Mr.

H. F. Close, of Bismarck, Mo. Into a piece of pipe of the desired size is fastened a triangular bit, as shown in fig. 30. A cap is screwed onto the upper end of the pipe, to which is attached a hose with swivel, permitting the pipe to be turned, auger-like, by a hand lever attached to the top, by which process the bit cuts down through the loose material. At the same time water is forced through the hose and down the inside of the pipe by a steam pump, thus moving the material loosened by the bit and carrying it upward around the outside of the pipe to the surface. By this method it is claimed a well can be sunk at the rate of 12 or 15 feet an hour.

CAPACITY OF WELLS.

The amount of water that can be supplied by almost any well within the lowland area is limited only by the capacity of the pipe. When a great amount of water is needed, either a large pipe is used or the number of wells is increased until the desired amount is

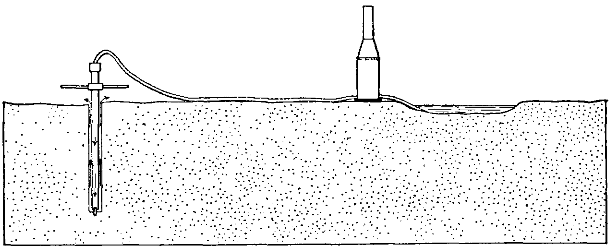


FIG. 30.—Diagram showing an ingenious method employed in sinking deep wells.

secured. An idea of the amount of water available within the region can be secured from the following table of so-called deep wells:

Deep wells in northern Arkansas.

Place.	Owner.	Depth.	Diameter.	Amount supplied per day.
		Feet.	*Inches.*	*Gallons.*
Walnut Ridge	Trumbull Wagon Co	61	6	104,000
Hoxie	Iron Mountain Rwy	62	10	45,000
Minturn	Southern Cooperage Co	60	1½	30,000
Alicia	Iron Mountain Rwy	75	6	[a] 9,000
Newport	Newport Ice and Cold Storage Co	97	6	40,000
Higginson	Iron Mountain Rwy	68	12	30,000
Augusta	Campbell & Vinson	100	6	50,000
Argenta	Buckeye Cotton Oil Co	75	6	([b])
Do	Rose City Cotton Oil Co	60	6	10,000

[a] Per hour. [b] Water supplies oil plant.

It is probable that the figures showing the amount consumed represent but a small part of the capacity of the well in each case, for it is invariably reported that the amount used lowers the water very little. The well supplying the railroad tank at Alicia has a capacity of 9,000 gallons an hour, and the pumper thinks this supply would be kept up even with constant pumping.

The great capacity of these wells is due to the loose and sandy nature of the material in which the water occurs, and the fact that it is saturated to within a few feet of the surface. As fast as the water is removed it is supplied, as the result of easy transmission through the sandy material and the downward pressure of the column of water between the lower limit of the well and the ground-water level. The supply is practically inexhaustible.

PROSPECTS FOR FLOWING WELLS.

The conditions for flowing wells are:

(1) A bed capable of holding and transmitting water. Such a bed is known as a reservoir. Its capacity for water may result from loose sand or gravel, porous consolidated rock, or fracturing. The capacity for water and the ease with which it moves increase with the open nature of the reservoir.

(2) A confining stratum above the porous bed to hold the water down and keep it from leaking out. It is necessary for the confining bed to be composed of close-textured rock, such as shale, clay, or other fine silts, through which the water can not readily pass.

(3) A head of water somewhere in the reservoir at a higher level than that of the surface where the well is desired. The minimum vertical distance that can exist between the water level of the head and the mouth of the well is determined by the distance they are apart and the porosity of the reservoir. The farther apart the greater the minimum difference of elevation between the two. This is due to the increase of friction with distance as the water moves through the reservoir. The more porous the reservoir the less will be the friction and consequently the less the minimum vertical difference that can exist between the two.

The very small difference in altitude between the highest and lowest parts of the lowland area preclude the possibility of securing artesian water from the Tertiary or Cretaceous rocks, even though all the other conditions were favorable. If flowing wells are sought within this region, it should be with an understanding that it is necessary to go through the Tertiary and Cretaceous into the Paleozoic rocks below.

While the securing of flowing wells from the Paleozoic rocks may not be outside the possibilities, the chances for doing so are slight. As has been noticed on preceding pages, these rocks contain excellent water-bearing formations, and their south dip would bring them, if the beds were continuous, under the younger deposits, in which case the chances of securing artesian water from them should be excellent. But these beds are truncated to considerable depths, and from their truncated edges a large amount of water passes out into the younger rocks, this being one of the sources of the ground water of the lowlands. It follows that if flowing wells be secured from these rocks, it must be from below the level to which they are truncated.

A further fact which is against the securing of artesian water from the Paleozoic rocks is in the system of east-west faulting, shown in fig. 20 (p. 101), which probably affects the old rocks beneath the Tertiary and Cretaceous deposits. By this faulting all the rocks have been broken in two along certain lines, and the beds on one side or the other have suffered vertical displacement, so that the southward movement of the water through the water-bearing horizons is cut off at the lines of disturbance.

While the securing of artesian water from the Paleozoic horizon within limited distances from the highland border seems within the possibilities, the chances are against success.

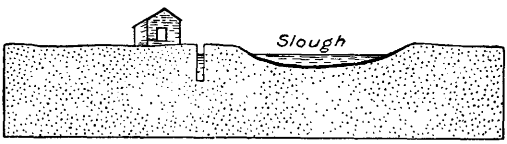


FIG. 31.—Well situated near an old slough.

SANITARY CONSIDERATIONS IN WELL SINKING.

Location of wells.—Too much care can not be exercised in the location of wells. Not infrequently are wells located on the borders of sloughs, the waters of which are stagnant in the summer season and are heavily charged with organic matter. Fig. 31 shows a well so situated. While these sloughs are always lined with very fine sediment that is largely impervious, more or less water is able to pass through it into the adjacent sand. The drawing of water from a well situated as shown in fig. 31, lowering the surface of the water in the well below that of the slough, invites the drainage from the slough toward the well.

In cases where, as a matter of convenience, it becomes desirable to locate a well near a slough, it should under no circumstances be an open one, and whether drilled or bored should go to such a depth below the bottom of the slough as to be out of reach of the downward-percolating, organic-charged waters.

When wells furnish water heavily charged with iron and organic matter the pipe should be "pulled" and driven elsewhere. As explained in another part of this paper, such water is probably due to the pipe being driven into a buried slough. Because of the concealment of the slough the location of good water can be determined only by experiment. Usually as good quality of water as the locality affords can be secured within a short distance of a well that supplies water of poor quality.

In no region should wells be located in barnyards or near other sources of surface pollution, except with intelligent advice. In a hilly region the surface drainage and stratigraphic conditions may be such as to permit a properly constructed well to be so situated; but in the lowlands of Arkansas, where there is but little, if any, surface drainage and the soil is porous, permitting the water freely to percolate downward, that practice can not be too strongly condemned. The watering places for barnyard fowls and the wallows for hogs are often immediately about wells from which water is used for drinking. Such disregard for sanitary conditions is excusable only among the most ignorant.

Depth of wells.—The usual depth of wells over the lowlands is from 15 to 40 feet. It might be accepted as a rule that the character of the water improves with depth, for the greater the distance from the surface the freer it is from surface contamination. As the sinking of wells within the region is such an easy matter, it would doubtless be advisable in most cases not to stop short of 60 feet, and to go beyond this depth would be better still.

In those cases where water is strongly charged with iron and organic matter a better quality may sometimes be secured by stopping short of the organic-charged bed, or, if not by this means, by driving on through it into the sand or gravel beds below.

In a few localities the surface sands are thick enough to form a permanent reservoir, and in such cases shallow wells can be sunk, which furnish soft water of excellent quality when not so situated as to be affected by sources of surface pollution.

Casing wells.—Next to the location and depth of a bored well the most important thing is the casing. The material most commonly used for this purpose in the lowlands is wood, evidently with the belief that the only object of casing is to prevent the well from caving in. Another and equally important object should be to keep out the surface water. For this purpose the wooden casing is wholly ineffective. The chief object of a deep well is to avoid the surface water, and unless the casing keeps out the surface water a deep well has no sanitary advantage over a shallow one. Besides, a wooden casing must in time decay, and by this means enough organic matter may be added to the water to produce serious results. The best casing is galvanized-iron pipe or tile carefully cemented at the joints.

Open wells.—Open or dug wells should never be used except where the greatest care is observed in the cleanliness of the surface for some distance about, and even then they are unsafe, as more or less surface water will find its way into them. When such a well is used the wall should be of stone or brick and not of wood, as is too often the case.

WATER RESOURCES OF THE PORTSMOUTH-YORK REGION, NEW HAMPSHIRE AND MAINE.

By GEORGE OTIS SMITH.

INTRODUCTION.

A hydrologic examination of the vicinity of Portsmouth Harbor was made by the writer in June, 1904. This work was done at the request of the War Department, and special attention was paid to the problem of securing satisfactory water supplies for the several forts at the mouth of Portsmouth Harbor. The geologic conditions which influence the water resources at these points were studied, and to obtain the best results it was found necessary to extend observations for about 10 miles northeast along the Maine coast. The results obtained in this investigation have been reported on in so far as they answered the direct purposes of the examination. The observations made in the course of this study and the conclusions based thereon are presented in this paper in view of the relation they bear to similar hydrologic problems in other parts of the coastal region of Maine. Elsewhere certain anomalous conditions prevail in the occurrence of ground water, and while each area may demand its own explanation, it is believed that the results obtained in the present study may be at least suggestive in the solution of the problems elsewhere.

The area discussed in this article extends from Portsmouth and Newcastle, N. H., to York Beach and Cape Neddick, Maine. Aside from the city of Portsmouth and the various villages in the towns of Kittery and York, the region has a special importance from the location here of the coast defenses and the extensive navy-yard, as well as the presence of a large summer population at several deservedly popular resorts. The question of an adequate and safe water supply thus becomes a vital one and demands thoughtful consideration.

SOURCES OF WATER SUPPLY.

The present water supply of the Portsmouth-Kittery region comes from three distinct sources—surface (lake or stream) water, ground water from surficial deposits, and ground water from rock.

SURFACE WATER.

The supply at the Kittery Navy-Yard best illustrates the first class, water from ponds on the western slope of Mount Agamenticus being piped by a gravity system into the town of Kittery and across to the navy-yard. Both in quality and quantity this supply is excellent.

GROUND WATER IN SURFICIAL DEPOSITS.

The city supply at Portsmouth belongs to the second class. Some 50 shallow wells have been sunk in the surficial deposits, and from this system of wells 1,000,000 gallons are reported to be pumped daily. The domestic supply for a great proportion of the farms in this region is of similar origin. Wells are dug to the surface of the water table, locations being selected where the water table and land surface nearly coincide. Thus the wells of this type are commonly very shallow, and in fact are often located on the edge of swampy areas. The quality of such supplies varies from excellent to very poor, and in most of the smaller surface wells the seasonal variation is considerable. A few general statements as to the surface geology of the region will serve to explain the nature of this second type of water supply.

Outside the limits of the larger river valleys, in which there are doubtless alluvial deposits of considerable thickness, the surface deposits are predominantly glacial till, with local accumulations of fine alluvium or swamp deposits. Stratified gravels and sands of glacial origin were noticed at only a few points, and these appear to be so local in their distribution as to have no special influence upon the movement of ground water. The cover of till is thin over large areas, and rock exposures are both large and numerous. In such areas, which may be said to be the rule in the town of Kittery, Me., swamps are of common occurrence, and much of the region is poorly drained by surface streams. The distribution of the till and the absence of any extensive deposits of stratified drift are the determining conditions in the occurrence of ground water in the surface zone. The supply from this source can draw from only a limited catchment area, and seasonal fluctuation must therefore be expected.

West of Portsmouth some excellent wells are reported, which derive their water from sand and gravel. Some of these are artesian, and the water is in this case under pressure because of impervious beds overlying the water horizon. This area was not visited, but is probably one of stratified drift, differing in this respect from the region under consideration. It is also true that artesian water from such deposits belongs rather to the type of supply described in the following paragraphs.

GROUND WATER OF THE DEEP ZONE.

General character.—The third kind of water supply in the Portsmouth-Kittery area is that obtained from the underlying rock. Water from this source differs from that of the two other classes in several important particulars, which will be discussed later. More than a score of wells in this vicinity have been drilled in the rock, furnishing examples of this type of underground supply of pure water. The depth of these wells, so far as figures are obtainable, varies from 27 to 275 feet, but inasmuch as they tap this water of the deep zone they may be classed together as deep wells.

The elevation of these wells ranges from 100 feet above sea level to approximately sea level. Their yield is also quite different, some being very successful, while a few were failures. Three of these wells in the town of York, which adjoins Kittery on the east, are artesian, and these will be described, as will the few failures and also several wells that are of especial interest from their location near the forts at the mouth of Portsmouth Harbor. Concerning several wells conflicting reports were heard, but the data given below were furnished by either the owners or the well driller, largely supplemented by personal observation at the wells and in the immediate vicinity.

Descriptions of wells.—The well on the place of H. E. Evans (now deceased), on the road between York Harbor and York Beach, was drilled in 1889 to a depth of 27 feet, with a diameter of 6 inches. Rock was encountered at a depth of 3 feet, and the principal source of water at 25 feet. This water rises 2 feet above the surface, so that the well is truly artesian. The flow is reported as 100 gallons per hour, and the water supplies two summer cottages.

The well owned by C. B. Moseley, and situated on the northwest side of Cape Neddick, was drilled in 1894, and like all the wells in this vicinity has a diameter of 6 inches. The total depth of this well was 28 feet, water being encountered at 27 feet. This water flows from the surface, and the supply is reported as 30 gallons a minute, that amount having been pumped for an hour, with the result that the water in the well was lowered 2 feet. This water supplies three houses, flowing into two lower on the slope, and being pumped into a third. The elevation of the well is about 40 feet above the sea level, and it is not far distant from the shore.

The well on the property of W. H. Wentworth, of York Beach, is located between the railroad and carriage road on Long Beach, and was drilled in 1889, to a depth of 70 feet. The well is located in a swamp back of the beach, and is approximately at sea level. The upper 16 feet was in mud and beach gravel, the remainder of the well being in solid rock, reported as "mostly trap." The water from this well rises $2\frac{1}{2}$ feet above the surface, and the amount is reported by the driller as 4,000 gallons per hour, without either diurnal or seasonal variation of the water level. The water is of excellent quality, and by means of a windmill is made to supply a boarding house and a number of cottages, twenty-five families being said to have been served by the supply.

The well on the grounds of Hotel Pocahontas, on Gerrish Island, about 20 feet above the sea level, is of special interest from its proximity to Fort Foster. This well was completed in 1895, being drilled to a depth of 40 feet, the principal source of water being at 39 feet, with other veins at 20 and 31 feet; the water stands 8 feet below the surface of the ground. The driller reports the flow to be 75 gallons per hour, although a much larger rating is given by the owner. The water is raised by a windmill, and partly supplies the hotel; another source of supply is a natural spring 7 feet above high tide and within a few yards of the shore. This spring has been excavated in the rock to a depth of 8 feet, and when not pumped overflows through the crevices in the rock.

The most important well in the area is at Hotel Wentworth, on Newcastle Island. The well is situated at an elevation of about 40 feet on the southwestern end of this island, on the eastern shore of which are situated Forts Constitution and Stark. The well was drilled some years ago, and the total depth is variously reported, but is said by the agent of the Jones estate, by whom the property was owned, to be about 275 feet. It could not be learned at what depth water was encountered, nor how near the surface water rises. The rate of flow is not known, except through information secured from the manufacturers of the steam pump in position over the well, who state that a Deane pump of this type should pump 30 gallons per minute when working efficiently. The engineer in charge states that in the middle of the summer this pump has been run night and day for two weeks at a time, with no appreciable diminution of the supply. The quality of the water is excellent, and is used to supply a large part of the Hotel Wentworth. This property has several surface wells fed by the springs, which form an auxiliary supply, but as these fail in the height of the season the deep well may be said to be the only supply for the dining rooms and the larger part of the hotel, one wing of which is supplied by city water from Portsmouth.

A short description should be given of the few failures in this region. In the vicinity of the Evans well, on Cape Neddick, two unsuccessful wells were drilled. One of these was drilled to a considerable depth without any water being encountered, this case being especially remarkable from the fact that the hole was located only a few hundred yards from the artesian well. Another at a slightly greater distance from the Evans well was drilled to a depth of 87 feet, at which level salt water was encountered, which rose to approximately sea level. This well, it should be noted, was drilled in the gabbro which makes up the greater part of Cape Neddick, while the dry well was in schist close to the gabbro contact, and the Evans artesian well was in slate and schist, all of which rocks will be mentioned in the following paragraphs.

Another unsuccessful well was drilled at Fort Stark, under direction of the Corps of Engineers of the Army, to a depth of 260 feet. At 130 feet fresh water was encountered, but only in small amounts, and at 260 feet salt water was struck. The site of this drill hole is now concealed by the fortification. In the same vicinity, on the Barrett estate, a well was drilled to the depth of 150 feet, at which depth it had to be abandoned on account of the crooked drill hole. A small amount of water of excellent quality was encountered, but not sufficient to warrant pumping.

GEOLOGIC CONDITIONS.

The geologic conditions which control, or at least influence, the occurrence of this water of the deep zone must now be considered. The problem is not a simple one, but the following observations may serve to explain to some extent the well data given above.

LITHOLOGY.

The prevailing bed rock over this area is metamorphic in nature. Schists that evidently represent metamorphosed sediments, together with well-bedded slates and quartzites, underlie the greater part of the area. The strike of these rocks is N. 60° to 80° E., with N. 70° E. possibly the prevailing direction. The dip varies also within only narrow limits, being 75° to 90° either to the north or to the south, and more commonly vertical. At only one locality were low dips observed. At the outer entrance to Portsmouth Harbor the rock is more gneissoid in character, and to a large extent represents metamorphosed igneous rocks of an acidic type. In what proportion these igneous rocks were of volcanic and in what of intrusive origin can not be stated, but both types are doubtless present.

Cutting these old metamorphic rocks are numerous dikes of diabasic and basaltic rock. Some larger masses belonging to the same intrusion have more of the gabbro texture, and the outer portion of Cape Neddick, as noted above, is composed of very massive gabbro. These basic intrusives are relatively much younger in age, and it is noticeable that the basaltic dikes cut not only the schistose rocks, but also the quartz veins which traverse the schists and slates. Some of these dikes cut across the schistosity and stratification, following joint planes, but more commonly they are parallel to the bedding and might be more properly termed intrusive sheets.

JOINTS.

The essential feature for the purpose of the present discussion is that all these rocks, whether of volcanic or sedimentary origin, have been so thoroughly metamorphosed that the foliated structure is characteristic for all. These rocks are much jointed, although no regular system of joints could be recognized as prevailing for any distance. The intrusive rock is also jointed, a system of three joint planes nearly at right angles to one another being noted in the gabbro of Cape Neddick. In general it is probable, however, that the intrusive rock is jointed to a less extent than are the older schists and slates.

The question to what extent the joints in the above rocks represent open spaces is most important. The prominence of these joints on the weathered surface suggests that the rock mass is considerably fissured, but there is also reason to doubt this conclusion. At the southern end of the navy-yard very extensive excavations are in progress for the purpose of removing a point which projects into the river channel. An examination of the piles of broken rock from this source shows that the quartzite has very irregular fractures, which appear to be very largely independent of either stratification or joint planes. Many of the joint planes are also seen to have been cemented with quartz in thin films. A few small faults were noted in this region, but it is probable that these also are well cemented.

ZONE OF STORAGE.

Presence of artesian water.—The physical character of the rocks of the area and their structures are plainly quite different from those observed in typical artesian basins. The rocks are compact and well cemented, so that in no strict sense can it be said that there is present a pervious stratum between impervious strata. Neither is there any approach to a basin structure, but rather the structure is that of closely compressed folds, in which the strata are steeply inclined. However, artesian water is known to exist in this area, as proved by the artesian wells already described, and in the other deep wells which did not flow the water encountered is under static pressure, as evidenced by the rise within the well. Essentially, then, the water supply of these deep wells is of the artesian type—that is, the water rises within the drill hole for a score or more feet above the level at which the drill tapped its flow. This supply of underground water is therefore somewhat exceptional in type, and the conditions presented deserve further consideration.

Mode of flow.—As noted above, the water-bearing rocks are not porous in the same sense as most rocks which form the pervious beds in artesian basins. The water circulation can not be through pore openings, but must be along the stratification partings, joint openings, and other less regular passages within the rock mass. It is difficult to state which class of these is the most important in governing the circulation of the water. The bedding and schistosity planes are of course the most persistent, although probably lacking the regularity and width of the joint openings, and from their approximately vertical position these partings would serve to conduct the water from higher to lower levels, and vice versa. Such of the joint planes as approach horizontality would furnish connecting passages between the vertical openings, yet how continuous such a system of openings is can not be stated, owing to ignorance of the extent to which these natural openings have been modified by cementation. It is believed, however, that the master joints of the area are nearly horizontal, so that movement of the water in the horizontal planes is less obstructed than the upward movement. The fact that the water tapped by the wells described above usually rises either to the surface and overflows the top of the well casing, or at least rises to a considerable extent within the well, indicates conclusively that there is static pressure and more or less confinement by the overlying rock.

If these joints and other partings were present throughout the rock mass, the essential condition of an impervious cover would be lacking and the ground water from the deep zone would escape at the surface. Two factors, however, appear to combine to prevent such natural escape except in rare cases like the spring near Hotel Pocahontas. The pressure under which the water circulates in the deep-rock zone is insufficient to overcome the internal friction within constricted openings in the higher parts of the zone of water circulation, especially as there is a greater degree of cementation along these upward-leading planes near the surface. This presumption of greater cementation near the surface is supported by the observations at the navy-yard excavations, as well as by the general theory of vein deposition. In view of the moderate depth of the three flowing wells, it may be true that this cementation is especially effective only to a depth of 20 to 100 feet, within which surface zone it may wholly stop water circulation.

The conclusion gained by this investigation is that the ground water in the deeper or rock zone circulates relatively slowly within the constricted natural openings in the rock. The water of this zone is contributed from distant areas rather than from the immediate vicinity, and the rate of circulation is so slow as to make the supply essentially free from seasonal variation. The elevation of the principal catchment area is not sufficiently great to cause the water thus flowing to be under great pressure—that is, the pressure is not usually sufficient to overcome the friction incident upon upward escape through the natural joint, stratification, or foliation planes, which are more or less thoroughly cemented near the surface. In such exceptional cases as the spring near Hotel Pocahontas on Gerrish Island the water from the deep zone does thus escape, probably through a less constricted opening. In the artificial openings of the wells the water is provided with a free vertical channel, in which it rises for 10, 20, or possibly hundreds of feet, and in the case of the artesian wells cited actually overflows at the surface. The extent to which the water thus rises is therefore a direct measure of the amount of pressure under which it circulates at the point reached by the drill hole, a pressure, however, that was insufficient to overcome the frictional resistance to upward flow along natural channels in the rock.

Another feature which appears characteristic of the wells in this area is that the water circulation is more or less confined to trunk channels rather than equally distributed throughout the water-bearing zone. This is not simply because the water prefers the trunk channels, but because the rocks are so indurated and free from pore openings that these larger openings are the exclusive channels of flow. This is shown by the well logs, which indicate the presence of definite flows at different levels, which are not determined by the presence of definite porous strata, but more probably by the position of joint planes or other openings within the mass of steeply inclined and highly indurated rock. Further proof of this is afforded by the case of the Wentworth well, where the drill dropped 1 foot at the point where the principal flow was encountered. Such a distribution of the water circulation along a limited number of well-defined channels would explain the marked difference between wells located in the same vicinity.

PRACTICAL CONCLUSIONS.

With the results of this investigation in mind, some definite statements can be made that may be of practical value to anyone interested in utilizing the water from the deep zone of flow.

Water that is truly artesian, or that is at least under sufficient pressure to make it rise in a deep well, exists in the rock underlying the area under consideration. The distribution of this supply of underground water is such that a few failures may be expected among deep wells drilled in this area, but the percentage of failures should be very small if some judgment is used in the selection of the location for drilling. The logs of the most successful wells show that the depth at which the best flows will be encountered can not be definitely predicted. In most cases an abundant flow should be expected at a depth of less than 100 feet, but in some localities the drill might reach a depth of 300 feet before the water was encountered in good quantity.

The location of a few successful wells suggests some precautions to be observed. Inasmuch as the cracks showing at the surface are not indicative of similar openings at considerable depth, they should not be considered as indicating that water-filled channels will be encountered by the drill with depth, and furthermore if such location is near the shore the presence of such surface cracks increases the liability of encountering sea water, which has followed passages extending from the submarine rock surface. Again, in selecting a place for locating a well, it will be preferable to avoid diabasic dikes and sheets which traverse the schist in many parts of the area. Several successful wells in York and Kittery, however, appear to have been drilled, in part at least, through this intrusive rock, but it seems probable that the schist is the better water-bearing rock, in that it contains more partings.

More specific conclusions have been submitted to the War Department relative to the conditions at the various forts. The above general statements, however, apply to practically all of the area described in this article. Furthermore, it is believed that the application of these conclusions may be safely made over a larger area. Geologic investigation of other portions of the Maine coast during the same season has led the writer to consider that the principles here formulated regarding the nature of the deep zone of flow constitute a tenable hypothesis for the explanation of the hydrologic conditions in these other regions. In these areas of thoroughly indurated and closely folded rocks the joints are the structural elements most important in the control of underground circulation, and thus there exists a type of artesian storage quite different from the basins usually described.

A GROUND-WATER PROBLEM IN SOUTHEASTERN MICHIGAN.

By Myron L. Fuller.

INTRODUCTION.

General statement.—In the late spring and early summer of 1904 the shallow wells throughout the region adjacent to the lower portion of Huron River, in southeastern Michigan, which up to that time had yielded abundant supplies of water, showed signs of failing. As the summer progressed the shortage became more severe, making it necessary in many cases to materially deepen the wells in order to secure the water necessary for ordinary domestic and farm purposes. Wide attention was attracted to the failure of the wells in the region, because the shortage was supposed to have been brought about through underground drainage by a powerful flowing well on Grosse Isle, a few miles to the east. Careful field investigations showed the improbability of such influence, the evidence indicating, on the contrary, the failure to be due to certain general causes of rather widespread application.

The explanation of the failure of wells in the region in question is similar to that in like districts at many points throughout the country, and it is with the object of calling attention to certain general factors, both temporary and permanent, which tend to induce a shortage of the ground-water supplies over large areas, that the present paper has been prepared.

Location of area.—The region in which the shortage of water in 1904 was earliest felt and in which it was severest is a belt perhaps 10 miles wide, extending in a northwest-southeast direction, parallel with and including Huron River from a point near New Boston, about 20 miles in a straight line above its mouth, to its juncture with Detroit River, 28 miles from Detroit. The greater part of the affected belt lies south of the river, only a strip a mile or two in width falling on the north side. To the south the affected area is not only much broader, reaching a width of 7 or 8 miles, but the shortage was more pronounced, reaching a maximum along Swan Creek, which parallels Huron River at a distance of from 3 to 5 miles on the south. South of Swan Creek the wells were affected only for a short distance, usually not over 2 or 3 miles.

The belt showing shortage lies in two counties, the relatively narrow strip north of Huron River being in Wayne County and the wider one south of the river in Monroe County. The villages principally affected are Willow, Waltz, Carleton, Flat Rock, and Rockwood. In the portion of the belt east of Rockwood and Newport and between these towns and the lake no shortage was reported up to August, 1904.

FIG. 32.—Rainfall map of Michigan.

Character of the country.—The entire region is characteristically flat, and, except in the vicinity of the streams, which have cut shallow channels for themselves, almost no inequalities recognizable by the eye are to be seen over large areas. The surface materials are generally clayey, although locally the clay may be overlain by thin sheets of sand, which in places takes the shape of low, flat, northeast-southwest ridges or terraces, representing old beach lines of the lake which formerly covered the region. Although excessively flat, the country has a gentle slope southeastward toward Lake Erie, usually not exceeding 5 feet to the mile. The main streams—Huron River and Swan Creek—flow in the direction of greatest slope to the southeast, while the smaller streams, including the tributaries of the large streams named, flow either along similar southeast lines or converge slightly toward the main drainage lines.

The region is a populous one. Roads follow nearly every section line, and houses are abundant, there being frequently from ten to twenty to a section. The farms are correspondingly small, but are under careful cultivation, and the owners appear to be prosperous. Three steam railroads and a trolley line give frequent communication with Detroit and afford abundant opportunity for the shipping of produce.

Climate.—The climate of the region is tempered to a certain extent by the proximity to Lake Erie, being, with the exception of the southwest corner of Michigan, the warmest in the State. The average minimum temperature is 39°, the average maximum 57°, and the average mean 48°. The rainfall, which is about 30 inches, is low as compared with certain other portions of the State, where it may reach 35 to 40 inches. (See fig. 32.)

There are, however, considerable areas in which the precipitation does not exceed 30 inches. Normally the rainfall is lowest in January, when it is under 2 inches, and highest in May and June, when it is over 3½ inches per month. About the head of Huron River the rainfall is greater than along the lower part of its course and serves to keep the stream somewhat higher than would otherwise be the case.

GEOLOGY.

SURFACE MATERIALS.

Character.—The materials overlying the rock in the region consist largely of what is locally called "clay," but what is more properly a clay with an admixture of sand and pebbles. The materials are not usually arranged in definite layers as in stratified deposits, but commonly exist rather as heterogeneous mixtures, although occasional beds of quicksand or gravel, or even scattered bowlders, may occur. In consistency the material is tough and clay-like, grayish blue when fresh, but becoming yellowish through oxidation of iron on exposure to the weather at the surface. Some bowlders occur in the part of the area nearest Detroit River.

Thickness.—Although the superficial materials have a flat surface, their thickness varies from place to place, because of differences in elevation of the buried rock surface, which reaches much nearer to the top of the ground in some places than in others. The clayey deposits are from 15 to 40 feet in thickness, 25 to 30 feet being a fair average in the regions back from the streams. The streams, however, have cut their channels into the clay to some depth and in places have even cut entirely through it into the rock. Occasionally the rock reaches nearly or quite to the ordinary surface, as in the large quarries at Newport.

In a broad way, the thickness of the clays may be said to increase as Detroit River and Lake Erie are approached. West of Carleton the thickness, as shown by wells, is commonly about 30 feet. East of that town the depth, though variable, is sometimes as much as 35 feet, while near Rockwood the thickness may be as high as 40 feet.

Origin.—The surficial materials are of somewhat diverse origin. The bowlders and the unstratified materials were derived from the glacial ice which once covered the region, the accumulation taking place under the ice or very close to its margin during halts in its retreat. The waters at that time stood higher than at present, covering the entire area under discussion and reaching back as far as the base of the hills near Ypsilanti. In them a portion of the clays and the sand locally covering the surface was deposited as the ice retreated. Ice and water deposition were simultaneous and without sharp lines of demarcation, making it difficult to differentiate one from the other. After the retreat of the ice from the region the waters finally sank, with several halts at different levels, to their present position. During these halts the deposits were subjected to more or less washing by the waves, with the result that beaches were cut in the clay or constructed of sandy materials derived from it. These are the so-called terraces, ridges, or beaches extending in a northeast-southwest direction across the region northwest of the area under discussion and between it and Ypsilanti.

ROCKS.

General statement.—As was pointed out in the paragraph in which the thickness of the surface deposits was discussed, the rock surface is irregular as compared with that of the overlying clays, rising at points until it is within a few feet of the surface and again sinking 20, 30, or 40 feet below it. There are no great inequalities, however, and even if the soil were removed the surface would still be very regular, with elevations rarely rising more than 20 feet above the surrounding level. The irregularities are entirely independent of the present streams, which in the main have been determined in location entirely by the surface deposits. The rocks underlying the clays in the lower Huron River region consist of limestones, sandstones, shales, etc., arranged in belts extending in a northeast-southwest direction, or at right angles to the course of Huron River. They are reached by all but the shallow wells and afford the greater part of the ground water found in the region.

FORMATIONS.

Dundee limestone.—In the northwestern portion of the area, or beyond a point a couple of miles northwest of Carleton, the rock is the Dundee limestone, a fairly pure, light-colored, flint-bearing Devonian limestone of perhaps 100 feet in thickness and dipping northwestward at a rate of 20 to 25 feet to a mile. It is characterized by waters more or less charged with sulphur in the form of hydrogen sulphide.

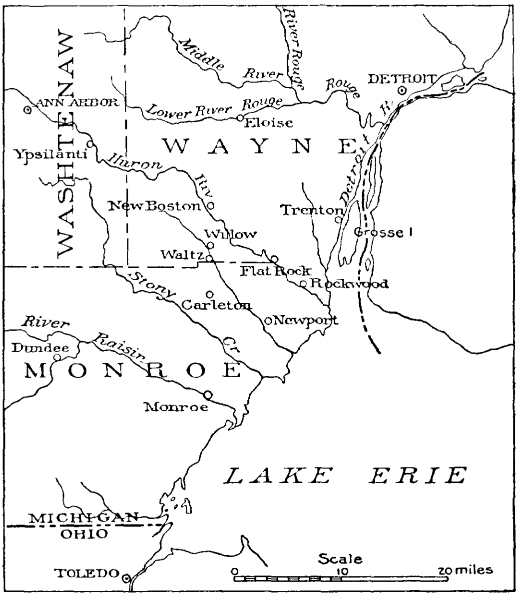


FIG. 33.—Sketch map of southeastern Michigan, showing area discussed.

"*Upper Monroe*" *beds.*—These are drab magnesian limestones, or dolomites, sometimes carrying sand and gypsum and other minerals. The dip is similar to that of the Dundee limestone. The waters are hard, but are not characterized by much sulphur.

Sylvania sandstone.—This is a white sandstone outcropping beneath the clay in the region at a point about a mile east of Carleton, nearly to the mouth of Huron River. The dip is somewhat flatter than those of either of the preceding formations and is more to the north than to the northwest. It yields water of a good quality.

"*Lower Monroe*" *beds.*—These are generally similar to the limestones and dolomites constituting the "Upper Monroe" beds already described, but are often more siliceous than the latter. They outcrop parallel to the Sylvania sandstone in a narrow belt along Lake Erie and Detroit River. Their waters carry some sulphur.

WATER SUPPLIES.

PRESENT CONDITIONS.

The conditions as regards water supplies vary considerably throughout the region under consideration, the variations being marked by differences in composition, head, volume, and in the amount of shortage shown in the time of drought. Each of the individual areas will be separately considered.

WILLOW-EXETER REGION.

General conditions.—The term "Willow-Exeter region" is applied to the area now or formerly furnishing flowing wells, which extends from the vicinity of Willow southwestward past Waltz into Exeter Township, Monroe County, at its northeast corner. The area in this township is mainly included in secs. 1, 11, 12, 13, and 14, with parts in secs. 2, 10, and 15. The belt lies transverse to the drainage of the region and is located mainly over the outcrop of the Dundee limestone.

There are several types of wells in the district—dug wells, obtaining a very limited supply of nonsulphurous water from the clays; drilled wells, passing through the clay and penetrating the rock and obtaining strong sulphur waters, which will frequently flow at the surface; and a combination of the dug and drilled types uniting the characteristics of both. Such wells are usually dug for about 15 feet and continued thence by a small drilled hole down to the rock, which is usually penetrated for a foot or two. These wells are particularly adapted to those cases where the water will rise nearly, but not quite, to the surface. They furnish under such conditions admirable opportunities for storage and will ordinarily yield much more water than the simple pipe wells, which often show a strong tendency to become clogged when water is most needed.

The depth of the wells varies from about 15 to 35 feet, of which all but a foot or two is usually through the clay. The depth is least at the eastern limits and greatest at the western border of the district. The area has been spoken of as one of flowing wells, but it is generally only at the lower points near the streams or in sags of the surface that good flows are obtained.

Condition of wells in 1904.—An examination of the wells of the region shows a lack of uniformity of conditions. Several of the surface wells are reported dry, while in others the supply is the same as usual. No decrease is noted in the wells in the sandstone, and most of the limestone wells, or those yielding sulphur water, show little if any material shortage, although a few reported losses, which in several instances were returned wholly or in part after cleaning. Some interference among the wells exists.

No evidence is afforded by the wells to show that there is any shortage, except such as would always accompany an unusually dry season. The moderate decrease due to drought has not been regular, but was first felt by the shallower wells or by those yielding small supplies, and last by the deeper and stronger wells. The shortage is naturally generally most noticeable in the flowing wells, in which a difference of a foot or two in head may determine whether they will flow or not. Shortage in previous years is reported.

The head of the water in relation to altitude declines from 622 feet above sea level in the western part of sec. 14, T. 5, R. 8, to 600 feet near the east line of sec. 19 of the next township east, or a little over 7 feet to the mile. This would indicate that the source of the supply was to the west, probably in the glacial hills near Ypsilanti.

CARLETON REGION.

The Carleton region is one of nonflowing wells lying between the Willow-Exeter and the Swan Creek flowing-well districts. The wells are commonly about 30 to 35 feet deep and probably enter for a few feet the Sylvania sandstone, from which they get supplies of nearly or quite sulphur-free water by pumping. In general no material shortage was reported in August, although the wells were somewhat lower than usual.

SWAN CREEK REGION.

General conditions.—This is a region of flowing wells extending along the valley of Swan Creek from near the Detroit Southern Railroad, 1½ miles northeast of Carleton, southeast to a point about the same distance from the Lake Shore station at Newport. At the north the district opens out and merges with the Huron River and Rockwood districts of flowing wells. The area is mainly over the outcrop of the Sylvania sandstone.

The wells are of the dug, drilled, or dug and drilled types. Except those of the first type they all obtain their water on entering the rock after passing through the stiff impervious clays. The wells have hitherto always yielded good flows of nonsulphurous water. Their depth commonly varies from 20 to 35 feet, according to location, the shallower ones being near the creek in the southern part of the district.

Condition of wells in 1904.—As in the Willow-Exeter region, the behavior of the wells is not uniform. In the Swan Creek region, however, nearly every well shows shortage, the amount varying from a barely noticeable decrease to a complete failure. The surface wells are very uniformly dry, although even here there are exceptions. Some of the artesian wells have stopped flowing, while others, though still running, rise to only a part of their former height. In the non-flowing drilled wells the loss of head is often but a few feet, but some of the drilled wells have entirely failed. In the combination dug and drilled wells the water has generally sunk so low that it no longer enters the dug part. The natural springs which formerly issued along the valleys have nearly all ceased to flow.

Suggestions of shortage have appeared several times in past years, a number of wells having previously ceased to flow or gone dry temporarily. The beginning of the present shortage was felt in 1903, but during the fall the supply returned in part, although it was low during the winter, and fell off rapidly again in the spring of 1904. At just what time the failure began can not be determined. No one was looking for a shortage, and it was only when wells began to go dry that attention was paid to their condition, and it was found that an almost universal shortage prevailed.

Supposed causes of shortage.—Nothing could be more variable than the opinions presented as to the cause of shortage. The most general of the explanations attributed the loss of water to subterranean drainage by a deep-rock well located at the southern extremity of Grosse Isle and flowing at the rate of a barrel a second. Credit was given to this supposed cause by many who would not otherwise have thought of it, because of the fact that one or two of the wells near Rockwood ceased to flow temporarily in the fall of 1903 only to begin again a short time after, and to continue until the spring of 1904, when they again ceased. These changes are said to have coincided, respectively, with the striking of the water vein, insertion of casing, and, finally, with the withdrawing of the pipe from the Grosse Isle well.

Others, however, see no connection with the Grosse Isle well, attributing the shortage to lack of rainfall, the frozen condition of the ground when the rains of the previous autumn fell, the extensive ditching of the land in recent years, and the consequent increase of run-off as compared with absorption, and to drainage by the quarry at Newport. All are possible causes and were investigated with the view of finding the determining factor.

Steps taken to increase supplies.—Several methods of remedying the shortage were tried, the first being the cleaning of the wells. In a few of the less serious cases this was effective and the supply returned, at least for a time, but in other cases the cause of failure was more deep seated and independent of imperfections of the well. In such cases cleaning did but little good and deepening of the well was resorted to. In some cases the dug part was carried a few feet deeper, and, by giving more storage space for the water, afforded temporary relief, but the amount of water was seldom materially increased. The most effective results were obtained by deepening the portion of the well in the rock. Where this was done more water was almost always obtained, although, of course, it had to be pumped to the surface.

HURON RIVER REGION.

General conditions.—This district extends along Huron River from a point a mile or two southeast of New Boston downstream to a point beyond Flat Rock, where it merges with the Rockwood and Swan Creek areas. The rock is largely Sylvania sandstone, except at the northern end of the district. The wells, as in the previous districts, are of the dug, drilled, or dug and drilled types, and range from about 25 to 60 feet in depth. A large portion of the wells flow, or did flow before the present shortage. At the northern end of the district the wells yield sulphur water, but in most of the remaining portions they yield water without sulphur.

Condition of wells in 1904.—In a broad way it may be said there is a general shortage of water in the region, but that it is not so severe as in the Swan Creek district, for along the Huron many wells still furnish good supplies of even flow, while in the latter region the failure is almost universal. The causes ascribed for the shortage are similar to those of the Swan Creek area, but with less weight given to the supposed influence of the Grosse Isle well. Cleaning and, more especially, deepening the wells generally resulted in an improvement in the conditions.

ROCKWOOD REGION.

General conditions.—The Rockwood area includes the region west and southwest of that town and between it and the Swan Creek area, together with the region near the town on the north side of Huron River. It can be considered as merging into the flowing-well areas of Swan Creek and Huron River on the west and into the Detroit River region on the east. The area is mainly over the outcrop of the Sylvania sandstone and yields waters generally free of sulphur. The wells are generally from 20 to 40 feet in depth and are nonflowing, except near Huron River.

Condition of wells in 1904.—The field work showed a marked shortage of supplies with many complete failures. Most of the artesian wells had flowed uninterruptedly for many years until they ceased in the summer of 1904, but a few stopped flowing in 1903, when the present shortage first began to be felt. During the winter of 1903–4 there was a slight increase over the preceding fall, but a considerable number of wells are known to have remained low all winter and one or two stopped flowing. While the flows of the individual wells stopped suddenly, the stoppage was not simultaneous in different wells, but extended over a considerable period of time. The wells in the region have always been somewhat sensitive, as if flowing at or near their maximum head, hence a slight decrease of the head would cause them to stop flowing rather abruptly. Several of the wells have always flowed roily water before storms and some ceased flowing during prolonged periods of westerly winds. The shortage is greatest west of Rockwood, becoming less as the town and Detroit River are approached. Many of the wells that have ceased to flow still yield water by pumping, while cleaning and deepening often add materially to the supplies.

Supposed causes of shortage.—The explanations of the shortage are the same as in the Swan Creek area, with special emphasis on the Grosse Isle well and the Newport quarry. On both of these supposed causes, however, opinions are divided, those not believing in their influence being as positive as those favoring such interference. It was noticeable, however, that the belief in both the quarry and deep well became less firm the nearer they were approached, being held rather by the owners of more distant wells than by those of the nearer ones.

DETROIT RIVER REGION.

This region includes the area between the Rockwood district and the shores of Detroit River. The region is low, being only a few feet above the river and lake level, and along the shore and creeks is often decidedly marshy. The region is, however, quite thickly settled and wells are abundant, but probably average under 20 feet in depth. In general there has been no trouble with shortage of water, although in a few instances the water was thought to be a little below its maximum summer level. No particular cause of shortage was advanced other than a general belief that the numerous salt and other wells might have had some effect. It is probable that in reality the water was as high as or higher than is ordinarily the case, as Lake Erie, which controls the ground-water level adjacent to its shores, stood about 15 inches above the normal in the summer of 1904.

GROSSE ISLE.

General conditions.—Grosse Isle is a north-south island about 9 miles long and 2 miles wide, lying on the American side of the international boundary in the Detroit River, its center being opposite the town of Trenton, 18 miles south of Detroit. The population is mainly located along the shores of the island, only one or two houses being situated in the interior, notwithstanding the entire island is under cultivation. The surface is mainly clay or clayey silts, but rock is commonly found not far from river level and in one point, where it rises slightly higher, is quarried.

Very few wells have been sunk on the island, the main supply being from pipes extending out beneath the surface to deep water in the river. The water is pumped directly from these pipes by means of windmills, no provision being made for filtering. There is some typhoid on the island. The few wells that have been sunk in the interior penetrate clay to the rock, which is entered at about 20 feet. The water of the dug wells is from the clay, but the drilled wells enter the rock and obtain an iron-bearing water carrying some sulphur. No shortage was reported in 1904, and no one had observed the slightest effect due to the big well at the southern end of the island.

Grosse Isle or James Swan well.—This well is located on the property of James Swan, opposite Snake Island, about three-fourths mile from the extreme southern point of Grosse Isle, and was 2 or 3 feet above the level of the river in 1904.

The well, which was sunk in search of oil or gas, was begun in 1903 and completed in May, 1904, having reached a depth of 2,375 feet without obtaining anything of value. The diameter at top is 10 inches, decreasing to 6 inches at the bottom. A 13-inch casing extends from the surface to the rock at 17 feet.

The first considerable flow of water was encountered at 420 feet, but at 450 feet a bigger flow was obtained. Both were fresh, but as the well was drilled deeper flows of sulphur water were encountered, which, although relatively small, were sufficient to impart a considerable amount of sulphur to the water as it issues from the pipe, and to be recognizable by taste and sulphur deposit on the grass and stones about the well.

Analysis of water from James Swan well, Grosse Isle.

F. K. OVITZ, analyst.

[Parts per million.]

Silica	188
Calcium oxide	7,616
Strontium oxide	376
Magnesium oxide	1,212
Sodium oxide	292
Potassium oxide	112
Sulphuric anhydride	11,871
Chlorine	248
Carbon dioxide	1,550
Iron and alumina	14
Loss on ignition	2,006
Total solids	25,485

The water is said to have been cased off during the progress of the drilling, from August, 1903, to May, 1904, when the casing was finally pulled. At present the water issues in a jet 11 inches high from the 13-inch pipe, forming a fountain of considerable size. (See Pl. IV.) The flow is calculated at about 50 gallons per second and forms two sizable streams as it flows away from the well. The water was tested to a maximum height of 22 feet above the surface. It is stated that the owner contemplates using the water for a public supply for the island.

SUMMARY.

The conditions of the wells at the present time have been described in detail in the preceding pages. With the exception of the narrow belt along the shore of Detroit River, where the supply is largely governed by the height of the river, the loss of supply has everywhere been felt in varying degrees. In the Willow-Exeter and Carleton regions the shortage is very slight, while along Huron River it is only moderate. In the Swan Creek and Rockwood regions, on the contrary, the shortage is excessive, a large proportion of the wells going dry and entailing much inconvenience.

DECLINE OF THE SUPPLY.

HISTORY.

The present season does not mark the beginning of the decline, but rather its culmination. Investigations made by Prof. W. H. Sherzer previous to 1900 showed that even the shrinkage of supplies had been in progress for many years. In his report on Monroe County,[a] he states that while continued drought makes no impression on many of the wells, the flow of others is reduced, or almost or quite stopped. The opening of new wells was found to affect the flow of others in the neighborhood, and the areas over which artesian waters could be secured were found to be becoming constantly more contracted. Wells in the southern part of Erie Township, back 3 miles from the lake, which formerly flowed, had then ceased.

The decline, noted by Professor Sherzer as having already progressed for some time, has continued to the present time. The areas of flowing wells outlined by him on his maps at that time are more extensive than those at the beginning of 1904, while by the close of the summer of that year very few flowing wells remained in some of the regions, as in the valley of Swan Creek and near Rockwood.

Not only have the artesian wells ceased to flow, but the water in the nonflowing wells is lower than formerly. In fact, the level of the ground water in the clayey portions of southeastern Michigan

[a] Geol. Survey Michigan, vol. 7, p. 194.

Wm A. Lamb.

A

B

VIEWS OF THE GROSSE ISLE, MICHIGAN, FLOWING WELL.

is distinctly lower than it was ten years ago, and much lower than it was twenty years ago. It is only in a limited district that the pronounced falling off occurred during 1904.

The general decline, which has been going on for many years, is probably due to a gradual and far-reaching change of conditions the nature of which will be considered on subsequent pages; but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question.

CAUSES OF THE DECLINE.

GROSSE ISLE WELL.

General statement.—It is this well which has most frequently been assumed as a cause of the shortage of water in the region under discusion. That it can not be the sole cause is readily shown by the fact that the decline had been going on for many years before its sinking

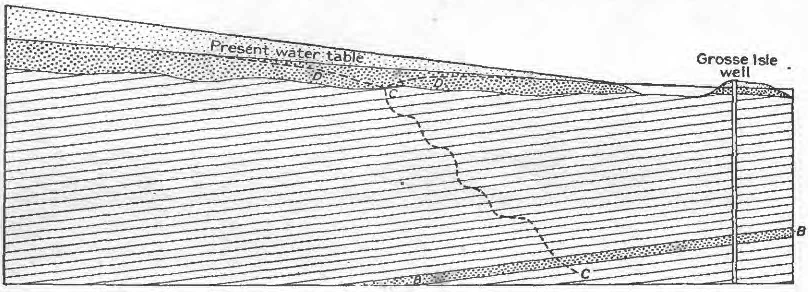


FIG. 34.—Actual and theoretical positions of water table. *B*, Water-bearing bed of Grosse Isle well; *C*, theoretical crevice leading from surface to water-bearing bed; *D*, depressed form which water table would have if water was being drawn into the rocks through crevice *C* in sufficient quantity to affect wells.

in 1903. That it might be the cause of the special decline in that and the following year did not, however, appear unlikely at first, a special argument being afforded by the behavior of the wells of J. E. Brown, etc., of the Swan Creek, and of Charles Bancroft, etc., of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned coincident with the insertion of the casing, only to cease again after its withdrawal in May, 1904. There are, however, many facts which seem to show that the shortage has no connection with the Grosse Isle well.

Districts affected.—The investigation made by the writer showed, as has been described, that while wells in the Swan Creek and Rockwood districts ceased flowing or failed to yield their usual supplies, other wells much nearer Grosse Isle maintained nearly their usual flow, those nearest, even those on Grosse Isle itself, showing no decrease whatever. The conditions of underground drainage would need to be very exceptional which would leave a near-by district unharmed while seriously affecting more remote districts.

Slope of water table.—With a view of determining the source of the water of the Swan Creek-Rockwood area, the head, or height to which the water would rise, was plotted for each well in the region. It was found that this head showed an increase going west of about 3 feet per mile, indicating a source in the hilly region to the northwest. The increase of head to the west (or decrease to the east) was regular, there being no local lowering with a reversed slope downward toward the rock such as would be present if the water was being drawn down into the latter through a fissure connecting with the stratum furnishing water to the Grosse Isle well (see fig. 34).

Geologic structure.—The precise point where the main water-bearing bed of the Grosse Isle well outcrops and whence its supply of water is derived can not be stated. The rocks incline regularly to the northwest (or rise to the southeast) at a rate of perhaps 20 feet to the mile. On the basis of this dip it would seem probable that the bed, which has a depth of 450 feet at the well, would come to the surface somewhere west of Leamington, Ontario. In the Huron River region, however, it would be even deeper than at the well, probably being, in the vicinity of Carleton, nearly 800 feet below the surface. The chance of there being any fissure through all this thickness of strata, by means of which connection between the deep-water beds and the surface wells might exist, is very slight. On the other hand, water can pass downward along the bedding planes with the greatest ease. Such is probably the case, the water being derived from the Ontario region rather than on the American side of the river.

Volume.—A strong impression is left on the mind of one visiting the Grosse Isle well by the immense volume of its flow, which is calculated to be between 45 and 50 gallons, or over a barrel, a second. When, however, it is recalled that the region in which the failure of the wells has been attributed to Gross Isle hole has an area of over 100 square miles, it will be seen that the amount which could be taken each second per square mile is not over half a gallon, or less than a thousandth part of a gallon per acre. The amount ordinarily taken from a square mile by the flowing wells of the Swan Creek and Rockwood districts was much more than this; in fact, the taking of a thousandth part of a gallon per acre each second would probably not have made noticeable effect on the flows.

Head.—The most convincing reason why the Grosse Isle well can not have affected the Swan Creek-Rockwood wells lies in a comparison of the heads of the water in the two localities. The head of the Grosse Isle well is 25 feet above lake level, or approximately 597 feet above sea level, while that of a considerable number of the Swan

Creek and Rockwood flows is less than this amount. In other words, the head of the Grosse Isle well is greater than many of the wells under discussion, and the water, if any connection existed between the two, would not be drawn from the shallow wells, but rather forced up into them.

Summary.—The evidence at hand gives no indication of any connection between the shortage of the shallow wells and the flow of the big Grosse Isle well, but affords, on the other hand, many indications that none exists. The supposed connection with the Grosse Isle well of the loss of water in the Brown and Bancroft wells in 1903 is the result of mere coincidence, the failure simply happening to take place at the height of the dry season of that year. That they should have failed in the still dryer season of 1904 was to be expected. The conditions were almost certainly local, as other wells in the vicinity were not similarly affected at the same time.

NEWPORT QUARRY.

The underdrainage caused by the quarry was, next to the Grosse Isle well, most commonly advanced as a cause of the shortage along Swan Creek. A visit was accordingly paid to the locality and the conditions investigated.

The quarry is located just east of the tracks of the Lake Shore and Michigan Southern Railroad at Newport and a few feet north of Swan Creek. The quarry is 200 to 300 feet across and is excavated to a depth of 18 feet in the limestone, which is reached after 10 or 15 feet of stripping. The creek flows on top of the rock surface, 18 feet above the bottom of the quarry, and is separated from the excavation by a small dike. Water enters at various points in small amounts, but is easily removed by pumping at a rate of about one-half a gallon a second (4-inch pipe, one-half full, but ejected with slight force). A part of the wells near at hand have been affected, but the decrease in the water supply is not universal even within a few hundred feet of the quarry. A quarter of a mile back no effect has been noted.

The small amount of water entering the quarry is in itself an indication that no extensive area is being drained, while the fact that only a part of the adjacent wells are affected, while those a short distance away are unaffected, shows that even in its vicinity the quarry may be neglected as a factor in the shortage of the water supply.

DEFORESTING OF THE LAND.

The existence of forests in a region, while not affecting the amount of water falling on the ground, tends to prevent its escape into the streams with the rapidity with which it runs off of nontimbered lands. By holding it back, even for a few hours, considerably greater quantities are allowed to soak into the ground than would otherwise be the case. Evaporation from the surface is also retarded, the ground remaining wet for much longer periods in wooded than in unwooded lands. The cutting of the timber must, therefore, be accepted as a factor in the general decrease of the supplies of the region. This, however, was effective only in the earlier days; it can not be considered as one of the immediate causes of the sudden shortage of 1903-4.

DRAINAGE BY DITCHES.

The region under discussion is exceedingly flat, and, because of its clayey soil and poorly developed stream system, was originally poorly drained, the low sags often holding water or remaining wet for long periods. All this has been gradually changed through drainage by ditches, with the result that much land has been reclaimed. The process, however, has not been without its drawbacks, for the ditches rapidly carry off much of the water which had previously soaked into the ground to become a part of the ground-water body. The result has been a gradual depletion of the ground water, especially within the past few years, so that the beginning of the present drought found an inadequate reserve supply in the ground.

DRAINAGE BY STREAMS.

The level of streams generally determines that of the ground water in their vicinity, the latter subsiding as the streams fall. During 1904 both Huron River and Swan Creek were unusually low and thus drew unusual quantities from the surrounding water table, which was thereby naturally lowered. Huron River, being a longer stream and one having its source in a region of greater rainfall, was not so low as Swan Creek, the entire course of which falls within an area of low rainfall. Moreover, the latter, flowing over clay nearly destitute of water, receives in considerable portions of its course only slight additions by percolation. It is probably for these reasons that the shortage is marked along its course rather than in any other part of the region.

EARLY FROST OF 1903.

This appears to have been an important factor in bringing on the present acute shortage. According to the official records, the permanent freezing of the ground took place on November 17, which was before the heavy autumn rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and spring months. This was made manifest by the low water in many of the wells during the winter, the result being that when spring opened the ground water was at an unusually low stage.

DEFICIENCY OF RAINFALL IN 1904.

Because of the fact that the ground was frozen during the autumn and winter, the ground was in much the same condition at the opening of the spring of 1904 as it was at the end of the preceding summer, and as month after month during the present summer went by with deficient rainfall the shortage began to be severe. The shortage of rainfall in 1904 is brought out by the climate and crop-sowing reports of the Government, which show that from the opening of spring until July the rainfall was only from one-eighth to a little over one-half of the usual amount. Late in July and in August considerable rain fell, but as it came largely as short, heavy showers the water, instead of soaking into the ground as in more gentle rains, formed streams and ran off rapidly. The part that soaked into the ground was entirely insufficient to compensate for the many dry months which had preceded, especially as the relatively wet months of August and September were followed by several months when almost no rain fell.

CONCLUSIONS REGARDING SHORTAGE.

No evidence was found to show that the Grosse Isle well had affected any of the wells whatever, nor that the Newport quarry was a factor in the failure of wells other than those situated within a few hundred feet of it. The deforesting of the region has been a factor in the general decrease of supplies in the past, but had no immediate connection with the present shortage. The ditching of the region was a prominent factor in the gradual depletion of the ground-water body, so that when the usual fall rains were prevented by frost from being absorbed and the winter was followed by a summer of exceptional drought, the conditions were ripe for the failure of water that followed.

FUTURE PROSPECTS AND REMEDIES.

The failure of the wells being due largely to the severe drought of 1903–4, it is probable that the return to the normal rainfall will result in an increase in the water supply, although, because of the excessive dryness of the ground, the increase in the available water may not be immediately noted. The full supply may not return until a wet year, or, perhaps, a succession of wet years, occurs.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey materials when dried out may, to a certain extent, crumble and become more or less clogged so that their capacity for carrying water is lessened or destroyed, even when the ground again becomes soaked. The return in any case will probably not be complete, as the thorough ditching which the region has undergone will result in a permanent lessening of the water supply of the region.

The wells in the lower Huron River region obtain their supplies in the upper few feet of the rock. The water, judging from its head, is derived from glacial deposits overlying the rock in the region northwest of the area under discussion. It probably traverses the upper more or less jointed and open portion of the rock, because there is less resistance to its flow through such crevices and openings in the rock itself than through the compact clayey deposits which generally overlie the rocks of the region. In its passage the water takes up sulphur and other mineral matter contained in the rock, its quality thus being changed from its relatively pure condition when it first left the drift.

It has been shown in the discussion of the wells of the region that a deepening has almost invariably met with at least partial success, especially where the wells have been sunk deeper into the rock. Throughout the entire region, however, the wells are unusually shallow, even for the surface-water type, a depth of 50 feet being exceptional. In many other regions in Michigan nothing is thought of going 50 to 100 or 150 feet in search of water. It is almost certain that wells of such a depth would in the lower Huron River region yield permanent supplies. Until such wells or at least wells entering some distance into the rock are sunk, a supply adequate to the demands in times of drought can not be expected.

APPLICATION TO OTHER REGIONS.

The history of the decrease of the water supply in southeastern Michigan is in many particulars identical with that in many other parts of the country where similar conditions exist. It is but one of the many striking examples of the failure of the water supplies which have attended the development of new regions, and its history may therefore be taken as a type.

Although the immediate failure of the wells in this, as in most other regions, was due to a deficiency of rainfall, many agencies tending to reduce the reserve supply of ground water had been working unobtrusively, but none the less surely, for a long series of years, with the result that when the precipitation failed to come up to its normal amount a severe shortage was immediately felt.

Probably the most general cause, or at least the one which has been active for the longest period of years, is the deforesting of the land, the result of which has been to increase the immediate run-off and the amount of evaporation. The factor is one which developed gradually, almost inappreciably, but none the less inevitably, as the country became older and the forests necessarily gave place to farms. It is an unavoidable incident in the growth of the country.

Next to deforesting one of the most common causes of the decrease in ground-water supplies is the drainage by ditches. Much of the finest land of our country lies along the flat flood plains of our great rivers or on broad, flat plains, as in Ohio, Indiana, Illinois, and some of the more western States. Considerable portions of such flat lands were originally ill drained, water perhaps standing for months in the flood plains of the river bottoms or in the numerous shallow but often broad sags of the almost equally flat uplands. Thousands of acres of such lands have been, as time went on, gradually reclaimed by drainage ditches and now form some of the richest and most valuable land in the country. Almost everywhere, however, as has been pointed out for the southeastern Michigan region, the ditching has resulted in a decrease of the ground-water body because of the rapidity with which the rain water is removed, it having much less opportunity than formerly to soak into the ground and become a part of the underground supply.

As in the case of the cutting of the forests, the loss of water due to the increase in the number of the drainage ditches is inevitable. But it need not, in most cases, entail any great hardship, for, as in the Michigan region, the ground-water supply is not often exhausted, but simply lowered, and an increase in the depth of the wells usually results in obtaining adequate supplies. It is seldom that the depth will be so great that the cost of wells will be prohibitive to the ordinary farmer.

A further point of interest brought out in connection with the investigation of the southeastern Michigan region is the effect of early frost in helping to bring about conditions of shortage. It is readily seen that no matter how great the rainfall on frozen ground, but little will be absorbed, and if the frost occurs before the autumn rains a heavy precipitation may be without result as far as the ground-water body is concerned. This is a factor which may occur in most of our Northern States at any time, and one which must be taken into account in any investigation of shortage.

WATER SUPPLIES AT WATERLOO, IOWA.

By W. H. Norton.

INTRODUCTION.

The investigation of the conditions at Waterloo was undertaken in response to requests from various officials and drillers. Those from the city authorities were due to an epidemic of typhoid fever, which had raged for several months. Since the 1st of October, 1903, when the epidemic had become so pronounced that all cases were ordered reported, there had been up to March 29, as I was informed by the mayor, 310 cases of typhoid, 35 of which were fatal. As the population of Waterloo is 16,000, the death rate from typhoid for these months alone was 219 to the 100,000, or about 20 per cent higher than the annual typhoid death rate in the Chicago typhoid epidemic of 1892.

The location of the typhoid cases, as platted by the city engineer, showed that they were distributed impartially over the entire water district. The few cases in homes that lay outside the district could be explained by the use of city water in school or workshop. The cases were distributed on all the five sewer-drainage areas of the city, and the theory that the epidemic was due to a clogging of certain sewers was untenable. Dust and flies as possible causes were excluded by the continuance of the epidemic unabated into and through the winter, and it was far too widespread to be due to the infection of milk or foods. Excluding these not uncommon sources of the disease, nothing remained but the city water supply, which was drawn from Cedar River and treated by mechanical filtration.

The intake of the supply is situated a short distance above the town, below the mouths of two small creeks, one of which drains a portion of the suburbs. Five or six miles up valley the sewage of Cedar Falls, a town of 6,500 inhabitants, discharges into the river, and within a very few hours at most reaches the intake of the Waterloo waterworks. During the winter this sewage is protected from oxidation on even this short journey by a cover of ice. Under these circumstances, whenever there are one or more cases of typhoid at the neighboring city the safety of Waterloo must depend solely upon the continuously efficient working of the filtration plant and the destruction by its coagulants of the noxious bacteria in the sewage-contaminated river water. An examination of the water made by Professors Albert and Beirring, of the University of Iowa, showed that not only the raw water of the river, but also the water after treatment at the filtration plant, was highly infected with micro-organisms, the colon bacilli being found in great numbers, and even the bacillus typhosus being recognized. The investigation of the workings of the filtration plant had shown that no tests were made of the amount of coagulants needed from time to time with the varying turbidity of the river, that the pipes through which the coagulants were admitted were sometimes clogged, and that the capacity of the filters was overtaxed by any demand beyond the usual daily consumption. During the epidemic there had been two occasions when the mains had been flushed at times of fires with water drawn directly from the river.

It was under these circumstances that the city officials asked for information from the United States Geological Survey as to the possibilities of other sources of supply than that now in use. They also employed as consulting sanitary and civil engineer Prof. A. Marston, of the Iowa State College of Agriculture and Mechanic Arts. As Professor Marston had already begun at the time of my visit to Waterloo a thorough investigation, and as he is advising with this Office, it seems unnecessary for me to make any specific recommendations as to the relative merits of different sources of supply or as to the methods of their utilization.

There need be considered, then, only the geologic conditions affecting ground and artesian water at Waterloo.

WATER SUPPLY.

GROUND WATER.

Waterloo is situated on a broad, ancient flood plain, which lies about 20 feet above the present river, and, up valley from the city, reaches more than a mile in width. Underlying the plain at a depth usually of not more than 20 feet is a floor of Devonian limestone. Where exposed to view the rock is shattered and closely jointed. Ground water, therefore, sinks readily through its surface layers to lower levels. The alluvium which has been spread over this valley floor of planation consists of sand and gravel, with some finer waste, and is the valley train of one of the Pleistocene ice sheets. Because of its loose texture, its ready drainage into Cedar River, and the pervious rock floor on which it rests, this broad terrace seems to contain no large store of ground water. On some farms of 80 acres, for example, there has been difficulty in getting a stock well, seven or eight attempts having been made before success was reached. The outlook for a supply of water from this source appears unfavorable, but a careful investigation of all its possibilities is being made by Professor Marston and by Mr. C. T. Wilson, the city engineer.

SPRINGS.

About 5 or 6 miles up valley strong springs rise from the limestone on both banks of the channel of Cedar River. On the right bank copious springs gush from crevices for several hundred feet along the bed and near the mouth of Dry Run, a tributary of the Cedar. At the time of my visit to the place the run was ponded by high water in the river and was filled by clear spring water, in distinct contrast with the muddy water of the trunk stream. Notwithstanding the high stage of water, the springs in two places made a noticeable mounding of the water surface. A few feet above these springs are the strong springs used by Cedar Falls for its water supply. On the left bank of Cedar River, about half a mile from the springs just mentioned, two groups of springs are found along a distance of about 500 yards. These were largely concealed from view at the time of my inspection by high water from the river, and I am told are not so strong as those of the right bank. The discharge of all the springs will be carefully measured when the stage of water in the river permits, and their availability will be considered, either as a sole supply or as a partial supply in connection with artesian wells.

ARTESIAN WELLS.

Geology of region.—Waterloo lies in a region whose geologic structure is well known through the work of the Iowa Geological Survey and the surveys of adjoining States. To the depth of several thousand feet the underlying rocks consist of alternating beds of limestones, sandstones, and shales whose general dip is southwestward. These beds thus come to the surface in successive belts toward the north and east, even the lowest of the series appearing as the country rock in central Minnesota and Wisconsin. Several of these beds are porous sandstones. Into these water soaks in large quantities in the areas where they form the country rock, and through them it slowly seeps for hundreds of miles and to depths of several thousand feet. These pervious layers are sheathed, in several instances, with impervious shales, and when tapped by the drill their waters, which are under hydrostatic pressure, rise toward the level of their sources in the higher ground of the States bordering Iowa on the north and northeast. The water may fail of reaching the surface, or on lower ground may overflow, but in either case the well is known as an artesian well. The geologic structure of the deep-lying rocks at Waterloo, on which its artesian conditions depend, is shown in the following section, which, though hypothetical, at least in the thickness assigned the different formations, is believed to be a close approximation to reality.

Hypothetical section at Waterloo, Iowa.

	Thickness.	Depth.
10. Devonian limestone and shales	125	125
9. Niagara limestone	135	260
8. Hudson shales	165	425
7. Galena-Trenton limestone	410	835
6. St. Peter sandstone (50–100)	80	915
5. Oneota limestone	400	1,315
4. Jordan sandstone	100	1,415
3. St. Lawrence dolomites and shales	200–400	1,600–1,800
2. "Basal sandstone"	Indeterminate.	
1. Algonkian quartzite or schist	Do.	

Water horizons.—The texture and conditions of each of these great formations remain to be considered.

The Devonian and Niagara limestones carry water only in their widened joints and crevices. The finding of any considerable amount of water in these beds is an accident whose probability is so slight that it may be neglected. Whatever water they may contain is under less head than that of lower horizons. Their waterways, if struck, would therefore lead off water from below instead of adding to it, and these rocks should be cased off.

The Hudson shale is dry. It is of importance to us because it forms an impervious bottom to the overlying formations and especially because it prevents the waters of the rocks beneath it from rising to the surface under hydrostatic pressure and being lost.

The Galena-Trenton, especially where a dolomitic or magnesian limestone, contains some artesian water in its crevices and fissures. Frequently its water is charged with sulphurous gases which soon escape on exposure to the air. The basal layers of this formation are often shaly and keep the waters of the underlying sandstone from escaping upward.

The St. Peter sandstone is the first important and dependable water-bearing formation of the series. Its grains are smooth and rounded and often but slightly cemented and the pore spaces of the rock are considerable. The capacity of the sandstone varies with its thickness and texture and these can not be predicted with any closeness. The St. Peter may range from 50 to 100 feet in thickness.

The Oneota is a creviced sandy limestone. While the drill passes through it the flow will probably be strongly reenforced from its fissures and sandy seams.

The chief water-bearing stratum of the series is the Jordan sandstone, the upper member of what has been known as the St. Croix, or the Potsdam. Its normal thickness is about 100 feet and its texture resembles the St. Peter. It is recommended that any artesian wells which may be sunk at Waterloo be carried to this sandstone.

The St. Lawrence dolomites and shales, which underlie the Jordan, are usually dry. Their normal thickness is about 200 feet, but they may be found to double that amount at Waterloo.

The "Basal sandstone," as the Iowa Survey has termed the lowest member of the Potsdam formation, is a deep bed of sandstone, more or less limy or clayey in places and in many of its layers so close textured as to be impervious. Toward the east and north, where it lies nearer the surface, its open textured layers are more numerous and thicker, and here its supplies of water are both more abundant and less heavily mineralized than toward the west and south, where it descends deep below ground and where its grains have been more firmly cemented. The thickness of this sandstone at Waterloo can not be predicted. It probably is greater than 200 or 300 feet and possibly, though not probably, may reach 1,000 feet, its thickness depending on the irregular relief of the Algonkian floor whose inequalities it covers.

It seems probable that the increase in supply from the water horizons of the Basal sandstone would not repay the additional cost of penetrating them and that their waters would be more heavily mineralized than those of the zones above, and perhaps be salty, thus lowering their value for manufacturing purposes. But as at Waterloo the amount of water obtainable is of prime importance, I should advise, if an artesian system should be decided upon tentatively and an experimental boring should be made, to sink this boring not only the 1,400 feet needed to test the capacities of the chief zones of flow—the St. Peter, the Oneota, and the Jordan—but also to drive the well to as much as 2,500 feet, if the Algonkian is not sooner reached, in order to probe deeply the Basal sandstone and to test its water resources here.

Quality of artesian water.—Deep wells, if properly constructed, are practically free from possibility of contamination. Artesian water is organically pure. Communities which use it need not fear the widespread epidemics of such diseases as those whose germs are carried in drinking water and which may visit cities using surface-water supplies because of conditions which can not always be foreseen and prevented.

In its long journey underground artesian water has taken up various minerals in solution, and at Waterloo the artesian water will be found less pure from a mineral standpoint than river water. It may be expected to contain in solution lime and magnesia carbonates, with some lime sulphate, together with the sulphates of magnesia and of soda. It is not at all probable that these minerals will be in quantities sufficient to render the water in the least unpalatable or injurious to the health, but several of them form scale in boilers on the evaporation of the water, and their amount in the artesian water found at Waterloo will probably be large enough at least to rank it as "poor" steam water (20 to 30 grains of incrusting solids to the gallon), and still more probably as "bad" steam water (30 to 40 grains of incrusting solids to the gallon). Possibly the water may carry its own "boiler compound" in minerals which will cause the injurious compounds to be thrown down in boilers mostly as sludge.

In a city like Waterloo, which has extensive manufacturing interests and anticipates a large industrial growth in the future, the hardness of artesian water is a serious drawback to its use as a city supply. In certain manufactures, such as ice factories, paper mills (if the water is free of iron), breweries, and bottling works artesian water may be preferable to surface waters, but for locomotives and the boilers of all manufacturing plants it is inferior to the supply now in use.

Quantity of artesian water.—Waterloo is a rapidly growing town with a population estimated at 16,000, and the needed daily water supply is placed by the city officials at 3,000,000 gallons. It is by no means certain that this large amount can be obtained from deep wells. It must be remembered that while the water stored in the water-bearing strata of the artesian field in Iowa is enormous, beyond the possibility of exhaustion, and the large intake area and its abundant rainfall insure its replenishing despite all drafts which may be made upon it, the amount of water which can seep through the sandstones at any locality is strictly limited, and the supply may be overdrawn at that place. At the best a 6-inch artesian could hardly be expected to furnish at this locality more than 250 to 300 gallons per minute. It may very probably not much exceed 200 gallons, and local causes which we can not anticipate may prevent the discharge from reaching 100 gallons a minute. At 200 gallons a minute, or 288,000 gallons a day, 10 wells would not quite give the required amount even if there were no mutual interference of the wells. It is taken for granted that interference will be made as little as possible by stringing the wells on a line normal to the hydraulic gradient and as far apart as possible consistent with utilizing their discharge. But, with all that can be done, there will be interference, and more than 10 wells will be needed to yield 3,000,000 gallons daily, even if the discharge of a single 6-inch well, the others being closed, should reach 300,000 gallons per diem.

Necessity for test wells.—If it should be thought best to use artesian wells for city supply, it would be advisable to put down an experimental boring. If the flow should be meager, the well could be utilized for park, school, factory, or its water run into the reservoir of the waterworks. If the yield should be generous, the work of sinking other wells should yet proceed with caution. The flow and head of each successive well will indicate the approach of the limit where interference may finally make the sinking of other wells unprofitable. The city should be prepared to find this limit before the desired amount of water is obtained and to deal with the case accordingly. To a certain extent the supply may be increased by deep pumping, or by what has the same effect—an air lift. Torpedoes are sometimes used, especially in the case of oil wells, and if this experiment were to be tried the Oneota limestone would be a suitable horizon.

Head.—The head of artesian water at Waterloo is enough to give flowing wells on the level of the flood plain on which the town is built. Wells may therefore be drilled wherever convenience may dictate. An estimate of a head of 20 to 30 feet above the datum just mentioned, while a rough one, is perhaps sufficiently close for practical purposes.

Decrease of flow.—The permanence of an artesian supply is an important factor. Artesian basins when limited in extent are sometimes overdrawn as a whole and the head of water greatly lowered. This cause of decrease or failure need not be considered in connection with so large a field as that of the upper Mississippi Valley.

The local area is frequently overdrawn by a large number of wells, even when the general field shows no sign of decrease. In the case of Waterloo it is assumed that the number of wells sunk will be kept well within the limit of mutual interference. It is assumed that the flow of water through the pervious water-bearing strata to the local area will be enough to meet the draft which the limited number of wells may make upon it, so that whatever interference and loss of head there may be will appear as the wells are drilled and will not seriously increase with the lapse of time.

Wells decrease in flow from several causes, which may be either prevented or remedied. Such are leakage into horizons higher than the water-bearing strata, imperfect or worn-out packings, corroded casings, clogging of the pores of water-bearing strata, and infilling of the bottom of the bore with débris from above. In the Iowa field the decrease of artesian flows, where such has been noticed, seems to be due largely to one or more of these causes, and at Waterloo they do not form any serious obstacle to an artesian supply.

SUPPLEMENTARY SUPPLIES.

The question of supplementing the artesian supply, if insufficient, is chiefly one of finance and engineering. The cost of bringing in spring water should be considered, and the cost computed also of combining artesian water with that of a filtration plant dealing with water from Cedar River. It may be found that artesian water costs sufficiently less than filtered water to enable it to be economically used as far as it can be obtained without serious interference of the wells. In this case the water from both sources combined would be proportionally less hard than the artesian water alone, and hence a better boiler water, but unless the filtration of the river water were bacteriologically complete the combination would be little less dangerous than the filtered water under the same circumstances.

WATER SUPPLY FROM GLACIAL GRAVELS NEAR AUGUSTA ME.

By George Otis Smith.

INTRODUCTION.

This paper is one of several in the present report which deal with the problems of water supplies of glacial deposits of different types and origins. No other source furnishes so abundant and pure supplies over such large areas as the drift, from which probably considerably over nine-tenths of the wells north of its southern limits obtain their water. The drift is likewise the source of a large proportion of the springs within its area, and furnishes the supplies of the waterworks of many of the smaller cities and towns. At the same time its composition and structure are so complex and variable that it is with great difficulty in many cases that an intelligent understanding of the true conditions can be obtained. It is with the view of presenting examples of the conditions in type deposits that this and other similar papers have been prepared.

The region described in this article was visited in June, 1904, by the writer, at the request of Governor J. F. Hill, chairman of the commissioners of the Augusta, Me., water district. The Silver Lake system of ponds had been considered among the possible sources for a new municipal water supply, and the visit was made in company with Mr. Allen Hazen, consulting engineer.

Spring Brook, which has its source close to these ponds, had been gaged and found to have a discharge insufficient for the demands of the city of Augusta, and the suggestion had been made that this supply could be augmented by water from the ponds in the vicinity. The problem presented at this time, therefore, was the examination of the Silver Lake drainage basin and the determination of the nature of its relation, if any, to the springs which supply Spring Brook.

In presenting the results of this investigation I wish to acknowledge my indebtedness to Mr. Hazen. Although we approached the problem from somewhat different points of view and followed different lines of argument, it was noteworthy that we arrived at

essentially the same conclusions. While the writer had this advantage of discussion of the field observations with a hydrographic engineer, the conclusions here presented are those based principally upon geologic data. Acknowledgments are also due to Mr. W. W. Albee, superintendent of the Augusta water district, for information furnished and for the sketch map accompanying this paper, which is based on the surveys of Mr. Samuel M. Gray, consulting engineer, who also ran the level lines, determining the elevations of the different ponds, as quoted on a following page.

GENERAL DESCRIPTION.

The Silver Lake group of ponds is situated about 5½ miles northwest of the city of Augusta, Me., at the place where the four towns—Augusta, Manchester, Belgrade, and Sidney—come together. Thirteen ponds are included in this system, with an aggregate area of 215 acres, ranging in size from 41 acres to 3, and in depth from 81 to 11 feet. Several of the ponds are connected by sluggish streams, but the system has no visible outlet. A half mile south of Tyler Pond, the southernmost of the group, there are scores of springs, the waters from which unite to form Spring

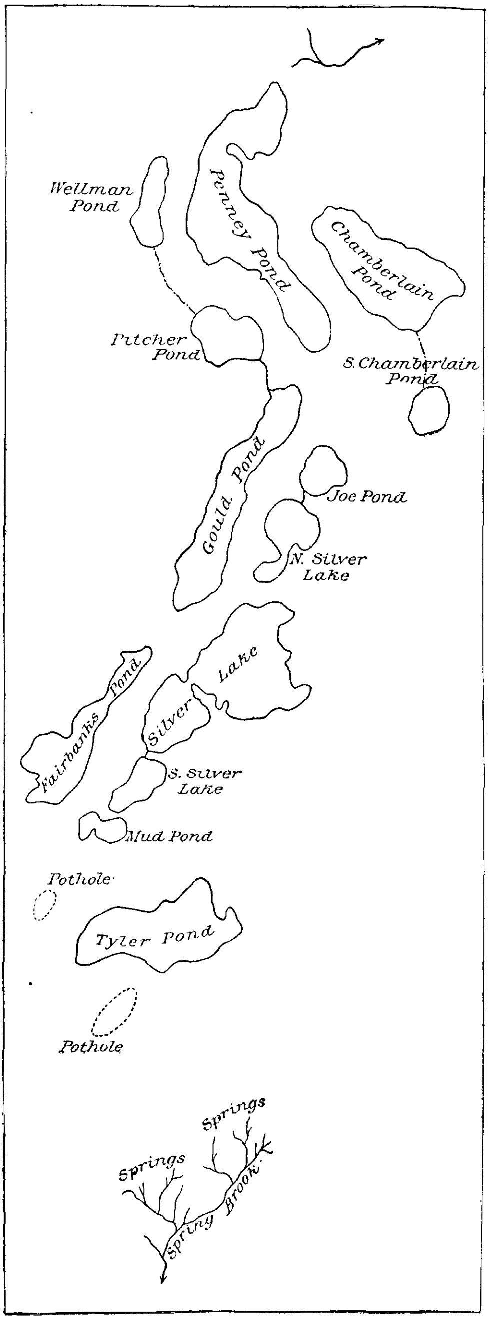


FIG. 35.—Sketch map of lakes near Augusta, Me.

Brook. This stream enters Bond Brook and thence reaches Kennebec River within the city limits of Augusta.

These ponds are located on a well-defined plateau, which has an elevation of about 300 feet above sea level, Augusta being situated at the head of tide on the Kennebec. This plateau is slightly diversified by a few rounded low hills and ridges, but along its southern border its surface is very level. The "caves," or V-shaped gulches, which have been eroded along the southern margin of the plateau well exhibit the material composing it. Rounded gravels with bowlders up to 1 foot in diameter and fine sand are interstratified, but no clay beds were observed.

The topographic details of this plateau and its composition indicate its features to have been formed by the deposits of a glacial stream. This is, indeed, the southern end of an extensive system of glacial gravels, which has been described by Stone as the Norridgewock-Belgrade system.[a] The basins containing the ponds, as well as the dry kettle holes, doubtless represent ice masses originally inclosed in these glacial gravels.

SILVER LAKE DRAINAGE BASIN.

The area included in this basin is $1\frac{3}{4}$ square miles. The topographic character of its surface and the sandy soil covering it make the conditions extremely adverse to any loss of rain water by run-off. The boundaries of the basin are not well marked except at the northern and southern ends, where there is a sharp descent into adjacent stream valleys. The drainage basin is subdivided by a winding ridge, which separates two chains of ponds.

The underground character of this basin can be inferred from the exposures of stratified sand and gravel along the southern margin of the plateau. The extent to which this basin is sharply bounded beneath the surface is largely a matter of conjecture. The occurrence of glacial till immediately bordering the plateau on both the east and west suggests that the underground limits of the basin may approximately coincide with the surface boundaries. The fact that ledges of slate also occur both on the east and west borders of the plateau may be regarded as substantiating this opinion.

SHAPE OF THE WATER TABLE.

In a mass of horizontally stratified gravel and sand, with no impervious beds and no marked relief in surface topography, the shape of the water table is important in its bearing upon the questions of underground flow. The factors of impervious strata and surface

[a] Stone, G. H., Glacial gravels of Maine and their associated deposits: Mon. U. S. Geol. Survey, vol. 34, 1899, pp. 181–184.

topography being here eliminated, the form taken by the water table will clearly indicate the direction of flow. Fortunately for this discussion the exact levels of the different ponds in December, 1903, are available. The water levels in these ponds, most of which are without outlets, indicate the position of the water table, or upper surface of the ground water, and these levels are given in the following table. The ridge already referred to separates the group of ponds into two chains, and the elevations for these will be given in separate columns—I being the elevations for the ponds of the eastern chain, and II for those of the western chain.

Elevation of water levels in Silver Lake pond system.

Name.	I.	II.
Chamberlain Pond	268.24	
Wellman Pond		266
Penney Pond		265.15
Pitcher Pond		263.05
South Chamberlain Pond	267.90	
Joe Pond	267.80	
Gould Pond		264.70
North Silver Lake	267.60	
Silver Lake	261	
South Silver Lake	259	
Fairbanks Pond		260.20
Mud Pond	257.30	
Tyler Pond	254.30	

The table brings out several noteworthy facts. In the first place, with the exception of Penney Pond, in both chains of ponds the elevations of the water surface decrease southward. This indicates a southward slope of the water table. The exception to this generalization is important, since Penney Pond lies at the northern end of the plateau and is separated from the neighboring ponds by a ridge, and, furthermore, has near its northern end one of the few places where a small stream was seen flowing outward from the plateau margin. Just south of Tyler Pond there is a deep kettle hole, which is perfectly dry. Barometric observations, however, explained this apparently anomalous condition by the fact that the bottom of the kettle hole is 5 feet above the water surface of Tyler Pond.

A second feature is the relative independence of the two chains of ponds. It is evident that the ridge separating them is simply the topographic expression of a structural element in this mass of glacial stream deposits. In fact there are also transverse ridges which cause similar variations in level of the water surface of adjacent ponds in the same chain. Thus Silver Lake is separated from North Silver Lake by a ridge only a few yards across, and the difference in water level is over 6 feet. The slope of the water table apparently varies considerably within this area, but the average slope is not far from 10 feet per mile. The direction of flow is largely controlled by the opportunity afforded for escape along the base of the bluffs forming the southern edge of the plateau, but possibly this flow is facilitated by a slight southern dip of the stream-laid gravels.

The southern slope of the water table over the greater part of this area indicates the direction of underground flow. This in turn at once explains the source of the springs at the head of Spring Brook. The supposition that these springs may be fed from some distant supply, such as Messalonskee Lake, 5 miles north of the springs, is at once controverted. While higher than the springs, this lake is probably 40 feet below the water table of the Silver Lake system, and indeed it is not unlikely that the northernmost pond of the group, Penney Pond, drains partly into a stream flowing northward into Messalonskee Lake.

PRACTICAL CONSIDERATIONS.

It is seen from the above description that the Silver Lake area constitutes a natural system of filter beds. The water falling upon the surface of the plateau slowly percolates through the interbedded sands and gravels. The water issuing from the springs is therefore of exceptional purity, and as regards quality no better water supply could be desired.

Unfortunately the quantity of flow in Spring Brook is insufficient, and one plan proposed was to erect a pumping station upon the plateau and use the pond water as an auxiliary supply. From the foregoing discussion of the conditions controlling the system of ground water in the Silver Lake area, it will be readily seen that such a procedure would be highly inexpedient. The flow of the springs is directly dependent upon the ground water of the plateau, and as it seems probable that there is little flow outward from this basin either to the east or west by reason of the bounding masses of till and rock, it follows that the annual discharge of the springs at the south end of the plateau approximately equals the amount contributed to the basin by the rainfall. The water of the thirteen ponds is merely the visible portion of the supply of ground water in this basin, and to pump from Silver Lake or Tyler Pond would be simply to draw from the same supply as that from which the springs derive their water. While each of these two ponds has a capacity measuring over 200 millions of gallons, yet pumping this water would surely tend to lower the level of the water table, and thus eventually to decrease the rate of discharge at the springs.

WATER SUPPLY FROM THE DELTA TYPE OF SAND PLAIN.

By W. O. Crosby.

TYPES OF GLACIAL DRIFT.

One of the most important sources of water supply in the glaciated regions of this country is the glacial drift. In New England and other regions where the rocks are largely crystalline the drift, in fact, constitutes almost the only source. Of the various types of glacial drift the till or hardpan is the most abundant and widely distributed, and in the aggregate yields large amounts of water. It is, however, the sands and gravels or the coarser parts of the stratified drift which afford the large and important sources of supply. There are many types of these latter deposits, the most common being those of the following list:

1. Valley or flood-plain deposits of Pleistocene and recent streams.
2. Terrace deposits of Pleistocene streams.
3. Outwash plains in front of moraines and elsewhere.
4. Normal sand plains or delta deposits formed in glacial lakes and other bodies of standing water.

The last type of deposits is very prominent in New England. Detailed investigations of such a delta have been made at Clinton, Mass., in connection with the building of the Wachusett reservoir of the water-supply system of Boston and the metropolitan district. Many borings were made in this delta, a large number of samples secured, and some sections made—in fact, an unusually thorough knowledge of its structure and composition obtained.

The Clinton sand plain (deposited in the glacial Lake Nashua) is in all respects typical of its class, the essential conditions existing in it being duplicated in many plains throughout New England. The results of the study of its structure and the relations thereto of the ground water are therefore of interest in showing the possibilities and characteristics of water supplies in sand plains in general.

Nashua River holds a unique place among the rivers of New England, inasmuch as it is the largest stream east of the Hudson-Lake Champlain Valley that flows throughout the main part of its course in a northerly direction. The deep northward-draining valley of the Nashua presents ideal conditions for the study of the phenomena of glacial lakes, for probably nowhere in New England was this phase of the closing stage of the Pleistocene ice sheet more typically developed.

Although Nashua Valley presents naturally a very attractive field for the student of glacial geology, it was rendered doubly inviting by the operations of the metropolitan water board in the construction of the Wachusett reservoir. This great reservoir, with an area of $6\frac{1}{2}$ square miles and a maximum depth of 129 feet, will be formed by the building of the Wachusett dam across Nashua River and of two auxiliary dams, known, respectively, as the "north dike" and the "south dike," and will reproduce in part the glacial lake which once adorned the upper valley of the Nashua.

The history of the Nashua series of lakes commenced when the retreating margin of the great ice sheet first began to uncover the southern water parting of Quinepoxet River, which unites with the Stillwater near Oakdale to form the Nashua.

During the earliest stage the impounded water of Quinepoxet Valley found an outlet, at an elevation of about 760 feet, across the southern water parting, flowing southward to Blackstone River and Narragansett Bay through the pass now occupied by Chaffin Pond and traversed by the Boston, Barre and Gardner Railroad.

When the ice sheet released its hold on the Malden Hill Ridge at the north limit of the ponded body the water fell to the level of the Boylston stage, finding near Boylston Center an outlet at an elevation of about 440 feet, through which it passed into the valley of Lake Quinsigamond and thence to the Blackstone. The opening of the Boylston outlet involved a change of level of about 300 feet, and such a complete abandonment of the Quinepoxet area that the two parts or stages of the lake nowhere overlap, but appear on the map as entirely distinct and separate bodies of water.

When the ice margin had finally retreated along the eastern water parting to the pass formerly traversed by the Central Massachusetts Railroad, 2 miles south of Clinton (to be closed by the south dike), the level of the lake was lowered about 70 feet, to the Clinton stage (see fig. 36); and its waters probably became tributary to Boston Harbor instead of Narragansett Bay, Concord and Merrimac valleys being still occupied by ice. This is an ideal outlet, narrow and well defined. The minimum elevation of the water parting in the south-dike pass is 365 feet—nearly 370 feet before the construction of the railroad.

THE CLINTON DELTAS.

FORMATION.

With the opening of the south-dike pass came a rapid development of the Clinton Plain, made possible by the necessarily rapid erosion

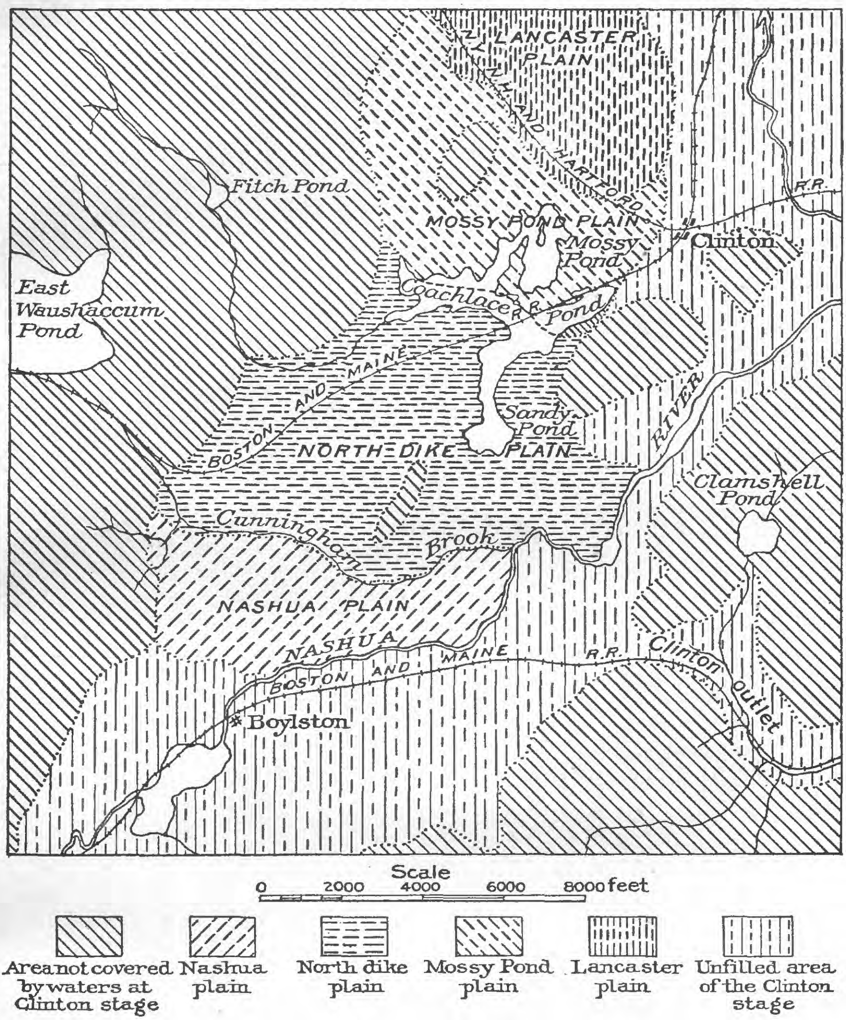


FIG. 36.—Extent of Lake Nashua at Clinton stage and location of the subdivisions of the Clinton plains. The larger portion of the area within the boundary of the lake at the Clinton stage is occupied by sand plains, the Clinton plains proper, the subdivisions of which are represented on the map, lying to the northwest, west, and southwest of Clinton.

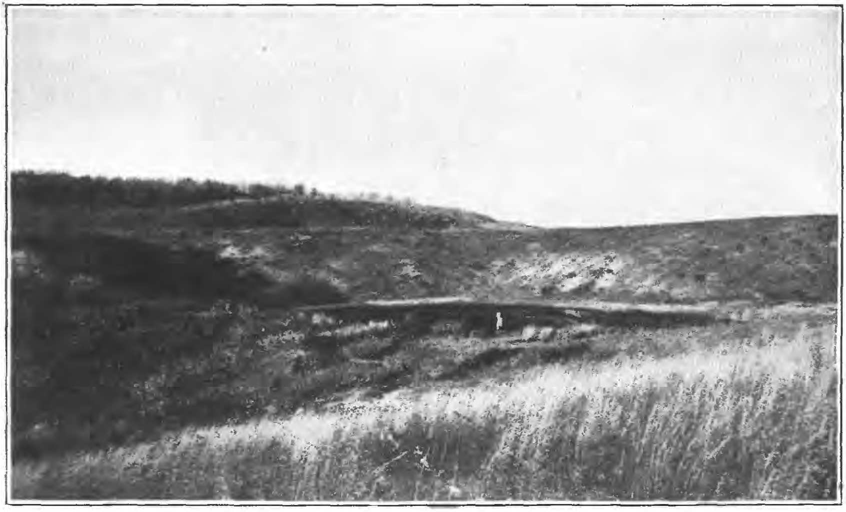
of the high and deep deposits of the Boylston stage. In fact, the waste of the Boylston Plain along the axis of the valley in the first few years after it became exposed to the rush of the Nashua and its tributaries, with a fall of from 10 to 20 feet per mile, must have been enormous; and we can not escape the conclusion that through the cooperation of the Nashua with the glacial streams from the northward the Clinton Plain was developed continuously along the southern margin of the ice to the outlet, the level of which was probably raised somewhat by the extension through it of the coarse topset layers of the delta.

GENERAL CHARACTER.

The delta plains of the Clinton stage, with normal elevations of 375 to 385 feet, are most broadly and typically developed in the districts immediately northwest and southwest of the village of Clinton, or in that part of the valley between South Lancaster and Boylston. They are, in part, indicated with a good degree of accuracy by the contour lines of the topographic map; and those southwest of Clinton are still more clearly and accurately expressed by the contour line of 370 feet on the map of the Wachusett reservoir, this contour tracing the outlines of the plains very closely where they are developed to the normal elevation. The post-Glacial erosive action of the river has left, as a rule, only meager remnants of the Clinton plains up the valley west of Boylston. North of Boylston, however, the valley is much broader, and the ravages of the river relatively much less, so that over an area of several square miles the deltas of the Clinton stage are preserved almost intact. In fact, it may be doubted if anywhere in this region can be found more normal or striking examples of this phase of the modified drift. The deforesting of the area to be covered by the reservoir brings out the various features of the plains in all their pristine distinctness and perfection, so that even in a merely topographic sense a very unusual opportunity is temporarily presented to the student of glacial geology.

Although, as the map shows, the Clinton plains are broadly and typically developed in the districts both immediately northwest and southwest of the village of Clinton, it is in the latter area that they have been most perfectly exposed for study by deforesting, and most fully explored, first, by drilling preparatory to the construction of the north dike, and second, by the excavation of the great trench subsequently filled with impervious material to form the core or cut-off of the dike. The main cut-off trench afforded a nearly continuous section, having an aggregate length of 9,556 feet and a maximum depth of 60 feet, and in addition to this there was a shorter secondary cut-off trench. The wash-drill borings, to the number of 1,131, with an average depth of 83 feet and a maximum depth of nearly 300 feet, are distributed systematically and somewhat uni-

Wm. A. Lamb.



A. KETTLE HOLE IN NORTH DIKE PLAIN, MASSACHUSETTS.

B. VIEW UP THE FOSS VALLEY OF CUNNINGHAM BROOK, MASSACHUSETTS.

formly over an area 9,000 feet in length (east-west) and 2,000 feet in breadth. Nearly 10,000 samples from these borings have been examined, in part somewhat exhaustively, and it is, perhaps, within bounds to say that in certain aspects no similar body of modified drift has been more thoroughly investigated. The available data seem, therefore, to justify a somewhat elaborate presentation and discussion, especially since they throw important light not only upon the structure of these deltas, but also upon the relations of the ground water to this structure; and since they are externally, also, rather impressive examples of the type, presenting ideal developments of all the normal features, including ice contact, frontal and erosion slopes, and the level, upper, or topset surface pitted by kettles.

In a broad way the Clinton deltas are coextensive with the lake at the Clinton stage (fig. 36). They are bordered on the east and west by slopes of rock, or till, and in the southern portion by the higher plains of the Boylston stage. The contact is marked in part by original ice-contact surfaces of the higher plains and in part by erosion slopes cut in these higher plains by the Clinton waters. The principal development of the Clinton plains is west of Nashua River in the region northwest and southwest of Clinton, in which region four successive delta stages are recognized, which, beginning with the earliest, or southernmost, and ending with the latest, or northernmost, are the Nashua, North Dike, Mossy Pond, and Lancaster plains. Their locations are shown in fig. 36. The surface of each of the plains is characterized by numerous kettles, due to the melting of buried or partly buried masses of ice; some of these kettles are of large size and contain ponds (Pl. V, *A*). The Nashua, North Dike, and Mossy Pond plains all show gentle slopes and faces to the south and east; the first two and the Lancaster Plain have steep ice-contact faces on the north. The Mossy Pond and Lancaster plains merge into each other, and neither the ice contact of the former nor the marginal slopes of the latter are typically developed. The sharp channel of Nashua River, eroded to a depth of 70 or 80 feet through the Nashua Plain, is a characteristic feature (Pl. VI, *A*).

NORTH DIKE PLAIN.

STRUCTURAL FEATURES.

It is proposed to consider here only that segment of the Clinton Plain crossed by the north dike and bounded on the north by Coachlace Pond and on the south by Cunningham Brook and Nashua River. For, as previously noted, this member alone of the Clinton series has been sufficiently dissected by borings and excavations to afford the data requisite to an understanding of its structure.

General topographic and bed-rock relations.—The North Dike Plain is approximately 2 miles long (east-west) by 1 mile wide in the general direction of its growth from north to south and divided midway of its length by the narrow and overlapping ridges of metamorphic slate or phyllite, on the most southerly of which the Catholic cemetry was formerly located. The western part of the plain is, in most respects, the more normal delta, at least in regard to its formal features—an almost unbroken plain sloping gently and evenly southward from a typical ice-contact margin fringed with kettles to a lobate frontal slope, which is separated from the ice-contact margin of the earlier Nashua plain by the foss valley of Cunningham Brook. In its under surface, also, the western part of the North Dike Plain is relatively simple and normal, since its northern half rests on an approximately plane bed-rock floor (ranging in elevation, as shown by several hundred borings, from about 330 to nearly 370 feet), which also slopes gently southward and is trenched to depths up to 50 feet or more by several southward-sloping and southward-converging rock valleys.

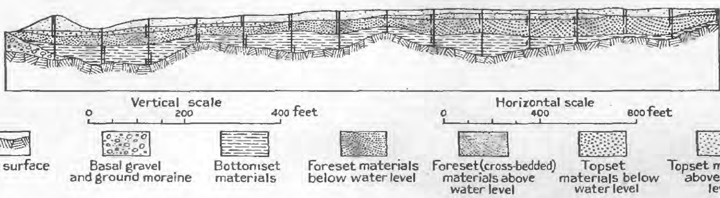


FIG. 37.—Selected east-west profile through a line of borings in westerly portion of north-dike area, Clinton, Mass.

The form of the bed-rock surface, so far as developed by the borings, is shown by the east-west profiles across the valleys (fig. 37).

The eastern half of the plain is far more irregular, both superficially and basally, than is the western half. Midway between the cemetery ridges and Burdette Hill it is widely divided by the kettle basins of Coachlace and Sandy ponds, continued southwestward in a string of more normal kettles; and approximately coincident in position and trend with this depression is the deep, pre-Glacial bed-rock gorge of Nashua River, to which several minor bed-rock valleys with separating ridges of schist are tributary.[a]

The most surprising and puzzling feature of the relations of this plain to the bed-rock contours is the fact that the basin or trough of Coachlace Pond, as it existed before the building of the north dike, although closely parallel to the deep, buried gorge of the Nashua, does not directly overlie it, but is superposed, with 120 to 130 feet of modified drift intervening, upon a distinct bed-rock terrace several hundred feet wide, with an elevation of 190 to 210 feet, separating

[a] Techn. Quar., vol. 12, p. 294.

A. EROSION OF THE NASHUA PLAIN, MASSACHUSETTS.

B. WASH DRILL IN OPERATION ON THE NORTH DIKE PLAIN, MASSACHUSETTS.

the gorge from a well-defined ridge of schist comparable with the cemetery ridges and rising to a maximum elevation of 280 feet, or within 100 feet of the surface of the Clinton Plain. This relation, whether fortuitous or not, clearly demands consideration in any discussion of the origin of the kettles. It appears from the foregoing that the broken eastern half of the North Dike Plain rests upon an unusually rugged bed-rock topography, with a maximum relief of nearly 300 feet and corresponding variation in the depth or thickness of the modified drift; and it may be added that the form of the bed-rock surface is without appreciable influence upon the contours of the delta, except, perhaps, in determining in some degree the location and trend of the north-south line of kettles, or ice-block depressions.

Relations to the ground moraine or till.—With a bed-rock topography of strong relief, the dominant trends of which are obliquely transverse to the direction of glacial movement, it might, perhaps, have been anticipated that the depressions would be deeply filled by the ground moraine. As a matter of fact, however, the borings show that the valleys, and notably the deep pre-Glacial gorge of Nashua River, are remarkably free from till; and this notwithstanding the fact that the North Dike Plain terminates both east and west in prominent drumloids, in which the bed rock is heavily covered with till. Usually the only thing really suggestive of till is a basal layer of gravel of obviously local origin, and ranging from a few inches to several feet in thickness, which many of the borings show resting upon the bed-rock surface. This basal gravel, varying from coarse to fine, but undoubtedly including much coarser material than the wash-drill samples indicate, might perhaps be interpreted as a washed till; but, if so, the washing has been singularly thorough, for the samples show it to be entirely devoid of clay and rock flour, and there is no apparent reason why it should be differentiated in origin from the rest of the modified and water-laid drift. West of the cemetery ridge, however, although the till is restricted to a few thin patches rarely exceeding 5 feet in thickness for the northern profiles, southward down the sloping bed-rock surface it increases somewhat, and in the two or three most southerly profiles it is practically continuous and varies in thickness from 2 to 30 feet.

Collection of boring samples.—The borings in the north-dike area were made with the wash drill (Pl. VI, *B*), which consists essentially of a strong casing pipe approximately 3 inches in diameter, and the drill proper or water pipe about $1\frac{1}{4}$ inches in diameter, and terminating at the lower end in a cutting edge with two small holes for the escape of water. The casing is driven into the ground by a cast-iron weight which encircles its uppermost length or drivehead, and, falling freely, strikes on a collar firmly attached to the lower end of the drivehead. In this collar is the outlet for the water, which, escaping from the lower end of the drill, rises in the annular space between the drill and the casing and brings up, if the head of water be sufficient, all material loosened by the action of the drill, except pebbles and stones too large for the channel, or exceeding about 1 inch in diameter. Larger stones are either displaced or broken by the drill or casing. The outflowing stream of turbid water discharges into a tub in which the coarser materials in suspension settle, while the clay and rock flour are largely washed away with the overflow. At convenient intervals, and especially when a change in the character of the discharge is noted, the water in the tub is poured off, a sample taken from the accumulated sediment, and the tub cleaned out preparatory to the collection of the next sample. In absorptive strata a part of the water may escape into the ground, reducing the velocity of the excurrent stream sufficiently so that only the finer detritus is brought up; or the water may be wholly lost and no sample obtained until the ground becomes saturated or the casing is driven deep enough to cut off the thirsty stratum. It has been found also that when the casing has reached the great body of fine sand and rock flour, of which the lower part of the deposit is chiefly composed, the drill may be run down below the casing 100 or even 150 feet, the water rising for this distance in an uncased well of its own making without collapse or serious caving of the walls. Of course any enlargement of this unprotected part of the hole must diminish the velocity of the water through it, and thus, as in the case of "lost water," tend to prevent coarse sand or gravel from coming up and make the samples more or less incomplete.

The majority of the samples were necessarily taken under the general conditions described above, and these are designated as regular or "incomplete" samples. These were supplemented for certain borings by special or "complete" samples, taken by holding a 2-quart glass jar under the discharge and allowing it to fill but not overflow, and then, after the material in suspension had settled, drawing off the water with a siphon. In cases of persistent turbidity (suspended clay) a few drops of hydrochloric acid were added to the water to curdle the clay and thus secure a more prompt and perfect separation. With these precautions the special samples can not fail to show in due proportion all the materials brought up by the water; but they are still likely to be imperfectly representative of the deposit as it exists in the ground when the detritus is coarse or of a composite (coarse and fine) character, or where any important part of the water is lost. The special samples were taken at regular intervals of 5 feet, and an extra sample whenever a change in the character of the discharge was noted, thus making sure that no important changes were overlooked.

Classification of boring samples.—The special samples, with the regular samples from the same borings, were submitted to elaborate mechanical analyses and filtration tests, to be described later; but the regular samples, as a whole, were far too numerous, as well as too incomplete in character, to justify anything more than a careful macroscopic examination, with a view to an approximate classification in accordance with the following scheme:

Classification of wash-drill samples from site of north dike.

1. Coarse gravel.	6. Superfine sand.
2. Fine gravel.	7. Rock flour.
3. Coarse sand.	8. Superfine rock flour.
4. Medium sand.	9. Clay.
5. Fine sand.	10. Bowlder clay.

The coarser and also the finer grades are, as usual, highly composite or have high uniformity coefficients, while the intermediate grades, especially No. 5, have, for reasons to be discussed later, a high degree of uniformity or relatively low coefficients. The uniformity coefficient is defined as the ratio of that size of grain than which 60 per cent is finer to that size than which 10 per cent is finer, this ratio varying inversely as the actual uniformity. A large number of determinations gave the following as the average or normal maximum sizes of grain in the four grades between medium sand and clay: No. 5, 0.45 millimeter; No. 6, 0.28 millimeter; No. 7, 0.16 millimeter; No. 8, 0.08 millimeter. The averages for the uniformity coefficients for these grades are as follows: No. 5, 1.96; No. 6, 2.11; No. 7, 2.25; No. 8, 1.53. These values of the uniformity coefficients are believed to be essentially normal for grades Nos. 5, 6, and 7, and technically so for grade No. 8. The values for grades Nos. 7 and 8 (2.25 and 1.53) are, in each case, the average of 38 determinations, with minimum and maximum values of 1.49 and 3.30 for grade No. 7 and 1.15 and 1.88 for grade No. 8. But it is very difficult or practically impossible to accurately measure the finer particles of grade No. 8, since they are in their minuteness on the border line of clay; and it is very obvious that where falling below the technical effective size (the size than which 10 per cent is finer), or even where aggregating less than 10 per cent of the whole, they may still be regarded as an important factor in determining the real uniformity as well as in their influence upon porosity and percolation.

General structure.—A normal delta, built by a swift and turbid stream in a body of standing water—that is, formed under the conditions existing in a glacial lake—embraces, as shown in fig. 38, three approximately horizontal beds, which Davis has fitly named the topsets, foresets, and bottomsets. In the topsets, composed mainly of coarse material (gravel and coarse sands, grades Nos. 1, 2, 3), stranded on the upper surface of the delta, and in the bottomsets, embracing chiefly the finest silt (rock flour and clay, grades Nos. 7, 8, 9) deposited in the standing water beyond the outer margin of the delta and subsequently covered, at least in part, by the continued extension of the latter, the growth is principally in the vertical direction and the lamination horizontal; while in the foresets, formed on the growing edge or frontal slope of the delta and made up almost exclusively of material of intermediate textures (medium and fine sands, grades Nos. 4, 5, 6), the growth is horizontal and the lamination oblique, the laminæ sloping downward in the direction of growth.

The topsets, formed on a surface already aggraded nearly to the base level, are, in spite of their coarseness, of relatively slight aggregate thickness, and they are likely to be much thinner than the combined foresets and bottomsets, this ratio varying directly as the depth of the basin in which the delta is built. It would perhaps appear to

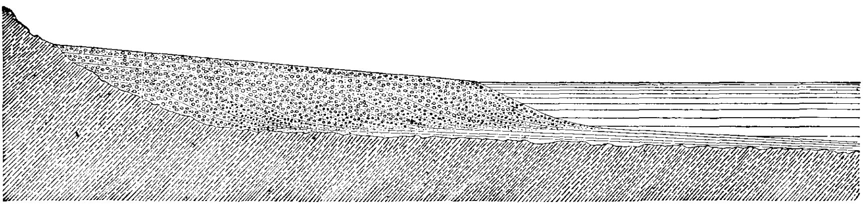


FIG. 38.—Diagrammatic section of a typical delta, showing topsets, foresets, and bottomsets (Gilbert).

many a natural if not a necessary assumption that the bottomsets also should be relatively thin, the foresets appearing thus as the dominant feature of the delta section. The relative thickness of the bottomsets must obviously tend to vary directly as the proportion of silt in the detritus delivered at the head of the delta by the tributary stream and inversely as the area of the basin beyond the frontal slope of the delta; and it is clear that the thickness of the bottomsets should increase from the head of the delta outward because of the increasing time and diminishing area of deposition. Although these principles may require some modification as applied to ordinary deltas, marine and lacustrine, they are believed to be especially applicable to the deltas of glacial lakes of limited area, largely because of their relatively rapid construction and the consequent sharp delimitation of the component features.

The well-determined high proportion of silt (rock flour and clay) in normal drift, averaging more than 50 per cent of the whole,[a] suggests for the limited basins of many glacial lakes an exceptional thickness of the bottomsets, especially toward the lee sides of the basins. The full thickness of the bottomsets is rarely disclosed in

[a] Proc. Boston Soc. Nat. History, vol. 25, pp. 115–140.

actual sections of important deposits;[a] but even this fact added to the foregoing consideration fails to suggest the great depth of the bottomsets indicated by the numerous borings in the north-dike segment of the plain formed in true delta fashion during the Clinton stage of glacial Lake Nashua.

The borings do not, as a rule, reveal the attitude or dip of the lamination, even when adjacent borings are closely compared; and general conclusions as to the relative thickness of foresets and bottomsets must rest largely upon the assumption that grades Nos. 4 and 5 belong especially to the foresets, and grades Nos. 7 and 8 to the bottomsets, and that grade No. 6 holds an intermediate position, marking the transition from the foresets to the bottomsets. These assumptions were sustained by observation wherever, in the course of the engineering operations, the deltas have been sectioned. The most important opportunity for direct observation of the structures below the surface was afforded temporarily during the construction of the north dike by the primary and secondary cut-off trenches, the former extending the entire length of the dike and ranging most of the way from 30 to a maximum of 60 feet in depth. Notwithstanding that the trend of the cut-off is at most points transverse to the direction of delta growth, the walls of the great trench showed in general, below the coarse gravel of the horizontal topsets, southward-sloping layers of medium to superfine sand, rarely more than 10 to 15 feet thick. Since the main purpose of the cut-off is to intercept the relatively pervious topset and foreset beds, it nowhere penetrates deeply the underlying and highly impervious bottomset strata; and hence these have nowhere been exposed for more than a small fraction of their thickness.

The low uniformity coefficient and consequent high porosity of the more characteristic material of the foresets seems to find a ready explanation in the obvious principle that, of the material swept by the distributaries of the glacial stream beyond the outer edge of the delta, only particles of a limited range in size could settle on any narrow zone of the frontal or foreset slope; and yet it is easy to see that the material would tend to become finer toward the bottom of the slope. In the standing water beyond the frontal slope the residuum of detritus in suspension must all settle eventually, with little or no assorting where the process is continuous, the resulting deposit becoming thus highly composite. The importance of this principle in its relations to the storage and movement of the ground water in the sand plains of the glaciated area is obvious.

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[a] Investigations of the clays associated with a sand plain at Barrington, R. I., made by J. B. Woodworth (Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 987–988), and M. L. Fuller (Jour. Geol., vol. 7, 1899, pp. 452–462), showed that the bottomset silts may be present in as great or greater bulk than the sands and gravels of the combined foresets and topsets.

The theory of the formation of delta plains in glacial lakes requires that the recession of the stagnant margin of the ice sheet should be intermittent or characterized by more or less prolonged halts, with, in general, a rather rapid recession from one halting place to the next. The essentially stagnant condition of the ice margin is proved by the rather rare distortion of the delta deposits due to a readvance of the ice. The glacial streams, superglacial and subglacial, tend constantly to build deltas in the standing water of the lake, but the normal form and structure are fully realized only where the ice margin recedes slowly enough, or halts long enough, to allow the deposit to be built up to the surface of the water. In other words, the determining factors are rate of recession, rate of deposition, and depth of water; and, assuming deposition as constant, the formation of a delta demands, in general, that the rate of recession shall vary inversely as the depth of the water, or at least that the rate shall be low when the water is deep, and practically zero for such exceptional depths of water as obtained in the north-dike area during the Clinton stage of Lake Nashua. In seeking an explanation of the intermittent retreat and prolonged halts of the ice margin, we naturally recognize climatic oscillations as probably an important, if not a principal, factor. The suggestion is ventured, however, that a still more potent cause may be found in the accumulation on marginal portions of the ice (as now on the peripheral tracts of the Malaspina and Bering glaciers) of englacial drift, which has become superglacial through ablation. Such a covering of drift must retard the melting of the ice, save, perhaps, where the contours of the latter favor the occurrence of standing or stagnant water. The condition here postulated appears, also, very favorable to the rapid building of an extended delta against the ice margin, since it affords an abundance of material in the most advantageous relation, especially if we assume superglacial streams as the chief active agency, as apparently we must with water from 100 to nearly 300 feet deep.

During the recession of the ice margin from the head of one delta to the head of the next delta of the series, the detrital tribute of the stream must be spread over the intervening tract as an imperfectly assorted and stratified, more or less tumultuous deposit of prevailingly coarse material, passing upward somewhat abruptly into the fine silts of the normal bottomsets. Thus we find a ready and adequate explanation of the varying thickness of gravel and coarse sand which many of the borings show between the bottomsets and the bed rock. The only wonder is that this record of a shifting ice margin is not more continuous. The observed facts and the natural tendencies seem, however, to leave us no alternative but to accept these basal accumulations as a normal feature of glacial deltas, a feature, too, which in its relations to the ground water must, notwithstanding its lack of continuity, be somewhat comparable with the foresets.

Effect of ground-water circulation.[a]—In the borings in the North Dike Plain there were encountered at depths ranging from less than 10 to 183 feet numerous layers of iron-stained or cemented sands and gravels from thin laminæ up to beds 55 feet in thickness, the latter probably, however, being composite in character. The materials commonly occur between relatively fine and impervious beds. The material is often of recent deposition, as indicated by the strong ochery color imparted to the water used in drilling, and appears to have been deposited along the course of subterranean drainage by waters passing downward through surface mold and muds and carrying ferrous carbonate derived from the soil and eventually changed to the ferric hydrate. The deposits occur anywhere from the surface to the lower limit of free drainage, but are discontinuous and patchy because the subterranean drainage is located in rather definite courses. They belong largely to the freely draining topset and foreset layers and are seldom represented in the bottomset layers, in which the water is relatively stagnant. Besides the ferruginous material just described there are considerable amounts of drift above the main water table in which a buff tint has been developed by oxidation of the contained iron or of the ferrous carbonate introduced by the ground water. The oxidation is not entirely dependent upon a position above the ground-water level, but is limited to the coarser and more pervious portions of the drift which, remarkable as it may seem, may be oxidized even below the level of the water table, while the firmer portions are often unoxidized even when near the surface.

WATER PROBLEMS.

Relations of the water table.—The North Dike Plain is so completely interrupted by the cemetery ridges as to destroy the continuity of the water table, and in no respect is the contrast of the easterly and westerly portions of the plain more marked than in their relations to the level of the ground water. For the easterly portion this level is, of course, determined by the ponds, and it is interesting to note that before the conditions were disturbed by the construction of the north dike the minor isolated kettle ponds were in substantial agreement as to water level with the Sandy-Coachlace basin. Above this level (about 334 feet) this part of the plain consists chiefly, and at most points wholly, of the foreset and topset beds, and the former especially are in general so highly pervious as to be without appreciable

[a] For complete descriptions of the ferruginous materials, buff and oxidized drift, etc., see Techn. Quar., vol. 17, pp. 64–67.

influence upon the water table, which is continued through them for long distances without sensible gradient or change of level. Where, however, the bottomsets or sediments of finer textures and higher uniformity coefficients than grades Nos. 5 or 6 rise above the pond level the water table promptly rises, attaining a maximum elevation of at least 365 feet and a maximum gradient of 5 to 6 per cent. We must assume cross bedding of the foresets with alternating, more or less pervious, sloping layers as a general fact, and observation shows that in spite of this the water table is a nearly level plane wherever it cuts this middle zone of the delta.

West of the cemetery ridges, where the North Dike Plain has its most continuous and perfect development, the relations of the water table are distinctly different. Its normal level seems to be 365 to 370 feet, with an extreme range of 360 to 375 feet, and averaging 30 feet higher than the level of the ponds to the north and east. Although highest to the north and tending to sink with the plain to the south, the level is, in the main, remarkably uniform and parallel with the surface at depths of 10 to 20 feet. The ground water is virtually impounded by high land to the west, the cemetery ridges to the east, high bed rock to the north, and the rising and impervious bottomsets to the south. The latter barrier especially prevents the water from escaping freely through the valley of Cunningham Brook to Nashua River. The impounded or almost lake-like condition of the ground water affords but little opportunity to note the influence of the varying sediments upon the water level, especially since it is at nearly all points held well above the bottomset beds.

Lost water.—We have noted that in porous and absorbent strata, especially above the level of the ground water, the water escaping from the drill may be partly or wholly absorbed, and thus fail to return to the surface. This phenomenon, as we should expect, is well-nigh universal in the coarse and pervious topset and foreset beds above the level of the ground water. But it also often recurs at various depths down, perhaps, to the bottoms of the deepest borings, and it is undoubtedly the most serious difficulty with which the drill men have to contend, and frequently necessitates driving the casing in advance of the drill.

Below the water level the loss of water may be attributed, in many cases, to the simple difference of head, the water standing at a higher level in the drill or casing than in the ground, and thus tending to escape into the latter. But, as the boring profiles clearly show, the deeper strata in which the water runs away are usually interstratified with relatively or practically impervious beds of superfine sand and quartz flour, often of considerable thickness. We may usually suppose that the water escaping into such intercalated beds, however great the depth, simply causes an equivalent amount to overflow on the water table at the point, however remote, where the bed in question is intersected by that surface. In many cases, however, the avidity and completeness with which the water is absorbed suggest what may be called "thirsty beds"—that is, pervious strata inclosed by impervious material to such an extent as actually or virtually to isolate them from the free-moving ground water above, while in their downward extension they may connect with some body of coarse gravel, possibly pertaining to an earlier ice margin, having more or less free drainage at a lower level, and thus tending to deplete or exhaust the water of tributary beds. This hypothesis has been found requisite to explain some of the hard-packed sands encountered in the north-dike borings;[a] and as an explanation of the "lost water," it possesses the great advantage of not requiring the prompt movement of a long column of water through material in which the friction, added to the inertia of the water, would tend, by loss of head, to minimize the result. In other words, the thirsty sand is right at hand, and not at some remote point perhaps scores or hundreds of feet above the point of escape of the water. This explanation really postulates a localized water table, limited to a single stratum, and far below the normal level of the ground water; but that these conditions do actually obtain we seem to have independent evidence in the "brown" or iron-stained sands to be described later, as well as in the hard-packed sands. The explanation might appear to accord best with the general fact that after a time the lost water returns—that is, ceases to run away. But for this phenomenon we have, perhaps, a simpler explanation in the natural tendency of the escaping water to close the interstices of the sand, and thus prevent its own escape. Again, this explanation is in harmony with the fact that loss of water is unusual below the general drainage level of Nashua Valley north of Clinton (elevation 200 to 250 feet); and the apparent exceptions may, perhaps, best be explained as due to the continued escape of the water through some higher previous stratum where the drill has gone below the casing, or even where it has not, since the water sometimes manifests a strong tendency to work its way up outside the casing.

It appears, then, that "lost water" may require, in different cases, three explanations: First, direct absorption by porous materials above the normal water table; this cause is nearly universal, though not always leading to a total loss, and often operates more or less continuously from the surface of the ground to the level of the ground water. Second, indirect absorption by porous materials above the normal water table, through the medium of intercalated porous strata.

[a] Techn. Quar., vol. 15, pp. 260–264.

Third, absorption by intercalated porous strata above a local low level of the ground water, determined by a relatively free drainage connection with a lower part of the valley.

Springs.—A common incident of the borings along the southern margin of the North Dike Plain, especially in the westerly portion, where the development is more continuous and normal, and after the drill has penetrated the relatively impervious bottomsets, is a more or less vigorous artesian flow, the ground water rising from a foot or two to 10 or 15 feet above the surface. This phenomenon is known by the drill men as a "spring." The artesian flow attains its maximum height above the surface when the boring is located in a kettle or other depression, and it never rises above the level of the head or northern edge of the plain. This flow is entirely independent of the head of water used in operating the drill. It usually subsides, partly or completely, spontaneously within a few minutes, although it may continue unabated until the water-bearing stratum has been cut off by the casing. As the profiles show, this phenomenon may be repeated once or many times in the course of a deep boring. That the spring is a true artesian flow is unquestionable, for it is never observed while the drill is above the normal water table, and only when the boring intersects pervious strata intercalated in impervious sediments, the pervious strata being supposed to be, and in many cases proved to be, continuous to the surface.

As indicated, the relations of the springs to the structure of the north-dike delta are most fully and clearly exhibited in the westerly portion, the north-south profiles of which show that the springs are strictly limited to the southern part of the plain; that they occur only in a thick and continuous series of bottomset strata; and that the elevations at which they occur increase to the southward with increasing elevation and depth of the bottomsets. In spite of their generally fine and impervious character, we must suppose that the bottomsets include some relatively pervious beds, which are, naturally, continuous upward and northward with still more pervious foreset beds. Southward these beds must become gradually finer and less pervious and die out as artesian horizons, and thus we find that the lower as well as the upper limits of the springs tend to rise to the southward.

Lost water and springs are terms denoting phenomena of distinctly opposite character, and for their interpretation we have in part assumed corresponding structural conditions, namely, limited pervious beds with free drainage in the case of lost water, and without free drainage in the case of springs. That these conditions actually exist may not be questioned, since they accord perfectly with the natural probabilities of the case, and since the two phenomena rarely concur even approximately, the springs occurring normally at lower levels in any given boring than loss of water, although the latter may now and then recur below the lowest spring, especially with borings of only moderate depth.

Even in borings in Coachlace Pond, water was frequently lost at depths of 25 to 100 feet, although the head of the water in the drill above the ground water in the bordering plain must be little or nothing. This seems to prove quite conclusively that the water is absorbed by thirsty or exhausted strata, and does not rise in saturated strata to overflow on the water table.

GENERAL CONCLUSIONS.

The conditions of deposition of a normal delta in a glacial lake determine for the relatively thick series of foreset beds a high degree of uniformity and consequent porosity; and for this series the relatively thin bottomsets form an impervious floor and the still thinner topsets a cover which, by virtue of its coarseness, permits the absorption of the total rainfall and minimizes loss by capillary flow and evaporation, both the composition and structure of the delta favoring extensive storage of water in the foresets.

Probably the most important distinction to be recognized among the deltas of glacial lakes is that based upon areal relation of the delta to the lake. Where this ratio is large, or the delta virtually fills the basin of the lake, as in the Clinton example, the bottomsets are likely to be relatively thick and to limit the development, at least in thickness, of the foresets. On the contrary, if the areal ratio is small, as in the case of a delta of limited area in a relatively large basin, the relation of the foresets to the bottomsets, and of both to the ground water, will be radically different. In the latter case, especially, the topographic relief and distinctness of the delta, where uneroded, attain their maximum development; and the highly pervious foreset and topset beds are then most likely to be free draining, the water table being relatively low and the storage capacity of the delta as a whole at a minimum.

The storage, as noted, must obviously be chiefly in the foreset beds, and these are likely in any case to be protected against loss by the relatively impervious bottomsets, not only downward but laterally as well, in the case of a delta in a basin of relatively limited area. This case is admirably illustrated by the westerly portion of the North Dike Plain, where, through the influenc chiefly of the inclosing bottomsets, the water table is held high above the normal drainage level of the district, and the chief loss of water may be assumed to be backward through the abrupt and irregular ice-contact slope.

Although the foresets must be assumed as subject to considerable variation in texture from layer to layer, it is probable that in any normal example they are throughout so readily permeable as to exert little influence through their structural relations upon the level or movement of the ground water, which simply fills them as it might an ordinary reservoir.

It must be noted, however, that, as the north-south profiles of the North Dike Plain clearly show, the foresets, in consequence of the diminishing power of the distributaries of the glacial stream, tend to become finer away from the head of the delta in the various directions of its growth. This fact, as well as the greater abruptness of the north or head slope, indicates, in spite of the southward-sloping structure planes, the chief loss of water of a free or uninclosed delta in the former direction. The most obvious exceptional cases would be where the delta heads against slopes of rock or till, or is closely joined by the bottomsets and foresets of the next later delta of the series.

Downward, the foresets must blend irregularly with the bottomsets, certain beds apparently retaining the relatively coarse and pervious character for a considerable distance after assuming the approximately horizontal attitude of the bottomsets. Thus are established the conditions favoring artesian flows and "springs," or favoring "lost water," hard-packed sand, and ferruginous layers if the interbedded pervious layers persist and find an outlet at a lower level.

The movement and storage of the ground water may, therefore, be regarded as highly differential and complex in the basal and frontal portions of a delta, while relatively uniform and simple in the topsets and the main body of the foresets.

WATERS OF A GRAVEL-FILLED VALLEY NEAR TULLY, N. Y.

By George B. Hollister.

INTRODUCTION.

General statement.—The valley whose waters are considered in the present paper is located a short distance northwest of Tully, in Onondaga County. On both sides the walls rise to heights of from 1,500 to 1,900 feet, or from 800 to 1,200 or more feet above the rock bottom, which in the vicinity of Tully is buried beneath 500 feet or more of gravels deposited in front of a glacial tongue when its front rested about 2 miles northwest of that town (fig. 39). The portion of the valley occupied by the ice is the relatively unfilled part north of the point indicated, lying mainly below the 900-foot level. The steep, northward-facing, irregular gravels represent the position of the ice front, while the relatively flat plain sloping to the south is built up of sands and gravels deposited by streams leading out from the ice margin.

In view of the fact that the conditions are similar to those in many other valleys in New York and elsewhere in the glacial region, and can, therefore, be considered as representative of a type, it has been thought desirable to present in this report the results of a somewhat detailed study of the quantity and quality of the water supplies in its deposits.

DESCRIPTION OF THE DEPOSITS.

The general character of the deposits has already been indicated. The southward-sloping plain extends southward through the Tioughnioga Valley to Cortland and beyond, being characterized in the vicinity of Tully by a subdued morainal surface with depressions occupied by ten or twelve lakes of sizes varying from a few feet to a mile or more in length. Some of them, notably Crooked and Song lakes, have no visible outlets.

Sections in ravines and gravel pits in the northward-facing escarpment show the material to be composed of gravels, sands, and clays. In a gravel pit on the road leading northward out of the slope on its westward edge at about the 1,160-foot contour, the gravels are rudely stratified and show a decidedly northerly dip. At about the level of the 1,140-foot contour is found a deposit of finely laminated blue clay which outcrops on both the eastward and westward ends of the fill at this elevation and appears to be continuous across its entire face. Above the clay are thin bog deposits with layers of gravel 2 or 3 inches thick and above the latter a bed of calcareous tufa from 8 to 15 feet thick. The clay is practically impervious and limits, at least to a large extent, the downward percolation of water through the gravels.

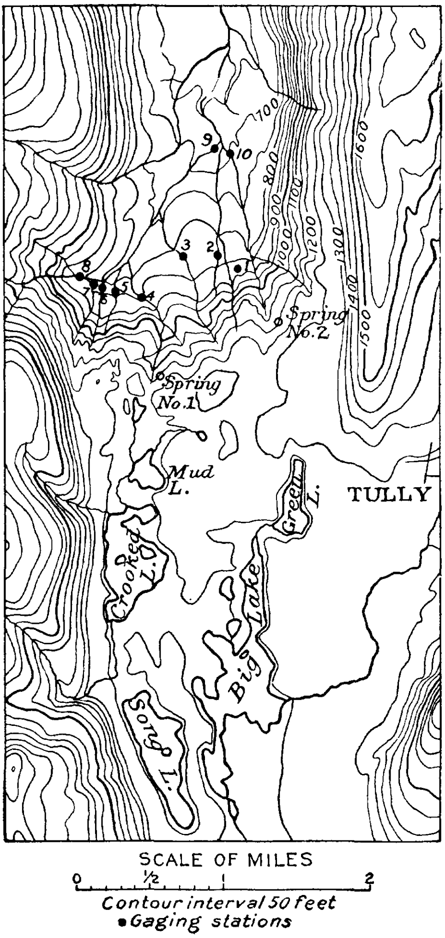

FIG. 39.—Sketch map of vicinity of Tully, N. Y.

WATER SUPPLIES.

SPRINGS.

Discharge.—A large number of copious springs issue from the northward-facing escarpment immediately above the belt of blue clay, occurring at intervals all the way across the valley. Ten of the streams formed by the springs were measured at short distances below their sources on November 7, 1904, by Mr. John C. Hoyt, of the United States Geological Survey, to ascertain the approximate total seepage from the glacial material northward. The locations of the measuring points are noted on fig. 39, and the discharge of the various streams and springs was as follows:

Discharge of spring-fed streams near Tully, N. Y.

	Second-feet.
No. 1	0.26
No. 2	.64
No. 3	.18
No. 4	1.33
No. 5	.09
No. 6	1.05
No. 7	.68
No. 10	1.23
Aside from the above surface flow, spring No. 1 delivers, through a 2-inch pipe, approximately	.75
Spring No. 2 delivers, through a 4-inch pipe, approximately	1.25
Total	7.46

Chemical character.—The relatively large amount of calcareous tufa which was observed on the northward-facing escarpment called attention to the highly impregnated character of the water of the Tully Springs and made it desirable to investigate this feature more fully. Not only was the deposit of tufa found, but calcareous deposits were also observed wherever water from spring No. 1 had splashed on the ground near a large metal kettle at the roadside, into which its water is conducted through a pipe.

LAKES.

Description.—The lakes of the area naturally divide themselves into two distinct series. Song, Crooked, and Mud lakes have no visible outlet, but the latter two receive the run-off from the adjacent shale hill on the west; they form the first series. Big and Green lakes form the second series. They have a tributary stream feeding them from the eastern hills and the Tully Valley and discharge into the west branch of Tioughnioga River at the southern end of Big Lake.

Chemical character.—On November 19 and following a series of samples were taken from springs No. 1 and No. 2 and from the various streams heading above the clay deposits referred to above, as well as from the lakes lying in the depressions of the moraine just south of the crest of the escarpment. Big Lake was sampled in rapidly flowing open water at its outlet. Song Lake, which lies without apparent inlet or outlet, was sampled at its northerly and southerly ends. A narrow strip of low marshy land connects it with Crooked Lake and indicates sluggish communication between the two. Another sample was taken at the southern end of Crooked Lake in a small circular basin separating it from the main lake by a narrow bar. A sample was taken from the hillside streams tributary to Crooked Lake, about 250 to 260 feet above its surface, and another sample at the north end of Crooked Lake at its outlet, a sluggish stream flowing northward into Mud Lake. Mud Lake was also sampled near its outlet into the small body of water still farther north. From the northern and southern ends of Green Lake samples were taken, which, with those secured from the springs and streams flowing down the escarpment, completed the series.

The analysis of the samples, principally for chlorine and alkalinity, reveal conditions of peculiar interest. The samples taken from the series of lakes without surface drainage, viz, Song, Crooked, and Mud, are comparatively low in chlorine and alkalinity as calcium carbonate, except the small and most northern of the series, lying at the crossroads 1½ miles west of Tully Center, whose alkalinity registered 91, between three and four times that of the others. On the other hand, in the second series, Big and Green lakes, the chlorine about doubles and the alkalinity increases to five or six times that of the western chain, being 89 and 115 for the north and south ends of Green Lake and 121 for Big Lake at its outlet. This is the more remarkable when it is remembered that Big and Green lakes drain into the Tioughnioga, while the others are without surface outlets.

Another feature of interest is that the analysis of water from the stream which drains the shale hillside into Crooked Lake shows about the same chlorine and alkalinity as Crooked Lake itself, indicating quite clearly that Song, Crooked, and Mud lakes are fed by surface flow and subsurface seepage from the adjacent shale hills and have an outward flow through the surrounding gravels, which keeps them relatively soft. On the other hand, the much greater hardness of Big and Green lakes, in spite of some surface drainage which they receive, indicates an easy interchange between the waters of those lakes and the ground water or possibly an eastward seepage from Song and Crooked lakes, during which the latter waters take up large quantities of calcium carbonate and sodium chloride from the glacial material.

The seepage waters forming the escarpment spring and streams likewise show a high percentage of chlorine and alkalinity, even higher in some cases than Big and Green lakes, indicating a still greater concentration of salts. Spring No. 1, on the east side of the moraine, had a chlorine content of 5.2 and alkalinity of 89. It is interesting to note that this spring lies about due north from Green Lake and that its waters analyze the same as those of the lake.

Spring No. 2, near the western side of the moraine, showed an alkalinity of 182, a very high percentage, while the streams on the western and central parts of the moraine showed alkalinity of 105 and 160, respectively. It is noteworthy that the alkalinity decreases as the western side of the valley is approached—where the softer seepage waters from the hills are more strongly felt.

Analyses of stream, lake, and spring water near Tully, N. Y.

LAKES DRAINING NORTH: NO SURFACE OUTLET.

Analysis No.	Iron.	Chlorine.[a]	Alkaline.[b]	Sulphates SO_3.	Remarks.
12	Trace.	2	22	0	South end Song Lake.
13	Trace.	2	17	0	North end Song Lake.
14	....	2	32	Trace.	South end Crooked Lake.
16	Trace.	2.8	22	Trace.	Outlet (north end) Crooked Lake.
17	Trace.	2	30	Trace.	Mud Lake near outlet.
25	Trace.	2	91	Trace.	Pond at crossroads west of Tully Center.

STREAMS AND SPRINGS NEAR TULLY.

Analysis No.	Iron.	Chlorine.[a]	Alkaline.[b]	Sulphates SO_3.	Remarks.
15	Trace.	2	23	Trace.	Stream from shale hill west of Crooked Lake.
20	Trace.	5.2	89	Heavy trace.	Spring on eastern part of moraine north of Green Lake.
21	Trace.	4	105	0	Stream on western part of moraine.
22	....	1.5	160	....	Stream near center of moraine.
23	0	4	182	Heavy trace.	Spring near center of moraine.
24	0	2.8	160	Trace.	Head of stream (same as No. 22) near center of moraine. Sample taken 150 yards north and 15 feet below No. 25.

LAKES DRAINING SOUTH.

Analysis No.	Iron.	Chlorine.[a]	Alkaline.[b]	Sulphates SO_3.	Remarks.
19	Trace.	5.2	89	Heavy trace.	North end of Green Lake.
18	Trace.	6	115	Heavy trace.	Outlet (south end) Green Lake.
11	0	3.5	121	Trace.	Outlet (south end) Big Lake.

[a] In parts per million.
[b] Alkaline carbonates reduced to an equivalent of calcium carbonate. Parts per million.

SUMMARY.

The presence of a large amount of underground water is revealed near Tully, N. Y., by numerous vigorous springs which occur on a northward-facing glacial escarpment, just above a heavy blue-clay deposit, approximately 1,140 feet above tide and about 100 feet below the crest of the morainal plain. These springs feed strongly flowing brooks which unite to form Onondaga Creek. From measurements made with current meter on November 7, 1904, the outflow of these seepage waters was found to be about 7.46 cubic feet per second, or approximately 4,847,000 gallons in twenty-four hours.

These waters when tested were found to be exceedingly high in alkalinity and chlorine, as was indicated by the occurrence of a thick bed of calcareous tufa from 8 to 15 feet thick just above the clay deposit.

Other evidences of like physical characteristics of the ground waters were also found in the Tully lakes which lie just south of the escarpment edge in a well-developed kettle moraine. Here Song, Crooked, and Mud lakes, which border the hills on the western side of the valley, though without surface outlet, are kept comparatively soft by the surface and seepage inflow of soft water from the hillside, while Big and Green lakes, which lie in the center of the valley well surrounded with glacial material, have relatively high alkalinity and chlorine, though they drain into the Tioughnioga River with swift discharge.

The marked difference in character of water in these two sets of lakes seems to point to the probability that subsurface water passes eastward from the Song and Crooked lakes series, through the glacial gravels, and, after becoming highly impregnated with calcium carbonate and sodium chloride by contact with the glaciated material, appears in the easterly—or Big and Green lakes—series greatly altered. The subsurface waters in this region in general, from whatever source, take up large quantities of the salts found in the glacial débris and appear highly charged with them in the various lakes and springs.

NOTES ON CERTAIN HOT SPRINGS OF THE SOUTHERN UNITED STATES.

By Walter Harvey Weed.

INTRODUCTION.

The importance and economic value of the natural hot waters of the United States as a factor of our national wealth is much greater than is generally realized. In some instances the waters are utilized on a large scale for heating, and in others they are bottled for shipment as table waters or are valuable as a source of carbonic-acid gas. In the majority of cases, however, the money spent by visitors, either sick or well, attracted solely because of the hot waters, forms a perennial source of wealth to the local community. The amount of money thus annually expended is very large, far larger, indeed, than is generally conceived, but in our own country it is difficult to estimate closely the amount. It has been stated in Germany that the money brought into the country and spent at Carlsbad and the lesser spas exceeds in amount the total value of the mineral production of the Empire. The waters of this country are as varied and as valuable as those of Germany and when accompanied by the diverse attractions seen at the various springs of France and Prussia will probably be as popular, though as yet the appreciation of the pleasure and health-giving results accruing from a visit to any of them is not general.

OCCURRENCE OF SPRINGS.

DISTRIBUTION.

The distribution of hot springs in the United States coincides very closely with that of the mountain uplifts. They are found in the Appalachian region of the Atlantic border, but are lacking in the Mississippi Valley and Great Plains regions except where the mountain uplifts—that of the Ozarks at Hot Springs, Ark., and the Black Hills at Hot Springs, S. Dak.—rise above the general level. In the Rocky Mountains, Great Basin, and Pacific coast regions hot and even boiling springs are very common, especially in connection with areas of recent volcanic action. Though the Western States contain great numbers of thermal springs, only the most prominent ones are generally known, and information about even these is confined to a statement of the temperature, sometimes accompanied by an analysis of the water, made in a commercial laboratory. Such geologic notes as have been made upon these western springs will be presented in a paper to be published later.

GEOLOGIC RELATIONS.

The thermal waters of the Atlantic border States are none of them of very high temperature, but they are widely known for their medicinal value, and practically all of them are utilized for health and pleasure resorts. The Virginian springs are the best known and longest studied. According to W. B. Rogers, whose classic researches on Virginia geology laid the foundation for our present knowledge of the region, the springs are confined to the Appalachian province, where the warm waters usually outflow from the western side of long anticlinal folds, especially the greater and overturned arches, whose erosion exposes the oldest rocks. There is as yet no reason to doubt the explanation offered by this geologist that the springs owe their heat to the normal downward increase of temperature of the earth's crust, surface waters having penetrated to considerable depth and ascended long faults and slip planes of the folded strata. There is, however, a lamentable lack of exact data concerning any of the Appalachian springs. Statements are freely made that the temperature does not vary and that the discharge is constant from season to season, but as no systematic records of temperature or of discharge appear to have been made, the accuracy of such statements may well be questioned, especially as it is well known now that in European springs formerly considered constant marked changes occur, not only from year to year, but from season to season. The highest temperature of any of the waters of the Appalachian region is that of the Boiler Spring, at the Hot Springs of Virginia, which is stated to be 106°. More commonly the springs of this region do not exceed 90°. At the hot springs of North Carolina, situated on the western side of the mountain region, the geologic conditions have been carefully investigated by Keith,[a] though without reference to the hot springs. The temperature of the water is here as high as 104°, and the spring comes up along a fault plane, affording a quick exit for waters which have seeped down through permeable sandstones to considerable depths, the throw of the fault being about 6,000 feet.

[a] Keith, Arthur, Description of Asheville, N. C., district: Geologic Atlas U. S., folio 116, U. S. Geol. Survey, 1904.

WARM SPRINGS OF GEORGIA.

The only thermal waters of the Southern Atlantic States known to exist, outside of the Appalachian region, are those of Warm Springs, Meriwether County, Ga. As information on these springs is scanty, and as the location, favorable climatic conditions, character of water, etc., all indicate their development into a great winter resort, some detailed notes are given herewith.

Location.—The Warm Springs of Georgia are situated about 85 miles south-southwest of Atlanta, along the branch line of the Southern Railroad running from that city to Columbus. The place is in the Piedmont Plain, whose gently undulatory surface runs eastward to the coast and southward to the lowlands of Florida. A long, low, wooded ridge, called Pine Mountain, rises above the plateau and forms the most conspicuous feature of this part of the State. As the region is unmapped the extent and relations of this ridge, said to be nearly 70 miles long, are as yet undetermined.

Geology.—The hot waters issue from the north base of a spur of Pine Mountain. The region surrounding Pine Mountain is underlain by micaceous schists with a general northeast-southwest foliation and steep dip. A few miles north of the springs these rocks are cut by an intrusive mass of granite, a prong of the great granite mass of central Georgia.[a] The schists are deeply weathered and mantled by red clays, but stream courses and railway and road cuttings afford exposures showing the nature and structure of these earlier rocks.

Pine Mountain is formed of sandstones and sandy shales. The summit is strewn with blocks of gray sandstone; the gulches show alternating beds of laminated sandstones and shales, often friable and loosely cemented. The general strike of these beds is with the ridge or mountain and the curving strike and steep dips near the springs (28°) show an anticlinal folding, the hot waters issuing from along a fracture at the base of an offshoot or spur of the main mountain mass. This fracture line coincides with a bed of well-indurated quartzite, and its course is marked by several small outflows of warm water besides the great springs supplying the bathing establishment. That faulting occurs is shown by the polished and striated surfaces on the quartzite ledges along the base of the slope, and it is noteworthy that these features are less marked and disappear a short distance away from the springs. This quartzite is underlain by more friable beds exposed along the roadside to the hotel and covered by similar rocks seen to the east.

The structural conditions indicate an ascent of the head water along an open channel in a great fracture. There is no doubt that if ordi-

[a] Watson, T. L., Granite and granite gneisses of Georgia: Bull. 9 A. Geol. Survey Georgia, 1904.

nary ground waters penetrate slowly to a sufficient depth they will be heated by the normal increase in temperature of the earth, a feature encountered in all mining operations. With sufficient head and an open conduit, permitting rapid ascent, they will rise to the surface and issue as hot springs. The Georgia springs, therefore, present no unusual features, save their occurrence outside of the area of Appalachian folding and their remoteness from recent igneous intrusions. Assuming a mean temperature of 60° F. at the locality, and a heat increment of 1° F. for each 60 feet of depth, the temperature indicates an ascent from a depth of about 1,600 feet below the present surface, a very moderate depth.

Composition.—An examination of the hot waters made on December 1, 1904, showed a temperature of 87° F. and a faintly alkaline reaction. Sulphuretted hydrogen was tested for but not found. There was not enough carbon dioxide present to be noticeable, the water being limpid and tasteless, but not flat.

No analysis has been made of the water by the Survey, but in the following table the result of an analysis made for and published by the owner is compared with an analysis of the water of Hot Springs, Ark. As will be seen the waters are almost identical, but the Arkansas water is hotter (temperature 146° F.) and deposits carbonate of lime about the outlet; the Warm Springs water forms no deposit and no old hot-spring deposits occur.

Analyses of waters of the Warm Springs of Georgia and Hot Springs of Arkansas.

[Grains per United States gallon.]

Solids, dissolved.	I.	II.
Carbonate of lime	6.099	7.14
Carbonate of magnesia	.097	1.03
Carbonate of iron	.087	.06
Sulphate of lime	.553	
Sulphate of soda	.862	.42
Sulphate of potash	.246	.19
Chloride of sodium	.011	.24
Alumina	.462	Trace.
Silica	1.410	2.59
Organic matter and combined water	.865	
Iodine	Trace.	Trace.
Bromide	Trace.	Trace.
Total solids dissolved	12.512	11.74

Analysis I.—Water of Warm Springs, Georgia, analyzed by H. C. White, State chemist.
Analysis II.—Water of Old Hale Spring, Hot Springs of Arkansas, State Geological Survey.

Discharge.—The discharge of the Warm Springs has been accurately determined by the engineers of the United States Geological Survey and found to be 1,892 gallons per minute.

HOT SPRINGS OF ARKANSAS.

REGION OF THE HOT SPRINGS.

CHARACTER AND LOCATION.

The most famous and most frequented health resort of the United States is probably Hot Springs, Ark., a city of about 12,000 permanent inhabitants that has grown up about the hot springs of the place, and exists wholly upon the money spent by the visitors to these springs. Originally a resort only for the sick and suffering, it has grown to be a great pleasure resort, and is practically the only one of the American resorts that is comparable with the great European spas in the attractions and diversions offered to visitors. The hot springs themselves and the mountains near by are the property of the United States Government, a fact not, perhaps, generally known. As a result the hot waters are carefully guarded against pollution, and equitably distributed to bath houses, whose luxurious appointments exceed those to be found anywhere else in the United States.

The Hot Springs of Arkansas are situated in the geographic center of the State, 50 miles distant from Little Rock, and about 75 miles east of the Indian Territory line. The locality is accessible by the Iron Mountain Railway and the Choctaw route, both of which run through cars from the large cities of the country. The location is 600 feet above sea level and lies at the easterly base of the mountain complex known as the "Ouachita Range," the near-by peaks of which are often called the "Ozark Range," although that name really applies to the mountains in the northern part of Arkansas and the southern part of Missouri.

HISTORY AND MANAGEMENT OF HOT SPRINGS REGION.

The Arkansas Hot Springs have been known since the early settlement of Louisiana. Although it is only a legend that they were visited by De Soto on his trip to the Mississippi, there is no doubt that they were used by the Indians before the advent of Columbus, as abundant evidence was found in early days that the Indians quarried the dense rocks near the springs for arrowheads and spearheads and utilized the waters for bathing.

In 1804 two members of the Lewis and Clark exploring expedition visited the place and found that white visitors had already used the waters for bathing. In 1818 the lands on which the springs are located were ceded to the General Government by the Quapaw Indians and became afterwards a part of the Territory of Arkansas. The ground about the springs was located by various claimants before the organization of the Territory of Arkansas, but by act of Congress the springs and the ground about them were reserved in 1834 for the United States Government, thus making the first national-park reservation in the country. Owing to the claims made by various parties to a private ownership of the springs, they remained in the possession of the claimants until the United States Supreme Court decided in favor of the Government in 1877.

Under acts of Congress the mountains adjacent to the springs are permanently reserved for parks, the hot waters are piped to various bath houses, and the supply is under the control of a superintendent of the Hot Springs Reservation, appointed by the Secretary of the Interior. The regulations now prescribed by that Department provide for a rental of land used by various individuals and for the payment of $30 per year for each tub used by bathing establishments. The income is used for the payment of administrative expenses, for the maintenance of a free bath house, for building roads and pathways on the mountains back of the springs and the adjacent mountains, and for gardening. The receipts amount to about $18,000 per year. The superintendent is charged, under supervision of the Secretary of the Interior, with the care of the entire reservation as well as its protection and improvement. It is therefore policed and improved by the Department. The results achieved by this wise system speak for themselves in the beautiful driveways, picturesque walks, and fine flower beds, which add their charm to the natural beauty of the place.

TOPOGRAPHY OF HOT SPRINGS REGION.

Central Arkansas consists of a low-lying, nearly level eastern portion and a hilly or mountainous western region. The first region extends from Mississippi River westward to Little Rock, Benton, and Malvern. The hilly country of the Ouachita Mountain system begins just west of the Iron Mountain Railway, where it has a width of 36 miles, and extends westward, gradually narrowing as it approaches Indian Territory. The eastern level country is part of the Tertiary Mississippi Valley region. The western hilly country consists of a central complex of hills, flanked by sharp spurs and ridges, which extend outward into a much lower country of slight relief. This hilly country is dignified by the name of the "Ouachita Mountain system," the ridges rising gradually in elevation westward.

that forms an embayment between the main Ouachita system and a small east-west spur on the south. The region is well watered and well drained. In the immediate vicinity of Hot Springs, Hot

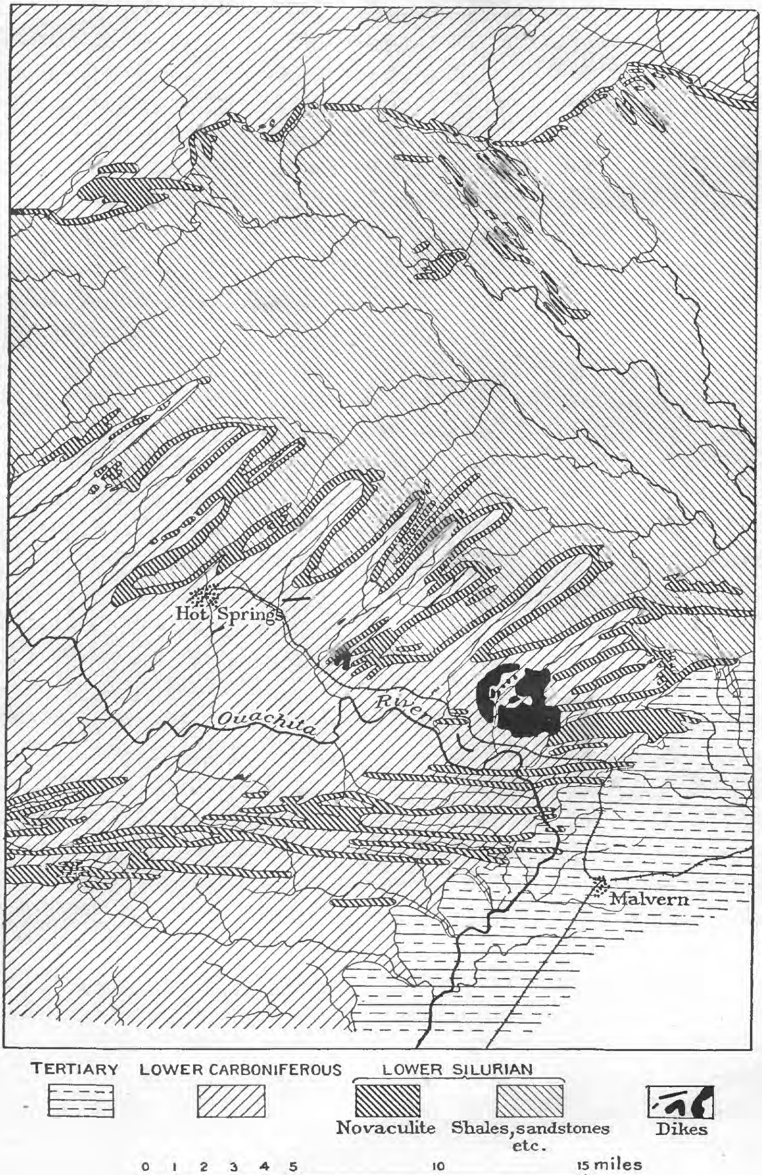

FIG. 40.—Geologic map of Hot Springs, Ark., and vicinity.

Springs Creek and Gulpha Creek, both of which flow into Ouachita River, drain the entire region, the former stream flowing due south and reaching the river 4 miles below the city.

Near the Indian Territory line the general level of the intermontane plain is 1,000 feet above tide and the crests of some of the ridges attain elevations above 2,500 feet. Near Hot Springs the mountain area seldom attains an elevation of more than 1,200 feet above the sea, or 600 feet above the surrounding country; yet, when seen from the lower country about it, the hills rise so abruptly that they appear to deserve their designation. The mountains near the Hot Springs are particularly impressive, and the local summits have received special designations, as "West Mountain," "Indian Mountain," etc. These mountains have been grouped together by some writers under the name of the "Ozark system," but they have been more fittingly christened the "Zigzag" Range by Professor Branner, of the Arkansas Geological Survey. This range has an extreme length of 25 miles and a width of 6 to 8 miles. The general trend of the ridges is almost at right angles to the system. These ridges are narrow and sharp, with a height of 500 to 600 feet, and they are particularly numerous in the vicinity of the Hot Springs.

The Hot Springs are situated in a valley between two wooded, rocky ridges known as "West Mountain" and "Hot Springs Mountain." The water issues from vents in the old, gray, hot-spring deposit, or tufa, that covers the basal slopes of Hot Springs Mountain east of Hot Springs Creek. This location is on the outer border of the mountain system. To the east the country falls away gently to Ouachita River, and the city of Hot Springs has been built partly in the ravine and the intermontane basin to the north and partly in the eroded plateau lying south of the springs and outside of the mountain area. The mountain slopes are rocky, and are often ribbed with abrupt cliffs and rugged ledges with extensive slopes of talus. They are generally thickly mantled with a heavy forest growth of oak, pine, chestnut, and other common forest trees, and they support a more or less abundant undergrowth. The ravines are generally narrow and the streams swift running, but good exposures of the underlying rocks are seldom seen, owing to the thick forests that cover the slopes. There is an evident relation between the hard rocks and the hills and between the softer rocks and the valleys, although the streams do not accord with any definite geologic structure, but flow in synclines, in eroded anticlines, and across the strike of the beds as well. Several gaps indicate old and now abandoned stream courses and show a prolonged period of adjustment, in which the streams shifted several times before reaching their present position. Although the springs are on the borders of these mountains, this location is not wholly outside of the mountain area, since the Trapp Mountain Range lies south of Ouachita River, so that the springs are on the north side of a synclinal basin

The lower country near the springs, upon which a considerable part of the city is built, is a dissected plain in which broad plateau levels alternate with shallow drainage courses that are tributary to Hot Springs Creek.

The climate of the region is a mild one, lacking both the extreme heat of summer and the cold of winter. In the summer months the air is tempered by the breezes from the mountains, and in winter the average temperature is very slightly below that which prevails at New Orleans and other southern cities. Flowers and shrubs of semitropical character grow in the open air, but the occasional frosts of winter are so sharp that a strictly semitropical vegetation will not exist.

GEOLOGY OF HOT SPRINGS REGION.

Character.—The rocks seen about Hot Springs are chiefly of sedimentary origin and were formed beneath the waters of a Paleozoic sea. They occur in well-defined formations, which were folded when the mountains of the region were formed by the compressive stresses of earth movements, and subsequently eroded by ordinary atmospheric agencies. These rocks are cut by a few narrow, insignificant dikes of igneous rock, which are supposedly connected with the large masses of granite and other igneous rocks now seen at Magnet Cove and Potash Sulphur Springs. In addition to the rocks mentioned there is a considerable area of dark-gray and porous travertine, or calcareous tufa, formed by the Hot Springs.

The sedimentary rocks seen in the vicinity of the Hot Springs consist of shales, sandstones, a few beds of impure limestone, and the rock called novaculite. This last-named rock, of which the well-known Arkansas whetstones are made, is the most conspicuous and important rock in the locality. It is the typical rock of central Arkansas, and, though found over a large area, the material pure enough to be used for whetstones is confined to the vicinity of the Hot Springs. It is this rock that has, by reason of its hardness and its resistance to erosion, made the mountains about the springs, and it forms the cliffs and prominent ledges seen in the district. The bedded rocks form a series, shown in the following table, in which the youngest beds are placed at the top of the column and the oldest strata at the bottom.

Section at Hot Springs, Ark.

Geological age.	Thickness in feet.	Character of rock.
Carboniferous.	200	Shales; gray or black graphitic shales with fragments of plant remains, red and yellow colored when altered. Sandstone, impure and clayey, with softer layers alternating with softer material.
	250	Quartzose sandstones, passing at times into conglomerates and well exposed along the basal slopes of Hot Springs Mountain.
Lower Silurian.	12	Novaculite breccia.
	5	Impure novaculite, with iron and manganese.
	100	Novaculite in thick and thin beds, with some layers of siliceous shales.
	75	Sandstone passing into novaculite.
	38	Shale, siliceous, and passing into novaculite.
	200	Massive novaculite, from which whetstone is taken.
	230	Shale, siliceous, with thin layers of novaculite.
	200	Impure novaculite. Shales, red and green and gray, with siliceous layers. Shales, black, and carrying fossil remains (graptolites). Limestone, thinly bedded, blue, and generally argillaceous.
	200	Sandstones.

Structure.—Near Hot Springs the rocks have been compressed into great folds which now form the mountains, and this compression is so great that the folds have been overturned, and in the gorge of Hot Springs Creek the section now exposed shows the younger beds resting beneath the older ones. In addition to this there has been some faulting in Indian Mountain, by which an overthrust has pushed up the older beds over younger ones. For this reason the section (fig. 41) is not always easily made out, but it can be seen in the slopes of West Mountain, although, as will be noted there, the younger beds lie below the older and the rocks have a dip of from 25° to 70°.

Fig. 42 shows a cross section through the low southern end of Hot Springs Mountain and up the valley along Main street. The rocks are well exposed along the line of this section, especially in the quarries and cliffs where the street excavations expose the rocks forming the steep, narrow mountain ridges.

The succession of beds exposed at this place has a steep dip northward, the inclination varying from 25° at the south end to 45° at the north end; all the beds are overthrown, the oldest being on top, as seen in the cliffs. The novaculites are the most conspicuous rocks; their creamy-white color, dense, even grain, remarkable hardness, and thin bedding are well seen in the beds of the section. The underlying graptolitic shales are also exposed, but the intervening shaly beds are hidden. The upper bed of novaculite passes upward into a

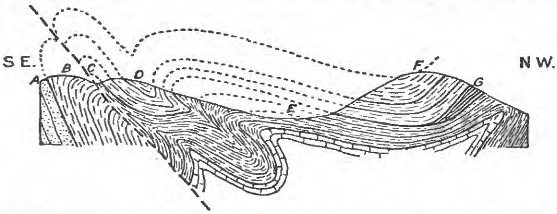

FIG. 41.—Geologic section near Hot Springs, Ark. *A*, Overlying sandstone; *B*, novaculites of Indian Mountain; *C*, fault line; *D*, faulted novaculites of Indian Mountain; *E*, graptolite shales; *F*, novaculites of North Mountain; *G*, brown and red shales.

bed of breccia 12 feet thick, which adjoins the beds of younger massive and coarse sandstone, aggregating about 200 feet in thickness. These are the rocks seen about the hot-springs vents. They grade into softer argillaceous sandstones, which, in turn, pass into varicolored soft shales usually having bright reddish or yellow tints, often graphitic.

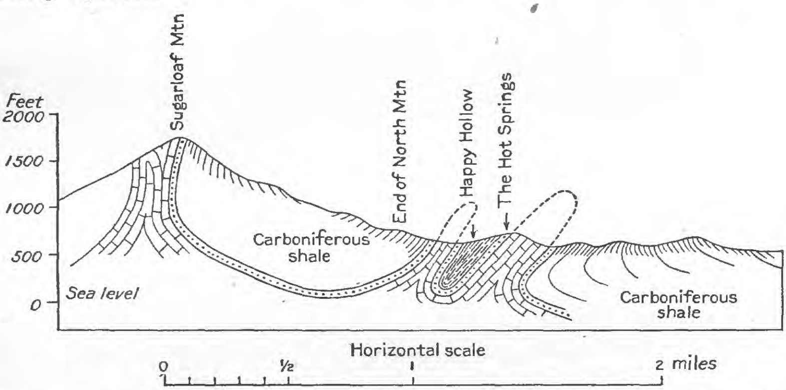

FIG. 42.—Geologic section through end of Hot Springs Mountain and the city of Hot Springs, Ark. Structure shown by novaculite (whetstone) beds and sandstones above them.

The Carboniferous shales, which are the youngest rocks of the district, are well exposed on Malvern avenue near the Park Hotel, where olive-colored sandy shales have been found to contain plant stems and fragments of fern fronds. The shales are rarely indurated enough to form slates, though a few quarries have been opened in them and slate of a poor quality extracted. Where the shales are slightly altered they are sometimes valuable for brick and terra-cotta burning, though most of the clay used for that purpose is derived from the disintegrated material washed into the creek bottoms.

The sandstones are of variable texture and composition. The coarser-grained rocks are nearly pure quartzose sand, but the intermediate beds are quite clayey. The chief sandstone horizon seen at the springs is the one lying just above the novaculites, and this rock is the one which is so prominent on Hot Springs Mountain and West Mountain.

The novaculites are the most interesting rocks of the region. They consist of nearly pure silica, containing less than one-half of 1 per cent of other material. The rock is very dense, homogeneous, of a cream or white color, and fine grained, resembling in appearance the finest Carrara marble. These rocks are used for whetstones, the finer-grained form being called Arkansas stone and the coarser-grained rock the Ouachita stone. This material has a marked conchoidal fracture and resembles chert in its general appearance, although, as will be shown later, this appearance is purely a superficial one, and the material differs markedly from chert in its origin and composition. Although brittle and lacking the toughness of chert, it was extensively used by the Indians, who quarried it by building fires upon the outcrops until the stones were heated and then quenched the fire with water, thus chilling the rock and causing it to split and spall into fragments which were easily removed. In this condition it was readily chipped by the use of round stone hammers, great quantities of which have been found by the early settlers and some of which have been seen by the writer at some of the more remote quarries. The rock is finely jointed, and in quarry faces this jointing is more conspicuous than the bedding planes. These phenomena may be well observed in almost any of the excavations along Main street, above the Government reservation. The finer-grained material seldom forms good outcrops, because of this jointing and also because the rock contains a small amount of water, which, when frozen during the frosts of winter, shatters the stone and covers the outcrop with fine débris. This débris is extensively used as a road material, and wherever applied forms a most excellent surface.

The novaculite formation is from 500 to 600 feet in thickness; this measurement including some flinty shales, some soft shales, and some sandstones. The novaculites proper are prominent members of the formation, occurring in beds from a few inches up to 12 or 15 feet thick. When these beds are less than 4 inches thick the rocks lose the novaculite character, and are more like flinty shales. When examined under the microscope the rock is found to present a very uniform appearance, and to consist of extremely minute interlocking grains of cryptocrystalline silica. Chemical tests show that this silica is quartz and not amorphous silica. Thin sections also disclose the presence of numerous cavities in the rock quarried for whetstones. These cavities have been found to present a rhomboidal outline, and to correspond in form and position to included patches of calcite found in the same rock where the bed passes beneath the creek levels. It has been assumed that these cavities are formed by the dissolution and removal of the calcite, and as the material from beneath the water level is of slight value as a whetstone it has been reasoned that the abrasive qualities of the Arkansas stone are due to the presence of these calcite cavities. The origin of the rock has been the subject of considerable speculation from the earliest times to the present. It has been commonly asserted that it is a very fine-grained sandstone, which has been indurated and altered by hot-spring action. This explanation is not adequate, however, since the same beds are exposed on the flanks of the Ouachita Mountain system for a total length of several hundred miles. Moreover, the character of the grains does not permit the assumption that they were originally rounded and that the spaces between have been filled by secondary deposition of silica, as is commonly the case with many quartzites. The writer's belief is that the evidence supports the opinion that the rocks were formed as a chemical precipitate in the deep seas of a Silurian ocean, and that comparatively little alteration beyond induration has taken place. Such a theory seems to accord very well with the chemical and physical nature of the rock and with the facts now known in regard to the origin of some of the early geologic sediments.

Igneous rocks.—Besides the sedimentary rocks just noted, there are four narrow dikes of igneous rock about one-half mile south of the mountain borders and near the city limits. These rocks are dark-colored mica traps, a form of rock called "ouchatite." They are chiefly interesting because they show that there was some deep-seated body of molten material from which the dike fissures were supplied. Small dikes are found north of the city, east of the city, and in considerable abundance about Potash Sulphur Springs and at Magnet Cove. These dikes have a generally east-southeast–west-northwest direction, showing that the fissures are parallel to the mountain sides. They are from 1 to 4 feet wide and are generally much altered, so that the outcrop is inconspicuous or is covered by vegetation. When the rock is broken black mica in small flakes is the only mineral seen.

Fossils.—The age of the sedimentary rocks is determined by the fossil remains found in them. The black shales which underlie the novaculites contain remains of a curious hydrozoa. These fossil remains are known as graptolites, and the forms identified at Hot Springs belong to the upper part of the lower Silurian age (Trenton and Utica). New types of these fossils peculiar to Hot Springs are illustrated in the novaculite report issued by the Arkansas Geological Survey. Besides these curious forms, a few shell remains (brachiopods and lamellibranchs), corals, and worm trails have been found.

The graptolites occur on the north side of the hill on a small stream drainage on the west side of the continuation of Park avenue. They are also seen in a very black shale forming the bluff on the west side of Park avenue above Hotel Hay and below the Barnes House. Similar fossils also occur on Whitington avenue, one-fourth of a mile above the head of Central avenue, at a point where the street crosses the creek.

Plant remains of lower Carboniferous age have been found in the shales exposed in the excavation for a cellar on the western side of Malvern avenue, 100 feet north of the Park Hotel. The shales are varicolored, brown, red, gray, and black, but the fossils occur in the olive-colored sandy shales. Similar fossils were also found in Ouachita avenue at Hot Springs.

WATERS OF THE HOT SPRINGS.

OCCURRENCE.

The hot waters issue from the base and lower portion of the slopes east of the valley. This area is a narrow strip, a few hundred feet wide and one-fourth mile long. In its general aspect this area is distinguished from the rest of the mountain by its patches of barren gray tufa, the old hot-spring deposit, and the absence of forest growth. From the descriptions given by earlier writers it is evident that this difference in appearance and vegetation was formerly very marked. To-day the springs are all covered, and mostly concealed beneath turf and shrubbery. The old tufa deposit is in large part covered by soil and plants. The creek is arched over and sidewalks and roadways are built on it. The space between creek and hillside is covered by the bathing establishments, which, in many instances, are built directly over large springs. The landscape gardener has modified the old slopes, filled up the gullies, and built roads and footpaths until the hot-spring area is a beautiful park and a fitting setting for the springs.

It is difficult for the average visitor of to-day to form an idea of the natural appearance of the springs. The larger springs formerly issued abruptly from the tufa slopes and did not possess the bowls and basins seen at the Mammoth Hot Springs of the Yellowstone. An artificial cutting made into the mound of the Cave Spring shows a section of the hot-spring deposit, and if the door be opened the waters will be seen flowing into the basin cut to collect them, and depositing creamy alabaster-like tufa and the brilliant emerald-green tufa whose color is due to the growth of hot-water algæ. Many of the smaller springs are mere oozes, with no well-defined channel. A considerable number of these are gathered into one reservoir at the base of the tufa bluff between the Arlington Hotel and the Superior bath house. Another spring is seen near the Hale bath house, where it issues from a cavity in the tufa and flows into a basin. There is constant flow from the tufa wall back of this masonry platform, forming the dripping spring, where thousands of visitors daily drink hot water direct from the rock. At this place also the green algous growth may be seen.

TUFA DEPOSITS OF THE HOT SPRINGS WATERS.

As already noted, the hot-spring area is characterized by a deposit of calcareous tufa, or travertine, formed by the hot waters, and covering not only a large part of the mountain slope about the existing hot springs, but also extending westward to the Happy Hollow ravine and occurring above the band stand, far above any existing springs in the slope. Tufa deposits are common about both hot- and cold-water springs whose waters carry carbonate of lime in solution. This material is precipitated when the carbon dioxide of the waters escapes upon exposure of the water to the atmosphere. At the Arkansas hot springs a very small amount of carbonate of lime is held in the waters, yet it is sufficient to coat the hot-water pipes and to fill wooden troughs used to conduct the waters. In Cave Spring and at Dripping Spring the tufa may be seen now forming. It is therefore not certain that the waters which formed the great tufa deposits of the place were any richer in lime carbonates than those of to-day. This tufa is seen in its natural state at many places about the springs, but is particularly well seen at Cave Spring, back of the Arlington Hotel. It is of a gray color and porous texture on the surface, but when quarried is pure white, compact, and crystalline.

This tufa consists almost wholly of carbonate of lime, carrying very small and varying amounts of manganese (oxide) and iron oxide. The manganese is frequently prominent as a black powder, or occurs in blackish layers through the rock. The analysis made for Owen in 1859 of the material deposited in the pipe accords so exactly with that of the deposit now forming that it is reproduced:

Analysis of hot-spring tufa formed in pipes carrying hot water to bath houses.

	Per cent.
Carbonate of lime	92.620
Sulphate of lime	.085
Carbonate of magnesia	3.060
Carbonate of iron	.210
Carbonate of manganese	.190
Potassa	.107
Silica	.119
Total	99.391

In Cave Spring the freshly deposited tufa is tinted orange by the algæ that live in hot water, and green by the species that flourish at slightly lower temperatures. These colors are purely vegetable and disappear if the deposit be heated.

This tufa deposit covers an area of approximately 20 acres, and varies from a few inches to 6 or 8 feet in thickness. Its occurrence shows that some of the springs formerly flowed to the west and that the waters covered a larger area than at present.

The broad area covered by the tufa does not mean that the hot waters covered this entire area at any one time, for the algous growth described as filling the hot-water streams causes a filling up of the channel and a diversion of the water to a different place. In two instances the waters built up mounds about the springs. The most noticeable of these is that of Cave Spring, which has been artificially breached in the development of a larger water supply from the spring. Above the music pavilion another area of tufa indicates the former presence of springs at a level higher than any now existing.

The thickness of the tufa deposit is likely to be overestimated, as it covers steep slopes and even forms cliff faces. The earliest description of the place tells of its forming overhanging masses alongside the creek, whose flood waters swept away its support. The natural exposures of conglomerate and sandstone outcropping near the pavilion show that the tufa is there underlain by hard rock. Farther west, however, the tufa overlies soft, shaly rocks, which have been digested by the hot waters and vapors for so long a time that the material is as soft as ashes. In the development of new water supplies near Spring No. 1 a pipe was driven 38 feet down into this material. Immediately beneath the tufa there is a breccia of novaculite sandstone or shale fragments cemented by iron oxide, manganese oxide, and carbonate of lime. This is seen under the tufa at Cave Spring and at Dripping Spring. It merely represents the old hillside débris cemented by the hot-water deposit and material deposited later beneath the tufa mantle.

The owners of the Hale bath house have cut a short tunnel into the tufa back of their establishment, and the natural heat of the ground is used for a vapor bath. There is no doubt that the ground back of Bath House Row is permeated by a network of fissures and is heated by hot-water vapors.

The tufa area is described by all earlier writers as being distinguished from the adjacent slope by its peculiar vegetation. In the improvement of the reservation this distinction has been largely obliterated, as flowers and shrubs have been freely planted. The tufa cliffs and rougher exposures show, however, the limestone-loving ferns *Cheilanthes alabamensis* Kunze and *Adiantum capillus-veneris* L., which occur nowhere else in this region. Owen mentions these ferns especially, besides numerous peculiar mosses and algæ, stonecrop, sage, lobelia, and senna as characteristic of the tufa area.

GEOLOGIC RELATIONS OF THE HOT SPRINGS WATERS.

In the geologic sketch already given the rocks from which the hot waters issue are described as sandstones and shales of lower Silurian age, occurring in sharply compressed folds. The hot waters issue from the sandstones seen well exposed back of the superintendent's office and near the music pavilion and from the overlying shales in the area west of the pavilion. These rocks form part of a steeply dipping anticline plunging beneath the surface toward the southwest. It may be compared to the partly buried prow of an upturned boat. The rocks arch around the mountain slopes, the different beds being revealed very much as the scales of an onion bulb are exposed when it is partly cut into. While the rocks are flexed into this great curve, the great and thick beds of hard sandstone and conglomerate were cracked while being flexed, and little slips and breaks were produced. The smaller cracks form a network of fractures, which in some places are seen to be filled with white quartz. The principal springs are arranged along a line running about north-northeast, or parallel to the axis of the fold forming Hot Springs Mountain. This line is believed to be a fissure corresponding to a fracture of the northwest fold—a fault fissure. Springs are common along such fractures in the novaculite region of Arkansas, and there is no reason to believe there is anything unusual in this one. The source of heat is discussed elsewhere.

COMPOSITION OF THE HOT SPRINGS WATERS.

Analyses.—The hot springs yield waters of remarkable purity. This, in fact, is the reason ascribed by some physicians for the efficacy of the water as a remedial agent. The very complete analyses given in this report show a very small amount of mineral matter. The purity of the natural waters of the region is well known. The water of Happy Hollow Spring has less mineral matter than any other of the waters known, except that of Poland Spring, of Maine. These waters rise through siliceous rocks, and the fact that the hot waters contain so little mineral matter, particularly silica, is evidence of their meteoric origin, and accords with the nature of the gases given off by the springs.

A direct comparison of the analyses with those made in earlier years is not convenient, since the analyses are given in parts per million, while those of the Arkansas Geological Survey are in grains per gallon. I have recalculated the analyses of the larger springs, however, and find them nearly identical with the later ones, showing conclusively that the nature of the waters is not changing with time.

The accompanying table gives a recapitulation of the analyses made by Mr. J. K. Haywood, of the Department of Agriculture:

Table of flows, temperatures, and analyses of waters of Arkansas hot springs.[a]

[In parts per million.]

Springs.	Degrees F.	Flow in gallons per 24 hours.	SiO_2.	SO_4.	HCO_3.	NO_3.	NO_2.	PO_4.	BO_2.	Cl.	Br.	I.	FeAl.	Mn.	Ca.	Mg.	K.	Na.	Li.	NH_4.	Total parts per million.
Egg	143.4	28,800	45.11	7.83	166.50	0.88	Trace.	Trace.	(b)	2.50	Trace.	Trace.	0.24	0.36	46.09	4.81	1.65	4.52	Trace.	0.302	280.792
Arsenic	129.0	c10,800	44.48	8.24	160.50	.44	Trace.	Trace.	(b)	2.50	Trace.	Trace.	.24	Trace.	44.64	4.77	1.98	4.46	Trace.	.060	272.310
Arlington	143.1	19,938	44.89	7.76	166.60	Trace.	0.0007	Trace.	(b)	2.50	Trace.	Trace.	.28	.22	46.36	4.88	1.65	4.52	Trace.	.02	279.6287
Cliff	132.6	3,600	43.55	8.63	160.50	.44	.0013	Trace.	(b)	2.38	Trace.	Trace.	.35	.22	44.61	4.68	2.01	4.48	Trace.	.043	271.8943
Avenue	143.4	17,280	44.31	7.85	166.50	.44	.0022	Trace.	(b)	2.38	Trace.	Trace.	.28	.22	46.58	4.58	1.65	4.51	Trace.	.084	279.3862
Boiler House	136.9	32,400	44.51	8.50	163.50	.75	.0013	Trace.	(b)	2.75	Trace.	Trace.	.21	Trace.	46.25	4.88	1.68	4.50	Trace.	.025	277.5563
Imperial (north)	141.4	d18,514	44.59	7.92	169.60	.33	.0041	Trace.	0.86	2.50	Trace.	Trace.	.35	.18	47.23	4.99	1.70	4.57	Trace.	.116	284.9401
Crystal	97.2	e2,000	46.28	7.88	172.60	.22	.0012	Trace.	(b)	2.50	Trace.	Trace.	.28	Trace.	48.35	4.90	1.80	4.54	Trace.	.065	289.4162
Rector	144.3	f51,840	44.91	7.60	166.50	.09	.0013	Trace.	(b)	2.50	Trace.	Trace.	.21	.11	46.18	4.97	1.68	4.64	Trace.	.062	279.4533
Cave	135.3	18,514	44.55	7.73	160.50	Trace.	.0016	Trace.	(b)	2.38	Trace.	Trace.	.21	.22	45.07	4.94	1.60	4.37	Trace.	.031	271.6026
Little Iron (north)	134.2	....	47.44	8.28	160.50	.18	.0012	Trace.	(b)	2.71	Trace.	Trace.	.12	.11	43.84	4.98	1.66	5.18	Trace.	.095	275.0962
Little Geyser	97.2	524	32.52	6.73	93.90	.18	.0008	0.13	(b)	2.43	Trace.	Trace.	.11	Trace.	25.89	3.18	1.31	3.68	Trace.	.025	170.0858
Little Iron (south)	133.3	....	46.17	8.35	166.50	.18	.0012	Trace.	(b)	2.57	Trace.	Trace.	.11	.12	46.22	4.93	1.60	4.87	Trace.	.043	281.6642
Ral	145.0	8,640	45.17	7.95	166.50	Trace.	.0033	Trace.	(b)	2.36	Trace.	Trace.	.11	.27	46.21	4.84	1.57	4.98	Trace.	.048	280.0113
Big Iron	147.0	201,600	49.59	7.84	168.10	.44	.0016	.05	1.29	2.53	Trace.	Trace.	.19	.34	46.93	5.10	1.60	4.76	Trace.	.040	284.8016
Imperial (south)	141.6	....	43.88	7.67	163.50	.27	.0010	Trace.	(b)	2.36	Trace.	Trace.	.09	.29	45.50	4.81	1.60	4.61	Trace.	.028	274.6090
Arsenic (north)	133.5	....	45.67	8.58	163.50	.44	.0020	Trace.	(b)	2.36	Trace.	Trace.	.09	Trace.	45.40	4.70	1.88	5.12	Trace.	.037	277.7790
Hitchcock	135.2	g35,000	44.74	10.63	162.00	1.55	.0016	Trace.	(b)	2.57	Trace.	Trace.	.09	Trace.	46.04	4.94	2.01	4.79	Trace.	.057	279.4186
Sumpter	133.5	13,292	44.35	8.75	159.00	1.33	.0010	Trace.	(b)	2.57	Trace.	Trace.	.09	Trace.	44.72	4.71	2.00	4.58	Trace.	.011	272.1120
Superior (north)	115.3	3,677	39.90	7.31	133.20	.31	.0010	.13	(b)	2.43	Trace.	Trace.	.09	.11	37.43	4.23	1.47	4.40	Trace.	.013	231.0240
Alum	114.8	1;152	45.56	7.95	166.50	Trace.	.0013	Trace.	(b)	2.57	Trace.	Trace.	.09	.11	45.97	4.84	1.65	5.59	Trace.	.069	280.9003
Superior (south)	134.8	1,723	44.79	8.03	162.00	Trace.	.0055	Trace.	(b)	2.43	Trace.	Trace.	.09	.18	44.73	4.76	1.64	4.67	Trace.	.025	273.3505
Twin (north)	144.3	f10,800	46.25	7.97	167.60	Trace.	.0010	Trace.	(b)	2.43	Trace.	Trace.	.09	.16	46.92	4.82	1.74	5.11	Trace.	.032	285.1230
Twin (south)	144.1	....	46.85	7.81	168.80	Trace.	.0008	Trace.	(b)	2.83	Trace.	Trace.	.22	.15	46.75	4.92	1.74	4.78	Trace.	.035	284.8858
Old Hale	144.8	g35,000	47.31	7.80	166.50	Trace	.0007	Trace.	(b)	2.50	Trace.	Trace.	.19	.29	46.82	5.01	1.69	4.73	Trace.	.028	282.8687
Palace	146.1	25,847	47.86	7.82	166.50	Trace.	.0008	Trace.	(b)	2.50	Trace.	Trace.	.19	Trace.	46.75	4.99	1.74	4.80	Trace.	.021	283.1718

Tunnel	125.4	800	49.95	7.98	146.70	.22	.0010	Trace.	(b)	2.58	Trace.	Trace.	.16	.14	39.61	4.95	1.73	4.66	Trace.	.037	258.7180
Maurice	139.6	[g]21,000	47.41	7.80	165.00	.27	.0008	Trace.	(b)	2.58	Trace.	Trace.	.21	.15	45.47	4.82	1.76	4.89	Trace.	.061	280.4218
Dripping	136.0	2,618	48.02	7.64	165.00	.22	.0003	.80	(b)	2.58	Trace.	Trace.	.22	.15	45.97	4.80	1.67	5.09	Trace.	.010	282.0203
Arch	129.0	(h)	50.90	7.50	157.50	.44	.0020	Trace.	(b)	2.67	Trace.	Trace.	.12	Trace.	43.00	4.92	1.72	4.99	Trace.	.011	273.7730
Haywood	124.5	[i]7,200	47.40	8.78	162.00	.34	.0008	Trace.	(b)	2.67	Trace.	Trace.	.19	.25	45.45	4.72	1.65	4.69	Trace.	.042	278.1828
John W. Noble	115.7	28,800	48.27	8.29	159.00	.34	.0013	Trace.	(b)	2.50	Trace.	Trace.	.19	.12	44.75	4.73	1.72	4.94	Trace.	.023	274.8743
Lamar	120.6	....	49.60	8.53	165.00	Trace.	.0013	Trace.	(b)	2.50	Trace.	Trace.	.22	.15	45.94	4.80	1.68	4.65	Trace.	.042	283.1133
H. W. Wiley	118.2	28,800	46.90	8.08	163.50	Trace.	.0016	Trace.	(b)	2.67	Trace.	Trace.	.24	.04	45.68	4.73	1.69	4.84	Trace.	.045	278.4166
Ed. Hardin	109.4	2,469	46.57	7.49	165.00	1.33	.0013	Trace.	(b)	2.50	Trace.	Trace.	.19	.20	46.32	4.79	1.70	4.65	Trace.	.023	280.7643
Eisele	120.0	9,600	48.84	8.71	163.50	.78	.0007	Trace.	(b)	2.58	Trace.	Trace.	.19	.11	46.33	4.92	1.68	4.70	Trace.	.023	282.3637
Stevens	127.2	5,760	46.65	15.78	169.60	Trace.	.0013	Trace.	(b)	2.67	Trace.	Trace.	.14	.08	49.93	5.07	1.76	5.28	Trace.	.036	296.9973
Horse Shoe	139.6	[g]40,000	49.81	7.86	171.10	Trace.	.0005	Trace.	(b)	2.50	Trace.	Trace.	.26	.27	46.61	5.07	1.60	5.42	Trace.	.030	290.5305
Army and Navy	142.5	35,000	50.51	9.41	169.60	1.33	.0030	Trace.	(b)	3.33	Trace.	Trace.	.28	.14	47.11	5.14	1.93	5.98	Trace.	.111	294.8740
W. J. Little	120.0	4,320	45.73	7.76	163.50	Trace.	.0010	Trace.	(b)	2.67	Trace.	Trace.	.19	Trace.	45.43	4.96	1.59	5.00	Trace.	.008	276.8390
Mud	118.9	[g]4,000	52.30	11.95	168.10	.44	.0016	Trace.	(b)	3.17	Trace.	Trace.	.29	Trace.	46.89	5.22	2.23	6.49	Trace.	.018	297.0996
Magnesia	136.9	[g]50,000	49.63	8.40	166.50	.44	.0008	Trace.	(b)	2.83	Trace.	Trace.	.33	.07	45.93	5.19	1.72	5.08	Trace.	.058	286.1788
Reservoir	115.3	[g]20,000	43.21	28.67	160.50	.22	.0013	.53	(b)	5.83	Trace.	Trace.	.44	None.	49.22	4.24	8.84	8.33	Trace.	.008	310.0393
Liver (cold)	46.4	659	12.50	2.50	12.10	.89	Trace.	Trace.	(b)	1.83	Trace.	Trace.	.34	Trace.	1.89	1.36	.94	2.10	Trace.	.009	36.459
Kidney (cold)	55.4	511	15.06	2.29	15.14	.44	.0007	Trace.	(b)	2.00	Trace.	Trace.	.34	Trace.	3.79	1.45	1.02	2.23	Trace.	.021	437.817
Fordyce	124.7	[g]25,000	49.16	8.21	166.50	(j)	(j)	.33	(b)	2.50	Trace.	Trace.	.18	.21	45.79	5.06	1.57	5.26	Trace.	(j)	284.77

[a] J. K. Haywood, analyst. [b] Small amount. [c] Includes Arsenic spring (north). [d] Includes Imperial spring (south). [e] Includes Little Iron spring (north) and Little Iron spring (south). [f] Includes Twin spring (south). [g] Estimated. [h] Could not be estimated. [i] Includes Lamar spring. [j] Not determined.

AsO_4 was tested for, but not found in any of the waters.

Gases.—The gases given off by the hot waters were carefully collected and analyzed. The results show that they consist of carbon dioxide, oxygen, and nitrogen. The ratio of oxygen and nitrogen corresponds very closely to that of atmospheric air, and, taking into account the relative absorption of the two gases by water, there can be no doubt that the oxygen and nitrogen given off by the water come from absorbed air.

Mineral contents.—The mineral matter of the waters has come from the rocks traversed by the waters. Recollecting the solvent power of hot water, it is rather remarkable that the waters are so pure. The underlying rocks are Silurian sediments resting on an unknown complex, but the Silurian rocks alone are competent to supply all the mineral matter of the waters.

SOURCE OF HOT SPRINGS WATERS.

From what has already been said in discussing the geologic and topographic relations of the springs, and from the composition of the water and of the gases, there seems no doubt that the hot springs correspond closely to the ordinary springs of the mountain region save in the very important element of heat. As will be shown later, it is believed that the waters of a very large but entirely normal spring or springs have been heated by vapors rising through fissures penetrating to unknown depths.

DURATION OF THE HOT SPRINGS.

Temperatures.—The question whether the hot springs are changing in character and will eventually either cease flowing or become cold springs is of both popular and scientific interest. In 1804 Dunbar and Hunter recorded a temperature of 150° F. for the larger spring and 154° F. for another spring. In 1859 the springs were carefully examined by David Dale Owen, State geologist, and a map of temperatures and elevations was published. In 1860 a more accurate map, together with records of temperature and outflow, was prepared by William Glasgow, jr., from careful instrumental surveys.

Since then many changes have been made about the springs, all of which have been dug out and inclosed in masonry arches, with the consolidation of two or more springs into one in some instances, the development of new outflows by digging wells or sinking pipes, and the drying up of adjacent natural outflows. For these reasons all the springs now existing can not be positively identified with those shown on the earlier maps, but a majority of them are so correlated without doubt.

The comparison of the old records mentioned with those recently made shows that the highest temperature known to-day is 147° F., as against 154° in 1804 and 150° by Glasgow and 148° by Owen in 1860. In a number of springs there is a decline of 2° since the latter date. Such a slight difference might, however, be due to differences in the manner or place of taking the temperatures, or the instruments used in the earlier years may not have been accurate. It is noteworthy that Owen's highest temperature, taken in 1859 with a standardized thermometer, was 148°, and that recorded now is 147°. In other words, the temperature is decreasing so slowly that the change is almost imperceptible in half a century. In one instance, that of Alum Spring, there is a very marked decrease in temperature, and as this is the only spring on the west side of the creek there is no doubt of its identity. In 1804 this had a temperature of 132°. In 1859 its temperature was 133°, according to Owen, and to-day it is but 114.8°.

Amount of outflow.—The comparison of outflow is more difficult. According to Dunbar and Hunter, the largest spring had an outflow of 11 quarts in eleven seconds in 1804, corresponding to 22,100 gallons per day, and the four largest springs had an outflow of 165 gallons per minute, or 237,600 gallons per day. Doctor Owen gives no measurements, but Glasgow gives the discharge of each spring—a total of 317 gallons per minute, or 450,480 gallons per day, as compared with 850,000 gallons per day at the present time. As the writer has shown elsewhere, the spring water is of meteoric origin, like most spring water, and probably varies somewhat from year to year, corresponding to variation in annual rainfall in some previous year, so that no definite comparison can be made with the early records, except to state that the volume of water discharged is very much greater. Supposing a practically constant amount of heat applied, this of itself would mean a slightly lowered temperature. In this connection attention should be called to the well put down by Major Torney, U. S. Army, in the Army and Navy Hospital, which is capable of yielding the amazing amount of 350,000 gallons per day without affecting but one very small spring (No. 40 of the list).

From a consideration of all these facts it is concluded that the springs are losing their heat so slowly that the loss is almost inappreciable.

Amount of mineral matter in solution.—No essential difference in the composition of the waters can be detected by a comparison of the analyses made for Owen or Larkin (1859) or for Doctor Branner, of the Arkansas Geological Survey, in 1889, with the elaborate and careful analyses made by the National Government. The waters are remarkable more for their purity than for their mineral contents. The material in solution consists mainly of bicarbonate of lime, which is so easily precipitated by the loss of carbonic-acid gas that a deposit forms in pipes, and rather rapidly where the spring waters drip, as in the walls about the bowl of Cave Spring. The total mineral matter for all the springs amounts to 1,367 pounds a day, equivalent to 249.5 tons a year. This amount of material carried by the hot water from the earth's interior to the surface must leave a very considerable cavity in the course of time.

HEAT OF THE HOT SPRINGS WATERS.

While there have been many theories advanced to account for the source of the hot waters, the only hypothesis that stands the test of scientific inquiry is the one which ascribes the heat of the waters to still hot but concealed bodies of igneous rock. It seems scarcely necessary to call attention to the absurdity of the idea that either slaking lime in the depths of the earth or chemical reaction of the waters with the atmosphere could be the cause of the heat. That the waters come from a depth sufficient for their heating by the normal increment of earth heat (1° for every 50 feet) seems unreasonable, since it would necessitate a depth of nearly 5,000 feet to give the waters their present temperature, even assuming that they were not cooled in their course upward. The composition of the gases given off by the waters shows that they contain atmospheric air as well as carbon dioxide. That the heat of the waters is due to the heat developed by the folding of the rocks, which is the theory given to account for the heat at the Virginia Hot Springs, is not probable, for the folding at Hot Springs is not more intense than elsewhere in the mountain regions of Arkansas, and no evidence of hot-spring action has been found at any other localities except where igneous rocks are present.

It is believed that the heat comes from a great body of still heated igneous rocks intruded in the earth's crust by volcanic agencies and underlying a large part of central Arkansas. The existence of such a mass is shown by the great bodies of granite seen at Potash Sulphur Springs and Magnet Cove, where the rocks have been exposed by the wearing down of the overlying sediments, though the igneous rocks seen were of course long since cooled. At Magnet Cove, moreover, there are tufa deposits which show the former occurrence of hot springs.

This hypothesis is strengthened by the occurrence of intrusive dikes at various localities about the springs, and their trend and occurrence indicate that the molten material which filled the fissures did not come from the bodies of rock now exposed at Potash Sulphur Springs or at Magnet Cove, but had some deep-seated source, whose location is indicated by the dikes as being approximately under the Hot Springs. Deep-seated waters converted into vapors by contact with this "batholith" of hot rock probably ascend through fissures toward the surface, where they probably meet cold spring waters which are heated by the vapors. As the igneous dikes near by are fissures reaching down to this great mass of igneous magma, which have been filled by it to form dikes, it is not unreasonable to suppose that fissures extend down to the now solid but still hot igneous mass,

NOTES ON CERTAIN LARGE SPRINGS OF THE OZARK REGION, MISSOURI AND ARKANSAS.

Compiled by MYRON L. FULLER.

The following account is based on memoranda furnished by E. Johnson, jr., who measured the flow of the springs in connection with stream measurements in the same region, and on geologic and other notes furnished by H. Foster Bain and E. M. Shepard. The investigations and measurements of the springs were made with the view of determining their availability as a source of water power, a question which had become of importance because of the needs of such power for plants contemplated in connection with the proposed construction of an electric railway through the district. The account is presented for the purpose of calling attention to the size, character, and importance of the springs which are typical of the Ozark region.

OZARK REGION IN MISSOURI.

GEOLOGY.

The springs which are described in the following pages are, with the exception of Mesamer and Boiling springs, situated on the south flank of the Ozark uplift, where a long structural slope opens the way for an important underground circulation, fed from a central table-land. The springs are in canyons where the streams have cut down into the rock and intersect some aquifer or water-bearing bed. The country rock is generally a cherty dolomite with irregular beds of sandstone, but the particular horizons which are most favorable aquifers have not been discriminated. The rocks are mainly lower Ordovician, but some Cambrian rocks of similar lithologic character occur in the vicinity.

Mesamer Spring is on the north flank of the Ozarks, well up toward the crest, but is in a dolomite and sandstone country of approximately the same age as that of the springs on the south flank of the mountains. Sink holes abound in the region. Boiling Spring is likewise on the northwest flank of the Ozarks, and is said to issue from a dolomitic rock, probably the Gasconade limestone.

GENERAL CONDITIONS.

The country as a whole is a plateau deeply cut by stream erosion, and underground circulation is unusually important. There are many deep, wide valleys which now contain no streams except in very wet weather, all the water going underground within a very short distance. This is so true that the value of the land for stock purposes, the main use except for timber, is largely determined by the presence or absence of springs. These are numerous, those described being only some of the best known. Intermittent as well as steady-flowing springs occur. One of the best known is in Shannon County, near the junction of Jacks Fork and Current River. This spring has a rhythmic flow with maxima approximately forty minutes apart. The minimum flow is much less than the maximum, but the water does not altogether cease flowing. Presumably the spring is the outlet of two or more underground channels, one of which has a chamber and siphon form.

All of the springs show marked fluctuation of discharge with variations in rainfall, which probably accounts for the great difference in past and present flows, such as is noted in the case of Blue and Alley springs.

DESCRIPTION OF SPRINGS.

Greer Spring.—This spring, which is owned by Greer & Mainprize, is located in sec. 36, T. 25 N., R. 4 W., $1\frac{1}{2}$ miles northeast of Greer post-office and about the same distance south of Eleven Point River. It is 8 miles northeast of Alton, the county seat of Oregon County, and 16 miles due south of Winona, Shannon County. About one-fourth its water issues from a cave lined with stalactites and stalagmites, situated at the head of a deep ravine cut in Ordovician rocks, mainly cherty dolomites, with occasional irregular beds of sandstone. The remaining three-fourths comes from a so-called "boil" 100 feet distant and 7 feet lower, the source of which is invisible. From the spring the water flows down a rapid descent through a narrow valley to Eleven Point River, 54 feet lower, furnishing power for a large gristmill on the way.

The water is colorless, except where contaminated by sediment washed in below its source in time of storm. It has no odor or taste and has a temperature of 54°. Other than the source of power mentioned, no use is made of its waters.

The maximum measurement of flow gave a result of 362 cubic feet per second, while the minimum flow is not far from 225 cubic feet. About 265 feet is a more common discharge. The minimum flow is equal to that of a stream 25 feet wide, 3 feet deep, flowing 3 feet per second, and represents the run-off of a large area of surface.

Van Buren or Big Spring.—This is located in the valley of Current River, 4 miles southeast of Vanburen, the county seat of Carter County, and has a large flow.

Fanchon Spring.—Fanchon Spring is located on the side of the left bluff of Current River, in sec. 9, T. 29 N., R. 2 W., 10 miles east of Eminence, the county seat of Shannon County. The spring is owned by a hunting and fishing club of St. Louis, and is said to yield sufficient water for power purposes.

Alley or Big Spring.—Alley Spring is located near Alley postoffice, in T. 29 N., R. 5 W., about 6 miles west of Eminence, Shannon County. It emerges as a stream from the base of a high dolomitic limestone bluff on the side of the comparatively broad valley of Jacks Fork, a tributary of Current River, with which its waters unite about one-half mile below the spring.

The water is odorless, tasteless, somewhat hard, and has a temperature of 53°. Its ordinary flow is 85 cubic feet per second, but is probably not more than 75 second-feet during the summer. It furnishes power for a grist and saw mill near its source. The flow of this spring in 1875 was reported by Dr. C. P. Williams[a] as 588 second-feet.

Blue or Round Spring.—This spring is located in sec. 20, T. 30 N., R. 4 W., about 14 miles northwest of Eminence. It originates in a natural limestone well about 84 feet in diameter at the rim and 48 feet deep. On one side is a high bluff; through an opening on the other side, 18 feet below the surface and 72 feet in length, the water escapes and flows into Current River, a quarter of a mile distant.

The water is odorless and tasteless and of a deep-blue tinge. The temperature is 54°. As given by Dr. C. P. Williams,[a] the flow in 1875 was 425 cubic feet per second, but when measured in 1904 by Mr. E. Johnson, jr., was only 23 second-feet. It has in the past furnished power to at least two mills, but no use is now made of it.

Mesamer Spring.—This spring, which is owned by the James estate, is located in sec. 17, T. 37 N., R. 6 W., 7 miles in a southerly direction from St. James. The spring issues as a subterranean stream from the base of a bluff in a gorge in the Gasconade limestone. The water is of a bluish tinge, without odor or taste, but fairly hard, and carries some sediment after heavy rains. Its temperature is 56°. The flow is affected by rainfall. According to the reports of the Tenth Census it then had a flow of 100 to 150 cubic feet per second, while on August 18, 1900, it had, according to H. B. Shaw, a flow of 125 second-feet. The minimum flow determined in 1904 by Mr. E. Johnson, jr., of the United States Geological Survey,

[a] Industrial Rept. Geol. Survey Missouri, 1877, p. 160.

was 86 second-feet. It has been utilized as a water power in the past and has been considered as a source of water supply for the city of St. Louis in connection with Water Fork of Meramec River, into which it flows at a point about one-half mile from its source and 12 feet lower down. The maximum combined flow of the two streams has been found by Mr. Johnson to be 150 second-feet.

Boiling Spring.—Boiling Spring is located in T. 36 N., R. 10 W., 6 miles in a southerly direction from Arlington post-office. It issues from the bed and bank of Gasconade River, near the base of a high dolomitic limestone bluff. Its water is of a bluish tinge, without odor or taste, but rather hard. It is not especially muddy even after rains. The temperature is 60° and the flow about 150 second-feet, but no use is now made of the water either for power or other purposes.

OZARK REGION IN ARKANSAS.

DESCRIPTION OF MAMMOTH SPRING.

Mammoth Spring, which is owned by Napoleon Hill and the heirs of J. W. Cochran, is located near the line between secs. 5 and 8, T. 21 N., R. 5 W., about one-eighth mile in a northerly direction from Mammoth Spring post-office. It issues as a subterranean stream near the base of a high cherty limestone bluff ("Third Magnesian limestone" of Swallow). The course of the underground river feeding the spring is thought to be marked in Howell County, 8 miles northwest, by a sink hole three-fourths mile long known as the "Grand Gulf." The spring itself is 64 feet deep at its mouth, the water apparently issuing from a large cavernous opening and from other large crevices in the rock.

The water is described as having a bluish tinge, but as being odorless and tasteless, and having a temperature of 58° or 59° in summer. The amount of water is somewhat affected by prolonged droughts, the water level varying 3 or 4 inches. The water is hard, having about 158 parts per million of lime and 139 parts of magnesia. Carbonic acid to the amount of 204 parts per million is reported.

The flow has been reported to be as high as 350 second-feet, but in 1904 it was as low as 150 cubic feet per second. This is, however, probably about its minimum volume. A large hotel has been constructed and a park laid out at the springs. The water is now used for power by a flour and cotton mill and further developments are contemplated.

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O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 145.]

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

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are allotted to every member of Congress, from whom they may be obtained, free of charge, on application.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the forty-sixth in Series O, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

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WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls.
WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls.
WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls.
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WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.
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WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87–141 pp.
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WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96–140 pp.
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PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls.
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The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

Correspondence should be addressed to

THE DIRECTOR,
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WASHINGTON, D. C.

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