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UNITED STATES DEPARTMENT OF THE INTERIOR

GROUND WATER IN NORTH-CENTRAL TENNESSEE

Prepared in cooperation with the
TENNESSEE DIVISION OF GEOLOGY

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 640

UNITED STATES DEPARTMENT OF THE INTERIOR
Ray Lyman Wilbur, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Water-Supply Paper 640

GROUND WATER IN NORTH-CENTRAL TENNESSEE

BY

ARTHUR M. PIPER

Prepared in cooperation with the
TENNESSEE DIVISION OF GEOLOGY

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ABSTRACT

This report describes briefly the physiography, stratigraphy, and geologic structure and the sources and chemical character of the ground water in a region covering 5,800 square miles on the northwest slope of the Nashville dome, in north-central Tennessee. It includes Cheatham, Davidson, Dickson, Houston, Humphreys, Montgomery, Robertson, Rutherford, Stewart, Sumner, Williamson, and Wilson Counties.

The region includes parts of two physiographic districts, the Nashville Basin and the Highland Rim plateau, both of which are sections of the Interior Low Plateaus province. The Highland Rim plateau comprises remnants of a regional peneplain, which was formed in the interval between late Upper Cretaceous and early upper Oligocene time and was subsequently arched and uplifted. Its present altitude within the region described is between 1,350 and 600 feet above sea level. The Nashville Basin is an elliptical depression 85 miles long by 50 miles wide formed by stream planation in the Ordovician limestones on the crest of the Nashville dome, and its floor is 700 to 550 feet above sea level. The period of stream planation has been ascribed to the middle Pleistocene. The principal streams are now intrenched 100 feet or more below the floor of the Nashville Basin.

The primary structural feature of the region is the Nashville dome, the southerly one of two domes on the axis of the Cincinnati geanticline. The Nashville dome is a flat elliptical flexure whose major axis strikes N. 20°–30° E. across the eastern part of the region. From the apex of the dome, in the southeast corner of the region, the axis plunges northward and southward between 5 and 10 feet to the mile. The flanks dip about 15 feet to the mile within 50 miles of the apex, but the western flank flattens in the more remote parts of the region. Superposed upon the Nashville dome are many secondary anticlines, synclines, and domes, which generally are less than 5 miles long and 100 feet high. Where the secondary folding is most intense the rocks are much jointed. One of the two principal sets of joints is approximately parallel and the other normal to the major axis of the Nashville dome. In the northwestern part of the region the rocks are complexly faulted and folded in an area which is roughly circular in plan and about 8 miles in diameter; this is the Wells Creek uplift. The deformation that produced the Nashville dome began at least as early as the Lower Ordovician and recurred as late as upper Oligocene time.

The oldest consolidated rock of the region is a cherty magnesian limestone of Lower Ordovician (Beekmantown?) age, which crops out only in the center of the Wells Creek Basin. The rocks exposed elsewhere on the Nashville dome range in age from Lower Ordovician (Chazy) to upper Mississippian, and each of the geologic systems within this range is represented. However, the geologic column is broken by one major unconformity, the complete hiatus including the Upper Ordovician and all of the Silurian and Devonian. At least 16 minor stratigraphic breaks occur. With the exception of the Chattanooga and Ridgetop shales, the strata are limestones, massive and thin bedded, pure, earthy, and cherty. Many of these limestones did not cross the axis of the Nashville dome, so that they overlap one another most complexly. The total maximum thickness of the exposed strata is about 2,530 feet, although the actual thickness in any one section is much less. A well drilled near the apex of the Nashville dome penetrates sandstone from 610 to 620 feet below the surface; the remaining strata include limestone, dolomite, and chert to a depth of 1,930 feet.

The unconsolidated rocks include sand and gravel of Upper Cretaceous age, which rest upon the Highland Rim plateau in a few small areas, stream terrace deposits, and the alluvium that forms the present flood plains.

Most of the rocks, being dense limestone, are devoid of original interstices, so that in general the ground water circulates in joints and openings formed by solution. The number and capacity of water-bearing openings are dependent upon the number and continuity of open joints, the solubility of the limestone, and the positions of the several strata with respect to present and past equilibrium profiles of solution channeling. Therefore, as many of the limestones are essentially equal in solubility, the occurrence of ground water is not related to stratigraphy but rather to geomorphologic history. No large body of cavernous limestone has been depressed with relation to the water table so as to become saturated with water. A few discontinuous beds of permeable sandstone exist.

Ground-water supplies adequate for domestic use can be obtained at most places from the limestone by drilled wells less than 200 feet deep, although some wells are dry, and comparatively few yield more than 10 gallons a minute. The largest wells that tap cavernous limestone yield as much as 300 gallons a minute perennially. It is generally inadvisable to drill much more than 350 feet in search of water, because of the tightness of the rocks and of the inferior chemical character of the water at great depths. In many parts of the region the most reliable sources of water are the large springs, especially those that issue from solution channels in the limestone. Twelve such springs within the region are known to discharge 1,000 gallons a minute or more each, and one, Hurricane Rock Spring, discharges about 27,000 gallons a minute from a single solution channel.

Generally the unconsolidated rocks other than the alluvium are drained and are not promising as sources of large supplies of water. The alluvium underlies flood plains that are subject to overflow, so that extensive development of its ground water is generally not feasible, even though some of its beds may be rather highly permeable.

Flowing artesian wells in the vicinity of Nashville tap the St. Peter (?) sandstone, but the area of artesian flow covers only the lower land along the Cumberland River, the water is inferior in chemical character, and the specific capacities of the wells seem to be small. Moreover, this stratum is itself discontinuous, so that it is not a source of water over an extensive area. Flowing wells also exist in several other small areas, all of which are below the Highland Rim plateau and most of which are on or below the Nashville Basin peneplain. In at least one area the artesian flow is assisted if not caused by the presence of gas in the water. Usually it is not possible to predict the depth or location at which flowing wells can be obtained.

In general most of the waters fall into three classes, according to the amount and kind of dissolved mineral matter. One class includes the calcium bicarbonate waters, which contain 50 to 500 parts per million of total solids and 30 to 300 parts per million of carbonate hardness and are essentially free from iron and hydrogen sulphide. Such are the waters which circulate freely through permeable beds and channeled limestone and issue from most of the springs and from wells less than 200 feet deep. A second class includes those highly concentrated calcium or calcium-magnesium sulphate waters with considerable noncarbonate hardness, and the third includes the brines or sodium chloride-sulphate waters. The waters of the last two classes can not be sharply discriminated. They occur both in deeply buried permeable beds and in slightly permeable beds at moderate depth; they issue from a few springs and from some wells less than 50 feet deep but generally occur in strata more than 100 feet below the surface. So far as is known they occur in all strata more than 350 feet below the surface. The dissolved solids range from 1,000 to 26,000 parts per million. Many of the moderately and highly concentrated sulphate waters, especially those in which magnesium is relatively concentrated, contain large quantities of hydrogen sulphide gas. There seems to be no relation between the stratigraphic position of most water-bearing beds and the chemical character of the ground water.

GROUND WATER IN NORTH-CENTRAL TENNESSEE

By Arthur M. Piper

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation upon which the present report is based is the first unit of a proposed survey of the conditions of ground-water occurrence throughout Tennessee. This survey seeks to inventory the principal sources of ground water and, so far as possible, to establish such general rules of occurrence as will measure the adequacy of those sources to meet the growing needs of urban, rural, and industrial development. Furthermore, it seeks to establish a proper basis for the detailed study of problems of local development, although economy of time prevents any full analysis of those problems.

This state-wide project was conceived by the division of geology of the Tennessee Department of Education in 1927, and active investigation was undertaken by the United States Geological Survey in financial cooperation with the State organization. The writer was assigned to the north-central portion of the State, a region which centers about Nashville, and spent the four months from mid-July to mid-October, 1927, in the field analyzing features of ground-water occurrence in relation to the stratigraphy and other geologic factors. Samples of water were collected from 101 representative wells and springs as a guide to the chemical composition of the ground waters. O. E. Meinzer, chief of the division of ground water of the United States Geological Survey, made a reconnaissance of the region with the writer during the last week of September and gave much constructive criticism.

LOCATION AND EXTENT OF THE AREA

The region described in this report lies between meridians 86° and 88° west longitude and parallels 35° 40′ and 36° 45′ north latitude. It embraces about 5,800 square miles in the north-central part of Tennessee and includes the counties of Cheatham, Davidson, Dickson, Houston, Humphreys, Montgomery, Robertson, Rutherford, Stewart, Sumner, Williamson, and Wilson. The location of the region with respect to the boundaries of the State and to the second unit of the State-wide project (which was studied in 1928 by F. G. Wells) is shown by Plate 1.

PREVIOUS GEOLOGIC INVESTIGATIONS

Systematic investigation of the geology of central Tennessee dates back a hundred years. In 1831 Troost [1] appealed to the State legislature for the organization of a State geological survey and was commissioned State geologist. His single-handed investigations of the mineral resources of the State continued for nearly two decades and ended in 1850. An outstanding achievement was the publication, in 1840, of a preliminary geologic map of the State.[2]

J. M. Safford was appointed State geologist and mineralogist in 1854 and filled that position for half a century, studying the coal, iron, phosphate, and other mineral resources. His comprehensive summary of the geology of Tennessee, first published in 1869,[3] has formed a sound basis for subsequent and more detailed investigations.

In 1903 was published the first detailed analysis of the stratigraphy of the phosphate deposits of the central part of the State, by Hayes and Ulrich.[4]

In 1909 a State geological survey was created to study the metallic and nonmetallic resources, the surface and ground water resources, and the physical geography of the State, working largely in cooperation with the United States Geological Survey. G. H. Ashley served as State geologist from 1909 to 1912, A. H. Purdue from 1912 to 1917, W. A. Nelson from 1918 to 1925, H. D. Miser during 1925 and 1926, and W. F. Pond from 1927 to the present time. In 1923 the organization became the division of geology of the Tennessee Department of Education. Under the auspices of the State Geological Survey, fundamental contributions to the geologic knowledge of the region have been made by Butts,[5] Dunbar,[6] Galloway,[7] Mather,[8] and Nelson.[9] Recently Bassler [10] has completed a detailed study of the stratigraphic section exposed on the eastern and western edges of the central basin in relation to the mineral resources of the region.

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[1] Troost, Gerard, Address delivered before the legislature of Tennessee at Nashville, October 19, 1831: Transylvania Jour. Medicine, vol. 4, No. 4, pp. 467-507, Lexington, 1831.

[2] Troost, Gerard, Fifth geological report of the State of Tennessee, 75 pp., map, Nashville, 1840.

[3] Safford, J. M., Geology of Tennessee, 550 pp., map, Nashville, Tennessee Bur. Agr. and Commerce, 1869.

[4] Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio No. 95, 1903.

[5] Butts, Charles, Geology and oil possibilities of the northern part of Overton County, Tenn., and of adjoining parts of Clay, Pickett, and Fentress Counties: Tennessee Geol. Survey Bull. 24 (Ann. Rept. for 1919, pt. 2-A), 45 pp., 1919.

[6] Dunbar, C. O., Stratigraphy and correlation of the Devonian of western Tennessee: Tennessee Geol. Survey Bull. 21, 127 pp., 1919; Am. Jour. Sci., 4th ser., vol. 46, pp. 732-756, 1918.

[7] Galloway, J. J., Geology and natural resources of Rutherford County, Tenn.: Tennessee Geol. Survey Bull. 22, 81 pp., 1919.

[8] Mather, K. F., Oil and gas resources of the northeastern part of Sumner County, Tenn.: Tennessee Geol. Survey Bull. 24 (Ann. Rept. for 1919, pt. 2-B), 39 pp., 1920.

[9] Nelson, W. A., Notes on a volcanic ash bed in the Ordovician of middle Tennessee: Tennessee Geol. Survey Bull. 25, pp. 46-48, 1921; Volcanic ash bed in the Ordovician of Tennessee, Kentucky, and Alabama: Geol. Soc. America Bull., vol. 33, pp. 605-615, 1922.

[10] Bassler, R. S., The stratigraphy of the central basin of Tennessee: Tennessee Dept. Education Div. Geology Bull. 38, 1932.

In addition to the works cited above the geologic literature includes many shorter papers that bear upon the problem at hand. Limitations of space preclude a complete tabulation at this place, although each paper that has contributed to the report is cited by footnote reference in the text.

Systematic study of the regional ground-water conditions of central Tennessee has not been attempted heretofore, although some general and local features have been discussed by Fullerton,[11] Glenn,[12] Nelson,[13] Safford,[14] and Switzer.[15]

ACKNOWLEDGMENTS

Adequate investigation of a regional problem such as is discussed herein would not have been possible unless the well drillers and residents throughout the region had contributed whole-heartedly from their experience with ground-water conditions. Individual mention of all who have contributed in this manner is, however, impracticable. The division of sanitary engineering of the State department of public health, through H. R. Fullerton, director, granted access to its files of data pertaining to ground-water supplies for municipalities. The division offices of the Nashville, Chattanooga & St. Louis Railway and of the Louisville & Nashville Railroad, through their engineers in charge of water supplies, contributed descriptive data for the wells and springs that they have developed along their respective rights of way.

Margaret D. Foster of the division of quality of water, United States Geological Survey, and D. F. Farrar, of the division of geology, Tennessee Department of Education, made the chemical analyses that form the basis of the discussion of the chemical character of the ground waters. R. S. Bassler, of the United States National Museum, described orally the major features of the general geology as a background for the field studies. The Tennessee Division of Geology contributed half of the funds available for the investigation and in addition furnished the automobile that was used for transportation in the field.

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[11] Fullerton, H. R., The water-supply problems of Tennessee: Am. Waterworks Assoc. Jour., vol. 17, No. 6, pp. 746–750, June, 1927.

[12] Glenn, L. C., [Notes on the ground-water resources of] Tennessee: U. S. Geol. Survey Water-Supply Paper 102, pp. 358–367, 1904; [Underground waters of] Tennessee and Kentucky: U. S. Geol. Survey Water-Supply Paper 114, pp. 198–208, 1905.

[13] Nelson, W. A., Mineral products along the Tennessee Central Railroad: Resources of Tennessee, vol. 3, No. 3, pp. 137–160, Tennessee Geol. Survey, July, 1913.

[14] Safford, J. M., Mineral springs [of Tennessee]: Tennessee State Board of Health Bull. 1, suppl., pp. 15–16, October, 1885.

[15] Switzer, J. A., The relation of water supply to health: Resources of Tennessee, vol. 3, No. 3, pp. 170–175, Tennessee Geol. Survey, July, 1913; vol. 4, No. 1, pp. 3–14, January, 1914.

GEOGRAPHY

TRANSPORTATION

North-central Tennessee is well served by primary transportation routes. The main line of the Louisville & Nashville Railroad passes northward through Nashville and gives direct communication with New Orleans and other Gulf ports and with Cincinnati. From Bowling Green, Ky., a branch extends southwestward through Clarksville, Tenn., to Memphis, on the Mississippi River. From its junction with the Southern Railway at Chattanooga the Nashville, Chattanooga & St. Louis Railway runs northwestward to Nashville, where it divides, one branch extending westward and northwestward to join the Mississippi Valley trunk lines at Paducah, Ky., and the other branch extending southwestward to Memphis. Numerous branch lines serve the tributary territory. The Tennessee Central Railway passes westward through the bituminous coal fields of the Cumberland Mountains to Nashville and thence follows the Cumberland River northwestward through Clarksville to the terminus of the railway at Hopkinsville, Ky. A small amount of local waterborne traffic follows the Cumberland River.

A well-graded, hard-surfaced highway connects Knoxville and Memphis, by way of Nashville, and crosses the area from southeast to west. In addition, a net of excellent State highways links the major towns and cities and is being woven ever closer.

NATURAL RESOURCES AND INDUSTRIES

North-central Tennessee is primarily an agricultural region, the fertile residual soils of the Highland Rim plateau being especially productive of tobacco, corn, and other crops. Over much of the central basin, however, the soil is thin and stony and is used for stock pastures or remains untilled. The untillable land is wooded in considerable part and yields large cuttings of cedar from the central basin, also of oak and other hard woods from the steep slopes of the Highland Rim escarpment and of the major stream valleys.

Mineral resources are not lacking in this region. Deposits of rock phosphate are worked at several localities in the central basin. Portland cement is manufactured in moderate amount at Nashville. Limestone for road metal, lime, and other products is quarried at many localities in the central basin and in the valleys that trench the Highland Rim plateau. Local facies of the Chattanooga shale are a possible raw material for bituminous paint. Deposits of brown iron ore in the western portion of the Highland Rim plateau have been worked during periods of favorable prices; those which fall within the region covered by this report are situated in Stewart, Montgomery, and Dickson Counties. Possible petroliferous areas exist at several localities in the western part of the Highland Rim plateau, although none produce commercially at present. A full discussion of these mineral resources is not pertinent in this paper.

Hydroelectric power is developed at several points along the Highland Rim and Cumberland Plateau escarpments immediately east of the area under consideration and is transmitted to the central basin. Potential power sites both within and near the region constitute an ample reserve for future development and for any likely industrial expansion.

CLIMATE

GENERAL FEATURES [16]

Climatic data are first recorded in Tennessee in 1834, although a well-coordinated system of observations did not exist for nearly half a century thereafter. In 1883 a State weather service was established under the direction of the United States Signal Service. In July, 1891, this work was transferred to the United States Weather Bureau and has since been continued in a more comprehensive manner under the uniform procedure of that organization.

North-central Tennessee, having a mean latitude of 36°, has a relatively mild climate, although its inland position and diverse physiography lend some rigor to its winters. However, it is not traversed by any of the principal transcontinental storm tracks, so that the climatic changes are neither highly frequent nor sudden. In general, the climate ranges from mild to temperate. The rainfall is abundant for the needs of agriculture but not excessive. The humidity is moderate, and the distribution of sunshine and cloudiness is desirable. The ground is rarely covered with snow for more than a few days at a time, and the period that is free from killing frosts is relatively long.

TEMPERATURE

The average mean annual temperature is fairly uniform throughout the region covered by this investigation and ranges from 58° F. at Clarksville to 59.7° F. at Johnsonville. In the valley of the Tennessee River, to the south and west, however, the mean annual temperature is higher, being 60.6° F. at Savannah, in Hardin County. To the east of the region, on the Cumberland Plateau, it is markedly lower, as at Crossville, Cumberland County, which has an average mean annual temperature of 55.4° F. The approximate geographic variation in average mean annual temperature is also shown by the isothermal map forming Figure 1.

[16] Adapted from Nunn, Roscoe, The climate of Tennessee: Resources of Tennessee, vol. 8, No. 1, pp. 7-45, Tennessee Geol. Survey, 1918.

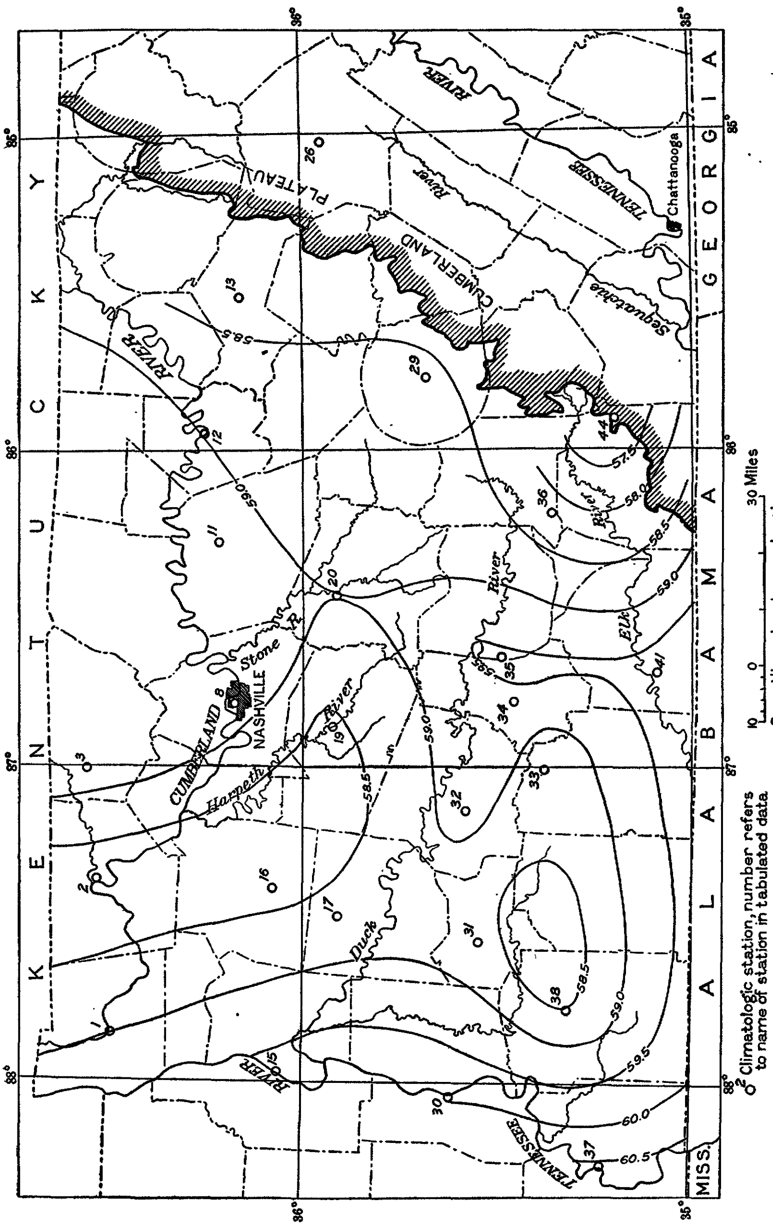

FIGURE 1.—Map of central Tennessee showing approximate variation in average mean annual temperature

The annual range between average monthly mean maximum and average monthly mean minimum temperature is about 40° F., from 37°–41° in January to 76°–79° in July at the several climatologic stations. The absolute range in temperature is much greater, however, the highest recorded temperature being 112° for the month of September at Clarksville and the lowest being 23° below zero during February at Johnsonville. For north-central Tennessee as a whole, therefore, the absolute recorded range of temperature is 135°, although it does not exceed 131° for any one climatologic station and is rarely more than 100° during any one year. At Nashville, for example, temperatures of 100° or higher have been registerd only for 13 out of 57 years, and temperatures of 0° or lower are similarly infrequent. It is noteworthy that although the average monthly mean minimum temperature occurs in January and the mean maximum during July, the absolute minimum and maximum have been recorded during February and September, respectively, at all stations. The published temperature data are summarized in the following tables, and the essential features of local and seasonal variations of temperature are also shown by Figure 2.

Average mean monthly and annual temperature at 25 stations in central Tennessee

[From publications of U. S. Weather Bureau]

No. on Figure 1	Length of record (years)	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
32	55	Ashwood	39.7	41.7	50.5	58.7	67.3	75.2	77.9	77.2	71.1	60.0	49.1	41.3	59.1
12	44	Carthage	38.8	40.9	50.1	59.1	67.3	75.3	77.7	77.1	72.1	60.1	48.9	40.5	59.0
3	30	Cedar Hill	38.4	39.2	50.1	58.8	67.5	76.4	79.1	78.3	73.0	60.8	49.4	40.0	59.3
2	64	Clarksville	37.0	39.5	48.5	58.3	66.3	74.4	77.9	76.4	70.7	58.5	47.5	39.7	58.0
41	32	Coldwater	40.7	41.4	51.5	59.1	68.0	75.5	77.9	77.0	72.6	61.2	50.2	41.5	59.7
13	13	Cookeville	39.2	41.6	49.2	58.6	65.6	73.8	76.0	75.1	70.5	59.6	48.7	41.4	58.3
26	16	Crossville (near)	37.5	38.7	45.8	56.4	63.0	70.8	71.0	72.0	67.6	56.7	45.6	38.4	55.4
16	35	Dickson	38.6	39.5	49.9	58.4	66.4	74.3	77.5	76.8	71.5	60.2	48.7	39.2	58.4
1	35	Dover	39.1	39.9	50.4	59.1	67.1	75.2	78.3	77.6	72.4	60.1	48.8	39.9	59.0
20	45	Florence	39.2	41.2	49.9	59.0	67.2	75.3	77.5	76.7	71.6	59.8	48.9	41.0	59.0
19	48	Franklin	38.3	40.0	49.9	58.3	66.4	74.7	77.3	76.5	71.6	59.4	48.1	40.3	58.4
31	41	Hohenwald	39.4	40.5	50.3	59.1	66.5	74.2	76.9	76.2	71.0	59.1	48.9	40.7	58.6
15	32	Johnsonville	39.8	40.8	51.5	59.7	68.0	75.9	78.8	78.2	72.7	60.6	49.4	40.5	59.7
11	19	Lebanon (near)	40.3	42.1	50.3	60.0	68.2	75.2	78.3	77.5	72.6	62.2	50.0	40.8	59.4
34	34	Lewisburg	40.5	41.4	51.0	58.5	67.2	75.7	78.2	77.6	72.1	60.8	49.3	41.2	59.4
33	39	Lynnville	39.2	41.0	49.9	58.5	66.5	75.1	77.3	77.1	71.3	59.7	48.8	42.5	58.7
29	47	McMinnville	39.9	41.9	50.7	58.5	66.8	74.5	76.9	76.2	70.9	59.5	48.7	41.2	58.8
8	57	Nashville	38.6	41.6	49.2	59.0	68.2	75.6	79.1	77.8	71.8	61.0	49.0	41.0	59.3
35	38	Palmetto	40.1	41.2	51.0	59.1	67.5	75.4	78.1	77.5	72.6	61.5	49.9	41.2	59.6
30	32	Perryville	40.1	41.0	51.9	59.4	68.1	76.0	79.1	78.5	72.1	60.5	50.2	40.7	59.9
17	20	Pinewood	40.3	41.2	49.2	59.0	66.3	74.5	77.5	76.3	71.6	59.4	48.4	39.8	58.6
37	41	Savannah	41.0	43.0	52.2	60.8	68.7	76.3	79.1	78.7	73.0	61.2	50.5	42.6	60.6
44	34	Sewanee	38.8	38.6	48.7	56.5	65.0	72.2	74.8	74.3	69.7	59.3	47.9	39.4	57.0
36	39	Tullahoma	39.0	40.3	49.9	58.1	66.0	73.5	76.5	75.7	70.6	58.8	47.7	40.6	58.1
38	43	Waynesboro	39.7	41.3	50.2	58.4	66.2	74.2	76.8	76.0	70.8	59.0	48.6	40.9	58.5

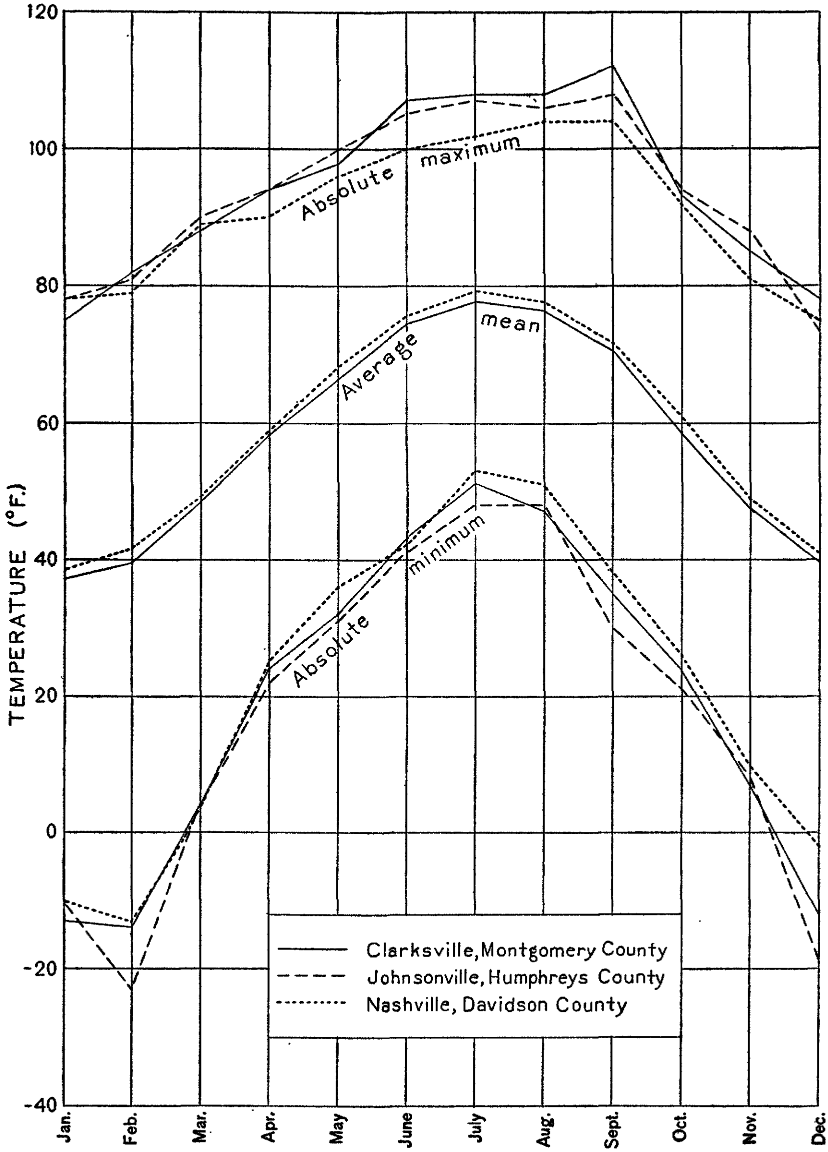

FIGURE 2.—Average mean monthly temperature and extremes of monthly temperature in north-central Tennessee

Extreme monthly and annual temperature at four stations in north-central Tennessee

[From publications of U. S. Weather Bureau]

No. on Figure 1	Length of record (years)	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
		Absolute maximum													
2	38	Clarksville	75	82	88	94	98	107	108	108	112	93	85	78	112
20	44	Florence	74	76	86	91	94	100	102	104	107	93	81	77	107
15	34	Johnsonville	78	81	90	94	100	105	107	106	108	94	88	73	108
8	57	Nashville	78	79	89	90	96	100	102	104	104	92	81	75	104
		Absolute minimum													
2	38	Clarksville	−13	−14	4	24	32	43	51	47	35	24	7	−12	−14
20	44	Florence	−10	−16	3	20	33	42	47	49	35	24	9	− 5	−16
15	34	Johnsonville	−13	−23	4	22	31	41	48	48	30	21	8	−19	−23
8	57	Nashville	−10	−13	3	25	36	42	53	51	38	26	10	− 2	−13

In the 12 counties covered by this report the average frost-free period or growing season ranges from 189 days at Dover to 210 days at Nashville. The shortest recorded frost-free period within the region is 158 days and the longest 261 days. These relations are portrayed by the following table:

Frost data for nine stations in north-central Tennessee

[From publications of U. S. Weather Bureau]

No. on Figure 1	Length of record (years)	Station	Date of last killing frost in spring		Date of first killing frost in autumn		Length of frost-free period (days)		
			Latest recorded	Average	Average	Earliest recorded	Maximum recorded	Average	Minimum recorded
3	24	Cedar Hill	Apr. 26	Apr. 12	Oct. 24	Oct. 9	215	196	171
2	36	Clarksville	May 1	Apr. 4	Oct. 24	Oct. 1	246	202	171
16	27	Dickson	May 2	Apr. 12	Oct. 21	Oct. 2	217	191	163
1	29	Dover	May 2	Apr. 13	Oct. 20	Sept. 27	212	189	164
20	36	Florence	Apr. 26	Apr. 7	Oct. 23	Oct. 1	230	200	174
19	36	Franklin	Apr. 27	Apr. 6	Oct. 25	Oct. 1	249	202	180
15	32	Johnsonville	May 2	Apr. 8	Oct. 22	Sept. 22	227	196	158
11	19	Lebanon	Apr. 26	Apr. 8	Oct. 23	Oct. 9	245	198	177
8	57	Nashville	Apr. 24	Mar. 31	Oct. 30	Oct. 8	261	210	175

Farther east, on the elevated Cumberland Plateau, the frost-free period is somewhat shorter, the average being 170 days at Erasmus, Cumberland County. At several stations on the Cumberland Plateau, however, the average frost-free period is just as long as in the lower country farther west.

RAINFALL

The average annual rainfall in central Tennessee ranges between 48 and 56 inches. It is least in the Nashville Basin and on the lowest part of the Highland Rim plateau, in Stewart and Montgomery Counties and increases irregularly toward the south and east. This normal variation of rainfall is brought out by the accompanying sketch map (fig. 3) and by the table of average rainfall at 45 climatologic stations.

Average monthly and annual rainfall at 45 stations in central Tennessee

[Data from publications of U. S. Weather Bureau]

No. on Figure 3	Station	County	Altitude (feet)	Duration of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Remarks
7	Ashland City (near).	Cheatham		1925–1927	4.56	2.87	5.14	2.70	1.66	1.41	2.08	9.28	1.03	5.71	4.65	7.19	52.11	Record complete for 1926 only; average not reliable.
32	Ashwood	Maury	725	1873–1927	5.06	4.47	5.36	4.74	4.13	3.96	4.27	4.09	3.38	2.77	3.61	4.22	50.06	Record incomplete for 2 years.
6	Byrdstown	Pickett	1,026	1892–1920	4.96	4.15	5.42	4.57	4.25	4.65	5.49	4.39	3.26	3.10	3.79	4.33	52.36	Record incomplete for 3 years.
12	Carthage	Smith	500	1885–1927	4.81	4.30	5.35	4.40	4.00	4.46	4.53	4.29	3.16	2.83	3.71	4.17	50.01	Record incomplete for 4 years.
3	Cedar Hill	Robertson	625	1897–1927	5.35	4.04	5.37	4.92	4.67	4.14	4.17	3.76	3.33	2.91	3.95	5.04	51.65	Record incomplete for 6 years.
5	Celina	Clay	560	1903–1927	5.37	3.82	5.27	4.47	4.50	4.12	4.77	4.47	3.72	3.44	3.25	4.74	51.94	Record incomplete for 1 year.
2	Clarksville	Montgomery	500	{1854–1883 {1888–1927	4.51	4.12	5.10	4.70	4.20	4.01	3.82	3.38	2.92	2.57	4.00	4.68	48.01	Prior to 1883 station located about 3 miles south of Clarksville and known as Glenwood Cottage; record incomplete for 8 years. Subsequent to 1888 record incomplete for 1 year.
41	Coldwater	Lincoln	624	1921–1927	5.17	4.72	6.18	4.78	4.34	4.03	4.58	4.29	3.04	2.97	3.57	5.40	53.07	
13	Cookeville	Putnam	1,117	1914–1927	6.76	3.95	5.67	4.91	4.53	4.31	4.77	4.61	3.20	4.40	3.85	4.77	55.73	Record incomplete for 2 years.
26	Crossville (near)	Cumberland	1,820	1912–1927	6.06	4.16	6.05	5.07	4.41	4.72	5.40	5.26	3.34	3.64	3.00	5.01	56.12	Do.
16	Dickson	Dickson	825	1896–1927	5.25	4.06	5.30	4.85	4.43	3.85	3.99	3.62	2.72	2.55	3.77	4.54	48.93	Record incomplete for 11 years.
1	Dover	Stewart	500	1898–1927	5.21	3.76	4.96	4.41	4.11	3.68	3.21	3.83	3.15	3.12	4.04	4.64	48.12	Record incomplete for 7 years.
25	Erasmus	Cumberland	1,695	1897–1919	5.85	4.60	6.72	5.55	4.37	5.55	6.07	5.00	3.73	3.46	3.48	5.38	59.76	Record incomplete for 5 years.
43	Fayetteville	Lincoln		1926–1927	3.08	3.39	4.70	3.95	3.78	5.24	1.88	8.95	0.33	2.44	5.77	9.23	52.75	Record for 2 years only; average not reliable.
20	Florence	Rutherford	560	1882–1927	4.77	4.30	5.36	4.45	3.99	3.84	4.40	3.80	3.22	2.67	3.47	4.23	48.50	Record incomplete for 2 years.
19	Franklin	Williamson	730	1890–1927	4.76	4.17	5.44	4.91	3.93	4.06	3.83	3.60	3.07	2.52	3.57	4.68	48.54	Record incomplete for 3 years.
23	Grace	White	920	1897–1905	4.97	4.73	6.61	4.60	4.21	6.75	5.67	6.23	2.75	2.64	4.19	4.71	58.06	Record incomplete for 4 years.
21	Halls Hill	Rutherford	610	1903–1927	4.81	4.03	5.22	4.59	4.26	4.75	5.02	4.10	3.11	3.16	3.33	4.54	50.92	
31	Hohenwald	Lewis	983	1883–1927	5.23	4.75	6.20	5.10	4.47	4.57	4.62	4.35	3.01	2.67	3.98	5.44	54.39	Do.
39	Iron City	Lawrence	600	1895–1916	5.04	4.95	6.40	4.96	4.30	4.38	4.41	4.36	3.61	2.47	3.27	5.81	53.96	Record incomplete for 6 years. Station located at St. Joseph, 5 miles northeast of Iron City, from December, 1895, to March, 1899.
15	Johnsonville	Humphreys	364	1883–1927	4.90	4.14	4.88	4.78	4.27	4.03	4.31	3.95	3.51	2.66	4.10	4.49	50.02	Record incomplete for 3 years.
4	Lafayette	Macon	1,000	1898–1909	5.05	3.17	6.46	4.16	3.67	4.25	4.07	3.75	4.36	2.64	3.95	3.94	49.47	Record incomplete for 6 years.
11	Lebanon (near)	Wilson	522	1902–1927	4.98	3.44	5.10	4.99	4.80	5.11	4.56	4.73	3.12	3.35	3.78	4.45	52.38	Record incomplete for 8 years.
34	Lewisburg	Marshall	727	1888–1927	5.09	4.67	5.91	4.56	4.13	4.08	4.47	4.73	3.22	3.05	3.22	4.97	52.10	Record incomplete for 4 years.
32	Liberty	De Kalb	672	1872–1927	5.42	4.52	5.90	4.60	3.92	4.50	5.02	4.49	2.96	3.16	3.71	4.17	52.37	Record lacking for 1877–1882, 1885–1895, and 1903–1912; record incomplete for 13 years.
40	Loretto	Lawrence	774	1916–1923	5.25	4.42	7.82	6.31	5.08	4.14	3.62	4.39	2.83	4.28	3.62	4.64	55.29	Record incomplete for 3 years.
33	Lynnville	Giles	744	1883–1927	5.01	5.10	5.78	4.74	4.42	4.46	5.28	4.19	3.41	2.94	3.40	4.91	53.95	Record incomplete for 7 years.

9	Madison	Davidson	500	1923–1927	4.54	3.85	5.45	4.21	5.02	3.83	3.14	4.45	2.80	3.29	3.94	6.19	50.71	
29	McMinnville	Warren	1,038	1872–1927	5.05	4.07	5.62	5.03	3.85	4.46	5.20	4.03	3.35	2.93	3.42	4.71	51.72	Record lacking for 1882, 1887–88, 1890, 1893; record incomplete for 10 years.
8	Nashville	Davidson	654	1839–1927	4.85	4.32	5.44	4.36	3.50	4.37	4.35	3.47	3.68	2.48	3.85	3.82	48.49	Record lacking for 1846–1849 and 1851–1870; record incomplete for 2 years.
18	Nunnelly	Hickman	620	1887–1905	4.35	4.07	6.26	4.37	3.86	4.22	3.60	4.04	3.37	1.92	3.85	4.46	48.37	Record incomplete for 5 years.
14	Oak Hill	Overton	1,000	1897–1903	5.26	6.45	7.72	5.97	3.57	5.82	5.83	4.48	3.14	3.44	4.82	4.27	60.77	Record complete for 3 years only.
35	Palmetto	Bedford	770	1883–1927	5.08	4.41	5.54	4.57	4.37	4.31	5.04	3.91	3.30	3.01	3.03	4.87	51.44	Record lacking for 1886–1892; record incomplete for 3 years.
30	Perryville	Decatur	377	1896–1927	5.09	4.01	6.06	4.64	4.08	3.93	3.91	3.53	2.89	3.04	3.99	5.00	50.17	Record incomplete for 8 years.
17	Pinewood	Hickman	520	1906–1926	6.10	3.65	4.80	5.33	4.70	3.56	3.98	4.02	2.82	2.78	3.35	5.20	49.41	Record incomplete for 9 years.
28	Rock Island	Warren	700	1927	5.11	4.03	5.61	4.74	4.59	5.07	5.59	4.33	4.03	3.28	3.02	4.67	54.07	Station at Walling until Jan. 31, 1927.
37	Savannah	Hardin	442	1883–1927	4.94	4.60	5.66	4.79	4.30	4.38	4.43	3.55	3.13	2.59	3.73	4.99	51.09	Record incomplete for 1 year.
44	Sewanee	Franklin	1,950	{1860–1861, 1895–1927}	5.22	4.64	5.87	4.85	4.23	4.95	5.31	4.96	3.05	3.25	3.60	4.83	54.76	Record incomplete for 4 years.
24	Sparta	White	920	1906–1922	4.98	3.15	4.84	4.16	4.10	5.03	6.07	4.21	3.95	2.97	2.90	4.69	51.05	Record incomplete for 6 years.
45	Tracy City	Grundy	1,900	1897–1909	4.53	5.09	5.82	5.05	3.72	4.56	4.98	5.06	3.32	3.22	3.50	6.18	55.03	Record incomplete for 4 years.
36	Tullahoma	Coffee	1,075	1883–1927	5.37	4.62	6.04	4.96	4.01	4.29	5.06	4.15	3.20	2.94	3.49	5.54	53.67	Record lacking for 1888 and 1890–1892; record incomplete for 5 years.
27	Walling	White	909	1904–1926	5.11	4.03	5.61	4.74	4.59	5.07	5.59	4.33	4.03	3.28	3.02	4.67	54.07	Record incomplete for 1 year. Station transferred to Rock Island, Warren County, Feb. 1, 1927.
38	Waynesboro	Wayne	753	1884–1927	4.85	4.45	5.71	5.02	4.30	4.24	4.62	4.42	3.14	2.59	3.60	5.00	51.94	Record incomplete for 1 year.
10	Worsham	Sumner	550	1902–1927	4.93	3.85	5.21	4.50	4.45	3.74	4.09	3.86	3.15	2.89	3.49	4.89	49.05	Record incomplete for 3 years.
42	Yukon	Lincoln	850	1896–1920	5.27	4.72	6.27	4.64	4.29	4.06	4.82	4.25	3.30	3.00	3.65	5.42	53.69	Record incomplete for 5 years. Station transferred to Coldwater, 4 miles west of Yukon, in 1921.

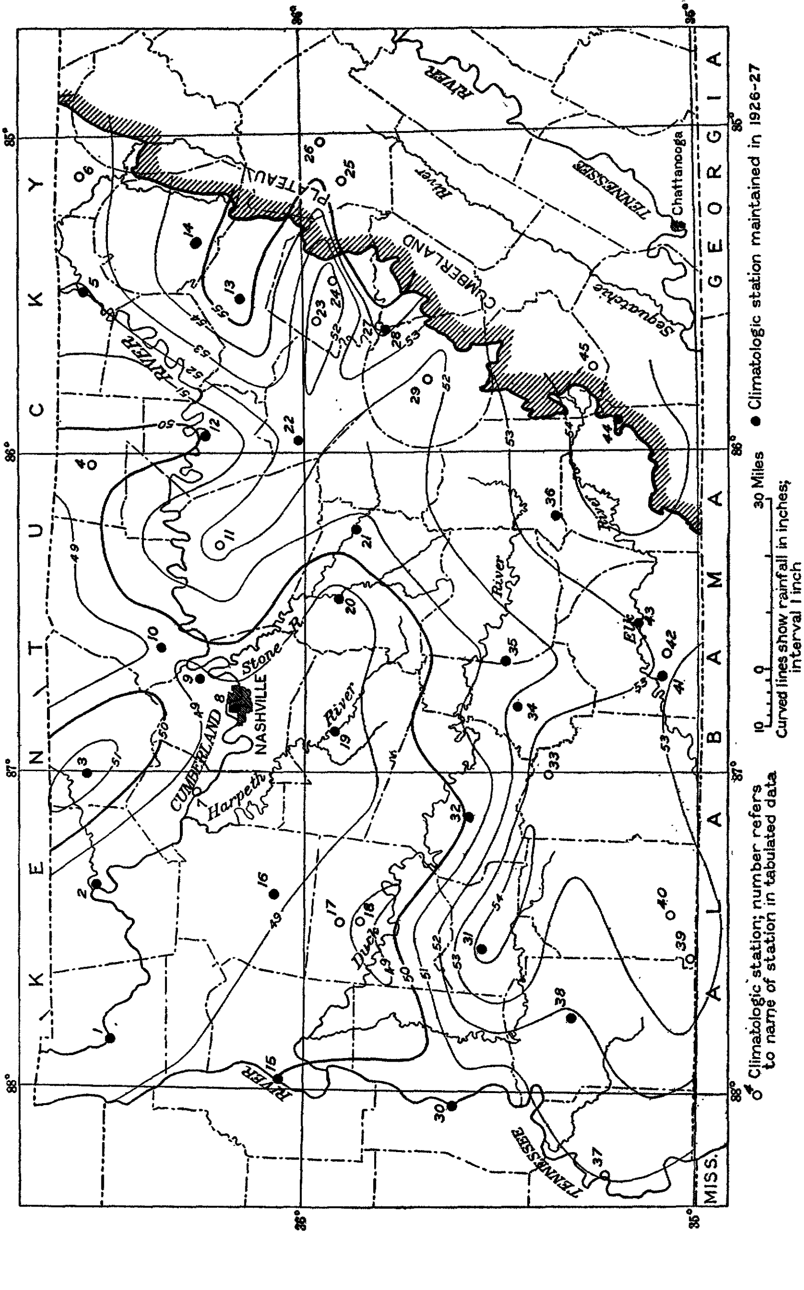

FIGURE 3.—Map of central Tennessee showing approximate variations in normal rainfall

In general there is some accordance between rainfall and surface contour, the major stream valleys receiving the least rainfall and the higher portions of the area the most. Minor topographic features may exert a pronounced local influence upon the rainfall, however, so that this relation does not persist in detail. Moreover, the rainfall during any year may differ greatly from the average and may not conform to the topography in any but the most general way. At Clarksville, for example, the greatest annual rainfall during the 61 years of record is 154 per cent of the average, and the least annual rainfall is 70 per cent of the average. The annual rainfall has been greater than the average 33 times, or 54 per cent of the period of record, and less than the average 28 times, or 46 per cent of the period. Variations of a similar order of magnitude occur at the other climatologic stations, though none of the records is as long as that for Clarksville. (See fig. 4.)

As is characteristic of a humid region, the seasonal variation in rainfall, though distinct, is small. This is brought out by the preceding table of average monthly and annual rainfall at 45 stations. The greatest average monthly rainfall comes in March and the least in October, although in a given year the maximum may occur in any of the winter months. Ample rain usually falls during the crop-forming period of the spring and early summer. At Nashville, for example, the normal monthly maximum is 5.44 inches, in March, and the minimum is 2.48 inches, in October. The extreme range is much wider, however, the greatest recorded monthly rainfall being 14.51 inches in January, 1882, and the least 0.10 inch in October, 1839.

For the year as a whole a measurable amount of rain falls on one day of every three or four, as is shown by the following table:

Average number of days with 0.01 inch or more rainfall at 4 stations in north-central Tennessee

[Data from publications of U. S. Weather Bureau for the period prior to and including 1920]

No. on Figure 3	Length of record (years)	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	29	Clarksville	10	10	11	11	10	9	8	8	6	6	7	10	106
20	37	Florence	10	9	10	9	9	9	10	8	6	6	7	6	99
15	26	Johnsonville	11	10	11	10	10	10	10	9	7	6	8	10	112
8	50	Nashville	12	11	12	11	10	11	11	9	8	7	9	11	122

However, many rainy periods of two or three days' duration occur and are followed by as much as 10 to 15 days of clear weather. Moreover, many of the days that are classified as rainy are clear for most of the time. On the other hand, heavy downpours lasting a few hours may occur at any season of the year, and the rainfall during a single

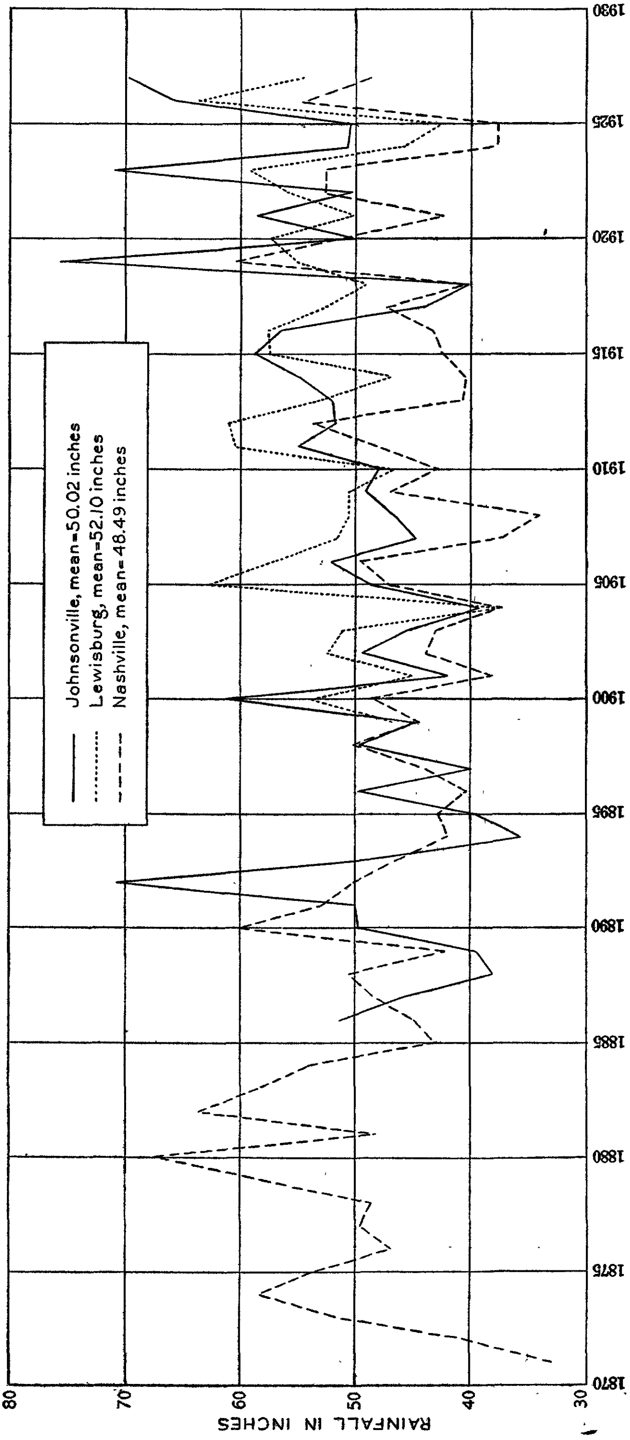

FIGURE 4.—Variations in annual rainfall at stations in central Tennessee

24-hour period may constitute most of the rainfall for the entire month. Some of these special features of the rate of rainfall are shown by the following table.

Maximum rate of rainfall at Nashville

No. 8, fig. 3. Data from publications of the U. S. Weather Bureau for the period prior to and including 1920]

Length of record (years)	Period	January	February	March	April	May	June	July	August	September	October	November	December	Annual
25	5 minutes	0.44	0.44	0.43	0.43	0.56	0.50	0.52	0.54	0.75	0.41	0.56	0.33	0.75
25	10 minutes	.62	.67	.53	.72	.71	.79	.83	.90	1.08	.56	1.02	.53	1.08
18	15 minutes	.67	.72	.59	1.02	.94	1.08	1.07	.98	1.18	.58	1.26	.78	1.26
18	30 minutes	.95	.97	1.05	1.64	1.43	1.71	1.47	1.18	1.51	.63	1.35	1.02	1.71
25	1 hour	1.23	1.06	1.23	2.09	1.56	1.94	1.83	1.78	1.84	0.91	1.81	1.12	2.09
18	2 hours	1.65	1.18	1.39	2.32	1.85	2.56	2.81	2.34	2.66	1.31	2.97	1.68	2.97
50	24 hours	3.51	5.25	4.53	5.04	2.82	4.39	5.09	5.65	4.93	2.50	6.05	4.10	6.05

The average annual number of days with appreciable snowfall, say 0.5 inch or more, is four. Falls of 2.0 inches or more occur only once or twice a year on the average.

SURFACE FEATURES OF CENTRAL TENNESSEE

PHYSIOGRAPHIC DISTRICTS

GENERAL FEATURES

The State of Tennessee presents a great diversity of surface forms, which for convenience of study and description are usually subdivided [17] into five physiographic provinces and eight sections. (See pl. 1.) From east to west these are the southern section of the Blue Ridge province, known locally as the Unaka Mountains; the Tennessee section of the Valley and Ridge province, known locally as the Valley of East Tennessee and properly including the Sequatchie Valley; the Cumberland Plateau and Cumberland Mountain sections of the Appalachian Plateaus province; the Highland Rim and Nashville Basin sections of the Interior Low Plateaus province; and the East Gulf Coastal Plain and Mississippi Alluvial Plain sections of the Coastal Plain province. The region covered by this investigation embraces the north half of the Nashville Basin and the northwest quadrant of the Highland Rim plateau.

With the exception of the Mississippi Alluvial Plain, the physiographic districts of Tennessee are the end products of successive erosion cycles acting upon rocks of different resistance and of diverse geologic structure, which have been uplifted several times. Each district is characterized by a distinct relative altitude and land form, which reflects its response to these geologic conditions and processes.

[17] Fenneman, N. M., Physiographic divisions of the United States: Assoc. Am. Geographers Annals vol. 18, No. 4, pp. 261-353, map, 1928.

Thus, the Unaka Mountains, being composed largely of dense crystalline rocks, have persisted through relatively long periods with high relief and rugged contour. On the other hand, the alternation of hard and soft and of soluble and insoluble beds in the faulted and closely folded rocks of the Valley of East Tennessee has facilitated erosion. Consequently this district has a low average altitude, although it is characterized by alternating valleys and ridges of moderate relief and mature contour, which reflect faithfully the geologic structure of the underlying rocks. Furthermore, the massive and very slightly deformed Pennsylvanian sandstones on which the Cumberland or "Cretaceous" peneplain was cut, although raised to relatively high altitude by subsequent uplift, have resisted erosion so that extensive remnants of the peneplain have been preserved virtually undissected. These remnants constitute the Cumberland Plateau. The underlying Mississippian limestones, however, offered much less resistance to mechanical and chemical denudation and, wherever the protective cover of Pennsylvanian rocks was breached, were reduced quickly to the profile of erosive equilibrium. The surface thus formed, an erosion terrace of very slight relief from 700 to 850 feet below the Cumberland peneplain, is the present Highland Rim plateau. After renewed upwarping, mechanical and chemical denudation trenched the Highland Rim plateau and cut another terrace—the Nashville Basin—on the Ordovician limestones in the central part of the State. This erosion terrace is between 200 and 600 feet below the Highland Rim plateau. These featureless terraces cut on the flat-lying limestones of the Interior Low Plateaus province contrast sharply with the diverse land forms on the poorly consolidated sand, clay, and silt that compose the Gulf Coastal Plain. Although the Coastal Plain is in general a westward-sloping plain, it ranges from hilly or rolling to gently undulating and reflects the differences in resistance of the rocks that immediately underlie its surface. As a result of their characteristic land forms, rock formations, and geologic structure, these physiographic districts have more or less distinct modes of ground-water occurrence. The modes that prevail in the Nashville Basin and the northern part of the Highland Rim plateau are brought out in the body of this report.

The Mississippi Alluvial Plain, unlike the other major physiographic divisions of the State, is a constructional stream plain that has not suffered general attack by destructive agencies.

HIGHLAND RIM PLATEAU

The interstream tracts of the Highland Rim plateau define a very slightly undulating plain (see pl. 2, *A*), which entirely surrounds the Nashville Basin and constitutes about 65 per cent of the region covered by this survey. (See pl. 1.) Formerly, however, it extended over the entire central portion of the State, from the Cumberland escarpment on the east almost to the Tennessee River on the west. It extends northward beyond the limits of this survey entirely across Kentucky and coincides with the Lexington Plain of that State. Southward it extends into Alabama, where it comes to an indefinite terminus. In Tennessee the plateau attains its maximum altitude, about 1,365 feet above sea level, in an outlying remnant near the southeast corner of Rutherford County, about 1 mile west of the junction of that county with Cannon and Coffee Counties. Thence it descends radially northward and westward, with a nearly uniform gradient. Its altitude in northeastern Sumner County is about 950 feet above sea level, in northwestern Stewart County about 575 feet, and in west-central Humphreys County about 725 feet. Hayes and Campbell [18] have likened the contour of the restored plain to that of an inverted spoon whose major axis trends N. 40°–60° E. and passes through the city of McMinnville, about 25 miles east of Rutherford County.

The interstream tracts of the plateau are veined by ephemeral drainageways which have very flat longitudinal and transverse profiles and usually show a local relief of less than 50 feet. At some localities bowl-shaped or spoon-shaped depressions without surface drainage dot the otherwise featureless plain. (See pl. 2, *B*.) The largest of these depressions or "sinks" are as much as a mile in diameter and 40 feet deep. They are most numerous in the tracts that lie between two converging major streamways, in the vicinity of the point of confluence.

The northern part of the plateau is trenched to a depth of 250 to 600 feet in two well-defined stages by the Cumberland River, whose ingrown meanders [19] swing laterally between 2 and 7 miles. Its larger tributaries also meander, and all occupy deep and narrow valleys which steepen abruptly at their heads. Along its common boundary with the Nashville Basin the plateau is deeply trenched by many subparallel drains several miles long and disintegrates into a maze of flat-topped linear ridges and outliers, as well as remnants that have been somewhat reduced by erosion. Hence the so-called Highland Rim escarpment, which separates plateau and basin, is by no means a linear feature. Its position as plotted on Plate 1 is generalized to delineate that area which is more the dissected plateau from the typical basin and is drawn tangent to the prominent headlands of the plateau. Outstanding among the outlying remnants of the plateau is the chain of hills that extends across southern Rutherford County

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[18] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, pl. 6, 1894.

[19] Meanders that are formed or accentuated by lateral shift coincident with downcutting. For original definition see Rich, J. L., Certain types of stream valleys and their meaning: Jour. Geology, vol. 22, p. 470, 1914.

and merges with Duck River Ridge in southwestern Williamson County.

NASHVILLE BASIN

The Nashville Basin is an elliptical depression in the Highland Rim plateau whose major diameter trends N. 30° E. through the approximate geographic center of the State. (See pl. 1.) The interstream tracts of its floor constitute a very slightly undulating plain about 80 miles long and 45 miles wide, the northern segment of which slopes northward and westward from an altitude of 700 feet above sea level in southern Rutherford County to 650 feet in the vicinity of Franklin and Columbia and 550 feet near Nashville. Hence the Nashville Basin is 200 to 600 feet below the surrounding Highland Rim plateau. The lower reaches of its drainageways—the Cumberland and Duck Rivers and their tributaries—are intrenched about 100 to 150 feet, so that the northwestern lobe of the plain is rolling and comprises many rounded steep-sided hills. Moreover, numerous isolated hills or monadnocks—erosion remnants of the higher plateau—are scattered over the floor of the basin along the Highland Rim escarpment. Hence this physiographic unit displays some diversity in detail of land forms.

The Nashville Basin is entirely surrounded by the Highland Rim escarpment, which is breached only by four narrow water gaps. These are the inlet and outlet of the Cumberland River, the one stream that traverses the basin, and the outlets of the Duck and Elk Rivers, which head upon the basin's floor. On the west, north, and east this bounding escarpment is well defined, although intricately serrate in plan. On the south, however, it is rather indefinite, and the open basin passes into a rolling terrane which is a dissected plateau.

The outline of the Nashville Basin traced on Plate 1 incloses that area in which stream erosion has proceeded well beyond the stage of maturity and which, if isolated monadnocks are disregarded, is approaching complete planation. About 35 per cent of the area covered by the investigation falls within the basin as thus defined.

PHYSIOGRAPHIC HISTORY

CUMBERLAND CYCLE

Hayes and Campbell [20] have concluded that the final stage in the formation of the regional peneplain of which the present Cumberland Plateau is a remnant was contemporaneous with the deposition of the calcareous Selma formation (middle and late Upper Cretaceous). They have also concluded that the peneplain was formed at or near sea level and that it was warped and uplifted at the beginning of the Ripley epoch (late Upper Cretaceous). Its present remnants in cen-

[20] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, pp. 124-126, 1894.

tral and western Tennessee as they have reconstructed the surface are from 2,200 to 1,000 feet above sea level.[21] The highest remnants occur along two intersecting axes of uplift which trend N. 20° E. near Chattanooga and N. 40°–60° E. near McMinnville. The lowest remnants are near the western limb of the Tennessee River. (See pl. 1.)

Shaw,[22] on the other hand, has expressed a belief that all peneplains of which remnants exist to-day in the Appalachian Plateaus province are younger than the floor on which the Cretaceous rests and younger than the unconformity at the top of the Cretaceous. He implies that the Cumberland peneplain is probably not older than mid-Tertiary.

HIGHLAND RIM CYCLE

The gently undulating plain that is defined by the interstream tracts of the Highland Rim plateau and formerly extended entirely across the Nashville Basin is clearly a product of subaerial erosion, inasmuch as it bevels warped Mississippian limestones. It is in fact an extensive terrace or peneplain, formed by the erosion from the former Cumberland Plateau of a wedge-shaped mass of rock whose base, from 700 to 850 feet high, is the Cumberland escarpment and whose apex coincides approximately with the western limb of the Tennessee River. The rock waste produced by this erosion was transported westward by streams and deposited as a series of coastal plain sediments in the northern lobe of the Gulf of Mexico, which at that time extended northward into southern Illinois and eastward within approximately 10 miles of the present site of the Tennessee River.

Hayes and Campbell[23] conclude from the character of the coastal-plain sediments that the beginning of the Highland Rim erosion cycle is represented by the Ripley formation (late Upper Cretaceous) and that planation was essentially complete at the time of deposition of the upper beds of the Vicksburg group (middle and early upper Oligocene[24]). Shaw,[25] however, tentatively correlates the Highland Rim peneplain with the sub-Pliocene or possibly the sub-Miocene unconformity in southern Mississippi. At the culmination of the cycle the peneplain was a featureless surface, probably drained by meandering streams with low gradient and with little capacity for the transportation of land waste. Lusk[26] concludes that the meander belt of the Cumberland River at the culmination of the Highland Rim

[21] Hayes, C. W., and Campbell, M. R., op. cit., pl. 5.

[22] Shaw, E. W., Ages of peneplains of the Appalachian province: Geol. Soc. America Bull., vol. 29, p. 586, 1918.

[23] Hayes, C. W., and Campbell, M. R., op. cit., pp. 124–126.

[24] Cooke, C. W., The correlation of the Vicksburg group: U. S. Geol. Survey Prof. Paper 133, pp. 1–10, 1923. Vaughan, T. W., Criteria and status of correlation and classification of Tertiary deposits: Geol. Soc. America Bull., vol. 35, No. 4, pp. 727–730, 1924.

[25] Shaw, E. W., Pliocene history of northern and central Mississippi: U. S. Geol. Survey Prof. Paper 108, p. 153, 1918.

[26] Lusk, R. G., Gravel on the Highland Rim plateau and terraces in the valley of Cumberland River: Jour. Geology, vol. 36, No. 4, p. 166, 1928.

cycle, for example, was about a mile less than the present swing of the meanders. Evidently this condition of erosional stagnation persisted for a considerable interval, during which the surface was lowered principally by solution of the limestone, and a mantle of residual clay and fragmentary chert, now preserved upon the upland tracts, was accumulated to a thickness of 90 feet or more. Even during the final stages of the planation, however, stream erosion probably continued actively along the Cumberland escarpment, for Lusk[27] notes the occurrence on the Highland Rim plateau near Celina, Clay County, of waterworn gravel whose particles are similar to pebbles of the Pennsylvanian conglomerates exposed in the escarpment. The gravel is presumably stream-borne. Hayes and Ulrich[28] describe deposits of coarse stream gravel on the plateau in the Columbia quadrangle, west of the Nashville Basin, although it is possible that these deposits represent the Tuscaloosa formation (see pp. 31–33), of late Upper Cretaceous age. The Highland Rim erosion cycle was brought to an end by renewed crustal warping and uplift accompanied by rejuvenation of the streams.

NASHVILLE BASIN CYCLE

GENERAL FEATURES

According to Hayes and Campbell[29] the rejuvenation that terminated the Highland Rim cycle was caused by renewed regional uplift and arching of the strata about an axis striking N. 40°–60° E. through McMinnville. At its culmination this crustal activity had elevated the Highland Rim peneplain to its present altitude, although the movement very probably occurred in several stages. Marked recession of the Mexican Gulf resulted. The major streams became intrenched upon the new-born upland but were forced to cut entirely new lower courses in pace with the marine recession. These lower courses were probably controlled chiefly by the form of the warped surface, though it is likely that stream capture and unequal rates of erosion were secondary factors in sculpture of the land surface. Thus the resultant courses of the Tennessee and Cumberland Rivers were established westward and northward away from the direct route to the Gulf.[30]

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27 Lusk, R. G., op. cit., pp. 164–170.

28 Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95), p. 1, 1903.

29 Hayes, C. W., and Campbell, M. R., op. cit., p. 119, pl. 6.

30 Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, pp. 105–120, 1895. Hayes, C. W., Physiography of the Chattanooga district, in Tennessee, Georgia, and Alabama: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pp. 1–58, 1899. Simpson, C. T., The evidence of the Unionidae regarding the former courses of the Tennessee and other southern rivers: Science, new ser., vol. 12, pp. 133–136, 1900. White, C. H., The Appalachian River versus a Tertiary trans-Appalachian river in eastern Tennessee: Jour. Geology, vol. 12, pp. 34–39, 1904. Johnson, D. W., The Tertiary history of the Tennessee River: Jour. Geology, vol. 13, pp. 194–231, 1905. Adams, G. I., The course of the Tennessee River and the physiography of the southern Appalachian region: Jour. Geology, vol. 36, pp. 481–493, 1928.

A drainage system being established, dissection of the upland progressed. The resistant chert of the lower Mississippian was first breached on the apex of the Nashville dome (see pp. 62–63), and the underlying soluble Silurian and Ordovician limestones were attacked by streams planing laterally at the local profile of erosive equilibrium. In this manner the Nashville Basin was formed, its bounding escarpments being maintained by the resistance of the Mississippian rocks.

HIGH-TERRACE STAGE

Galloway [31] notes that waterworn chert and quartzite gravel caps several hills at altitudes of 580 to 700 feet above sea level in the vicinity of Lavergne, Walter Hill, and Lascassas, in northern Rutherford County. He implies that these deposits, which are about 500 feet below near-by portions of the Highland Rim plateau and 100 feet above the floor of the Nashville Basin, indicate a stage of equilibrium in the dissection of the Nashville dome. Lusk [32] describes alluvium-veneered stream terraces at an altitude of about 700 feet in the valley of the Cumberland River near Celina and Gainesboro, to the east of the area covered by this report. Furthermore, flat-topped ridges and terrace remnants at an altitude of 550 to 600 feet in the vicinity of Clarksville seem to define a belt of stream planation several miles wide which follows the lower course of the Cumberland Valley. From this seeming terrace the surface rises by an old-age profile to the Highland Rim plateau, at an altitude of about 700 feet, and descends by precipitous youthful slopes to the present stream. Other related features exist within the region, but in the absence of topographic maps it was impossible to discriminate them during the course of the reconnaissance. These terrace remnants may well be the product of general stream planation. The lithology of the post-Vicksburg strata of the Gulf Coastal Plain does not seem to offer a clue to a precise dating of this high-terrace stage. Galloway [33] has expressed a belief that the cutting of the high terrace began in late Pliocene time, although he gives no basis for his assignment.

PENEPLAIN STAGE

After the conclusion of the high-terrace stage the erosive power of the streams was again quickened, and the soluble Ordovician limestones in the apex of the Nashville dome were reduced locally by lateral planation and solution to the profile of equilibrium of the Cumberland River and its chief tributaries, the Harpeth and Stone Rivers. Farther south the Duck River and the Elk River, tributaries of the Tennessee River, also cut their beds to grade in the Ordovician

[31] Galloway, J. J., Geology and natural resources of Rutherford County, Tenn.: Tennessee Geol. Survey Bull. 22, p. 21, 1919.
[32] Lusk, R. G., op. cit., pp. 167–168.
[33] Galloway, J. J., op. cit., p. 21.

limestones. The gradients of the Duck and Elk seem to have been flatter at the beginning of the peneplain stage, however, so that their erosive power was less, and the planation they accomplished lagged behind that of the more northerly streams. The culmination of this stream work approached peneplanation and carved the Nashville Basin virtually to its present dimensions and topography. Erosive equilibrium seems to have been comparatively short-lived, however, for the Nashville Basin peneplain does not carry a thick mantle of residual soil, like the older Highland Rim plateau.

The Nashville Basin erosion cycle was by no means complete when it was terminated by uplift. The numerous monadnocks along its borders were yet in the youthful or mature stage, and the bounding escarpments were yet receding. Local deposits of gravelly detritus at the bases of these upland remnants, where the stream gradients flatten abruptly, attest the activity of the erosive agencies.

Hayes [34] correlates the Nashville Basin peneplain with the Coosa peneplain of the region about Chattanooga, which he implies is post-middle Tertiary, but does not date precisely. Shaw [35] suggests that the Coosa peneplain may be correlative with the two or three upland plains of northern Mississippi which lie above the Brookhaven terrace. To the Brookhaven terrace Matson [36] and Berry [37] ascribe post-middle Pliocene age. If the physiographic correlations by Hayes and Shaw and the stratigraphic correlations by Matson and Berry are correct, the beginning of the Nashville Basin cycle does not antedate the sub-Miocene unconformity of Mississippi, and the peneplain stage of the cycle is older than middle Pliocene. On the other hand, Galloway [38] states that the peneplain stage of the Nashville Basin cycle began at the end of the Pliocene and was terminated by further warping in middle Pleistocene time, but he does not give the basis of his assignment. Proof of the age of this and other physiographic features of the region can not be obtained in the absence of accurate topographic maps.

RECENT CYCLE

During relatively late geologic time the upwarping of the Nashville dome was resumed and the streams were again rejuvenated. The Tennessee River, which bounds the region on the west, has since deepened its channel at least 75 feet. The Cumberland River has intrenched itself about 100 feet at Nashville and somewhat less

[34] Hayes, C. W., op. cit. (Ninteenth Ann. Rept.), pp. 31, 56, 1899.

[35] Shaw, E. W., Pliocene history of northern and central Mississippi: U. S. Geol. Survey Prof. Paper 108, pp. 139, 153, 1918.

[36] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pp. 188–189, 1917.

[37] Berry, E. W., The flora of the Citronelle formation: Idem, p. 195.

[38] Galloway, J. J., op. cit., pp. 22–23.

upstream. The lower reaches of its major tributaries, the Harpeth and Stone Rivers, have kept pace with the downcutting, although the trenching dies out upstream and the heads of the streams flow on the Nashville Basin peneplain. The meandering portions of the stream courses are now somewhat ingrown, with gravel-veneered slip-off slopes on the inner sides of the meanders, but the linear reaches of the streams have merely deepened their channels without lateral planation. Hence the present erosion cycle is clearly in a very youthful stage.

DRAINAGE SYSTEM

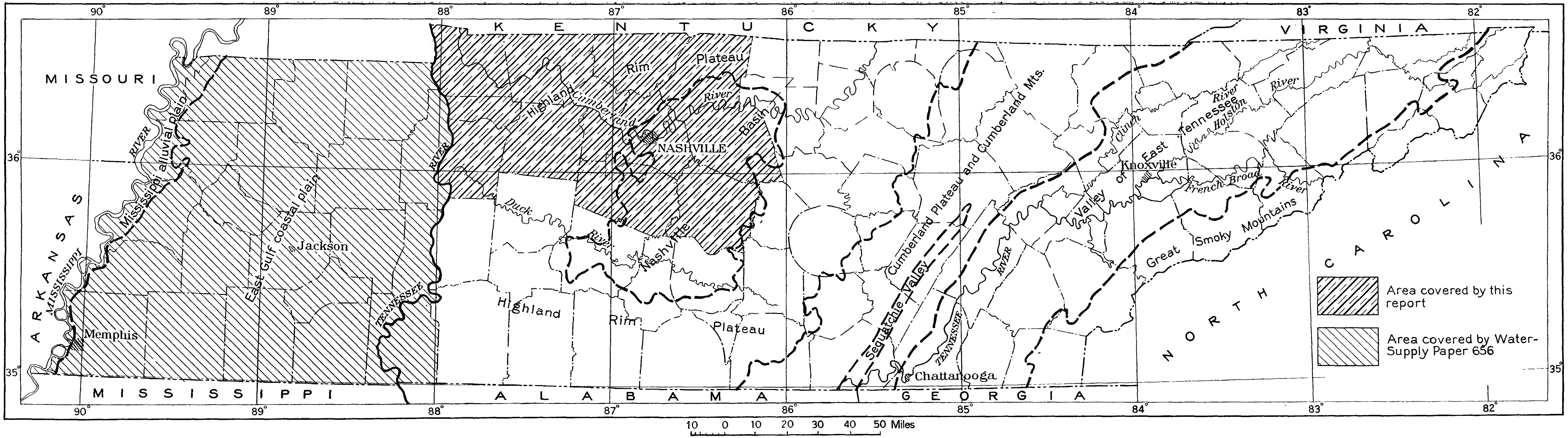
SURFACE STREAMS

The surface waters of north-central Tennessee are all drained into the Gulf of Mexico by way of the Mississippi River. The immediate master streams, however, are the Tennessee, Cumberland, and Green Rivers, tributaries of the Ohio River. (See pl. 3.)

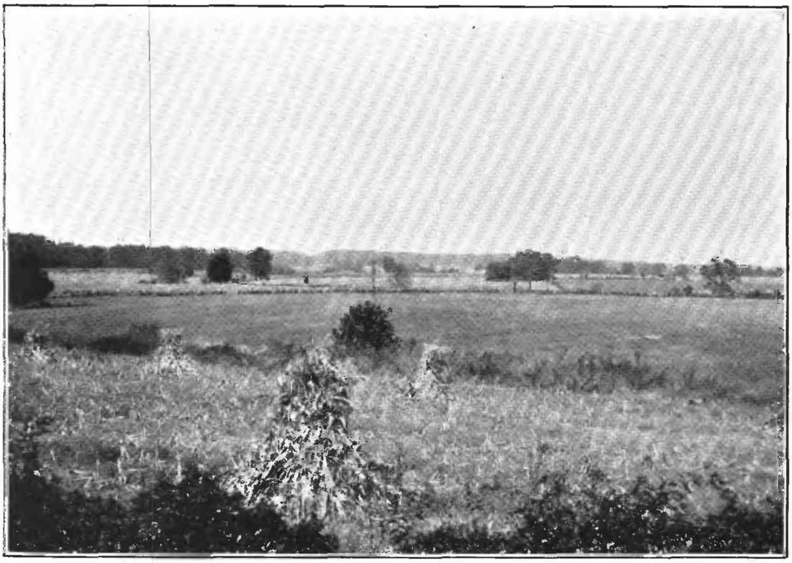
The Tennessee River rises in the Valley and Ridge province in extreme southwestern Virginia and follows that physiographic province southwestward to Chattanooga. Thence it swerves westward across northern Alabama and northward, nearly in the opposite direction from its upstream course, entirely across Tennessee and enters the Ohio River in western Kentucky about 50 miles above the junction of that stream with the Mississippi. The western limb of the Tennessee River bounds the region covered by this report on the west. The Duck River, the only noteworthy tributary of the Tennessee within the region, heads on the Nashville Basin peneplain and flows westward and northwestward across southern Humphreys County.

The Cumberland River rises on the Cumberland Plateau in southern Kentucky and follows a tortuous course westward across north-central Tennessee, swerves northward at Dover and flows parallel to the Tennessee River into Kentucky. It joins the Ohio River about 70 miles above its mouth, or 20 miles above the Tennessee River. The two largest tributaries of the Cumberland from the south, the Stone and Harpeth Rivers, head on the Nashville Basin peneplain in Rutherford and Williamson Counties and flow northwestward to the major stream. The Red River, which enters the Cumberland from the northeast at Clarksville, drains a considerable portion of the northern Highland Rim plateau.

The Green River rises on the Highland Rim plateau in north-central Tennessee and central Kentucky and flows northwestward to its junction with the Ohio River. Its headwater tributaries drain the extreme northeast corner of the region covered by this report and portions of the adjoining counties of Macon and Clay.



INDEX MAP OF TENNESSEE, SHOWING PHYSIOGRAPHIC DISTRICTS AND PROGRESS IN SURVEY OF GROUND-WATER RESOURCES

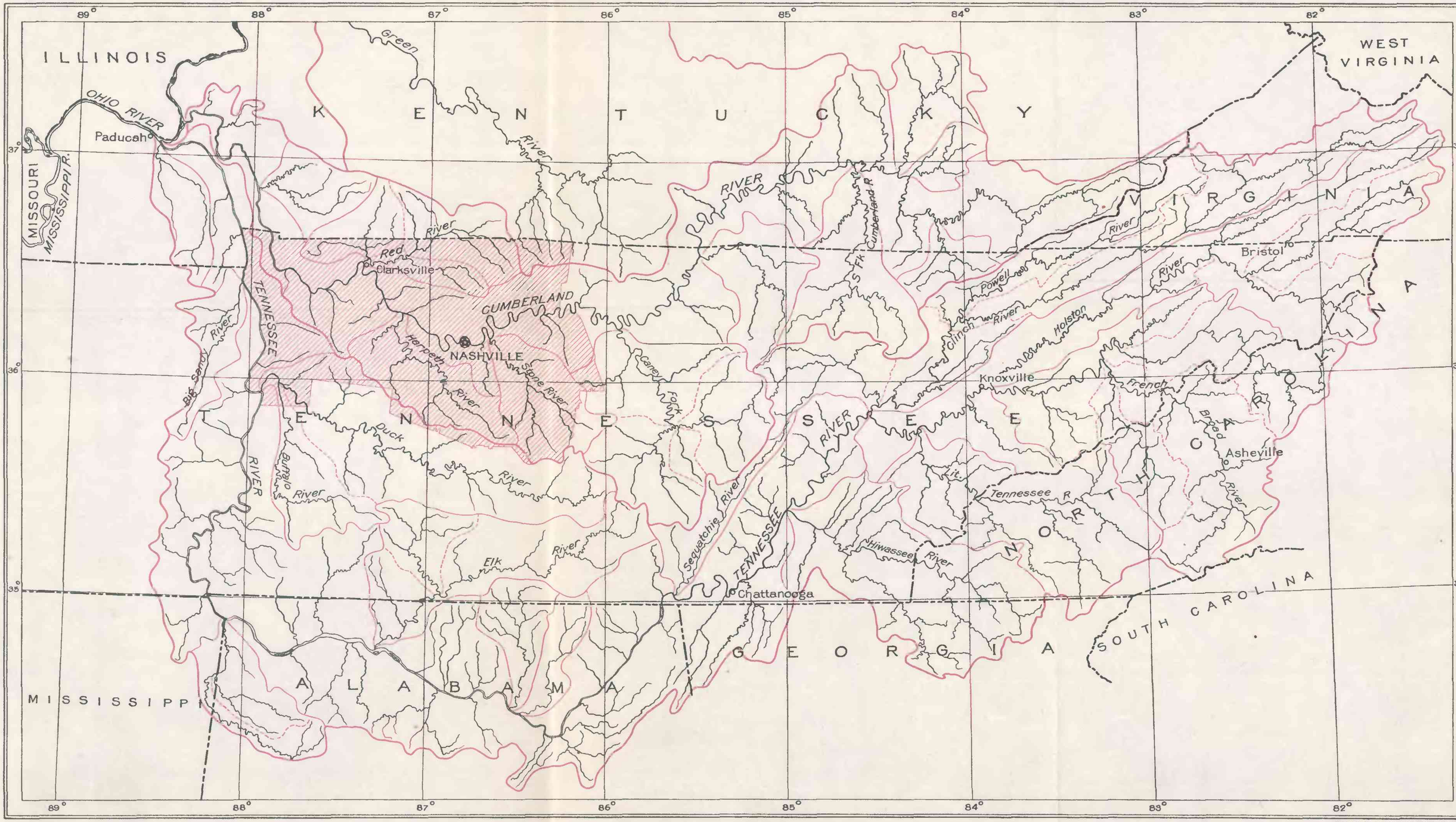


A. TYPICAL TOPOGRAPHY OF THE INTERSTREAM TRACTS OF THE HIGHLAND RIM PLATEAU

View looking north from a point 6 miles east of Cedar Hill, Robertson County.

B. SINK-HOLE TOPOGRAPHY ON UPLAND PLAIN

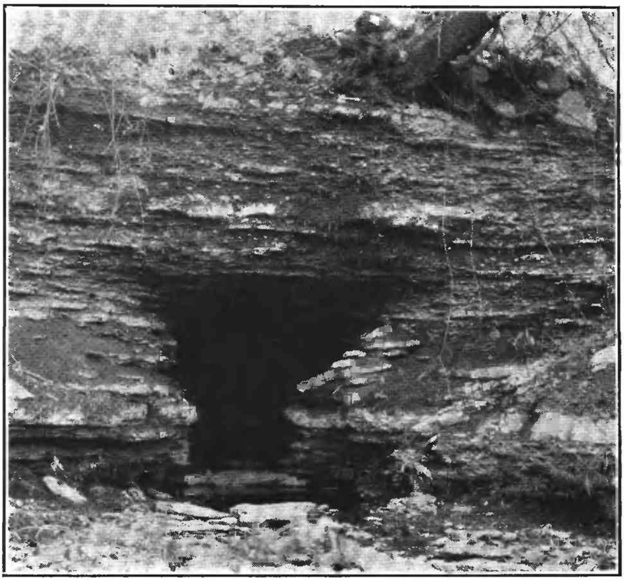
View from a point 3 miles northeast of Clarksville, Montgomery County.



MAP SHOWING AREA COVERED BY THIS REPORT (SHADED PORTION) IN RELATION TO DRAINAGE BASINS OF THE TENNESSEE, CUMBERLAND, AND GREEN RIVERS

10 0 10 50 100 Miles

1932



A. SUBSURFACE DRAINAGE CHANNEL OF THE NASHVILLE BASIN PENEPLAIN, NEAR GLADEVILLE, WILSON COUNTY

Floor of channel is 10 feet below plain; exposed by collapse of thin-bedded limestone roof.

B. LOVE DAVIS CAVE, 3 MILES SOUTHWEST OF SMYRNA, RUTHERFORD COUNTY

A subsurface drainage channel deroofed by solution and slump along a joint.

Although the rocks of central Tennessee are but slightly deformed and are for the most part limestones, they vary widely in resistance to abrasion and solution. Hence the streams tend to follow the less resistant and more soluble beds, and the drainage pattern tends to express the geologic structure of the subsurface rocks. This is especially true of the smaller tributary streams, which at many places follow the strike of the beds faithfully.

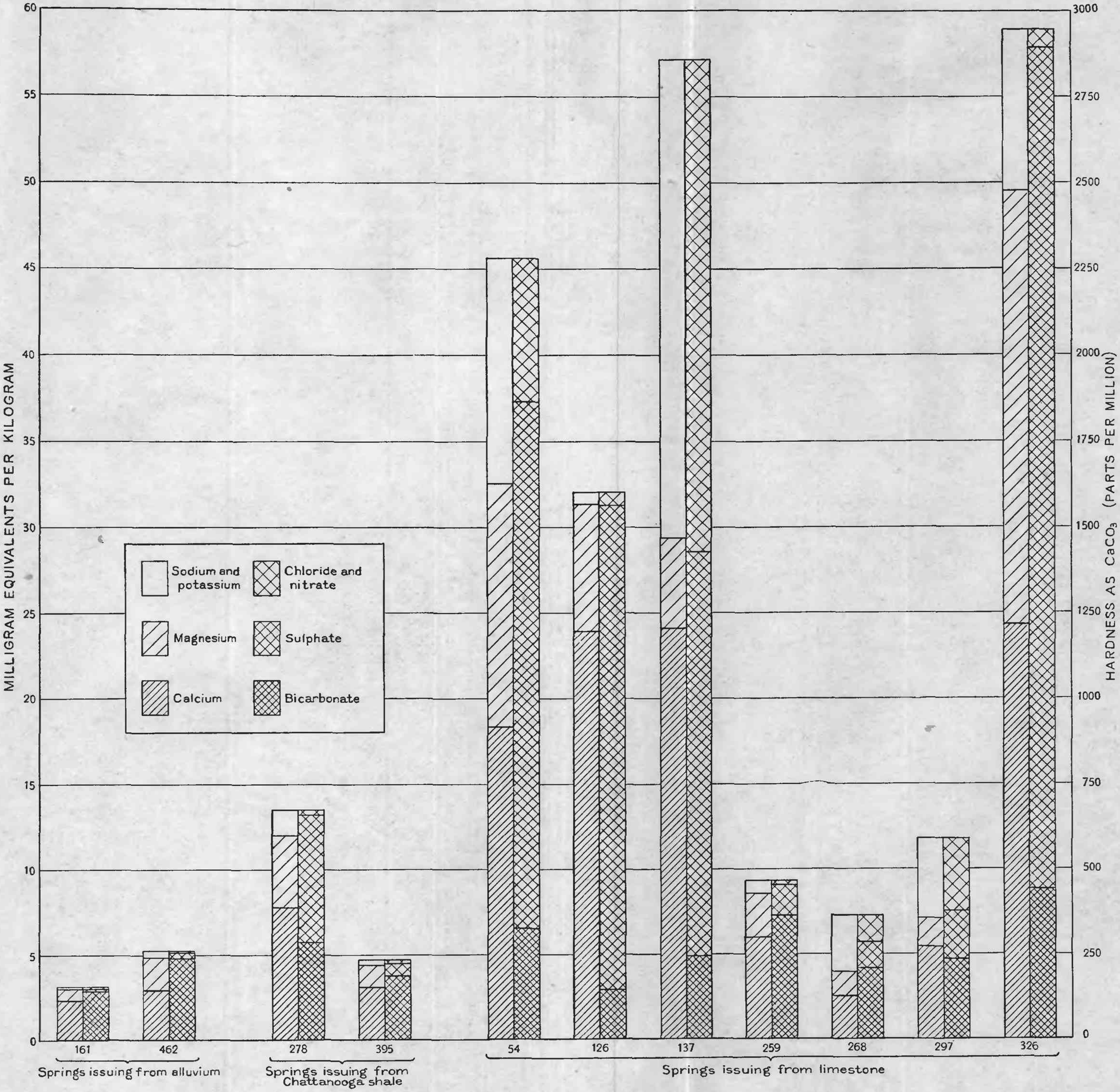
UNDERGROUND DRAINAGE

Many extensive tracts in north-central Tennessee, both on the Highland Rim plateau and on the floor of the Nashville Basin, have no permanent surface streams but are drained into underground channels in the limestone. Elsewhere minor streams flow for a distance on the surface, then disappear into sink holes and are added to the subsurface drainage. These underground passages are by no means fortuitous but tend to develop a definite drainage system which is tributary to the surface streams and is an integral part of the regional drainage mechanism. Under favorable circumstances the underground streams may degrade their channels very rapidly and so may even become pirate streams and capture other underground channels or divert surface streams. The factors that govern the development of such an underground system are discussed on pages 69–74. Here and there the roofs above the larger of these underground channels are breached by collapse (see pl. 5, *A*, *B*), by solution, or by stream erosion, so that sizable "caves" and galleries are exposed. Locally these features are most striking.

STRATIGRAPHY

SEQUENCE AND GENERAL CHARACTER OF THE ROCKS

The rocks of north-central Tennessee include both unconsolidated and consolidated sedimentary types, but no igneous rocks indigenous to the region are known. The unconsolidated rocks are stream-bed, stream-terrace, and coastal-plain deposits of Upper Cretaceous and Quaternary age, none of unquestioned Tertiary age being recognized. Extensive Pleistocene deposits are lacking, so that the Quaternary beds are for the most part of Recent age. The consolidated sedimentary rocks are chiefly limestone and cherty limestone, with some beds of shale and a very few beds of sandstone. Those which are exposed at the surface range in age from Lower Ordovician (Beekmantown) to Mississippian, and all the geologic epochs of that interval are represented. The sequence is parted, however, by many minor disconformities and by one major unconformity, which causes the omission of the entire Devonian and Silurian systems over an extensive part of the region.



CHEMICAL CHARACTER OF WATER FROM REPRESENTATIVE SEEPAGE SPRINGS IN NORTH-CENTRAL TENNESSEE

In general the occurrence of ground water in any region depends in some measure upon the texture of the rocks, so that the stratigraphy is a guide to the development of ground-water supplies. Hence the stratigraphy of north-central Tennessee is here discussed in some detail. However, few of the stratigraphic units have a distinctive lithology over any large portion of the area, so that identification of the beds must rest upon the contained fossils, and it is difficult to apply in practice the relations between stratigraphy and occurrence of ground water.

The stratigraphic sequence and general lithologic character of the rocks are summarized in the following table, and each of the stratigraphic units is described in the succeeding pages. The sequence of description, however, is the inverse of that which is usually followed in geologic reports, in that the formations are described from the top of the geologic column downward—that is, in the order in which they are encountered by the driller.

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Stratigraphic section for north-central Tennessee

System	Series	Correlation	Formation	Thickness (feet)	Character of strata	Water-bearing properties
Quaternary.	Recent.		Alluvium.	Variable.	Gravel, sand, and silt composing flood plains of master rivers and of the larger secondary streams. Pebbles are mostly rounded fragments of chert from Mississippian limestones and chert and quartzite from Pennsylvanian conglomerates.	Possibly a potential source of ground water locally, provided development is made practicable by flood control.
Tertiary (?).	Miocene (?) or Pliocene (?).		High-terrace gravel.	Variable.	Rounded to subangular gravel, sand, and silt on river terraces, locally several hundred feet above present stream beds; poorly assorted at many localities.	Drained in large part, but probably will yield supplies of household magnitude.
Cretaceous.	Upper Cretaceous.		Eutaw formation.	10.	Red micaceous sand with fossilized wood and interstratified layers of white clay. Known only in small remnant areas alo g the divide between the Tennessee and Cumberland Rivers in northwestern part of the region.	More or less completely drained.
			Tuscaloosa formation.	30 (?).	Gravel derived largely from chert of Mississippian limestones with a minor portion of sand and clay. Known only in isolated areas on the Highland Rim Plateau in the vicinity of the Tennessee River.	Probably drained in large part, although some facies should be excellent water bearers if below the water table; probably will yield moderate supplies locally.
			Unconformity			
Carboniferous.	Mississippian.		St. Louis limestone.	110–140.	Massive and medium-bedded fine-grained gray to blue limestone; cherty and moderately fossiliferous; weathers to a bright-red clay with many rounded fragments of chert.	Yields large quantity of ground water to solution-channel springs and to wells that reach the bottom of the zone of weathering.
			Disconformity (?)			
			Warsaw formation.	100.	Coarsely crystalline gray to blue heavy-bedded cherty limestone, shale, and calcareous sandstone; highly fossiliferous; weathers to brick-red clayey soil with many chert fragments.	Similar to St. Louis limestone under like conditions of topography and physiographic history.
			Fort Payne formation.	90–275.	Siliceous shale, chert, flint, cherty crinoidal limestone, and calcareous sandstone of extremely variable character, progressively more argillaceous from northwest to southeast.	Very cherty facies supply springs of moderate size; calcareous sandstone supplies seepage springs in zone of weathering; earthy facies yield little water.
			Disconformity (?)			
			New Providence shale.	0–55.	Coarsely crystalline white to gray crinoidal limestone in layers 12 to 18 inches thick separated by thin bands of green and blue shale, locally massive; cross-bedding is characteristic at many places.	Not known.

			Ridgetop shale.	5–107.	Light-blue to green clay which incloses several thin beds of earthy sandstone, earthy limestone, and chert; green phosphatic shale (Maury glauconitic member) at base.	Not known.
			-Disconformity-			
Carboniferous or Devonian.	Mississippian or Upper Devonian.		Chattanooga shale.	0–45.	Black fissile carbonaceous shale with thin seams of bituminous matter and disseminated small crystals of pyrite; Hardin sandstone member locally at base.	Topmost beds supply many so-called chalybeate and sulphur springs in zone of rock weathering along Highland Rim escarpment; not generally water bearing beneath cover.
			-Unconformity-			
Devonian.	Middle Devonian.		Pegram limestone.	0–35.	Heavy-bedded light-gray limestone 12 feet thick, locally, with a basal member of white or brown coarse fossiliferous sandstone. Not widespread.	Basal sandstone member may be source of ground water in eastern Dickson County and vicinity.
			-Disconformity (?)-			
			Camden chert.	45+.	Alternating layers of dense bluish-gray limestone and yellowish chert, each 2 to 9 inches thick, known only at two localities in southern Humphreys County.	
			-Unconformity-			
	Lower Devonian.	Oriskany (?) group.	Harriman (?) chert.	20–40.	White, gray, and buff nonfossiliferous cherty limestone; known only in the Wells Creek Basin, Stewart County.	
			-Disconformity-			
		Helderberg group.	Birdsong limestone.	10–20.	Thin-bedded and somewhat cherty fossiliferous limestone; known only in the Wells Creek Basin, Stewart County.	
			-Unconformity-			
Silurian.		Cayuga group.	Decatur limestone.	0–70.	Heavy-bedded light-gray, relatively pure limestone.	
		Niagara group.	Lobelville formation.	0–75.	Thin-bedded earthy limestone and variegated shale.	
			Bob formation.	0–75.	Massive pure limestone and variegated shale.	
			Beech River formation.	0–106.	Calcareous shale and shaly limestone with chert.	
			Dixon limestone.	0–44.	Earthy red limestone and red and purple shales.	
			Lego limestone.	0–46.	Compact light-gray subcrystalline limestone.	
			Waldron shale.	0–10.	Light-gray shaly limestone.	
			Laurel limestone.	0–33.	Massive purple and reddish limestone.	
			Osgood limestone.	0–22.	Thin-bedded compact light gray, blue, or reddish earthy limestone.	
			-Disconformity-			
		Albion sandstone.	Brassfield limestone.	3–30.	White or blue cherty fossiliferous limestone.	
			-Disconformity-			

Stratigraphic section for north-central Tennessee—Continued

System	Series	Correlation	Formation	Thickness (feet)	Character of strata	Water-bearing properties
	Upper Ordovician.	Richmond group.	Fernvale formation.	0–40	Soft green or chocolate-colored shale with bands of coarsely crystalline gray and mottled phosphatic limestone.	
			Arnheim limestone.	0–3	Blue granular crystalline limestone with interbedded shale.	
			—Unconformity—			
		Maysville group.	Leipers limestone.	0–100	Knotty earthy limestone and interbedded shale, or granular crystalline limestone without shale.	
			—Disconformity—			
	Middle Ordovician.	Trenton group.	Catheys limestone.	50–100	Knotty earthy limestone and shale with heavy bands of impure blue limestone.	
			Cannon limestone.	0–250	Massive pure dove-colored and gray limestone, also earthy cherty blue limestone.	
			Bigby limestone.	30–100	Mainly granular crystalline gray or brown laminated and cross-bedded phosphatic limestone.	
			—Disconformity—			
			Hermitage formation.	40–80	At western edge of Nashville Basin chiefly medium-bedded sandy and phosphatic subgranular limestone with local beds of shale. Toward the northeast and east grades into flaggy blue-gray sandy and earthy limestone, calcareous sandstone, and shale.	
			—Disconformity—			
Ordovician.		Lower part of Black River group.	Lowville limestone.	40–110	Upper member consists of thin-bedded dove-colored limestone and yellowish-gray shale. Lower member (Carters limestone restricted) is massive compact white or light-blue cherty limestone.	Water-bearing properties of the pre-Mississippian limestones are variable from place to place and are dependent upon (1) solubility of the rock; (2) intensity of jointing, which is in turn dependent upon (*a*) competency of the stratum, (*b*) localization of stresses; (3) geomorphologic history of the district.

			-Disconformity-		
Lower Ordovician.	Chazy group	Stones River group	Lebanon limestone.	80–125	Thin-bedded compact bluish-gray, dove-colored, or brown limestone with partings of yellow clay; beds 1 to 6 inches thick; fossils abundant at many localities.
			Ridley limestone.	95–120	Massive fine-grained blue-gray to brown cherty limestone; not highly fossiliferous.
			Pierce limestone.	23–28	Thin-bedded blue or drab brittle limestone with local heavy beds of bluish-brown coarse crystalline limestone; highly fossiliferous.
			Murfreesboro limestone.	70+	Massive brittle drab cherty limestone.
			-Unconformity-		
	Beekmantown group (?).				Light-gray fine-grained, slightly cherty magnesian limestone of the Wells Creek Basin, Stewart County.

QUATERNARY SYSTEM

ALLUVIUM

The master streams of north-central Tennessee and the lower courses of their larger tributaries are bordered by flood plains, which, along the Cumberland River, attain a maximum width of nearly a mile on the concave side of meanders. These plains, which have a flat transverse profile and terminate abruptly landward against the rock erosion slopes of the valley, are constructed of alluvium, which comprises beds of silt, sand, and gravel. The coarser particles of the alluvium are for the most part rounded fragments of chert from the Mississippian limestones and sandstone and quartzite pebbles from the Pennsylvanian conglomerates. The alluvium lies upon normal slip-off meander slopes or upon the sloping rock sides of a youthful stream trench, so that the deposits thin rapidly toward the margins of the plain. They are probably not more than 50 feet thick at most localities.

Without known exception, the alluvial flood plains are subject to overflow at high stages of the streams, so that they are wholly unsuited for town sites or industrial developments. Hence the alluvium has not been developed as a source of ground water, and its water-bearing properties are not known. If beds of thoroughly assorted gravel exist below the water table, however, properly constructed wells should yield large supplies of water. Consequently, these deposits are a potential but unproved source of ground water wherever the flood plains can be protected from overflow, so that industrial or suburban development is feasible.

TERTIARY(?) SYSTEM (MIOCENE? OR PLIOCENE?)

HIGH-TERRACE GRAVEL

The high-terrace gravel, which Galloway has assigned to the late Pliocene but which according to Shaw may be as old as Miocene (see pp. 19–21), occurs here and there in the valleys of the Tennessee and Cumberland Rivers and their major tributaries as a veneer upon rock terraces that are as much as several hundred feet above the present streams. This old gravel, like the recent alluvium, is composed largely of waterworn chert from the Mississippian limestones and of quartzite pebbles from the Pennsylvanian conglomerates. Generally, however, it is poorly assorted, so that its water-yielding capacity is not likely to be large. Moreover, the deposits are for the most part of slight extent and are rather thoroughly drained, and hence they are not a potential source of large quantities of ground water. Locally, however, they are likely to yield supplies adequate for domestic use.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

EUTAW FORMATION

The Eutaw formation, a coastal-plain deposit of Upper Cretaceous age, has been identified by Wade [39] about 9 miles north of the Tennessee-Kentucky boundary in Trigg County, Ky., and thence has been traced southward about 10 miles beyond the boundary into Stewart County, Tenn. Throughout this distance the formation occurs only on the crest of the divide between the Tennessee and Cumberland Rivers. It does not occur elsewhere in the region investigated, although undoubtedly it was deposited rather generally, for it crops out over extensive areas farther south in Wayne and Hardin Counties, as was pointed out first by Miser.[40]

At the locality in Trigg County, Ky., described by Wade the Eutaw formation consists of red micaceous sand that contains streaks and pellets of white clay, the whole 10½ feet thick. The correlation is based upon the presence of *Halymenites major* Lesquereux.

As the Eutaw formation occurs only on the crest of the divide in north-central Tennessee, it is subject to drainage by the many tributary streams that flow from this upland divide and hence is not likely to retain large quantities of ground water.

TUSCALOOSA FORMATION

The Eutaw formation at the locality in Trigg County is underlain by at least 31 feet of gravel that Wade [41] correlates with the Tuscaloosa formation, because of its lithologic character and its position beneath the fossiliferous Eutaw. From this locality the Tuscaloosa formation has been traced southward into Tennessee, its outcrop forming a band that surrounds the Eutaw formation. Wade has also identified the formation along the Nashville, Chattanooga & St. Louis Railway about 2 miles east of McEwen, where there is "resting on chert of the St. Louis formation about 30 feet of very compact hard white chert gravel which is typical of the Tuscaloosa." Several drilled wells in the vicinity of McEwen—Nos. 163, 164, 165, and 166 (pp. 159–160)—are reported to pass through 200 to 230 feet of unconsolidated material before reaching solid rock. Part of this material may belong to the Tuscaloosa formation, but the records of the wells do not discriminate between gravel and residual chert, so that it is impossible to estimate the thickness of the Tuscaloosa formation at this locality. The Tuscaloosa formation caps the higher hills of an extensive area in eastern Humphreys County and southwestern

[39] Wade, Bruce, The occurrence of the Tuscaloosa formation as far north as Kentucky: Johns Hopkins Univ. Circ., new ser., No. 3, pp. 104–105, 1917.

[40] Miser, H. D., Economic geology of the Waynesboro quadrangle: Resources of Tennessee, vol. 4, No. 3, p. 107, Tennessee Geol. Survey, 1913.

[41] Wade, Bruce, op. cit., p. 104.

Dickson County. (See pl. 4.) In this district no paleontologic evidence of the age of the formation has been found, so that the correlation is based upon the lithology of the material, the geographic relation to localities at which paleontologic evidence exists, and the relation of the deposits to the Highland Rim peneplain. The geologic map of Tennessee [42] (see pl. 4) also shows a small outcrop of the formation capping the divide between Long Creek and Cross Creek near Bear Spring, Stewart County. Furthermore, the deposits of waterworn chert and vein quartz gravel on the Highland Rim plateau in southwestern Dickson County and adjacent portions of Hickman County, which are described by Hayes and Ulrich,[43] may also belong to the Tuscaloosa formation.

The Tuscaloosa formation as exposed in a cut on the Nashville, Chattanooga & St. Louis Railway about 2 miles east of McEwen, Humphreys County, is described by Wade [44] as consisting of about 30 feet of very compact white chert gravel which rests upon weathered St. Louis limestone. The individual pebbles are well rounded, and most of them are less than an inch in diameter, although some are as large as 6 inches. Some sand is mixed with the gravel, although very little clay is present. The gravel of the Tuscaloosa formation can generally be differentiated by three criteria from the stream-terrace gravel with which it may be associated. In the first place, the individual pebbles and cobbles of the Tuscaloosa formation are well rounded, and many of them are almost spherical, whereas those of the terrace gravel are generally flat, elongate, or even subangular. Small discoidal pebbles of quartzite are abundant in the terrace gravel at many localities. Second, the Tuscaloosa gravel is composed for the most part of chert from the Mississippian rocks, whereas the terrace gravel is derived in large measure from quartzite and sandstone. Third, pellets of iron oxide are not known to occur in the Tuscaloosa gravel, whereas they have been observed in the stream deposits.

The Tuscaloosa is the oldest formation of the Upper Cretaceous series in the East Gulf Coastal Plain province, although the deposits that exist in north-central Tennessee probably represent only some of the uppermost beds of the type section in the vicinity of Tuscaloosa, in central-western Alabama. In north-central Tennessee the formation was laid down as a coastal-plain deposit along the western edge of the Cumberland peneplain, underwent planation during the Highland Rim cycle, and subsequently has been almost wholly eroded by the Tennessee River during the Nashville Basin and recent erosion cycles.

[42] Nelson, W. A., Geologic map of Tennessee, 3d ed., Tennessee Geol. Survey, 1923.
[43] Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95), p. 1, 1903.
[44] Wade, Bruce, op. cit., pp. 103–104.

The Tuscaloosa formation crops out only on upland tracts which are thinly populated and in which there has been little or no ground-water development. Hence, its water-bearing properties are not known, although it may be inferred from the lithology that the permeability is high. However, the formation is probably drained over extensive areas and therefore may not contain much water.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES

ST. LOUIS LIMESTONE

The St. Louis limestone, the youngest of the marine sediments of north-central Tennessee, is generally a massive or medium-bedded fine-grained bluish-gray limestone, which locally contains a great deal of nodular and cellular chert (see pl. 6, *A*) and some beds of shale and sandstone, particularly in the lower part. So far as is known, the top of the formation has not been observed in the region covered by this survey, so that its total thickness before the region was peneplaned during the Highland Rim cycle is not known. However, in northern Overton County,[45] northeast of this region, it is 110 to 140 feet thick. Safford [46] has estimated its maximum thickness in central Tennessee as 250 feet, although he probably included in this estimate the underlying Warsaw formation. The St. Louis limestone is identified by the massive colonial corals *Lithostrotion basaltiforme*, which occurs at all horizons through the area, and *Lithostrotion proliferum*, which occurs locally in the lower part of the formation and which is distinguished from the much more abundant *L. basaltiforme* by having cylindrical rather than polygonal corallites. According to Butts,[47] *Archeocidaris* and *Melonites* are abundant and *Lithostrotion proliferum* occurs sparsely immediately above a bed of earthy limestone that is about 10 feet above the base of the formation, and this sequence is diagnostic throughout northern Overton County. Hayes and Ulrich [48] also note the presence of *Melonites* just above the base of the formation in the Columbia quadrangle, so that this fossil may prove to be a trustworthy stratigraphic guide throughout the region.

The St. Louis limestone is the topmost formation over the greater part of the Highland Rim plateau from the central part of Sumner County westward to the Tennessee River (see pl. 4), although outcrops of the unweathered rock are seen only in the stream beds. All the upland tracts which it underlies are covered by a thick mantle of bright-red soil and clay that contains many rounded fragments of chert and silicified colonies and fragments of the characteristic fossil

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[45] Butts, Charles, Geology and oil possibilities of the northern part of Overton County, Tenn., and of adjoining parts of Clay, Pickett, and Fentress Counties: Tennessee Geol. Survey Bull. 24, p. 19, 1919.

[46] Safford, J. M., Geology of Tennessee, p. 339, 1869.

[47] Butts, Charles, op. cit., p. 18.

[48] Hayes, C. W., and Ulrich, E. O., op. cit., p. 3.

Lithostrotion basaltiforme. This mantle, which is locally at least 100 feet thick, is the insoluble residuum from the weathering of the rock, the calcareous matter having been dissolved by soil water percolating downward through joints and entering the underground drainage system. Naturally, the depth of weathering is not the same at all places, so that the surface of separation between the mantle of residuum and the unweathered rock is extremely uneven. (See pl. 6, *B*.) The St. Louis limestone seems to be more soluble than the other Mississippian formations, so that in it such features as solution channels, sink holes, and caves have developed more extensively than in the other rocks under similar conditions of topography and geomorphologic history. (See pp. 78–86.) Indeed, the presence of numerous sink holes and other features of solution has been invoked as a means of identifying the St. Louis limestone wherever the unweathered rock does not crop out. However, this criterion should be employed with caution.

The St. Louis limestone yields a large quantity of ground water to tubular springs (see pp. 92–95), the discharge of which is the underground run-off from large upland tracts of the Highland Rim plateau. The coarser phases of the cherty residuum from the weathered rock yield moderate supplies to drilled wells, especially at and just above the base of the weathered zone. The unweathered rock, however, yields water only in wells that encounter a water-bearing crevice or solution channel.

WARSAW FORMATION

Beneath the St. Louis limestone and probably separated from it by a slight stratigraphic break [49] is the Warsaw formation, which is not differentiated from the St. Louis limestone on Plate 4. Butts [50] also states that the formation is relatively heterogeneous and in Overton County comprises equal parts of calcareous sandstone, shale, and limestone. The upper third of the formation in that area is mostly sandstone, some of the layers of which are highly calcareous and resemble limestone in the unweathered condition but weather by solution of the calcareous matter into a loose aggregate of quartz grains. In many localities the very top of the formation is composed of layers between 2 and 4 inches thick of clastic, ripple-marked sandstone. The middle third is compact, thick-bedded limestone that contains many fragmental fossils, and the bottom third usually comprises alternating beds of shale and limestone together with several sandy layers that weather to resemble coarse yellow sandstone. Toward the south and west the limestone beds contain an abundance of dark chert, and the sandy facies of the formation seem to be less well developed or to be truncated by an unconformity between the

[49] Butts, Charles, op. cit., p. 18.
[50] Idem, pp. 16–17.

Warsaw and the overlying St. Louis limestone, although the detailed stratigraphic relations are not known.

The Warsaw formation is highly fossiliferous, especially in its central and upper parts, although the remains are usually fragmental and are difficult to classify because they generally decompose as rapidly as the inclosing rock. Butts, in Overton County, recognized *Tricoelocrinus woodmani* or a closely related form, *Productus magnus*, *Spirifer subequalis* (common), *Spirifer tenuicostatus*, *Spiriferella neglecta*, *Brachythyris subcardiformis*, and *Worthenopora spinosa*. Mather,[51] in eastern Sumner County, differentiated not far below the top of the formation a key bed that is thickly crowded with fragments of *Spirifer washingtonensis*. The lower part of the formation, however, resembles the underlying Fort Payne formation so much that at many localities the two are not readily separable.

The Warsaw formation, which is about 100 feet thick, crops out on the Highland Rim plateau in eastern Sumner County and forms a broad belt along the higher slopes of the stream valleys farther west. Like the overlying St. Louis limestone, it weathers on all the upland tracts to a brick-red clayey soil containing many fragments of chert, and unweathered rock crops out only in the stream valleys.

The sandstone beds that constitute the upper third of the Warsaw formation in Overton County may be water-bearing farther west where they pass beneath the St. Louis limestone, although they have not been noted in the records of the few wells that have been drilled to or below their horizon within the region of this investigation. Furthermore, these sandstone beds are not well developed or are entirely absent in the western part of the region, so that their value as a source of water remains problematic. Even if the beds persisted toward the west they probably would yield only saline water of high concentration where they were deeply buried.

FORT PAYNE FORMATION

The Warsaw formation is underlain, with seeming conformity, by the Fort Payne formation, an exceedingly heterogeneous and variable assemblage of siliceous and calcareous shale and sandy, cherty, and earthy limestone. In Stewart County, in the northwestern part of the region, the upper part of the Fort Payne formation is very thick bedded and consists of alternating bands of dense dark bluish-gray limestone and persistent bands of dense dark-colored chert from 1 inch to 1 foot or more in thickness. (See pl. 6, *C*.) Throughout the region the topmost beds of the formation are generally cherty, although toward the east and south this cherty facies thins noticeably and the limestone becomes more earthy. In Cheatham County the greater

[51] Mather, K. F., Oil and gas resources of the northeastern part of Sumner County, Tenn.: Tennessee Geol. Survey Bull. 24, (Ann. Rept. for 1919, pt. 2-B), p. 25, 1920.

part of the formation consists of beds of somewhat earthy blue limestone between 2 and 18 inches thick, which are accompanied by quartz geodes from 1 to 12 inches in diameter and by nodular and irregular tabular masses of chert. The amount of chert decreases noticeably and the proportion of earthy limestone and calcareous shale increases from the top of the formation toward the bottom. In the south-central and southwestern parts of the region, especially in Williamson, Dickson, and Humphreys Counties, the upper part of the formation includes many beds of coarse sandy limestone or calcareous sandstone, whose weathered and leached outcrops resemble buff sandstone. Locally, in the same district, the lower part of the formation, according to Safford,[52] is a massive blue-gray limestone whose maximum thickness is 150 feet. According to Mather [53] the upper 50 to 60 feet of the formation in the northeastern part of the region, in Sumner County, consists of thin-bedded buff or brownish-gray limestone that contains numerous geodes and much tabular chert. This upper division is underlain by about 30 feet of relatively pure coarsely crystalline limestone in massive beds, which inclose tabular masses of light-brown or milky-white chert from 3 to 12 inches thick that become less abundant in the lower beds of the division. Estimates by several geologists of the thickness of the Fort Payne formation range from 90 to 275 feet, although the stratigraphic limits of the sections covered by these estimates, especially the lower limit, may not be strictly equivalent.

The Fort Payne formation is essentially nonfossiliferous in north-central Tennessee, although locally, as in western Overton County,[54] the upper 20 feet contains many fragments of crinoids, the presence of which differentiates these beds from the overlying Warsaw formation. However, fossils are comparatively abundant in the Fort Payne of other areas and also in beds that underlie the Fort Payne. The formation is now classified by Butts,[55] who has studied the formation over a broad region in Kentucky, Tennessee, and Alabama, as containing beds of Keokuk, Burlington, Fern Glen, and late Kinderhook age.

The Fort Payne formation forms the Highland Rim plateau in eastern Sumner County and crops out extensively over the middle and lower slopes of the dissected part of the plateau along the Highland Rim escarpment and in the valleys of the Tennessee and Cumberland Rivers. The formation is deeply weathered throughout the upland areas, and the weathering has generally produced a reddish or yellowish-buff soil that contains much dense chert in subangular fragments. In many places the tabular chert has not disintegrated, although the calcareous matter of the intervening limestone layers

[52] Safford, J. M., Geology of Tennessee, p. 340, 1869.
[53] Mather, K. F., op. cit., p. 24.
[54] Butts, Charles, op. cit., p. 15.
[55] Butts, Charles, Geology of Alabama: Alabama Geol. Survey Special Rept. 14, pp. 166–167, 1926.

has been completely leached, so that the layers of chert are separated only by seams of yellowish clay a few inches thick. The beds of earthy limestone weather to masses of soft shaly clay.

In general the beds of the Fort Payne formation are not highly soluble, so that large solution channels are less extensively developed and tubular springs are less abundant in this formation than in the overlying St. Louis limestone. Locally, however, these springs are a reliable source of water. In many places the dense tabular cherts have been minutely fractured by weathering, so that they yield water rather freely to springs and to drilled wells, although drilling in such material is extremely difficult. The calcareous sandstone members in the upper part of the formation supply many perennial springs from their weathered and leached outcrops along the Highland Rim escarpment in Williamson County and adjacent areas. (See pp. 210–211.) However, their water-yielding capacity where they lie beneath cover and are unweathered is not known, except that the earthy limestone facies of the formation has no promise as a source of water.

NEW PROVIDENCE SHALE

The Fort Payne formation is underlain locally by the New Providence shale, the type section of which in Tennessee occurs at Whites Creek Spring, 12 miles north of Nashville, as described by Bassler.[56] At this locality the New Providence shale is 35 feet thick and consists of coarsely crystalline white to gray crinoidal limestone in layers 12 to 18 inches thick, which are separated by thin bands of green and blue shale. At many places the rock is but an assemblage of crinoid fragments and other fossils loosely cemented by greenish shale, which is entirely decomposed by weathering so that the fossils are freed in great abundance. Toward the southwest, west, and east the formation thins notably and pinches out within a distance of 5 to 10 miles. The New Providence shale also occurs in eastern Sumner County, where, according to Mather,[57] it comprises variable beds of shale and shaly limestone that have a predominant bluish-green tint and inclose many geodes. However, chert is not a common constituent. At most localities the more calcareous strata are less than 10 inches thick, but in places they are very massive. Cross-bedding occurs at many localities and is locally developed to a remarkable degree, the divergence between the false and the true bedding being as much as 10°. In this area the New Providence shale attains a maximum thickness of 55 feet along the Highland Rim escarpment north of Bransford and Bethpage but thins toward the northeast.

In the Whites Creek Springs section the most abundant and characteristic fossils are the bryozoan *Rhombopora incrassata* Ulrich and the

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[56] Bassler, R. S., The Waverlyan period of Tennessee: U. S. Nat. Mus. Proc., vol. 41, pp. 218–220, 1911.
[57] Mather, K. F., op. cit., pp. 21–23.

brachiopods *Rhipidomella michelinia* L'Eveille and *Chonetes illinoisensis* Norwood and Pratten. The species listed by Bassler are as follows:

Favosites valmeyerensis Weller.
Beaumontia americana Weller.
Zaphrentis cliffordana Edwards and Haime.
Amplexus rugosus Weller.
Amplexus brevis Weller.
Cladoconus americana Weller.
Monilopora crassa (McCoy).
Rhipidomella michelinia L'Eveille.
Chonetes illinoisensis Worthen.
Spirifer vernonensis Swallow.
Lasiocladia hindei Ulrich.
Rhombopora incrassata Ulrich.
Cystodictya pustulosa Ulrich.
Fenestella regalis Ulrich.
Ptilopora cylindracea Ulrich.
Metichthyocrinus tiaraformis (Troost).
Barycrinus cornutus (Owen and Shumard).
Catillocrinus tennesseensis (Troost).
Halysiocrinus perplexus (Shumard).
Synbathocrinus robustus Shumard.
Schizoblastus decussatus (Shumard).

The New Providence shale is separated from the overlying Fort Payne formation by a slight disconformity and was probably truncated by erosion before the deposition of the younger beds. Furthermore, Bassler[58] believes that the formation was not deposited widely over the area but was limited to definite embayments that converge radially toward the Nashville dome. (See pp. 62–63.)

RIDGETOP SHALE

The Fort Payne formation, or the New Providence shale where present, is underlain locally along the northern and western sides of the Nashville dome by the Ridgetop shale, a formation of Kinderhookian age. The type section[59] of the formation, along the Louisville & Nashville Railroad between Baker and Ridgetop, in Davidson County, consists of light-blue to green clay that incloses several thin beds of earthy sandstone, earthy limestone, and chert. The lowermost bed of the section as defined by Bassler is characteristically a layer of sandy chert about 1 foot thick. Miser[60] and Swartz,[61] however, have shown that the Maury green shale of Safford and Killebrew[62] should be included with the Ridgetop shale, although in some reports it has been regarded as the upper member of the underlying Chattanooga shale. The Ridgetop shale, including the Maury member, is 102 to 107 feet thick at the type section, although at Whites Creek Spring, about 5 miles to the southwest, it is but 41 feet thick. Like the overlying

[58] Bassler, R. S., The Waverlyan period of Tennessee: U. S. Nat. Mus. Proc., vol. 41, pp. 220–222, 1911; Early Mississippian rocks of northern Tennessee [abstract]: Geol. Soc. America Bull., vol. 36, No. 1, p. 221, 1925.

[59] Bassler, R. S., The Waverlyan period of Tennessee: U. S. Nat. Mus. Proc., vol. 41, pp. 216–218, 1911.

[60] Miser, H. D., in Drake, N. F., Economic geology of the Waynesboro quadrangle: Resources of Tennessee, vol. 4, p. 100, Tennessee Geol. Survey, 1914. Miser, H. D., Structure of the Waynesboro quadrangle with special reference to oil and gas: Idem, vol. 7, p. 201, 1917.

[61] Swartz, J. H., The age of the Chattanooga shale of Tennessee: Am. Jour. Sci., 5th ser., vol. 7, pp. 28–29, 1924.

[62] Safford, J. M., and Killebrew, J. B., The elements of the geology of Tennessee, p. 141, Nashville, Foster & Webb, 1900.

New Providence shale, the Ridgetop shale was deposited only in embayments on the northern and western flanks of the Nashville dome, according to Bassler.[63] The basal Maury glauconitic member is an extremely variable but persistent bed, which may be a green, blue-black, or black shale, a brown sandy shale, or even a buff sandstone. Its lower part is glauconitic at many places and generally contains kidney-shaped phosphatic nodules. Swartz[64] has concluded that this basal member is a lithologic but not a chronologic unit, that it was deposited universally throughout the region and that it is separated from the underlying Chattanooga shale by an unconformity that decreases from west to east and probably disappears between central and eastern Tennessee.

The uppermost 20 feet of the Ridgetop shale at the type locality and the earthy limestone member that occurs 62 feet below the top of the formation are abundantly fossiliferous and contain numerous bryozoans, ostracodes, and other genera of known Kinderhook age, as noted by Bassler.[65] The sandy shale and chert member whose top is 15 to 20 feet below the top of the formation contains such pseudo-Devonian fossils as *Striatopora* and *Michelinia,* but the presence of well-developed species of *Palaeacis*, *Productus*, and *Agaricocrinus* is conclusive evidence of post-Devonian age. The Ridgetop shale is the "fetid shale" of Safford, which Safford and Killebrew[66] and Hayes and Ulrich[67] included with the overlying Fort Payne formation as the so-called "Tullahoma limestone" or "Tullahoma formation." At this horizon have been found many unnamed bryozoans and numerous species of ostracodes, of which only one, *Ctenobolbina loculata* Ulrich, has been named. The other genera collected at this horizon in Hickman and Maury Counties have been studied by Winchell,[68] whose list of species follows:

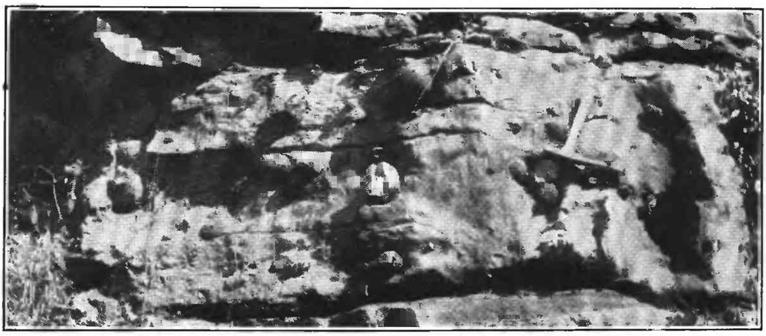
Spirifera hirta? White and Whitfield.
Rhynchonella sageriana Winchell.
Chonetes multicosta Winchell.
Chonetes pulchella? Winchell.
Producta concentricata Hall.
Chonetes fischeri Norwood and Pratten.
Zaphrentis ida? Winchell.
Conularia byblis White.
Leda bellistriata? Stevens.
Solen scalpriformis Winchell
Discina saffordi Winchell.
Pleurotomaria hickmanensis Winchell.
Phillipsia tennesseensis Winchell.

CARBONIFEROUS OR DEVONIAN SYSTEM

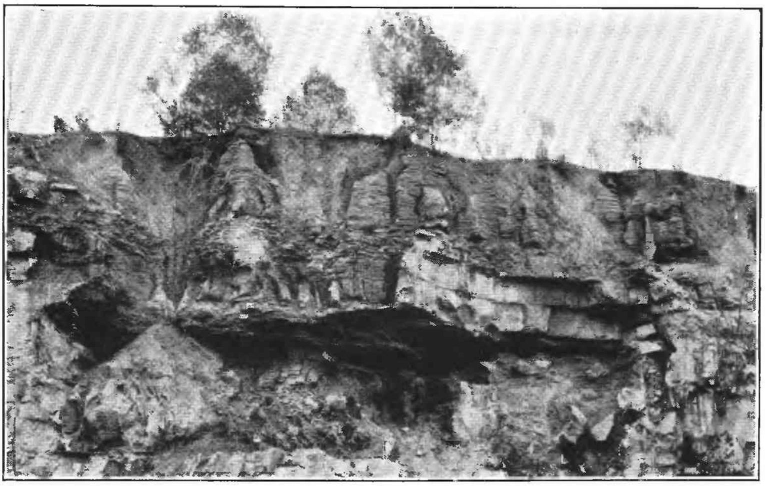
CHATTANOOGA SHALE

The ubiquitous basal member of the Ridgetop shale is underlain by the Chattanooga shale, which is known locally as the "black shale"

[63] Bassler, R. S., op. cit. (1911), pp. 220-222.
[64] Swartz, J. H., op. cit., p. 29.
[65] Bassler, R. S., op.cit. (1911), pp. 217-218.
[66] Safford, J. M., and Killebrew, J. B., op. cit., pp. 143-144.
[67] Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95), p. 3, 1903.
[68] Winchell, Alexander, in Safford, J. M., Geology of Tennessee, pp. 442-446, Nashville, 1869.

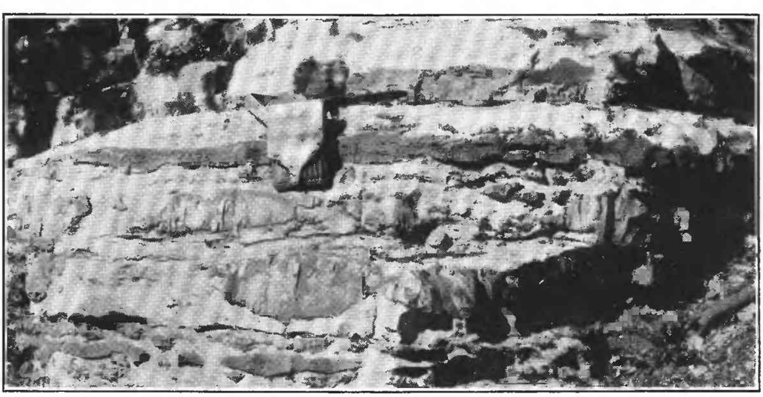


A. NODULAR CHERT IN LOWER PART OF ST. LOUIS LIMESTONE ON STATE HIGHWAY 11, ABOUT 3 MILES NORTHWEST OF ADAMS, ROBERTSON COUNTY



B. RESIDUAL CLAY OVERLYING ST. LOUIS LIMESTONE, 1 MILE WEST OF ERIN, HOUSTON COUNTY

In quarry of Southland Lime Co.



C. TABULAR CHERT IN LIMESTONE OF FORT PAYNE FORMATION AT CEDAR SPRING, 4½ MILES NORTHWEST OF MODEL, STEWART COUNTY or "black slate." This formation is a black or dark-brown fissile carbonaceous shale that contains thin seams of bituminous matter and disseminated small crystals of pyrite.

Generally the carbonaceous shale is between 20 and 35 feet thick, but it attains a maximum thickness of 45 feet, as on Bledsoe Creek 3 miles north of Bransford, Sumner County,[69] and is entirely absent at a few localities, as in the vicinity of Dog Creek, 3 miles northwest of Kingston Springs, Cheatham County.[70] Northeast of the region under investigation, on Flynn Creek, 5 miles south of Gainesboro, Jackson County,[71] the Chattanooga shale thickens greatly in an area about 2 miles in diameter and attains a maximum thickness of 149 feet, apparently having been deposited in one or more pre-Chattanooga sink holes. Similar features may exist elsewhere, although none have been found in north-central Tennessee. In the south half of the Nashville Basin the carbonaceous shale is underlain by a phosphatic sandstone, the Hardin sandstone member, which attains a maximum thickness of 15 feet in Wayne County.[72] In the north half of the basin, however, this sandstone is generally only a few inches thick. The Hardin sandstone has usually been considered to be the basal member of the Chattanooga shale, although it is not unlikely that at many localities in the region here described the Hardin has been confused with the sandstone member at the base of the underlying Pegram limestone. (See p. 41.)

The Chattanooga shale in Tennessee has long been considered to be of late Devonian or early Mississippian age or possibly to represent a transition between these two periods; but recently Swartz [73] has concluded that in central and western Tennessee it is wholly of earliest Mississippian age. In view of the doubt that still exists regarding its age, it is classified by the United States Geological Survey as Devonian or Carboniferous. Because of its characteristic lithology, the shale is a convenient datum plane for tracing the geologic structure and for delimiting the major stratigraphic groups. However, it has some limitations for these purposes, inasmuch as it lies unconformably upon strata that range from Upper Ordovician to late Middle Devonian in age, the whole of the Devonian and Silurian systems being locally unrepresented.

Many seepage springs issue from the uppermost part of the Chattanooga shale wherever it crops out on the steeper slopes. These springs are the source of most of the so-called chalybeate and sulphur water. The water from them carries a moderate quantity of iron

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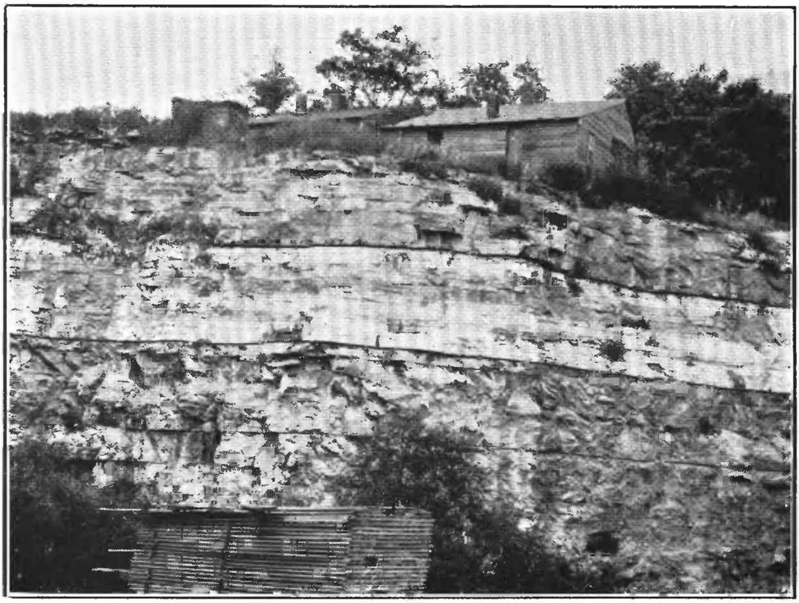
[69] Mather, K. F., op. cit., pp. 19–20.

[70] Jillson, W. R., Unique Devonic sandbar: Pan Am. Geologist, vol. 40, No. 5, pp. 333–337, 1923.

[71] Lusk, R. G., A pre-Chattanooga sink hole: Science, new ser., vol. 65, pp. 579–580, 1927.

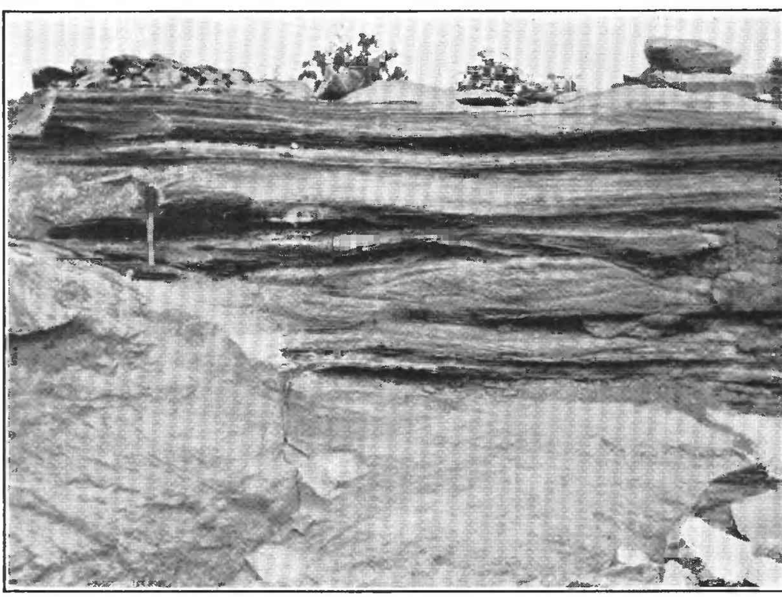
[72] Miser, H. D., Mineral resources of the Waynesboro quadrangle, Tenn.: Tennessee Geol. Survey Bull. 26, p. 23, 1921.

[73] Swartz, J. H., op. cit., p. 28.



A. BIGBY LIMESTONE EXPOSED IN ABANDONED QUARRY SOUTH OF TENNESSEE CENTRAL RAILROAD AT LOVEMAN'S CROSSING, EAST NASHVILLE

The upper, middle, and lower members are, respectively, the Ward, "Dove," and "Capitol" limestones of Safford. The top of the Hermitage formation is a few feet above the floor of the quarry at the right.



B. SANDY CROSS-BEDDED LIMESTONE ("CAPITOL" LIMESTONE OF SAFFORD) NEAR BASE OF BIGBY LIMESTONE, EXPOSED IN WEATHERED OUTCROP IN SMALL QUARRY AT HAMILTON AND MORRISON STREETS, NASHVILLE and sulphate (SO_4), probably derived from oxidation of the pyrite; generally it also carries a noticeable amount of hydrogen sulphide, although the quantity of this gas is usually less than 5 parts per million. Many drilled wells obtain water supplies large enough for household use from the upper part of the shale close to its outcrop. In general the Chattanooga shale is not likely to be notably water bearing where it lies beneath deep cover and is unweathered, it being not unlikely that the ground water which is supposedly encountered in the shale in eastern Dickson County and elsewhere actually issues from sandstone of Devonian age.

DEVONIAN SYSTEM

Although a rather full sequence of Middle and Lower Devonian formations is exposed in the western valley of the Tennessee River,[74] rocks of the Devonian system are known at very few localities in north-central Tennessee. Those whose stratigraphy is well known are of Middle Devonian age, but Foerste [75] has identified Lower Devonian beds in the Wells Creek Basin of Stewart County. If the Chattanooga shale is wholly of Mississippian age, the Upper Devonian series is absent in north-central Tennessee.

MIDDLE DEVONIAN SERIES

PEGRAM LIMESTONE

The type locality of the Pegram limestone is at Pegram, Cheatham County. The formation has been defined and its occurrence in central Tennessee described by Foerste.[76] In the type section it is a relatively pure heavy-bedded light-gray limestone that attains a maximum thickness of 12 feet at its westernmost exposure in the quarry north of the Nashville, Chattanooga & St. Louis Railway at the bridge across the Harpeth River. Eastward from that locality the member thins, and 3 miles to the southeast, at Newsom, in southwestern Davidson County, it is only 3 feet thick. At Newsom the formation contains the diagnostic blastid *Nucleocrinus verneuili*, as well as *Stropheodonta demissa*, *S. perplana*, *Rhipidomella penelope*, and *Nucleospira concinna*. The only other known occurrence of the Pegram limestone in north-central Tennessee is at the whirl on the Buffalo River, which is 2½ miles north of Bakerville, Humphreys County, and 46 miles west and somewhat south of the type locality. At that place the formation is a massive bed 3 feet thick, which is

[74] Dunbar, C. O., Stratigraphy and correlation of the Devonian of western Tennessee: Tennessee Geol. Survey Bull. 21, 127 pp., 1919.

[75] Foerste, A. F., Silurian and Devonian limestones of western Tennessee: Jour. Geology, vol. 11, p. 692, 1903.

[76] Foerste, A. F., Silurian and Devonian limestones of Tennessee and Kentucky: Geol. Soc. America Bull., vol. 12, pp. 425-426, 1901.

similar in lithology to the rock of the type section and is characterized by species of *Heliophyllum*, *Blothrophyllum*, *Cystiphyllum*, *Cyathophyllum*, *Cladopora*, and Bryozoa. Foerste [77] correlated the upper part of the formation with the Sellersburg limestone of Indiana, which is of late Middle Devonian (Hamilton) age, and implied that the lower part was of early Middle Devonian ("Corniferous" Onondaga) age. Dunbar [78] has correlated the entire formation with the Jeffersonville limestone of Indiana, which is early Middle Devonian (Onondaga). The Pegram limestone is undoubtedly separated from the underlying strata by a disconformity at the two localities that have been described.

Recently Pohl [79] has shown that limestone of upper Pegram age is accompanied locally by an underlying sandstone member, of probable lower Pegram age, whose maximum known thickness is 35 feet. He describes the type section and occurrence of this member as follows:

Section in district 4, Trousdale County, Tenn., in road cut on hill 1½ to 1¾ miles southwest of Valentine's store

	Feet
Mississippian:	
Chattanooga shale—	
Dead-black, thinly fissile shale with thin bed of conodont-bearing sandstone at base	To top of hill.
Gray blocky shale carrying abundant Lingulas and a few Mississippian conodonts	7
Possible break.	
Devonian (?): Black shale like first with lenses of fine, black sandstone near base, grading without apparent break into limestone below	8
Devonian:	
Pegram limestone (Sellersburg formation)—Dark-brown semicrystalline limestone carrying numerous large heliophylloid corals, becoming purer gray below and very conglomeratic (semiedgewise) near base	About 4
Pegram limestone (Jeffersonville formation)—White, brown, or pink coarse sugary sandstone, very fossiliferous at top; barren and exhibiting extremely unsettled conditions of deposition in lower 4 feet. Fauna: *Leptaena rhomboidalis*, *Stropheodonta* aff. *S. hemispherica*, *Stropheodonta demissa*, *Leptostrophia* aff. *L. perplana*, *Schuchertella* sp., *Spirifer* cf. *S. varicosus*, *Cystodictya gilberti*, *Fenestella* sp., *Rhipidomella* aff. *R. vanuxemi*, *Hadrophyllum orbignyi*, *Chonetes* aff. *C. mucronatus*, *Centronella?* *glansflagae* cf. *Pholidostrophia iowensis*, *Polypora* sp., *Loculipora* sp., *Cystodictya* sp., *Ambocoelia* sp., crinoid stems	9
Silurian: Niagaran. Formation undetermined.	

[77] Foerste, A. F., op. cit. (1901), pp. 425–426.
[78] Dunbar, C. O., op. cit., p. 91.
[79] Pohl, E. R., personal communication, February 5, 1929.

Specimens from the type locality [of the Jeffersonville limestone] at the Falls of the Ohio show in an insoluble residue from fresh material the presence of about 1 per cent silica in the form of small biterminal quartz crystals. There is apparently a complete absence of transported sand grains.

Fresh specimens of the massive limestone from the lower portion of the Pegram limestone (Jeffersonville) in the vicinity of Pegram, Cheatham County, Tenn., retain in their insoluble residues from 15 to 20 per cent sand grains of minute size, most of which are more or less completely frosted. The distance they have been transported is apparently considerable.

In outliers near and on the Highland Rim plateau north of Hartsville, Trousdale County, Tenn., are present outcrops of a varying thickness of the Jeffersonville formation. The almost exclusive constituent is here a coarse biterminally crystalline quartz sand which has undergone no abrading. The occurrence of much of the sand would suggest a diagenetic origin in which the calcium carbonate originally present has been replaced by a secondary accretion of crystalline quartz about the original sand grains.

I suspect that the sandstone has a considerable subsurface distribution, for the extent of its areal distribution is indicated in the presence of the identical sandstone in the western portion of Davidson County, 50 miles to the southwest of its occurrence in Trousdale County.

Many test wells that have been drilled in search of oil in eastern Dickson County (see pp. 142, 144–146) encounter ground water, which is reported to issue from the Chattanooga shale. It is extremely doubtful, however, whether the typical shale is sufficiently permeable to be water bearing, and hence the true source of the water is likely to be in some permeable bed that lies just above or just below the shale. It is possible that the source is the basal sandstone member of the Pegram limestone, which may persist westward beneath cover. This possibility is somewhat enhanced by the fact that in general the Devonian formations are more persistent toward the west.

CAMDEN CHERT

At the "whirl" on the Buffalo River, in southern Humphreys County, the Pegram limestone is underlain by 45 feet of alternating layers, from 2 to 9 inches thick, of dense bluish-gray limestone and yellowish chert. These strata are believed by Dunbar [80] to be transition beds between the Camden chert of Safford and Schuchert [81] and the overlying Pegram limestone, inasmuch as the fauna contains both the very diagnostic *Amphigenia curta*, of Camden age, and later species, such as *Spirifer macrothyris*. Strata which are very similar to those at the "whirl" crop out 5 miles farther west at Hurricane Rock Spring (No. 181, p. 161), on the Duck River, and are probably also to be correlated with the Camden chert. The formation is not known to occur elsewhere in north-central Tennessee.

[80] Dunbar, C. O., op. cit., pp. 80–81.

[81] Safford, J. M., and Schuchert, Charles, The Camden chert of Tennessee and its lower Oriskany fauna: Am. Jour. Sci., 4th ser., vol. 7, pp. 429–432, 1899.

LOWER DEVONIAN SERIES

Rocks of Lower Devonian age are known at two localities in the Wells Creek Basin, Stewart County, but have not been identified elsewhere in north-central Tennessee.

HARRIMAN (?) CHERT

At one of these localities, in the south bank of the Cumberland River about 1 mile southwest of Cumberland City, white, gray, and buff cherty limestone as much as 40 feet thick crops out above the Birdsong limestone. It is generally very poorly exposed. Foerste [82] has suggested that this cherty limestone may be correlative with the Camden chert, of Middle Devonian age, but Dunbar [83] has correlated it provisionally with the Harriman chert, of Lower Devonian (Oriskany) age, on the basis of a single valve of *Spirifer murchisoni?*. The detailed stratigraphic relations and areal extent of the Harriman formation in north-central Tennessee are not known.

BIRDSONG LIMESTONE

At the other locality of Lower Devonian rocks, which is at the top of a section in a railroad cut about 3 miles southwest of Cumberland City, Foerste [84] has identified limestone of the Linden group, of Helderberg age. Dunbar [85] has correlated this limestone with the Birdsong shale, and Bucher [86] has recognized in it such Helderberg fossils as *Atrypa reticularis*, *Leptostrophia beckii*, a small *Delthyris*, and *Meristella*. According to Dunbar, the formation overlaps eastward upon the Silurian rocks and is generally absent by erosion east of the Tennessee River. In the Wells Creek Basin it is represented by 10 to 20 feet of thin-bedded and somewhat cherty limestone, which is not commonly well exposed. The areal extent of this stratigraphic unit in north-central Tennessee has not been traced.

SILURIAN SYSTEM

The rocks of Silurian age that crop out on the western and northwestern flanks of the Nashville dome (see pp. 62–63) in Tennessee constitute a classic section which has long been a field of paleontologic and stratigraphic study and which has been studied in detail

[82] Foerste, A. F., Silurian and Devonian limestones of western Tennessee: Jour. Geology, vol. 11, p. 693, 1903.
[83] Dunbar, C. O., op. cit., p. 74.
[84] Foerste, A. F., op. cit. (1903), pp. 690–692.
[85] Dunbar, C. O., op. cit., p. 58.
[86] Bucher, W. H., The stratigraphy, structure, and origin of Wells Creek Basin, Tenn.: Tennessee Dept. Education Div. Geology [in preparation].

by Foerste,[87] Pate and Bassler,[88] and Miser.[89] This section comprises rocks of Cayuga, Niagara, and Albion age. The rocks of Cayuga age constitute the Decatur limestone; those of Niagara age are divided into the Lobelville, Bob, Beech River, Dixon, Lego, Waldron, Laurel, and Osgood formations; and those of Albion age are the Brassfield limestone. These formations, whose general characteristics are given in the stratigraphic section (p. 27), constitute a somewhat variegated stratigraphic unit, which is 233½ feet thick at Clifton, Wayne County.[90] The Silurian rocks thin northward and eastward along the flank of the Nashville dome and finally wedge out in Macon County, slightly east of the area represented by Plate 4. According to Miser,[91] this thinning is due to post-Silurian erosion that truncated the section at the top and is not primarily due to overlap, the only overlapping unit in the Silurian being possibly the Lobelville formation. The detailed stratigraphy of the Silurian rocks has been untangled at only a few places in north-central Tennessee, so that full discussion is not possible at this time.

As shown by Plate 4, the Silurian rocks crop out in north-central Tennessee along the base of the Highland Rim escarpment and its outliers in Williamson, Cheatham, Davidson, and Sumner Counties. According to Foerste[92] a rather full sequence of these rocks is also exposed in the Wells Creek Basin of southeastern Stewart County.

ORDOVICIAN SYSTEM

GENERAL FEATURES

The Ordovician system of north-central Tennessee includes rocks of Upper, Middle, and Lower Ordovician age, the top of the system being placed at the top of the Richmond group. In this region the Brassfield limestone, of Albion age, rests disconformably on the Fernvale formation (of early Richmond age, according to Ulrich), and the underlying Arnheim limestone, which is the basal formation of the typical Richmond group of Indiana, rests unconformably on the Leipers limestone (of early Maysville age, according to Ulrich). The stratigraphic break at the base of the Richmond group is considered by Ulrich and Bassler to be of considerable magnitude and greater than the break at its top, the formations with which the

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[87] Foerste, A. F., Silurian and Devonian limestones of Tennessee and Kentucky: Geol. Soc. America Bull., vol. 12, pp. 395–444, 1901; Silurian and Devonian limestones of western Tennessee: Jour. Geology, vol. 11, pp. 554–583, 679–715, 1903.

[88] Pate, W. F., and Bassler, R. S., The late Niagaran strata of west Tennessee: U. S. Nat. Mus. Proc., vol. 34, pp. 407–432, 1908.

[89] Miser, H. D., Mineral resources of the Waynesboro quadrangle, Tenn.: Tennessee Geol. Survey Bull. 26, pp. 18–22, 1921.

[90] Pate, W. F., and Bassler, R. S., op. cit., pp. 411–412.

[91] Miser, H. D., op. cit., pp. 18–22; also personal communication.

[92] Foerste, A. F., Silurian and Devonian limestones of western Tennessee: Jour. Geology, vol. 11, pp. 690–694, 1903.

Leipers is in contact ranging in age from early Richmond (Arnheim limestone) to late Devonian or Mississippian (Chattanooga shale). Hence they include the rocks of Richmond age in the Silurian system. The angular discordance is usually much too small to be discernible in a small outcrop and is apparent only when diagnostic faunal horizons are traced long distances.

The Ordovician system comprises many limestone and calcareous-shale formations which were deposited in successive broad overlapping belts from east or west across the Nashville dome. According to Ulrich [93] and Bassler,[94] the succession of overlaps was due to crustal oscillation. Hence the Ordovician formations do not follow one another in simple succession but interfinger in a rather complex manner, which can be traced in the field only by precise classification of the fauna.

UPPER ORDOVICIAN SERIES

FERNVALE FORMATION

The Silurian rocks are underlain disconformably at several places in the western part of the region by the Fernvale formation, whose type locality is at Fernvale,[95] in the valley of South Harpeth Creek, southwestern Williamson County. This formation is made up largely of soft chocolate-colored and green shale with one or more beds of coarsely crystalline flesh-colored or mottled limestone and, locally, a basal member of highly ferruginous reddish or even vermilion limestone from 5 to 6 feet thick. At some places the lower beds are conglomeratic and highly phosphatic. Where the formation is thin it may be composed wholly of shale. The Fernvale formation, which ranges in thickness from 40 feet to the vanishing point, occurs only in scattered small areas on the western flank of the Nashville dome. Hayes and Ulrich have explained this discontinuity by the hypothesis that the formation was deposited only in elongate embayments, but this hypothesis is not generally accepted.

ARNHEIM LIMESTONE

The Fernvale formation is underlain at a few places in Williamson County and possibly elsewhere by the Arnheim limestone, which is made up of blue granular crystalline limestone and interbedded shale. Usually the Arnheim limestone is less than 3 feet thick.

LEIPERS LIMESTONE

The Leipers limestone takes its name from Leipers Creek, a tributary of the Duck River in extreme southwestern Williamson County

[93] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 416–419, 428–430, 1911.

[94] Bassler, R. S., Embayments and overlaps in central Tennessee [abstract]; Geol. Soc. America Bull., vol. 34, p. 132, 1923.

[95] Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95), p. 2, 1903.

and the adjacent part of Maury County. In the type region the complete section comprises eight members, as follows:

Section of the Leipers limestone in the type region

[Hayes, C. W., and Ulrich, E. O., op. cit., p. 2]

	Feet
Unconformity.	
Earthy blue limestone, dense in fresh exposures but weathering knotty; current-bedded, inasmuch as its only common fossil, *Platystrophia lynx*, is generally waterworn; may be absent.	
Soft calcareous light-blue shale, which occurs at very few localities. This is the horizon of the branching bryozoan *Bythopora gracilis* (Nicholson), which is very abundant in the vicinity of Cincinnati	Thin or absent.
Earthy limestone and calcareous shale, widely distributed; contains *Orthorhynchula linneyi* and *Tetradium fibratum* and is very similar lithologically to several beds in the underlying Catheys formation which hold the same species; thickness not more than	7
Knotty impure limestone and shale, blue and gray; extremely fossiliferous, monticuliporoid Bryozoa being especially abundant. Of more than 50 species of fossils, the most characteristic are *Amplexopora columbiana*, *Homotrypella nodosa*, and *Strophomena planoconvexa*	5–12
Granular crystalline gray limestone, sandy at some places, slightly phosphatic, and sparingly fossiliferous. Maximum thickness more than	40
Thin-bedded, shaly limestone which is extremely fossiliferous. Of the fossils, the most diagnostic are a long, hinged form of *Platystrophia laticosta*, a species of *Hindia*, and several undescribed bryozoans	6–14
Mottled crystalline limestone which contains shells of *Ctenodonta*, a large branching *Escharopora*, and a small ramose bryozoan (*Bythopora*); not present in all sections. Maximum thickness	20
Shale and thin-bedded limestone, of which an undetermined species of *Bucania* or *Salpingostoma* is characteristic. Maximum thickness	10
Catheys formation or Cannon limestone.	

Elsewhere in north-central Tennessee, however, these eight members can not always be differentiated; at one locality the entire formation may be knotty earthy limestone, and at another it may be granular crystalline limestone. The upper half of the Leipers limestone contains deposits of rock phosphate at three horizons, each of which has been the scene of mining activity at one or more points in the central basin. These deposits have been described by Hayes and Ulrich.[96]

Ulrich [97] has concluded that the fauna of the Leipers formation, which is of undoubted Upper Ordovician (Maysville) age, is very

[96] Hayes, C. W., and Ulrich, E. O., op. cit., p. 5.

[97] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 299–300, 1911.

similar in its general aspects to and is actually a recurrence of the fauna from the underlying Catheys formation of Middle Ordovician (upper Trenton) age. Moreover, the Leipers and Catheys formations are very similar in lithology, so that extreme care must be used if they are to be discriminated accurately in the field.

On the west side of the Nashville dome the Leipers formation reaches a maximum thickness of 100 feet but locally has been completely removed by erosion that began in Upper Ordovician (Lorraine) time. Toward the east, however, the formation thins and becomes less persistent, and over extensive areas on the east side of the basin it is entirely absent. These stratigraphic relations are due in small part to post-Leipers erosion but more especially to the fact that the Leipers formation overlaps or transgresses the flank of the Nashville dome from the west and was not deposited uniformly over the entire region. Northwest of the type area, however, in the Wells Creek Basin of Stewart County, the formation has not been found, although the stratigraphic relations have not been traced in detail, and it is not clear whether the omission is due to erosion or to overlap. At most localities the formation lies immediately beneath the Chattanooga shale, although at some it is separated from the Chattanooga shale by Silurian and Devonian rocks.

MIDDLE ORDOVICIAN SERIES

CATHEYS LIMESTONE

On the north and west sides of the Nashville Basin the Leipers formation is underlain by the Catheys limestone, whose type area is the basin of Catheys Creek,[98] a tributary of the Duck River in Lewis and Maury Counties. The two formations are separated by a slight erosional unconformity. The Catheys formation, as deposited, was not less than 50 feet and in some places was at least 100 feet thick, but the subsequent erosion removed much of the accumulated material. The upper half of the formation is as a rule made up of compact impure blue limestone in layers from a few inches to 4 feet thick, separated by thin layers of calcareous shale. Northward from the type locality more and more beds of fine-grained impure limestone appear in this part of the formation. The fossil fauna, which is restricted to the fine-grained beds and with them increases in abundance toward the north, includes Brachiopoda, Mollusca, Crustacea, and, locally, Bryozoa. Several large ostracodes, of the genera *Leperditia* and *Isochilina*, are especially characteristic of these beds. The lower half of the formation is made up of highly variable beds of fossiliferous knotty and fine-grained earthy limestone and shale, many of which are identical in lithology with the overlying Leipers formation. In these beds *Cyclonema varicosum* is probably the most diagnostic fossil.

[98] Hayes, C. W., and Ulrich, E. O., op. cit., p. 2.

Locally the basal member is a rather massive coarsely crystalline limestone which incloses masses of *Stromatocerium pustulosum* from 3 inches to 3 feet in diameter. At some places this *Stromatocerium*-bearing bed is replaced, at least in part, by siliceous shale which is filled with portions of the sponge *Pattersonia aurita* and corals of the genus *Columnaria*. Elsewhere the basal member resembles the granular beds of the underlying Bigby limestone and, in common with that formation, contains *Rafinesquina alternata* in abundance, although always in association with characteristic Catheys Bryozoa, such as *Heterotrypa parvulipora*. The lower half of the Catheys formation also contains corals of the genera *Streptelasma* and *Tetradium*, which, with the *Stromatocerium* and *Columnaria* to which reference has been made, are recurrent in the overlying Leipers formation, as is pointed out by Ulrich.[99] The Catheys fauna is of late Middle Ordovician (upper Trenton) age.

The Catheys limestone crops out over extensive areas of medium altitude in eastern Williamson County and in southern Davidson and Sumner Counties. It also crops out on the upper slopes and tops of the higher ridges in eastern Wilson County and along the east, south, and west sides of Rutherford County. (See pl. 4.) The Catheys fauna has not been recognized in the Wells Creek Basin of Stewart County.

CANNON LIMESTONE

The Cannon limestone was originally defined by Ulrich [1] as including all the strata that lie below the Chattanooga shale and above the Hermitage formation on the east side of the Nashville dome, the type region being Cannon County. As thus defined, the formation comprises an upper portion whose maximum thickness is about 100 feet and a lower portion 150 to 200 feet thick. The upper portion contains a Catheys fauna and is the eastward extension of the typical Catheys limestone. The lower portion consists for the most part of massive gray limestone, some beds of which are granular and others knotty and earthy; many of the strata are highly fossiliferous.[2] This lower portion is equivalent to the Perryville, Flannagan, and Bigby formations of Kentucky, though the typical Bigby limestone is wholly or in part missing in and about Cannon County.

Later Ulrich [3] redefined the Cannon limestone by excluding the Catheys limestone at the top and the Bigby limestone at the bottom, so that the term might be applied to the strata on both the east and west flanks of the Nashville dome. The redefined formation includes

[99] Ulrich, E. O., op. cit., pp. 299–300.

[1] Idem, pp. 417–418, 429.

[2] Galloway, J. J., Geology and natural resources of Rutherford County, Tenn.: Tennessee Geol. Survey Bull. 22, p. 53, 1919.

[3] Ulrich, E. O., in Secrist, M. H., The zinc deposits of east Tennessee: Tennessee Dept. Education Div. Geology Bull. 31, p. 16, 1924.

50 to 250 feet of limestone. The Cannon fauna is of late Middle Ordovician (Trenton) age, though it is not within the scope of this project to reclassify the fossil species according to Ulrich's restricted definition.

The Cannon limestone crops out beneath the Catheys in areas of medium altitude on the east flank of the Nashville dome. It is generally absent on the west flank of the dome, though at some places its truncated and overlapping edge comes between the Catheys and Bigby limestones. It is not known to exist in the Wells Creek Basin of Stewart County.

BIGBY LIMESTONE

The Catheys limestone, or the Cannon limestone where that formation is present, is underlain at most places on the north and west sides of the Nashville dome by the Bigby limestone, the type locality of which is the basin of Bigby Creek, a tributary of the Duck River in western Maury County. At and near its type locality the Bigby limestone comprises relatively homogeneous beds of semi-oolitic or granular crystalline phosphatic gray or bluish limestone. Beds of sandy calcareous shale several feet thick occur locally at the top of the formation, and shaly beds occur locally at its base. The formation ranges in thickness from 30 to 100 feet, but the minimum thickness as deposited was about 50 feet. In the upper part of the formation in this region bryozoans are very abundant, especially *Constellaria teres*, *C. florida emaciata*, *C. grandis*, and *Eridotrypa briareus*. Other fossils are found only in local thin shaly layers or in small lenticular beds of pure limestone. The lower fourth of the formation is almost devoid of fossils except *Rafinesquina alternata* and the minute forms of Mollusca which are common to all the phosphatic limestones of central Tennessee.

As the formation is traced northeastward to and beyond Nashville it is found to thicken materially and become less granular and more fossiliferous. At Nashville it is separated from the overlying Catheys formation by a minor disconformity and is divisible into three distinct members, which are well exposed in an abandoned quarry south of the Tennessee Central Railroad at Loveman's crossing, in eastern Nashville. (See pl. 7, *A*.) The topmost member, which is generally about 28 feet thick, is a dark-blue medium-grained limestone, which contains a few large colonies of *Stromatocerium pustulosum;* this is the Ward limestone of Safford.[4] The member is underlain by 8 to 12 feet of very compact, brittle, heavy-bedded limestone which is dove-colored on fresh surfaces but chalky white on weathered surfaces; this is the "Dove" limestone of Safford. The basal member at Nashville is the "Capitol" limestone of Safford, about 25 feet

[4] Safford, J. M., The geology of Tennessee, pp. 277-278, 1869. Jones, P. M., Geology of Nashville and vicinity [thesis, Vanderbilt University], 56 pp., map, Nashville, 1892.

thick, which is a medium-bedded phosphatic sandy limestone made up in large measure of fragments of shells and corals. Its individual laminae are characteristically cross-bedded (pl. 7, *B*), as is well shown in the masonry of the State capitol at Nashville, the rock for which was quarried from this member.

Still farther east,[5] in Trousdale and Smith Counties, beyond the area represented by Plate 4, the Bigby limestone is 120 to 150 feet thick, of which fully half consists of very compact light bluish-gray or tan limestone. The formation as a whole contains much more subcrystalline matter than the Bigby limestone of the type locality. Moreover, the faunal differences are even more striking than these lithologic differences, nearly all the beds in Trousdale and Smith Counties being profusely fossiliferous and containing a large and varied fauna. In this fauna the Mollusca predominate and the Bryozoa and Brachiopoda that characterize the Bigby limestone of the type locality are rare or absent altogether.

In Rutherford County, according to Galloway,[6] the Bigby limestone is variable in lithology and is at most 30 feet thick. In the central-western part of the county, near Almaville, it is a gray massive granular laminated limestone, of which some beds are sandy and others are shaly and highly fossiliferous. The most abundant species of the locality are *Hebertella frankfortensis*, *Rhynchotrema increbescens*, *Hallopora multitabulata* var., *Platystrophia colbiensis*, *Tetradium minus*, and several undetermined species. The characteristic fossils of the type locality are not present. North of Almaville the formation is a granular gray or brown laminated and cross-bedded limestone that contains no fossils.

The Bigby limestone is relatively persistent at its proper horizon along the west and north sides of the central basin but is thin or absent at most places on the east side.[7] Its fauna is of Middle Ordovician (middle Trenton) age.

HERMITAGE FORMATION

The Bigby limestone is underlain disconformably, in all parts of the Nashville Basin, by the Hermitage formation ("*Orthis* bed" of Safford), whose type section is at Hermitage station on the Tennessee Central Railroad, in eastern Davidson County. In the Columbia quadrangle Hayes and Ulrich [8] subdivided the Hermitage formation into two portions, the upper of which, about 40 to 50 feet thick, is composed of medium-bedded sandy and phosphatic subgranular limestone that is accompanied locally by a small amount of shale. Many of these beds are crowded with the silicified shells of *Dalmanella testudinaria*

[5] Hayes, C. W., and Ulrich, E. O., op. cit., p. 2.
[6] Galloway, J. J., Geology and natural resources of Rutherford County, Tenn.: Tennessee Geol. Survey Bull. 22, pp. 51–52, 1919.
[7] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 416, 1911.
[8] Hayes, C. W., and Ulrich, E. O., op. cit., pp. 1–2.

(*Orthis testudinaria* of Safford), which is the most characteristic fossil species of the formation. The lower portion of the formation, from 12 to 20 feet thick, is composed of thin-bedded earthy and sandy blue limestone whose beds are separated by seams of gray or bluish shale. At Nashville the formation retains these same general characteristics, the subgranular upper beds with the characteristic *Dalmanella testudinaria* being well exposed in the quarry south of the Tennessee Central Railroad at Loveman's crossing, in the eastern edge of the city, although they are much thinner than in the Columbia quadrangle. Toward the center of the Nashville Basin, in Williamson County and western Rutherford County, the formation consists almost wholly of flaggy beds of blue-gray sandy and earthy limestone separated by seams of shale. These beds are usually devoid of fossils, are locally phosphatic, and at many places simulate thin-bedded earthy yellowish sandstone on weathered surfaces. Toward the northeast these flaggy beds grade laterally into a highly variable series of impure limestone, shale, and calcareous sandstone with local beds of cherty material.

The Hermitage formation ranges in thickness between 40 and 80 feet in the Nashville Basin and crops out at its proper horizon throughout the area. It is well exposed in the valley of the Harpeth River in the vicinity of Franklin, where it is quarried at several points, and in the valley of the Cumberland River about Nashville. In Rutherford County and southern Wilson County it crops out only on the upper slopes of the higher hills and ridges that surround the Nashville Basin. In the Wells Creek Basin of Stewart County strata that are equivalent to the Hermitage formation ("Saltillo limestone" of Foerste [9]) crop out beneath the Brassfield limestone, of basal Silurian (Albion) age, although their thickness and the nature of the contact are not disclosed. The Hermitage formation is of Middle Ordovician (basal Trenton) age.

LOWVILLE LIMESTONE

In north-central Tennessee the Hermitage formation is underlain disconformably by limestones that have heretofore been called Carters limestone but are herein designated Lowville limestone, in accordance with Bassler's assignment.[10] Beds of post-Lowville Black River age are not known to occur in north-central Tennessee. Bassler has divided this formation into an upper member, composed largely of thin beds of very dense dove-colored limestone and yellowish-gray shale, and a lower member, which comprises beds of compact white or light-blue cherty limestone from 1 to 4 feet thick. The upper member, which contains the guide fossil *Tetradium cellulosum* and such other forms as *Columnaria halli*, *Streptelasma profundum*, and

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[9] Foerste, A. F., Silurian and Devonian limestones of western Tennessee: Jour. Geology, vol. 11, p. 690, 1903.

[10] Bassler, R. S., The stratigraphy of the central basin of Tennessee: Tennessee Dept. Education Div. Geology Bull. 38, p. 60, 1932.

Dystactospongia minor, has long been correlated by Ulrich and Bassler with the Lowville limestone of New York. Recently Bassler [10] has correlated this member with the "Tyrone formation" of Miller [11] in central Kentucky. It is generally present on the north and east flanks of the Nashville dome but according to Bassler is absent on the west flank. The lower member of the Lowville limestone is generally present on all sides of the Nashville dome. It is correlated by Bassler with the "Oregon formation" of Miller in central Kentucky [12] and with the beds originally called Carters limestone, from the basin of Carters Creek,[13] a tributary of the Duck River in central-northern Maury County. This member is here designated the Carters limestone member of the Lowville limestone, which is a restriction of the name Carters as heretofore used. The member is somewhat more earthy on the west side of the Nashville dome than on the east.

Nelson [14] has identified a bed of greenish sticky clay or bentonite 21 inches thick and 8 feet below the top of the Lowville limestone at Singleton, Bedford County, about 50 miles southeast of Nashville. He has also identified the same stratum tentatively in the vicinity of Nashville and as far north as Highbridge, Ky., and as far south as Birmingham, Ala. Its maximum known thickness is 10 feet, near Highbridge. This bentonite is classified by Larsen as a decomposed volcanic ash.

The Lowville limestone ranges from 40 to 110 feet in thickness in north-central Tennessee, though it is commonly about 65 feet thick; its lower member, the Carters limestone member, is 40 to 60 feet thick in its type locality. The Lowville limestone crops out in an irregular band along the middle slopes of the hills that surround the Stone River Basin in Rutherford County and southeastern Wilson County and is widely distributed in the valley of the Cumberland River as far downstream as Nashville. It also crops out over a large area in the valley of the Harpeth River, where it extends downstream within 1½ miles of Franklin. Northwest of the Nashville Basin, in the Wells Creek Basin of Stewart County, the Lowville limestone also crops out, overlain by limestone of probable Hermitage age and underlain by limestone of Beekmantown(?) age.[15] (See p. 191.) Both the upper and lower contact zones are concealed in that area.

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[10] Bassler, R. S., op. cit., p. 64.

[11] Miller, A. M., The lead and zinc-bearing rocks of central Kentucky: Kentucky Geol. Survey Bull. 2, pp. 14–16, 1905.

[12] Idem, pp. 13–14.

[13] Safford, J. M., The geology of Tennessee, p. 263, 1869. Hayes, C. W., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Columbia folio (No. 95), p. 1, 1903.

[14] Nelson, W. A., Volcanic ash bed in the Ordovician of Tennessee, Kentucky, and Alabama: Geol. Soc. America Bull., vol. 33, pp. 605–615, 1922.

[15] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 671, 1911.

LOWER ORDOVICIAN SERIES

LEBANON LIMESTONE [16]

The Lowville limestone is underlain disconformably by the Lebanon limestone, the type locality of which is the city of Lebanon,[17] Wilson County. The Lebanon limestone generally comprises many beds of compact brittle light-gray, dove-colored, or bluish-gray limestone in alternation with thin seams of bluish-gray or yellow clay. The layers of limestone are from 1 to 6 inches thick, and those of clay only a fraction of an inch. Some of the limestone beds are sandy, others are laminated, and still others are mottled; some layers are dense and unfossiliferous, others are coarsely crystalline; furthermore, the beds show ripple and rill marks at many different horizons. At many places a massive bed of drab coarsely crystalline unfossiliferous limestone from 2 to 11 feet thick, very similar lithologically to the underlying Ridley limestone, occurs in the lower half of the formation.

The Lebanon limestone is fossiliferous at many horizons, although some beds are barren and others are composed almost entirely of the shells of one or several species. The most abundant and characteristic fossils of the formation are

Plectambonites sp.
Scenidium anthonense.
Batostoma libana.
Escharopora briareus.
Leperditia fabulites.
Orthis tricenaria.
Phragmolites grandis.
Pianodema subaequata.
Pachydictya cf. P. foliata.
Pterygometopas troosti.
Rhynchotrema minnesotensis.
Chasmatopora sublaxa.
Streptelasma cf. S. parasiticum.
Zygospira saffordi.

The Lebanon limestone ranges in thickness from 80 to 125 feet and in general thins westward. It crops out in a band from half a mile to 5 miles wide along the base of the hills that bound the Nashville Basin peneplain in Rutherford County. It also covers extensive areas in Davidson, Williamson, and Wilson Counties. (See pl. 4.) The generalized form of its outcrop is an elliptical band surrounding the Nashville dome. (See pp. 62–63.) The formation is not known to crop out in the Wells Creek Basin of Stewart County. (See p. 191.)

RIDLEY LIMESTONE

The thin-bedded Lebanon limestone is underlain, in seeming conformity, by the Ridley limestone, the type section [18] of which extends half a mile southward from the Davis mill (formerly Ridley's mill),

[16] This discussion of the Lebanon limestone and the underlying formations of the Stones River group is adapted in large part from Galloway, J. J., Geology and natural resources of Rutherford County: Tennessee Geol. Survey Bull. 22, pp. 32–45, 1919.

[17] Safford, J. M., and Killebrew, J. B., The elements of the geology of Tennessee, p. 125, Nashville, Foster & Webb, 1900.

[18] Safford, J. M., The geology of Tennessee, p. 261, 1869.

near Jefferson, northwestern Rutherford County. The Ridley limestone is for the most part a massive, dense light-blue, dove-colored, or light-brown limestone, which at some places contains abundant bluish-black or white chert. Locally, as at Sulphur Spring, 1¼ miles north of Jefferson, it contains thin-bedded or platy members. The color of the formation is due largely to the presence of bituminous matter, the odor of which is usually noticeable when the rock is freshly broken; at many places it is streaked with granular fucoid markings of lighter color. The weathered rock is light gray and has a finely granular appearance, but the weathering does not extend more than 1 or 2 inches into the rock.

The Ridley limestone can not be discriminated from the older Murfreesboro limestone on the basis of lithology alone. These two formations are alike in color, in hardness, and in brittleness; they contain about the same amount of chert and bituminous matter; each is platy at a few places; their changes on weathering and their influence upon topography and soil are identical. Hence the Ridley limestone can be identified only where it is fossiliferous or where its contact with the overlying Lebanon limestone or the underlying Pierce limestone is exposed.

The Ridley limestone is not highly fossiliferous, although *Stromatocerium* is locally abundant. The most common and diagnostic species are *Stromatocerium rugosum*, *Camarella volborthi*, *Hebertella bellarugosa*, *Gonioceras anceps*, *Orbignyella sublamellosa*, *Liospira convexa*, *Rafinesquina minnesotensis*, and *Protorhyncha ridleyana*.

The Ridley limestone is from 95 to 120 feet thick, although most of the measured sections are between 100 and 105 feet. It crops out over the greater part of the Nashville Basin peneplain in Rutherford County and is also exposed in Davidson, Williamson, and Wilson Counties. (See pl. 4.) In spite of its rather general distribution, however, complete sections of the formation are exposed at few places on account of the low relief of the area of outcrop.

PIERCE LIMESTONE

The Ridley limestone is underlain by the Pierce limestone. The two formations seem to be conformable except at Jefferson, Rutherford County, where the contact surface between them is undulating with respect to the bedding planes. The Pierce limestone takes its name from Pierce's mill,[19] half a mile south of Walter Hill, Rutherford County. It is rather variable in lithology and comprises many layers of dense blue or gray unfossiliferous limestone between half an inch and 2 inches thick and one or more massive beds of coarsely crystalline bluish-gray or brown fossiliferous limestone. The coarsely

[19] Safford, J. M., op. cit., p. 261.

crystalline beds may occur at any horizon in the section; furthermore, their composite thickness is generally between one-third and two-thirds the thickness of the formation. The platy layers are separated by very thin seams of calcareous shale, which weathers rapidly and allows the rock to disintegrate into a mass of loose slabs. In general the Pierce limestone is lithologically very similar to the Lebanon limestone, although it is much thinner; it also resembles platy facies of the Murfreesboro and Ridley limestones.

The fossil fauna of the Pierce limestone is rich in the number of species and of specimens alike. The bryozoans are especially abundant and valuable as stratigraphic guides. The most common and characteristic species are *Nicholsonella pulchra*, *N. frondifera*, *Anolotichia explanata*, *Stictoporella cribilina*, *Pianodema stonensis*, and *Batostoma* sp.

The Pierce limestone, which is from 23 to 28 feet thick, crops out in narrow peripheral bands surrounding the minor structural domes that expose the Murfreesboro limestone in central Rutherford County. (See pl. 4.) Even though the outcrops are narrow—usually less than a quarter of a mile wide—complete sections are exposed for study at only a few localities.

MURFREESBORO LIMESTONE

The Pierce limestone is underlain by the Murfreesboro limestone, the oldest formation to crop out at the apex of the Nashville dome, whose type locality [20] is the vicinity of the city of Murfreesboro Rutherford County. The contact between the two seems to be strictly conformable except at a point half a mile west of Lofton, Rutherford County, where the upper 10 feet of the Murfreesboro is missing. The Murfreesboro limestone is generally a thick-bedded dense, brittle, dark bluish-gray or drab limestone, which emits a bituminous odor when freshly broken and contains much disseminated chert. The individual beds are from 6 inches to 4 feet thick and in some sections are separated by thin partings of shale or sand. This facies of the formation is lithologically almost identical with the Ridley limestone, which lies above it. On Bradleys Creek at Lascassas, however, a shore phase of the formation is exposed, the lower 15 feet of the 27 feet of beds that crop out being sandy, laminated, sun-cracked, and ripple-marked limestone that contains laminated chert nodules.

The Murfreesboro limestone contains few fossils other than fucoids (?), but silicified forms are abundant at some places in the chert débris that remains after advanced weathering. The most common and diagnostic species are *Salterella billingsi*, *Lophospira perangulata*, *Liospira abrupta*, *Helicotoma tennesseensis*, *H. declivis*, and *Leperditia fabulites*.

[20] Safford, J. M., and Killebrew, J. B., op. cit., p. 125.

The Murfreesboro limestone crops out in north-central Tennessee only at the apexes of small structural domes along the two forks of the Stone River and within the city limits of Murfreesboro, in central Rutherford County. (See pl. 4.) Its total outcrop area is about 15 square miles. The exposed beds are about 70 feet thick, although the base of the formation is not exposed and the total thickness is indeterminate at the surface.

The test well drilled by the Franklin Oil & Fuel Co. 1½ miles north of Murfreesboro (No. 427, pl. 4, and p. 60) has its casing head about 15 feet below the top of the Murfreesboro limestone and passes through dense bluish-gray and dove-colored limestone to a depth of 285 feet. What portion of these unexposed beds should be correlated with the Murfreesboro limestone is problematic.

PRE-LOWVILLE ROCKS OF THE WELLS CREEK BASIN

The group of low rounded hills that coincides with the apex of the Wells Creek uplift, in southeastern Stewart County (see pl. 4 and pp. 65–67), exposes a light-gray fine-grained slightly cherty limestone of indeterminate thickness which Ulrich [21] has called the "Wells chert." Ulrich states that the "Wells chert" lies beneath the Lowville limestone, though the contact is concealed by detritus, and that its base is not exposed. Over most of its outcrop this limestone is concealed by a thick mantle of residual clay and chert, in which most of the chert fragments are porous or even spongy, soft, and red or brown. In some places this chert débris is highly fossiliferous, the fauna listed by Ulrich comprising slender gastropods of the genera *Hormotoma* and *Coelocaulus*, which are especially abundant, as well as *Ophileta*, *Helicotoma*, *Holopea*, a small *Orthoceras* that resembles *O. primogenium*, a species of *Protocycloceras*, a slender *Salterella?*, *Cameroceras* sp., *Cyrtoceras* cf. *confertissimum*, *Maclurea emmonsi?*, an orthoid similar to *Orthis electra*, a striated *Syntrophia*, and an *Isochilina* which resembles *I. armata*. This fauna is classified by Ulrich as of "Canadian" age, which corresponds to the Beekmantown group of New York. On the basis of this classification the "Wells chert" seems to be separated from the overlying Lowville limestone by a stratigraphic hiatus which is equivalent to the entire Stones River group.

Foerste [22] refers casually to the "Wells limestone" of the central part of the Wells Creek Basin but also lists a "Wells" fauna [23] to which he ascribes an "upper Stones River" age, in seeming conflict with Ulrich's classification.

[21] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 671, 1911.

[22] Foerste, A. F., Silurian and Devonian limestones of western Tennessee: Jour. Geology, vol. 11, p. 691, 1903.

[23] Idem, pp. 705–706.

Bucher [24] discriminates two stratigraphic units in the pre-Trenton rocks of the Wells Creek Basin. The upper unit is possibly as much as 500 feet thick and comprises strata of dense light-gray and blue crystalline limestone; it includes at its top the strata of Lowville age above described. It is much thicker than the Lowville limestone of the Nashville Basin and may well prove to contain rocks of Stones River age, as is suggested by Foerste's faunal list. Bucher states that his collections of fossils have not yet been classified and that it is not known if they confirm Ulrich's conclusion that the stratigraphic break between rocks of Lowville age and the "Wells chert" in this district is equivalent to all the Stones River group. The lower unit, which is perhaps 200 feet thick, comprises alternating layers of dense light-gray limestone and crystalline dolomite as much as 30 feet thick. At one place the dolomite grades laterally into calcareous shale and sandstone 28 feet thick. Bucher classifies this lower unit as of upper Beekmantown age, in accord with Ulrich's classification.

Exact classification of these pre-Lowville rocks of the Wells Creek Basin remains a work of the future. Furthermore both the names "Wells chert" and "Wells limestone" conflict with the firmly established Wells formation in the Pennsylvanian of eastern Idaho. In view of these conditions, these rocks are not named as a stratigraphic unit in this report and are regarded as of uncertain age, possibly as old as Beekmantown.

ROCKS NOT EXPOSED AT THE SURFACE

GENERAL FEATURES

The Murfreesboro limestone is the oldest formation that crops out in the Nashville Basin, and the limestone of Beekmantown (?) age is the oldest that crops out at any place in north-central Tennessee. The general character of the underlying strata is disclosed by the following records of two deep wells that have been drilled in the Nashville Basin in search of petroleum. However, there is no sound basis upon which these records can be correlated with the strata that crop out in adjacent regions, inasmuch as the unexposed rocks are parted by at least one major unconformity and can not be differentiated with certainty by petrographic character.

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[24] Bucher, W. H., The stratigraphy, structure, and origin of Wells Creek Basin: Tennessee Dept. Education Div. Geology [in preparation].

Driller's log of test well on Arthur Stevens property at Bordeaux, 3 miles northwest of Nashville

[No. 295, pl. 4]

	Feet
Limestone, blue; fresh water at 85 feet	0–141
Limestone, black; hydrogen sulphide water at 195 feet	141–240
Limestone, brown	240–380
Limestone, gray	380–475
Limestone, brown	475–525
Limestone, gray	525–550
Limestone, brown, bituminous	550–625
Limestone, gray	625–645
Limestone, brown	645–695
Limestone, gray	695–700
Limestone, brown	700–926
Limestone, white	926–932
Limestone, brown	932–938
Limestone, gray	938–968
Limestone, blue	968–1, 000
Limestone, brown; small yield of hydrogen sulphide water at 1,030 feet	1, 000–1, 043
Sand and limestone, white; large yield of water from 1,050 feet downward	1, 043–1, 140
Sandy limestone, brown	1, 140–1, 160
Sandy limestone, gray	1, 160–1, 165
Sandstone, white, principal water-bearing bed	1, 165–1, 175
Calcareous sandstone, white	1, 175–1, 205
Calcareous sandstone, brown	1, 205–1, 210
Limestone, gray	1, 210–1, 240
Limestone, brown	1, 240–1, 260
Limestone, gray	1, 260–1, 320
Limestone, dark brown	1, 320–1, 325
Limestone, gray	1, 325–1, 365
Limestone, brown	1, 365–1, 373
Limestone, gray	1, 373–1, 420
Rock, white, dense	1, 420–1, 424
Limestone (?), dark blue, very hard	1, 424–1, 430
Limestone, light gray; upper 3 feet very hard; 20 per cent of sample from 1,060 feet is crystalline and insoluble matter	1, 430–1, 466
Sandy limestone, brownish gray, bituminous; 24 per cent of rock made up of sand	1, 466–1, 473
Limestone, white, dense	1, 473–1, 476
Sandy limestone, dark gray, soft	1, 476–1, 485
Limestone, yellowish, dark gray, soft	1, 485–1, 491

Diameter of well, at top, 10 inches; at bottom, 6 inches; total depth, 1,491 feet; completed in September, 1924. On July 25, 1927, well flowed about 35 gallons a minute of water with temperature 66° F. Casing head in middle of Bigby limestone.

Partial log of Franklin Oil & Fuel Co.'s test well on J. M. Alsup property, 1½ miles north of Murfreesboro, Rutherford County, Tenn.

[No. 427, pl. 4]

	Feet
Record missing	0–40
Limestone, fine grained, light gray and dove-colored; water bearing at depth of 70 feet	40–90
Limestone, dense, dark bluish gray; phosphatic sandy limestone at base	90–210
Limestone, dense, light gray and dove-colored	210–285
Magnesian limestone, dense, white, yellowish, or gray; little or no chert	285–330
Magnesian limestone, fine grained, light gray, containing dense white chert	330–440
Magnesian limestone, white or light gray; little or no chert	440–610
Sandstone, dark buff; grains of chert and of magnesian limestone in calcareous and ferruginous cement	610–620
Magnesian limestone, massive or crystalline, white or light gray; little or no chert	620–680
Magnesian limestone, fine grained, light gray or yellowish, containing much white or light-gray chert and scattered crystals of pyrite	680–995
Magnesian limestone, very fine grained, yellowish; little or no chert; calcareous sand at depth of 1,080 feet	995–1,150
Limestone, bluish gray, fine grained	1,150–1,170
Magnesian limestone, yellowish gray; no chert; calcareous sand at depth of 1,200 and 1,235 feet	1,170–1,240
Magnesian limestone, gray, granular, cherty	1,240–1,255
Magnesian limestone, fine grained, yellowish gray; moderate amount of white or smoky chert	1,255–1,355
Magnesian limestone, fine grained, white or yellowish gray, iron stained; contains rounded grains of chert and magnesian limestone, also moderate amount of white chert	1,355–1,425
Dolomite, dense or crystalline, white, with white and smoky chert	1,425–1,465
Magnesian limestone, dense or fine grained, light buff or gray; no chert	1,465–1,540
Magnesian limestone, white or light gray, dense, with much banded bluish-gray chert and some crystalline quartz	1,540–1,600
Magnesian limestone, dense or fine grained, white or light gray, moderately cherty	1,600–1,680
Magnesian limestone and dolomite, massive, very light gray; no chert	1,680–1,715
Dolomite, light gray, very cherty, with much iron oxide	1,715–1,725
Dolomite, dense, white to dark gray, extremely cherty, with some crystalline quartz	1,725–1,795
Dolomite, dense or fine grained, dark gray; no chert	1,795–1,810
Dolomite, light gray, extremely cherty, with much iron oxide	1,810–1,825
Dolomite, white to dark gray, massive and crystalline; white and smoky chert very abundant from 1,845 to 1,860 feet	1,825–1,930

Diameter of well, at top, 10 inches; at bottom, 8 inches; depth in October, 1927, 1,930 feet, with drilling in progress. Log based upon examination of cuttings sampled by Franklin Oil & Fuel Co. at each multiple of 10 feet from a depth of 40 to 1,930 feet. Casing head about 15 feet below top of Murfreesboro limestone.

ST. PETER (?) SANDSTONE

Several deep wells in southern Kentucky reach a somewhat variable sandstone or sandy limestone stratum which has been correlated by Munn [25] and by Shaw and Mather [26] with the St. Peter sandstone of the upper Mississippi Valley. This stratum is in the lower part of the Ordovician system of that area and is from 1,470 to 1,600 feet below the Chattanooga shale. Butts,[27] on the other hand, presents data which suggest that the supposed St. Peter sandstone penetrated by wells in western Kentucky and southern Indiana is not a single stratum but rather comprises several sandy layers at different horizons in a mass of sandy limestone and dolomite. No one of these layers can be correlated certainly with the typical St. Peter sandstone.

In north-central Tennessee sandy strata are penetrated by several deep wells in the vicinity of Nashville and by the Franklin Oil & Fuel Co's. test well near Murfreesboro. The character and stratigraphic relations of the strata at Nashville are shown by the preceding log of the test well on the Arthur Stevens property at Bordeaux, in which beds of sandstone, sandy limestone, and calcareous sandstone were penetrated from 1,043 to 1,210 feet below the surface. The top of this group of beds is about 1,500 feet stratigraphically below the Chattanooga shale. In the well near Murfreesboro the sandy stratum is only about 10 feet thick, and its top is about 610 feet below the surface, or 1,400 feet below the Chattanooga shale. The sandy beds penetrated by the wells near Nashville seem to constitute a single stratum at approximately the same geologic horizon as the supposed St. Peter sandstone of Wayne County, Ky. The sandy bed in the well near Murfreesboro is also at about the same horizon, though it can not be inferred that this bed is a southward extension of the stratum penetrated at Nashville. If these sandy beds penetrated in Kentucky, at Nashville, and near Murfreesboro constitute a single stratum, it thins notably toward the southeast.

The St. Peter sandstone of the upper Mississippi Valley is a persistent water-bearing stratum, so that, if present in central Tennessee and if its water-bearing properties remain unchanged, it constitutes a potential deep source of water in this region. Its promise as a source of ground water is discussed in the descriptions of Davidson and Rutherford Counties (pp. 134, 179).

[25] Munn, M. J., Reconnaissance of oil and gas fields in Wayne and McCreary counties, Ky.: U. S. Geol. Survey Bull. 579, p. 17, 1914.

[26] Shaw, E. W., and Mather, K. F., The oil fields of Allen County, Ky.: U. S. Geol. Survey Bull. 688, p. 39, 1919.

[27] Butts, Charles, Geology and mineral resources of Jefferson County, Ky.: Kentucky Geol. Survey, ser. 4, vol. 3, pt. 2, pp. 33–36, 1916.

GEOLOGIC STRUCTURE

NASHVILLE DOME

The major feature of geologic structure in central Tennessee is the Nashville dome. This is a very broad elliptical flexure whose axis trends N. 20°–30° E. and passes near Fosterville and Lascassas, in eastern Rutherford County, and close to Norene, in southeastern Wilson County. At the apex of the dome, which is approximately at the center of the southern boundary of Rutherford County, about 2 miles south of Fosterville (pl. 4), the top of the Chattanooga shale—the most reliable horizon marker of the area—is 1,300 feet above sea level. From its apex the axis of the dome plunges northward and southward between 5 and 10 feet to the mile. The transverse dips are generally slightly steeper, however, and are about 15 feet to the mile within 50 miles of the apex. This average dip is so slight that it is likely to be undeterminable in any one outcrop.

The top of the Chattanooga shale—or the projected original position of that stratum prior to the erosion of the Nashville Basin—is between 1,100 and 1,300 feet above sea level in most of Rutherford County, which occupies the highest part of the dome. On the east flank of the dome this horizon marker is about 700 feet above sea level at McMinnville and at Celina, which are approximately at the respective centers of Warren and Clay Counties. On the west flank of the dome—on which lies the greater part of the region covered by this report—the Chattanooga shale slopes northwestward and is about 900 feet above sea level at Franklin and Columbia, the principal cities of Williamson and Maury Counties, respectively. It is between 350 and 400 feet above sea level at most places in the central part of Dickson County and in the vicinity of Ashland, in Cheatham County. Farther west, however, the average dip of the strata is either very flat or else reverses in a shallow syncline, for the Chattanooga shale crops out at several places along the Tennessee River (pl. 4) between 325 and 400 feet above sea level. These outcrops are the only known exposures of the Chattanooga shale west of Williamson and Cheatham Counties within the region covered by this report. Furthermore, very few deep wells have been drilled to this shale in the intervening area, and the thickness and stratigraphy of the overlying beds have not been worked out in any detail. Consequently the data at hand are inadequate to show accurately even the general features of the structure in that part of the region that lies west of the Highland Rim escarpment.

The Nashville dome is the southerly one of two major structural domes on the crest of the Cincinnati arch, a geanticline whose axis appears from beneath Cretaceous and Tertiary rocks in northeastern Mississippi and northwestern Alabama and trends about N. 30° E.

through central Tennessee and Kentucky to Cincinnati, Ohio. At Cincinnati the axis of the geanticline splits, one branch trending northwestward and passing near Logansport, Ind., and the other branch trending slightly east of north and passing close to Lima, Ohio. Crustal warping along this axis began as early as Middle Ordovician time and has continued at intervals until comparatively recent geologic time, for the Highland Rim peneplain was deformed about this axis as late as the upper Oligocene (pp. 19–20). During much of the Paleozoic era part or all of the axial portion of the arch was above sea level intermittently. In several epochs formations characterized by distinct faunas were deposited simultaneously on opposite sides of the arch or sediments were not deposited along the axis. This condition was especially prevalent during the Silurian and Devonian periods. In north-central Tennessee warping along the axis of this arch apparently began near the end of the Murfreesboro epoch, in Lower Ordovician time, for Galloway[28] points out that near Lascassas, in northeastern Rutherford County, the Murfreesboro limestone is folded with reference to overlying strata.

SECONDARY FOLDS

Although the average dip of the strata in the Nashville dome is generally less than 15 feet to the mile, so that the rocks appear horizontal in small outcrops, secondary folds in which the rocks dip more steeply occur at many places on the flanks of the dome. These secondary folds are generally less than 5 miles long and not more than 100 feet high.

Several secondary folds of this sort that occur on the highest part of the Nashville dome in Rutherford County have been described by Galloway.[29] They are shown on Plate 4 by the outcrops of the Pierce and Murfreesboro limestones, which are exposed only where the apexes of the folds have been cut through by erosion. The largest of the secondary anticlines of this group is an ovoid fold about 6 miles long, 3 miles wide, and 80 feet high whose axis trends about N. 20° W. through the eastern part of Murfreesboro. The complement of this fold is a syncline from 1 to 3 miles wide and 40 to 80 feet deep which adjoins it on the west and whose axis extends southeastward from a point on the Stone River about 2 miles west of Murfreesboro to Gum, a distance of about 9 miles. Just west of this syncline, in the vicinity of the Barfield and Marshall Knobs, is the largest secondary dome within the county, a fold which is nearly 6 miles in diameter and 100 feet high. The remaining secondary folds of Rutherford County are considerably smaller. The Nashville pike crosses the

[28] Galloway, J. J., Geology and natural resources of Rutherford County, Tenn.: Tennessee Geol. Survey Bull. 22, pp. 62, 65, 1919.
[29] Idem, pp. 61–62.

Stone River about 2 miles northwest of Murfreesboro, near the apex of a dome about 1½ miles in diameter and about 75 feet high. From this point downstream about 3 miles the river cuts across a number of small anticlines and synclines which are well exposed in the river bluffs. Along the east fork of the Stone River between Jefferson and Lascassas there are five well-defined domes and several smaller ones, six of which bring the Pierce and Murfreesboro limestones to the surface. The largest one is a dome about 3 miles in diameter and more than 100 feet high just west of Walter Hill. The northeast flank of this dome is transected by the river, which exposes 27 feet of the Pierce limestone and 70 feet of the Murfreesboro limestone. About 2 miles south of Walter Hill is another dome about 2 miles in diameter and more than 80 feet high. The easternmost of this group of folds is a double canoe-shaped plunging anticline about 3 miles long, 2 miles wide, and 50 feet high. The town of Lascassas is close to its apex. The axis of this fold is well defined and strikes about N. 80° E.; it crosses the principal axis of the Nashville dome. Other secondary folds within the county are shown on Plate 4.

Secondary folds comparable in size with those of Rutherford County also occur in other parts of the Nashville Basin, especially in southern Williamson County. None of them, however, were mapped in the course of the reconnaissance upon which this report is based.

On the Highland Rim plateau the rocks are not well exposed and the structure is generally concealed. In several places where the plateau has been trenched by streams, however, secondary folds are also exposed. In the northeastern part of Sumner County five anticlines and domes from 1 to 2 miles long in the Mississippian rocks have been mapped by Mather,[30] who points out the probability of other folds in the same district. These folds are more than 20 miles west of the axis of the Nashville dome.

The Harpeth River gap in southern Cheatham County discloses an elliptical dome about 4 miles long by 2 miles wide, with about 60 feet vertical closure as described by Jillson.[31] Its southwest flank is transected by the Harpeth River, and the stratigraphy and structure are well exposed in the river bluffs and in cuts along the Memphis-Bristol highway. The major axis of this fold strikes N. 40°–50° W. and is slightly concave toward the north. At the apex of this fold, which is about 2 miles N. 30° E. from Kingston Springs, near the mouth of Dog Creek, the top of the Chattanooga shale is about 650 feet above sea level. Jillson[32] expresses the belief that the Chatta-

[30] Mather, K. F., Oil and gas resources of the northeastern part of Sumner County, Tenn.: Tennessee Geol. Survey Bull. 24, pp. 27–30, 1920.

[31] Jillson, W. R., Geology of the Harpeth River area, Tennessee: Oil and Gas Jour., vol. 23, No. 6, pp. 68, 70, 1924.

[32] Jillson, W. R., Unique Devonic sandbar: Pan Am. Geologist, vol. 40, pp. 333–337, 1923.

nooga shale was not deposited across the apex of the dome, that the lowest beds of the Fort Payne formation rest upon the Hardin sandstone member with a minor stratigraphic break intervening, and that therefore folding about this axis began before Mississippian time. He states further that folding was renewed at a later time, however, for the Fort Payne formation and overlying beds of Mississippian age are deformed nearly as much as the Chattanooga shale.

In the vicinity of White Bluff, in the central-eastern part of Dickson County, the strata are arched into one or more anticlines. These secondary folds have been disclosed by deep wells that penetrate the Chattanooga shale (pp. 144–145), but they have not been mapped in detail. They seem to be associated with a marked structural depression in northeastern Dickson County and northwestern Cheatham County, in which the Chattanooga shale is 50 feet or more below sea level as indicated by the records of several deep wells. Doubtless other secondary folds will be found in the area north and west of the Highland Rim escarpment and within the region covered by this report when the stratigraphy is traced in detail.

Bassler [33] has pointed out that in many places in central Tennessee sharp inclinations of the strata are due not to folding or warping of the crust but to collapse and slumping of strata above caverns formed by solution. On the Highland Rim plateau features of this sort exist where solution caverns have formed in the Ordovician limestone and the overlying Mississippian strata have collapsed, these strata being in some places nearly vertical. Bassler points out further that at some places in the Nashville Basin the topographic slopes seem to conform to the rock strata, which may rise with the slope of a hill and descend to its base on the opposite slope, but that such features may be due to slump above solution openings rather than to original structure. Similar features are associated with the unconformity at the base of the Chattanooga shale, for at several places in the northern part of the Nashville Basin the Hardin sandstone member of the Chattanooga fills pre-Mississippian sink holes 30 to 40 feet deep, whereas in adjacent areas the member is less than a foot thick. A similar feature was noted by Lusk [34] in the Flynn Creek Basin, in the central part of Jackson County, where the Chattanooga shale fills a preexisting sink hole 2 miles in diameter and as much as 100 feet deep.

WELLS CREEK UPLIFT

In the vicinity of Cumberland City, in the southeastern part of Stewart County, and the adjacent part of Houston County the strata

[33] Bassler, R. S., Sink-hole structure in central Tennessee [abstract]: Washington Acad. Sci. Jour., vol. 14, p. 374, 1924.

[34] Lusk, R. G., A pre-Chattanooga sink hole: Science, new ser., vol. 65, pp. 579–580, 1927.

are complexly folded and faulted in a manner that is unique for central Tennessee. The area of deformation covers a roughly circular area about 8 miles in diameter, and the strata involved range from the limestone of Beekmantown (?) (earliest Ordovician) age to the St. Louis limestone. This structural feature is known as the Wells Creek uplift, from the name of the stream that drains most of the area of deformation. Its relation to the forces that caused the upwarping of the Nashville dome and the formation of its superposed secondary folds is unknown. However, it is possible that crustal warping began in the Wells Creek area quite as early as in the Nashville Basin, for the Wells Creek section may lack the entire Stones River group, of Lower Ordovician age (pp. 57–58), and lacks much of the Middle Ordovician and Upper Ordovician (Richmond) group.

The unique structure of the Wells Creek uplift was first recognized by Safford,[35] who pointed out that the strata in the center of the deformed area are older than any other rocks exposed in central Tennessee and that they dip vertically or at high angles. Safford interpreted the structural feature as a high dome, with the strata cropping out in successive bands concentric about the apex of the dome and dipping away from the center of the basin. He also pointed out that the Mississippian rocks are both folded and faulted for several miles away from the area of intense deformation, as is exposed in the bluffs of the Cumberland River several miles upstream and downstream from Cumberland City.

Jillson [36] has pointed out certain similarities of the structure of the Wells Creek uplift to that of Jeptha Knob, in Shelby County, Ky., and Serpent Mound, in Adams County, Ohio. He assumes that all these features are contemporaneous and concludes that they were produced by forces transmitted by a body of igneous magma a few thousand feet beneath the surface.

Very recently Bucher has started to map the structure of the Wells Creek uplift in detail. His prelimininary report [37] is abstracted in the following paragraphs:

Topographically the Wells Creek Basin is an elliptical depression in the Highland Rim plateau (pp. 16–18) bounded on all sides by an erosion scarp 225 to 275 feet high. This depression is about 2½ miles long and 2 miles wide, and the longer axis trends nearly due north. The floor of the basin comprises three topographic units, which are also stratigraphic and structural units. These are a central hill, which is rudely circular, 2,700 feet in diameter, and about 80 feet high; a ringlike lowland plain 1,500 to 3,500 feet wide surrounding the central hill; and a belt of foothills 1,500 to 2,000 feet wide sur-

[35] Safford, J. M., Geology of Tennessee, pp. 147-148, Nashville, 1869.
[36] Jillson, W. R., An isothrustic hypothesis: Pan Am. Geologist, vol. 40, pp. 251-258, 1923.
[37] Bucher, W. H., The stratigraphy, structure, and origin of Wells Creek Basin, Tennessee: Tennessee Dept. Education Div. Geology (in preparation).

rounding the lowland and abutting against the bounding scarp. The central hill is composed of limestone and dolomite of Beekmantown (?) age, which are faulted into blocks of all sizes and every conceivable orientation and locally are reduced to a breccia of blocks not more than 2 feet in diameter. These rocks are at least 1,000 feet higher than their normal altitude outside the uplift. The ring-shaped lowland is underlain by poorly exposed pre-Trenton post-Beekmantown limestones, which are likewise complexly faulted, though much less brecciated than the rocks of Beekmantown (?) age. The fault blocks of this unit also are in every conceivable orientation, and vertical beds occur almost a mile north of the center of the uplift. Radially outward from the center of uplift the faulting becomes more orderly and the strike of the rocks tends to become parallel to the outer margin of the lowland. Faulting is least complex in the belt of foothills.

The area of structural deformation, however, is about 8 miles in diameter and extends well beyond the topographic basin. From the erosion scarp that bounds the topographic basin the Mississippian rocks dip radially outward into a ring-shaped syncline, which is rudely concentric about the center of the uplift and whose axis is about 2¼ miles from it. In this syncline the rocks are commonly faulted and brecciated more complexly than at the outer margin of the topographic basin. In its deepest part they are depressed about 300 feet below their normal altitude in the adjacent areas and about 1,300 feet below their projected position at the center of the uplift. Surrounding this ring-shaped syncline is a zone about 2 miles wide in which the rocks rise to their normal altitude, though broken by many normal faults. These faults are in part tangential to the trend of the zone and in part radiate about the center of the disturbance, but the tangential faults are the more common. Several can be traced for more than a mile along the strike, and one is more than 4 miles long; the vertical components of their displacements are several hundred feet. In addition to these major faults there are many secondary fractures, which divide the rocks into blocks of all sizes. Abrupt changes in strike and dip of the blocks are common, and in many places the beds are vertical.

The zone of maximum uplift and brecciation at the center of the disturbance is believed by Bucher to be the result of a violent shock or explosion and the marginal zone of depression to be due to collapse of crustal material as if into a void. A hypothesis to account for the forces and for the transfer of subcrustal material is yet in the formulative stage.

FAULTS AND JOINTS

Faults, which are fractures along which the rock strata have suffered relative displacement, are comparatively rare in north-central Tennessee except in the Wells Creek Basin. Galloway [38] has noted two faults of small displacement in the Ridley limestone in Rutherford County. One of these crosses the Stone River at Jefferson, in the north-central part of the county, and can be traced about a quarter of a mile from the river in each direction. Its strike is about N. 25° E., its dip about 80° E., and its vertical displacement about 20 feet. The other fault occurs 2 miles south of Christiana, in the south-central part of the county. Its trace, which can be followed on the surface for a little less than half a mile, strikes about N. 40° E. The vertical component of the displacement is about 50 feet at the center of the fault but diminishes rapidly in both directions; the southern block is downthrown.

A third minor fault cuts the Fort Payne formation in the north bluff of the Duck River about a tenth of a mile upstream from Paint Rock Bluff, in southwestern Humphreys County. This fracture strikes N. 65° W. and is approximately vertical; the northern block is downthrown an unknown distance. It is well exposed in the river bluff and in the cut bank of the Memphis-Bristol highway.

These faults are clearly younger than the Nashville dome and its associated secondary folds, but their exact age is unknown. All are of such a magnitude that they may be due to slumping of the roofs of large solution caverns formed at a comparatively recent time.

At many places in north-central Tennessee the limestones and other compact rocks are much jointed, especially along and near axes of relatively intense secondary folding. Where these joints are well developed they are generally between 2 and 10 feet apart. As a rule they are closer together in the thin-bedded and platy limestones and farther apart in the thick-bedded, dense, and brittle limestones, although these relations are by no means invariably true. Commonly the joints of this region are approximately vertical and those at any one place fall into two sets, which divide the rock into rhomboidal blocks. Most common directions of jointing in north-central Tennessee are N. 55°–65° W. and N. 25°–45° E., and the joints of the northwesterly set are generally the more persistent and cut across those of the northeasterly set. These directions are approximately but in most places not precisely normal and parallel, respectively, to the axis of the Nashville dome. The other joints, generally less persistent along their strike than those of the dominant two sets, commonly fall in the acute angle between N. 65° E. and S. 70° E.

As joints and bedding planes are the most common seats of solution channels, it follows that the water-bearing properties of limestone are closely related to the number and direction of its joints. These relations are discussed on pages 150–155.

[38] Galloway, J. J., Geology and natural resources of Rutherford County, Tenn.: Tennessee Geol. Survey Bull. 22, pp. 62–63, 1919.

GROUND WATER

OCCURRENCE OF GROUND WATER IN LIMESTONE

TYPES AND ORIGIN OF WATER-BEARING OPENINGS

As Meinzer [39] has pointed out, no rock differs more radically with respect to yield of water than limestone. In some regions limestone ranks among the most productive water-bearing rocks; in other regions it is as unproductive as shale. These differences are related in part to differences in the mode of origin of limestone and in part to differences in the history of the rocks after they were laid down as calcareous sediment.

The pore space of any rock may be termed continuous if the voids are connected with one another or discontinuous if the voids are not connected.[40] Continuous pore space is that which renders the rock permeable to water or to other fluids; discontinuous pore space, although it may aggregate a considerable part of the total volume of the rock, does not impart permeability. Both types of porosity are common in limestone.

The pore space of a rock may also be termed primary if it existed in the sediment from which the rock was formed by consolidation, or secondary if it has been formed after the consolidation of the rock. Newly deposited calcareous sediment may contain many interstices and have considerable aggregate porosity. However, during compaction and lithification of the sediment, calcite generally crystallizes between many of the grains, so that the original interstices tend to become filled. Hence such primary pore space as remains in the consolidated rock may be largely discontinuous and may not render the rock permeable. The pure thick-bedded limestones of the older rock systems, such as those of Paleozoic age in central Tennessee, are generally very dense and contain no primary pore space visible to the eye other than minute openings in bedding planes. According to Howard [41] the pure calcareous rocks that have appreciable primary porosity are chalk, oolitic limestone, primary crystalline limestone and dolomite, and coral limestone. Such rocks are not common in north-central Tennessee. The earthy limestones and those that are interbedded with shale are also commonly without continuous primary pore space that might store and transmit water. The sandy limestones and calcareous sandstones, on the other hand, may have considerable primary porosity if the original interstices between the sand grains are not entirely filled with calcareous cement.

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[39] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, pp. 131–137, 1923.

[40] Murray, A. N., Limestone oil reservoirs of the northeastern United States and of Ontario, Canada: Econ. Geology, vol. 25, No. 5, p. 453, 1930.

[41] Howard, W. V., A classification of limestone reservoirs: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1155, 1928.

Secondary porosity in limestone is due to (1) fractures, including (*a*) joints caused by contraction of the sediment during consolidation, (*b*) joints and faults resulting from crustal movement, (*c*) joints due to mineralogic changes; (2) solution openings related to present or former erosion surfaces; and (3) intercrystalline voids produced by mineralogic change. This classification is essentially that given by Howard. Secondary pore space in limestone is in large part continuous and therefore renders the rock permeable. That caused by joints and solution openings is by far the most common and most efficacious in imparting large water-yielding capacity to the rock.

Joints are fractures along which there has not been appreciable displacement of the rocks. They are produced by internal stresses such as those induced by shrinkage or by external stresses that accompany deformation of the earth's crust. Commonly they are nearly plane and approximately vertical (dip 75°–90°); some extend for long distances and to considerable depth, whereas others are very short in both horizontal and vertical extent. In sedimentary rocks such as limestone flat or nearly horizontal joints generally do not form unless the rock is very thick bedded, the stresses that tend to form such joints in crystalline rocks being dissipated by sliding of one bed upon another. Furthermore, the vertical joints may extend across one stratum or several strata. At any particular locality the joints generally occur in one or more sets, each set comprising several or many fractures that are approximately parallel; these sets of joints intersect at various angles and divide the rock in rhomboidal blocks. Many joints are tight and not water bearing, but the walls of others stand apart so that they constitute ground-water conduits with large transmission capacity. In some places joints are close together and in others far apart, their position depending upon differences in the competence of the strata to resist fracture and upon differences in the intensity of external stresses causing crustal deformation. In some regions where there has been intense deformation the rocks have been displaced along the fractures, producing faults and breccia zones that extend far below the surface and may yield unusual amounts of water. However, faults are not common in north-central Tennessee except in the Wells Creek Basin (pp. 65–67). Not only do joints generally become tighter with depth but they also become farther apart, so that the chances of striking a water-bearing opening of this sort in drilling a well become less as the depth increases. The intersections of joints with one another are especially likely to be open and to permit circulation of ground water. Although any joint may intersect others, the circulation is easiest where the joints of the principal sets intersect and where, in addition to the vertical joints, horizontal fractures or open bedding planes occur.

Solution openings in limestone are of two kinds—(*a*) intergranular spaces produced by etching the faces of crystals or grains of rocks that have some primary porosity, by selective leaching of the more soluble constituents from such nonhomogeneous rocks as magnesian limestone and gypsiferous limestone, or by leaching the cement between the insoluble grains of a calcareous sandstone; (*b*) tubelike channels formed in pure massive limestone by enlargement of joints or of primary openings along bedding planes. The tubular solution openings are the type commonly found in the limestones of north-central Tennessee.

Calcium carbonate, which makes up practically all of a pure limestone, is almost insoluble in pure water. However, it is appreciably soluble in rain water, which contains small quantities of carbon dioxide absorbed from the air. Also, it is especially soluble in soil water, which commonly contains an abundance of carbon dioxide produced by decomposition of the unstable organic acids leached from partly decomposed vegetation.[42] Under favorable conditions these natural solvents may percolate considerable distances before they are neutralized. Rain water or soil water may enter joints or bedding planes and convert tight fractures into relatively open crevices [43] by etching the limestone walls, or it may enter primary pore spaces and enlarge them by etching the faces of crystals or grains. The rate at which the limestone is etched depends upon many factors, of which the principal are the chemical composition and crystallinity of the limestone, the permeability of the limestone, the rate of circulation of the ground water, the amount and seasonal distribution of rainfall, the concentration of carbon dioxide and natural acids in the ground water, the thickness, composition, and texture of the soil, and the type and density of vegetal cover. For the etching to be continuous it is essential that the circulation be free, so that the saturated water will be continuously displaced by unsaturated water at the surface of the limestone.

As is pointed out by Fuller,[44] the sheet form of solution passage is the first stage in the enlargement of fractures or bedding planes in dense limestone. The small solution openings first formed eventually unite into an exceedingly narrow sheetlike opening which by differential solution may develop into a large irregular cavity. (See pl. 5, *A*.) Under favorable conditions solution may progress until the limestone is ramified by a network of caverns, some of which may grow to great size. The smaller channels commonly follow joints or bedding planes, but some of the larger channels and caverns do not

[42] Murray, A. N., and Love, W. W., Action of organic acids on limestone: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1467–1475, 1929.

[43] Spencer, A. C., U. S. Geol. Survey Press Bull. July 17, 1922.

[44] Fuller, M. L., Summary of the controlling factors of artesian flows: U. S. Geol. Survey Bull. 319, p. 12, 1908.

seem to be related to any preexisting openings of that sort. A single passage in the Mammoth Cave of Kentucky is more than 8 miles long. Many such passages are 20 feet high, a few as much as 75 feet high, and some as much as 50 to 150 feet wide. The great vertical wells of the Mammoth and other caves have diameters of 10 feet or more and depths of more than 200 feet. At many places in north-central Tennessee there are similar solution caverns, such as Dunbar Cave, near Clarksville (No. 53, pl. 4), whose passages are 10 to 20 feet wide and are reported to sum up to 7 miles in length, and Ruskin Cave, in Dickson County (No. 211, pl. 4), which is about 20 feet high and 75 feet wide at its largest section.

Although the large channels in limestone are formed principally by solution along preexisting bedding planes or joints, mechanical erosion doubtless plays a part in the formation of those that transmit turbid water. For example, the channel of Ruskin Cave maintains a slight and uniform northward gradient across thick beds of dense cherty limestone that dip about 5° S. The blanket of alluvial sand and clay that covers the floor of this and many other large channels is adequate evidence of the erosive power of the large underground streams that formerly existed in north-central Tennessee.

Sinks or sink holes are natural openings that extend from the land surface down to a cavernous zone in the limestone. They are of two general types—solution sinks and collapse sinks—and their modes of origin are described in the following paragraphs.

The solution sink commonly originates at a vertical joint or at the intersection of two joints, the upper part of the crevice being enlarged by the solvent action of water that is descending from the land surface to the zone of saturation. At first the descending water is largely depleted in solvent power before it percolates far below the surface, so the deeper part of the joint is not likely to be enlarged appreciably. The result is a conical depression in the limestone, the base of the cone being at the land surface and its apex pointing downward. As this depression increases in diameter and depth, the insoluble soil subsides appreciably. This subsidence is commonly the first surface indication of the solution sink; it is very generally mistaken for incipient foundering of the roof of an underground channel. In course of time the walls of the sink are cut back by solution and possibly by corrasion, so that a very large surface depression, with or without a functional swallow hole at its center, may be produced. The diameters and depths of such sinks in any area afford clues to their relative ages and to the depths of the channels into which they discharge. The natural wells, which are rudely cylindrical, are commonly formed in a similar manner where etching goes on at about the same rate from top to bottom of the original crevice. Both funnel-shaped sinks and natural wells also form underground between solution channels at two different levels.

The collapse sink, as the name implies, is formed by foundering of the roof of a subsurface channel. Its formation depends upon many factors, of which the principal are the strength and thickness of the roof strata, the orientation and spacing of joints in the roof beds, the inclination of the strata, the depth of the channel below the surface, the width, height, and shape of the channel, and the weakening of the roof strata by solution. Obviously, there are many possible combinations of circumstances that will cause collapse. Generally a collapse sink flares upward, and its diameter at the surface is related to the depth and to the span of the channel. Collapse sinks range from shafts a few feet in diameter caused by subsidence of a single joint block to depressions many hundred yards across caused by foundering of the rocks above an extensive cavernous zone. Valleys several miles long may be formed by gradual collapse of the roof above a major underground stream.

The calcareous rocks differ appreciably with respect to their strength to resist fracture and their solubility. Dolomite and magnesian limestone are less soluble than pure calcareous limestone, but when they are subjected to weathering they may also become porous or even cavernous by solution. Earthy limestone and calcareous shale are intermediate in composition between limestone and shale; they are also intermediate in water-yielding capacity. They are generally less cavernous than limestone but somewhat more friable and brittle and hence more jointed than shale. Several of the formations in north-central Tennessee comprise alternating beds of limestone and thin layers of shale. In such rocks a bed of shale may check the downward percolation of ground water and localize the formation of solution channels in the lower part of a limestone bed. Other beds of shale may act as ground-water dams. Some limestone, especially certain shaly beds, contains crystals and small masses of gypsum, the hydrous sulphate of calcium, which is dissolved readily by water without the presence of natural acids. Such rocks may become very highly cavernous when leached by circulating water.

Where a body of ground water in limestone has a free upper surface or water table, the limestone is presumably dissolved most rapidly in the zone between the highest and lowest positions occupied by the water table in its seasonal fluctuations, for in that zone the ground water percolates relatively rapidly and is most likely to contain natural acids. The limestone is also presumably dissolved above the water table and to a relatively shallow depth below the water table, for there likewise the ground water circulates rather freely. However, the ground water at considerable depth below the water table probably circulates slowly and before it moves a great distance becomes saturated in calcium bicarbonate and thereby depleted in solvent power, as its natural acid is neutralized by reaction with the limestone. Consequently, it is commonly held, as by Swinnerton,[45] that below the water table the limestone does not dissolve readily and continuous systems of large solution passages do not form. This hypothesis seems to be compatible with the relation between the principal systems of solution channels and the surface streams (pp. 23–24) in north-central Tennessee. On the other hand, Davis[46] contends that limestone caverns are formed in part by solution and in part by corrasion and that they may be formed at any depth below the water table.

Where a stratum of limestone has primary permeability or is thoroughly jointed and is overlain and underlain by impermeable rocks, ground water may circulate along that stratum under hydrostatic pressure, as through a conduit. Under such conditions, if the geologic structure is favorable, circulation may take place to considerable depths below the water table. If the circulation is relatively rapid, so that ground water passes entirely through the limestone conduit before it becomes saturated, then the original openings in the limestone may be enlarged by solution from one end of the conduit to the other, regardless of its depth below the water table. Such conditions are not known to have existed in north-central Tennessee.

Systems of solution passages may be formed in limestone during successive erosion epochs and then buried beneath younger sediments after submergence.

In some regions the limestone formations can be discriminated more or less sharply by the abundance and size of the solution passages and other water-bearing openings. This is true to some extent in parts of north-central Tennessee, but generally the effect of differential solubility is a secondary factor in determining the water-bearing properties of the limestone of this region.

SOURCES AND CIRCULATION OF GROUND WATER

In general the ground water that occurs in the limestone of north-central Tennessee is derived from two sources—meteoric water, or that which falls as rain and percolates to the water table, and connate or fossil water, or that which was trapped in the sediments by the deposition of overlying beds and has not since been flushed from the rocks. The waters of meteoric origin are those which circulate freely through joints and solution openings and are discharged from most springs and wells. They generally contain only small or moderate amounts of dissolved mineral matter and are suitable for most ordi-

[45] Swinnerton, A. C., Changes in base-level indicated by caves in Kentucky and Bermuda [abstract]: Geol. Soc. America Bull., vol. 40, p. 194, 1929.

[46] Davis, W. M., Origin of limestone caverns: Geol. Soc. America Bull., vol. 41, No. 3, pp. 475–628, 1930; The origin of limestone caverns: Science, new ser., vol. 73, No. 1891, pp. 329–330, 1931.

nary domestic or industrial uses. However, some ground water of meteoric origin may be trapped by beds of impermeable shale so that its circulation is impeded or prevented, and it may then become so highly concentrated as to be unfit for most purposes. The connate waters of north-central Tennessee generally occur in rocks at great depth, do not circulate, and do not receive water from the surface. In marine sediments such as the calcareous formations of this region the connate waters invariably contain a very large amount of dissolved mineral matter and are unfit for practically all uses. The chemical character of these two types of water is discussed on pages 120–123.

In any region that is underlain by thick bodies of massive limestone, such as north-central Tennessee, many areas between the perennial rivers and creeks are wholly devoid of surface streams although they receive their proportionate amount of rainfall and obviously contribute water to maintain the flow of the perennial streams. The run-off from such areas is diverted into joints and solution channels of the limestone by sinks, or swallow holes, each of which is a rude funnel gathering water from the surface. However, not all the depressions that have no surface outlet divert water into the channels of the limestone, for the floors of many are doubtless tightly puddled by clay or other impermeable débris. The sinks range in size from open joints and other small crevices to large pits formed by solution or by the collapse of the roof above an underground channel or by a natural well that reaches the surface. The walls of a large sink may gradually be cut back by solution, by corrasion, or by collapse, so that its drainage area increases correspondingly. Some depressions of this sort in north-central Tennessee drain several square miles by means of intermittent or perennial creeks that discharge into natural wells or other solution openings at the bottoms of the pits.

The water that enters the joints and solution openings of the limestone from the sinks percolates downward to the zone of saturation, the upper boundary of which in some districts is about as sharply defined in limestone as in other rocks. Under such conditions the network of joints and solution openings, both great and small, is filled with water up to a certain level, which is the water table. Only those openings that exist below the water table generally yield perennial supplies to wells. In some places, however, a well that passes through limestone will not strike a water-bearing opening until it has been drilled a considerable distance below the water table. When the well strikes the water-bearing opening the water will generally rise in it about to the level of the water table. In other limestone districts extensive networks of solution passages exist above the regional water table and yet are wholly or partly filled with water. This water may be in transit downward to the zone of saturation or it may be trapped above underground dams that obstruct major solution channels (see pp. 82–83) and thus may constitute one or more bodies of perched ground water. Under such conditions the static level of the ground water in wells may not define a simple surface, so that it is difficult or impossible to recognize the regional water table. These conditions led Martel [47] to deny the existence of a water table in limestone regions.

Practically all the surface water that is diverted by the sink holes is discharged into some surface stream at points of lower altitude through tubular or fracture springs (pp. 92–95). By accretion of water gathered by many sinks, perennial underground streams may be formed and may flow for miles through solution passages before reappearing at the surface. Also, a perennial surface stream may disappear wholly or in part into a sink or solution channel, flow underground for a distance, and reappear at the surface one or more times. These phenomena have been summarized by Meinzer [48] as follows:

> Some of the large caverns contain streams that do not differ greatly from surface streams. Like the surface streams, they generally flow about at the level of the water table. As the result of a heavy rain or the rapid thawing of snow they may receive great quantities of surface water directly through sink holes and may, like the surface streams, become greatly enlarged. In times of flood they may lose some of their water by percolation into the smaller crevices, but at low stages they are fed by the body of ground water that occupies all crevices below the water table. Rarely there is a passage through the limestone that leads from a sink hole, where the water is taken in, to a point of discharge at a lower level, without extending down to the water table. Such a subterranean passage is essentially a dry wash that is arched over by a natural bridge. Its discharge is extremely irregular and ceases as soon as the flood water has disappeared.

Underground drainage systems of this sort are characteristic of pure thick-bedded limestones. Davis [49] states that the underground channels which constitute these systems differ from surface drains in that they are looped and do not have well-defined gradients. Martel [50] contends that the underground streams are similar to surface rivers in that they comprise rapids, cascades, and static reaches, are dendritic, and have floods. He contends further that the underground streams differ from surface rivers in that they include very abrupt and extreme constrictions, siphons both upright and inverted, abrupt falls, and pools of large volume; also in that they are looped and in many places are partly or completely dammed by rock that has fallen from roof or walls. Some of these differences seem not to be permanent characteristics, however, if the underground streams

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[47] Martel, E. A., Nouveau traité des eaux souterraines, pp. 305–306, Paris, 1921.

[48] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, p. 134, 1923.

[49] Davis, W. M., written communication to O. E. Meinzer, Mar. 25, 1930.

[50] Martel, E. A., op. cit., pp. 228, 242–246.

are compared with surface streams that are in the corresponding stage of development (pp. 78–82).

The major ground-water conduits are not all single channels passing directly from point of intake to point of discharge, for some large springs that issue from them are relatively invariable in yield and discharge clear water even during floods. Hurricane Rock Spring (No. 181, pp. 161–162), in Humphreys County, is of this sort. Where such conditions exist the system of channels must store temporarily enough water to clarify the turbid inflow, even though the gradient directly from area of inflow to point of discharge may be relatively steep. Obviously, this storage capacity can not exist unless the channels ramify so widely that they are very flat or unless they comprise many voluminous pools of nearly static water.

The volume of water thus stored temporarily in cavernous rocks may be truly enormous, as is shown by the behavior of the Major Johnson group of springs on the Carlsbad irrigation project, New Mexico. These springs are about 3½ miles southwest of the McMillan Dam, 60 feet below the crest of its spillway, and 40 feet below the lowest point of the floor of the reservoir. The discharge of these springs was 272 second-feet in 1921, when the reservoir was full, and it has been shown that under those conditions the springs were supplied chiefly by water that leaked from the reservoir into cavernous rocks.[51] As soon as the reservoir becomes empty, however, the discharge of the spring group begins to decrease, and in the course of about a month it declines to a minimum of approximately 40 second-feet, this minimum discharge being the normal ground-water discharge of the spring basin as long as the reservoir is empty. The decline is due to cessation of leakage from the reservoir and to gradual draining of the water stored temporarily above the normal water table. On the assumption that the rate of decline is uniform throughout the month, about 300 million cubic feet (2,250 million gallons) of water must be stored temporarily in the cavernous rock that drains into this spring group. This volume of water would fill a reservoir 1 mile square to a depth of nearly 11 feet.

On the other hand, some trunk channels must pass directly from intake to outlet, for the discharge of many tubular springs increases considerably and becomes extremely turbid for a brief period after a heavy rain. Such springs are common in north-central Tennessee, and a typical example is the municipal spring at Murfreesboro, Rutherford County (No. 439, pp. 187–188).

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[51] Meinzer, O. E., Renick, B. C., and Bryan, Kirk, Geology of No. 3 reservoir site of the Carlsbad irrigation project, New Mexico, with respect to water-tightness: U. S. Geol. Survey Water-Supply Paper 580, pp. 23–24, 1927.

CYCLES IN THE FORMATION OF UNDERGROUND DRAINAGE SYSTEMS

In any district underlain by limestone the joints and solution passages are integral and tributary parts of the regional drainage system. Furthermore, the work of the ground water modifies profoundly the normal sequence of land forms that are cut elsewhere on insoluble rocks by subaerial erosion. Several workers, including Beede [52] and Cvijać,[53] have sought to define the stages of the erosion cycle in a limestone district in terms of the land forms produced directly or indirectly by the solvent action of the ground water. As thus defined the youthful stage of the cycle is characterized by progressive capture of surface drainage by the underground streams and by the appearance of scattered solution sinks. In the mature stage the drainage is virtually all underground and the surface valleys of youth are entirely disorganized by solution sinks and scattered collapse sinks, which together cover most of the region. At this stage there exists the strongest topographic expression of the solvent action of the ground water. In late maturity collapse sinks become numerous and valleys are formed by foundering of the roofs above the major solution channels, much of the drainage being brought to the surface again. In the stage of old age the last solution channels are unroofed and a plain drained by a normal system of surface streams is formed; this plain is the final product of the cycle.

These definitions of the stages of the erosion cycle in terms of the minor land forms produced by solution are somewhat unsatisfactory, however, for they imply that certain minor forms invariably accompany each of the major topographic forms by which the stages are best known. Such a fixed association of major and minor forms is not necessarily true. It seems more rational to analyze the cyclic history of the surface and underground drainage systems independently, though by analogous stages.

In the first or youthful stage of its history a surface stream advances by headward erosion, branches repeatedly, and encroaches upon an undrained upland by expanding fanlike until a rough equilibrium is reached between the erosive powers of adjacent streams. Its valleys have steep longitudinal gradients and are V-shaped in transverse profile; the valley slopes intersect the upland plain in sharp angles. There are many undrained remnants of the upland between the tributary streams, but they are gradually reduced in size. In the stage of late youth or adolescence the angular shoulders at the crests of the valley walls disappear from the profiles and are replaced by curves that are convex upward. The stage ends when the upland remnants

[52] Beede, J. W., The cycle of subterranean drainage as illustrated in the Bloomington, Ind., quadrangle: Indiana Acad. Sci. Proc. for 1910, pp. 81–111, 1911.

[53] Cvijać, Jovan, Hydrographie souterraine et évolution morphologique du Karst: Inst. géog. alpine, Recueil des travaux, vol. 6, pp. 375–426, Grenoble, 1918 (abstracted at length by Sanders, E. M., The cycle of erosion in a karst region, after Cvijać: Geog. Review, vol. 11, pp. 593–604, 1921).

have been narrowed to linear divides but have not been reduced in altitude.

In the analogous stage of the underground cycle solution channels are first developed beneath the slopes of the deeper surface valleys and extend themselves headward beneath the uplands. The stage may be considered to end when the entire region is underlain by a network of channels and when linear divides first appear between the underground systems. As in a dense massive limestone the channels are generally formed by etching the faces of blocks bounded by joints and bedding planes, both lateral and vertical connections will be made from crevice to crevice as the process of solution goes on. Ultimately the small solution openings become braided or looped in both horizontal and vertical projections. Such a looped pattern without large trunk channels may be considered characteristic of this first stage. The divides between the underground drainage basins may or may not coincide with the surface divides, and they may even shift laterally with seasonal or annual variations in the distribution of rainfall.

The joints in massive dense limestone may be so tight that the ground water percolates slowly below a new upland, even though the surface streams occupy deep trenches and the hydraulic gradient is steep in consequence. Under such conditions the solution channels may extend themselves headward very slowly, especially if the limestone is impure or is interbedded with less soluble layers, and the surface streams may progress beyond the first stage of their erosion cycle before the underground system diverts any considerable part of the surface run-off. On the other hand, if the joints are open or the limestone has considerable primary continuous porosity and is especially soluble the underground drainage system may develop very rapidly and may pass through the first stage of its cycle before the upland is completely drained by surface streams. Under these conditions extensive upland tracts might be thoroughly drained into underground channels before surface drainage became established.

In north-central Tennessee, where the limestones are nearly horizontal and not excessively jointed and where the rainfall is moderately high, the surface streams seem to pass through their youthful stage before the system of underground solution channels is well established. Indeed, in areas of youthful topography in this region the solution channels are small and discontinuous and do not extend to great depths. Generally the limestone becomes tight and not water bearing at 75 feet or less below the surface. Locally small quantities of ground water drain from the upland and pass through the imperfect system of underground channels as perennial or intermittent cascades, but most of the drainage is carried by surface streams.

In the second or mature stage of the surface erosion cycle the interstream divides are lowered gradually, the valleys are widened, and in transverse profile the lower parts of the valley slopes become concave upward. A process of integration goes on by which the branches that have the greatest erosive power drain more and more of the total drainage area and become major tributaries of the trunk stream. They also erode their beds downward to a local profile of equilibrium, below which they can not cut effectively, and subsequently they aggrade their lower reaches. Provided the rocks are equally resistant to erosion and the erosion cycle is not interrupted by crustal movement or other cause, the pattern of the surface drains remains dendritic or branching. The mature stage ends when the principal divides begin to disintegrate into groups of isolated hills.

In the analogous stage of the underground cycle integration of the solution channels goes on, those which gather the largest amounts of surface water and those which discharge at the lowest points increasing in size most rapidly and becoming major ground-water conduits. These conduits may converge toward a common point of discharge or they may diverge toward several points of discharge after the manner of distributaries on the delta of a surface stream. Also, they are likely to be connected by small looped channels or to be looped themselves. At the same time the divides between the underground drainage systems are lowered as new channels are etched at lower altitudes and the hydraulic gradient that induces circulation of the ground water is reduced. Collapse sinks may reach the surface in this stage of the underground cycle, but if the limestone is thick bedded, strong, and not closely jointed and if the large solution channels are not close to the surface such sinks may not be numerous. If the limestone is highly permeable and particularly soluble, the cycle of underground channeling may well reach maturity while the surface streams are still extremely young. As the surface streams into which the ground water discharges lower their beds, the ground-water conduits seek lower points of discharge until a condition of equilibrium is established and then extend themselves laterally. The profile of the ground-water conduits after such equilibrium has been established defines a surface that may be designated the equilibrium surface of solution channeling. Below this surface the ground water does not circulate effectively and hence probably does not etch the limestone appreciably except where deep artesian circulation takes place (pp. 96–98). As circulation is controlled by points of discharge into the surface streams, the equilibrium profile of solution channeling is generally adjusted to the local equilibrium profile of erosion, and the ground-water conduits tend to adjust themselves to the surface streams where the rocks are equally jointed and equally soluble throughout. However, where the rocks are unequally soluble a local equilibrium profile of solution may be established above the surface streams by a bed that is impermeable or more or less insoluble. Such a local equilibrium surface of solution may be either temporary or permanent, depending upon the character of the restraining bed.

In their final or old-age stage the surface streams widen their valleys by lateral planation at the equilibrium profile of erosion, and the divides are gradually worn down by the tributaries. As planation progresses the grades of the streams decline, and their capacity to transport the mechanical products of erosion diminishes and finally becomes essentially zero. Ultimately the divides are essentially destroyed and the entire region is reduced nearly to a plane surface, the peneplain, which is the final product of the erosion cycle.

In a corresponding manner, once the ground-water conduits have been established at the equilibrium profile of solution channeling they tend to extend themselves along this profile within the limits imposed by the stratigraphy and structure. Ultimately there tends to be produced at this level a network of large solution channels in which most of the ground-water circulation takes place. Such a network may be considered as defining a peneplain of solution.[54] Collapse sinks should be most numerous in this stage of the underground cycle, and under favorable circumstances much of the drainage may be returned to the surface by the formation of collapse valleys.

The ultimate product of the underground cycle would be the same as that of the surface cycle—a peneplain drained in large part by subsurface channels of very low gradient. This condition probably existed on the Highland Rim peneplain of north-central Tennessee (pp. 19–20), which in its final form seems to have been drained largely by a network of solution channels about 100 feet below the surface. These channels are those which are entered by numerous wells and from which issue many large tubular springs (pp. 92–95). Indeed, the final steps in degradation of the peneplain may have been effected wholly by solution and by ground-water circulation, for in some places the mantle of insoluble rock waste that overlies the bedrock extends downward practically to a zone of extensive solution channeling. (See pl. 6, *B*.)

Although the cycles of surface erosion and of underground solution start simultaneously whenever an area is raised above regional base-level, and although the two processes tend to a common ultimate product, the peneplain, the analogous intermediate stages of the two cycles may not be even roughly contemporaneous. If the limestone is readily soluble and is permeable even before being attacked by the natural solvents, and if the area is raised only a moderate amount above base-level, underground planation by solution may be far advanced while the surface streams are yet very immature. These conditions would presumably be the optimum for the formation of large solution and collapse sinks and for sculpturing the surface by

[54] Meinzer, O. E., Geology of large springs: Geol. Soc. America Bull., vol. 38, p. 215, 1927.

the secondary effects of underground solution rather than by surface erosion. On the other hand, if the limestones were relatively insoluble or not equally soluble and not highly permeable, and if the area were raised far above base-level, the land might be sculptured almost entirely through corrasion by surface streams. Indeed, it seems that diversion of the drainage into solution or collapse sinks might begin at any stage of the surface erosion cycle, or, on the other hand, that surface streams might breach the underground channels and disrupt the subsurface drainage until a relatively late stage of the underground cycle. Furthermore, both the surface and subsurface cycles are likely to be interrupted by crustal movement or other cause before the peneplain stage is attained, and both the stratigraphy and the structure may cause profound modifications of the ideal cycles that have been outlined. Hence, many complex patterns of subsurface drainage channels may exist.

In a given area, the cycle of channeling by solution proceeds most rapidly where the rocks receive the largest or most constant inflow of water from the surface. Generally this condition exists near the perennial surface streams, provided their channels are somewhat above the profile of equilibrium and have not been rendered impermeable by natural puddling. In north-central Tennessee the most cavernous limestone and the largest solution channels generally occur within the meander belts of the major streams, or in the acute segments between converging tributaries in the vicinity of their confluence. Many of the largest subsurface openings are evidently by-pass channels that convey a part of the perennial stream flow across meanders or from one tributary to another by a course that is shorter than that of the surface stream. From channels of this sort issue some of the largest perennial springs of the region, including Hurricane Rock Spring (No. 181, pp. 161–162), whose discharge on September 10, 1927, was about 60 cubic feet a second (27,000 gallons a minute). Generally the limestone underlying the floors of all those valleys in north-central Tennessee that are occupied by perennial streams is somewhat channeled, the equilibrium profile of active ground-water circulation seeming to be 50 to 75 feet below the mean low-water surface of the Cumberland River.

RELATIONS OF WATER-BEARING OPENINGS TO GEOLOGIC AND PHYSIOGRAPHIC HISTORY

Relation to stratigraphy.—Even relatively pure limestone differs somewhat in solubility; furthermore, limestone formations may be separated by impermeable rocks such as shale or by permeable rocks such as sandstone. Hence many conditions of ground-water circulation may result. A bed of impermeable shale or a stratum of limestone that is not readily soluble or is not jointed may prevent circulation downward. Consequently, a perched body of ground water and a local equilibrium surface of solution may be created, and the stratum just above the barrier may become extensively channeled by solution. This condition exists in north-central Tennessee, where the impermeable Chattanooga shale (pp. 39–41) underlies the Mississippian limestones. Much of the ground water that is reported to occur in the uppermost part of the shale may circulate in small solution openings that follow its upper contact. Also beds of impermeable shale in some of the thin-bedded and shaly limestone formations may uphold bodies of ground water and induce channeling considerably above the regional equilibrium profile of solution. A local equilibrium profile of solution, if created by a bed that is slowly soluble, may be only temporary. Once the restraining bed is breached, further extensive channeling may take place at a lower equilibrium profile, either local or regional, and the lower system of channels may drain the upper system through natural wells.

Sandstone strata may accelerate the cycle of solution channeling in limestones with which they are interbedded by facilitating deep percolation of meteoric water.

During an erosion interval that follows an epoch of limestone formation a system of solution openings may be formed, which may not be filled during the subsequent epoch of sedimentation. Hence an unconformity may be accompanied by openings of this sort, which may be filled with fossil water of the date of submergence or may serve as conduits for ground water of meteoric origin if the unconformity crops out at the present time. In several places in north-central Tennessee the Chattanooga shale, which rests unconformably upon limestones ranging in age from Middle Devonian to Ordovician, fills unmistakable sink holes in the underlying surface, as has been noted by Bassler [55] and Lusk.[56] However, no water-bearing openings associated with this erosion surface were noted. Some of the highly concentrated connate waters (pp. 120–123) that occur in the Ordovician limestones of this region may be trapped in solution openings associated with unconformities.

Relation to structure.—All features of geologic structure, both folds and faults, may affect the ground-water conditions in limestone profoundly. Thick-bedded pure limestones are rather brittle, so that, where folded, they are generally broken by closely spaced joints, which constitute water-bearing openings. Some of the thinner-bedded formations in the folded areas and all the rocks in the unfolded areas may be much less jointed, so that in them the ground water circulates much less freely in the early stages of the subsurface cycle. An impermeable or slightly soluble bed folded in

[55] Bassler, R. S., Sink-hole structure in central Tennessee [abstract]: Washington Acad. Sci. Jour., vol. 14, p. 374, 1924.

[56] Lusk, R. G., A pre-Chattanooga sink hole: Science, new ser., vol. 65, pp. 579–580, 1927.

a synclinal trough may uphold a large body of perched ground water far above the regional water table. As a limb of a fold, a bed of the same sort may constitute a ground-water dam that inhibits horizontal extension of the subsurface drainage system. Where the dip is greater than the inclination of the topographic surface, a soluble limestone that is inclosed by less soluble or by impermeable beds may be channeled to considerable depth, so that it retains water under artesian head. Where the dip is less than the inclination of the topographic slope and in the same direction inclosed water-bearing beds are likely to discharge as hillside springs above the level of the perennial streams. On the other hand, where the limestones are thick and are more or less equally soluble, folding might impede but probably would not prevent development of the normal subsurface drainage system. However, the channels would presumably be looped in a more complex pattern than in horizontal beds, for solution would take place largely along the inclined bedding planes and along joints transverse to the beds.

Faults and the breccia zones that commonly accompany them in rocks as brittle as limestone may constitute ground-water conduits extending to great depth. Furthermore, the walls of a fault are likely to be jointed for considerable distances from the principal fracture. Hence a fault and the accompanying secondary fractures may promote ground-water circulation and subsurface channeling.

Relation to physiographic history and land forms.—If limestone that has been rendered cavernous by solution were depressed somewhat by subsidence of the crust, the water table would rise with relation to the equilibrium profile of solution, so that channels that were formerly above the water table would be filled with water and might become ground-water conduits of very large transmission capacity. Under favorable conditions water might also be retained under artesian pressure. Obviously this sequence of events is ideal for producing the maximum water-yielding capacity in a water-bearing limestone.

Conditions that are analogous with those just outlined exist in some parts of the north-central United States, where the deposition of extensive sheets of glacial débris caused the water table to rise and to submerge cavernous portions of the Galena and Niagara limestones. The occurrence of ground water under these conditions is described by Meinzer [57] as follows:

> Before the glacial epoch these limestones [Galena and Niagara] lay at the surface over wide areas and were subjected to extensive weathering. Then they were overridden by successive ice sheets and became covered with glacial drift. To-day the water table in most places passes through the drift mantle, leaving the underlying cavernous limestone within the zone of saturation. In these areas limestone

[57] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, p. 132, 1923.

is considered an excellent water bearer, and many limestone wells will yield from 100 to several hundred gallons a minute. Where these same formations are so deeply buried that they have never been leached they are often not regarded as aquifers by deep-well drillers, who search for the water-bearing sandstones between the limestones.

The relation between solution caverns in the limestone and the physiographic history of the Mammoth Cave district of Kentucky is described by Lobeck.[58]

Generally the sequence of events in the geologic and physiographic history of north-central Tennessee has not been such as to cause the immersion of any extensive bodies of cavernous limestone in the zone of saturation. Instead, that region has been uplifted recurrently, so that the cavernous limestones have been in part drained by rejuvenated streams and by deeper ground-water conduits. Hence the capacity of wells and springs that issue from these rocks is limited. Furthermore, in areas where the water table has been depressed below the cavernous portions of the limestone, water is not usually confined under artesian head. In a few small areas of north-central Tennessee, however, the water table has been raised so much as to saturate cavernous rock and to produce artesian conditions (pp. 96–98), probably because a major ground-water conduit became dammed through deposition of silt, collapse of its roof, or some other cause.

Where the water table has been depressed slightly below a body of cavernous limestone, either by uplift of the earth's crust or because the stream to which the water table is adjusted has eroded its bed downward, a lower equilibrium profile of solution is established. Consequently a new set of solution channels tends to form at that level. In many places the lower channels tend to follow the same joints as the upper channels and to join themselves to the upper channels by vertical solution channels or natural wells. Ultimately the channels of the upper set would be drained except when water flowed through them in passing to the water table. If the water table were depressed several times and the interval between successive depressions were long enough for solution planation to become extensive, the body of limestone would be ramified by dry caverns at several levels, whereas the water table would be far below the surface. On the other hand, each cycle of solution channeling might be interrupted at any stage, so that many complex conditions with respect to size and pattern of water-bearing openings might result. Conditions of this sort occur very commonly in the valleys of large streams that have cut downward by several stages, in each of which a local equilibrium profile of erosion and a correlative equilibrium profile of solution have existed temporarily.

[58] Lobeck, A. K., The geology and physiography of the Mammoth Cave National Park: Kentucky Geol. Survey Pamphlet 21, pp. 41–47, 1928.

On the other hand, when a region underlain by cavernous limestone is raised a considerable distance by rapid crustal movement, its streams are rejuvenated and much lower equilibrium profiles of erosion and of underground channeling are established. The effect of the uplift upon the ground-water conditions then depends upon the relative rates of surface erosion and subsurface channeling. Where the rocks are extremely soluble and much fractured, a poorly drained elevated plateau with a deep water table would result. If, however, the cycle of stream erosion should proceed more rapidly than the cycle of underground channeling, there would tend to be formed in such a region two separate systems of subsurface conduits—one formed in association with and adjusted to the streams that formerly drained the upland and another adjusted to the base level of the rejuvenated streams. The conduits adjusted to the rejuvenated streams might not extend themselves beneath the uplands, and the two systems might remain virtually without underground connections, the channels associated with the uplands ultimately being completely destroyed by erosion. Conditions of this sort prevail in north-central Tennessee, where the Highland Rim plateau is drained in large part by underground solution conduits that generally are not connected with the solution conduits associated with the Nashville Basin peneplain (pp. 16–21).

The conduits that drain the Highland Rim plateau have been breached by tributaries of the rejuvenated Cumberland River; from them issue tubular springs, of which many discharge 100 gallons a minute or more perennially (pp. 92–95). Along the Highland Rim escarpment the limestones are generally not channeled to any great extent, and there seems to be little or no ground-water percolation much below the surficial mantle of weathered rocks. Such percolation as does take place below the steep erosion slopes of the escarpment occurs largely as a ground-water cascade in the weathered rocks. For the most part this cascade is intermittent, but locally there is continuous percolation that supplies perennial springs.

RELATION TO UTILIZATION OF GROUND WATER

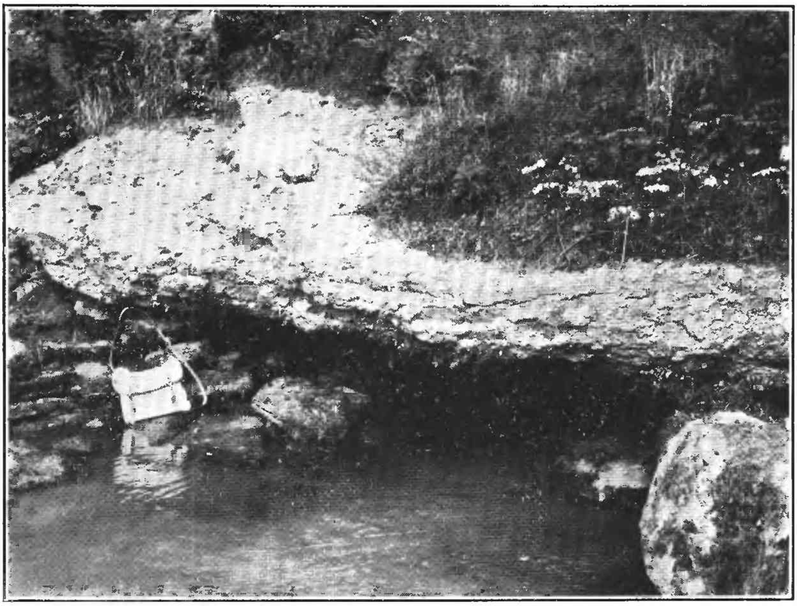
Not only do limestones in different regions differ greatly in water-bearing properties, but there is also a great diversity in the yield of wells and springs that issue from the same bed in a given locality. Obviously, the yield of a well or spring depends upon the size and transmission capacity of the joint or solution channel from which its water is derived. Hence, a considerable element of chance enters into the search for a supply of ground water, for one well may enter a large water-bearing channel and be virtually inexhaustible, whereas other wells only a few feet away may be practically dry because they do not find any water-bearing openings, or because they enter dry channels or channels that are filled with clay.

The courses followed by some of the larger underground channels may sometimes be traced approximately on the surface where sink holes or natural wells occur in line, the altitude and relative size of the sinks and the altitude of the associated ground water being used to discriminate channels that are related to different levels of planation by solution. Furthermore, some solution channels follow persistent joints and may be approximately straight for considerable distances. Hence, where the limestones are broken by one or more well-defined sets of joints the most probable courses of a water-bearing channel can be projected approximately by drawing lines through the proved wells or springs and parallel to the dominant sets of joints. Obviously the uncertainty of these projected courses increases with the distance from the proved sites. Solution channels may also be formed at several altitudes along a single joint, so that the course of a shallow channel which can be traced by springs, dry caverns, or small sinks may coincide with that of another water-bearing channel at greater depth. However, solution channels and joints usually depart somewhat from a true plane, so that wells located at sites chosen by one of the methods of projection outlined above may not be successful in finding a large yield of water. Moreover, the traces of many large solution channels that are proved by existing wells and of most small channels and joints are not indicated at the surface. Hence the development of ground-water supplies in limestone by drilling wells is likely to involve failures even under the most favorable circumstances.

In north-central Tennessee the limestones fortunately are somewhat jointed at most places, and small openings along the joints and along bedding planes are generally water bearing 50 feet or more above and below the level of the perennial surface drains. Hence, sufficient water for household use and for watering stock can be obtained by wells of moderate depth in most parts of the region. However, the water found in the deeper crevices in many places holds considerable dissolved mineral matter and may be unsatisfactory in chemical character for some uses. Comparatively few wells yield as much as 100 gallons a minute. The water-bearing properties of the limestones in different parts of the area are discussed in the county descriptions (pp. 124–233).

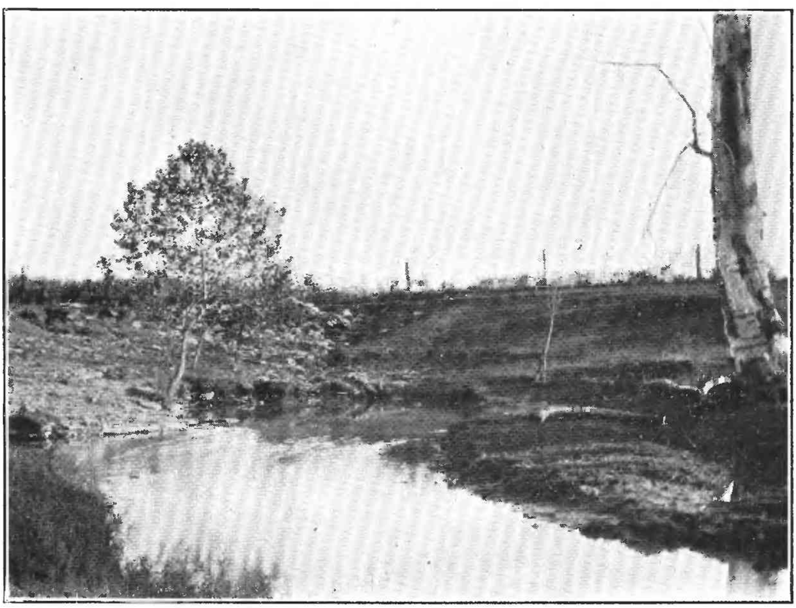
In studying the sanitary condition of a water supply from the limestone or the possibility of interference between two or more sources, it is frequently desirable to trace the direction of flow of the ground water. For this purpose the use of a water-soluble dye, such as the sodium salt of fluorescein, is usually effective.[59] The principle of its use is to dose the circulating ground water with a solution of the dye

[59] Dole, R. B., Use of fluorescein in the study of underground waters: U. S. Geol. Survey Water-Supply Paper 160, pp. 73–85, 1906. Stabler, Herman, Fluorescein, an aid to tracing waters underground: Reclamation Record, vol. 12, pp. 122–123, 1921.



A. ORIFICE OF TUBULAR SPRING IN RIDLEY LIMESTONE ON SOUTH BANK OF WEST FORK OF STONE RIVER, 2¾ MILES NORTHEAST OF FLORENCE, RUTHERFORD COUNTY

No. 416, Plate 4. Approximate yield August 7, 1927, 1,000 gallons a minute.



B. BIG SPRING, 6½ MILES EAST OF LEBANON, ON THE NASHVILLE BASIN PENEPLAIN

No. 329, Plate 4. Approximate yield October 14, 1927, 1,800 gallons a minute.

at a sink hole, well, or temporary test pit, and then to take samples of water from all possible points of discharge in springs or wells and examine them for traces of the dye.

The sodium salt of fluorescein is sold under the commercial name "uranin." Its solution has a characteristic fluorescent green color by reflected light, and it can be detected by the eye in a solution whose concentration is as low as 1 part of the dye in 40,000,000 parts of clear water, if proper technique is followed.[60] When the concentration of the solution is very low the characteristic color is seen best if the sample is placed in a test tube or a long glass tube and viewed in full daylight before a white background by looking along the axis of the tube. If the examination is made by a suitable fluoroscope the limit of visibility has been placed at 1 part of pure uranin in 10,000,000,000 parts of clear water.

Uranin is altogether harmless in water used for domestic and other common purposes. It is not decolorized by contact with leached sand or gravel and has been shown to persist as long as three years in such material.[61] However, dilute solutions of uranin may be partly decolorized by calcareous soils or by waters such as those that generally issue from limestone, which contain a large amount of calcium carbonate or other calcium salts, and may be completely decolorized by peaty formations and by mineral acids other than carbon dioxide.

A solution of uranin is somewhat heavier than pure water, so that it sometimes settles to the bottom of stagnant pools until the stream is agitated, as by the sudden influx of a larger amount of water. Consequently, the rate of movement of the dye may be slightly less than that of the water, and one dose of the dye may produce distinct color two or more times at a related point of discharge.

On the other hand, it was found in the experimental work of the United States Public Health Service at Fort Caswell, N. C., that uranin floated on the water table in unconsolidated sand and was even drawn up into the capillary fringe and there trapped.[62]

The dye is most readily handled as a solution containing 2 or 3 ounces of uranin for each gallon of water, which is poured into the selected well, sink hole, or other opening at the rate of about 1 ounce of uranin an hour for each 500 gallons a minute of estimated underground flow. Dosage at this rate should be continued for at least an hour where the distance to the most remote point of observation is less than 1 mile, or for a longer period where the distance is greater. If the solution is poured into a dry sink or natural well, enough additional water should be poured in to assure the uranin being carried down to the water table. Before the introduction of the uranin, a

[60] Stiles, C. W., and others, Experimental bacterial and chemical pollution of wells via ground water and the factors involved: U. S. Public Health Service Hyg. Lab. Bull. 147, pp. 84–85, 1927.
[61] Idem, pp. 85–86.
[62] Idem, p. 79.

blank sample of water should be taken from each of the observation wells and springs and preserved as a standard of comparison. Samples are then taken at regular intervals at each of the observation points and compared with the corresponding blank sample, and the collection of samples is continued until the arrival and passing of the uranin have been noted. From the interval of time between the dosing of the ground water and the appearance of the dye at a point a known distance away the rate of movement can be computed. This is usually determined from the interval between dosage with the dye and its first appearance at the point of observation, the resultant figure being probably a minimum value. Though a positive result from a field test with uranin gives useful information, a negative result is not conclusive, for the uranin commonly advances as a very narrow band,[63] which may pass between two observation wells and thereby escape detection.

An instructive example of the use of uranin in tracing the flow of ground water in limestone has been described recently by Crouch.[64] A disappearing stream was traced to springs as much as 5 miles distant, and the rate of movement was found to be about 160 to 185 feet an hour.

SPRINGS

GRAVITY SPRINGS

GENERAL FEATURES[65]

Many localities in north-central Tennessee have no perennial streams of consequence, and hence the springs are an important present and future source of water supply for municipal and industrial uses. The value of any spring for these purposes is determined by the amount and variability of its discharge, by the temperature of its water, and by the amount and character of the dissolved and suspended matter in its water.

Most of the springs in this region are gravity springs—that is, they percolate from permeable beds or flow from large openings in the rocks under the force of gravity, much as a stream flows down its channel. In such springs water does not issue under artesian pressure. These gravity springs may be further classified as seepage springs, in which the water percolates slowly from the many small interstices of a permeable material; as fracture springs, in which the water flows from one or more joints or other fractures in the rocks; or as tubular springs, in which the water issues freely from large tubelike channels that are

[63] Stiles, C. W., and others, op. cit., p. 73.

[64] Crouch, A. W., The use of uranin dye in tracing underground waters: Am. Waterworks Assoc. Jour., vol. 19, No. 6, pp. 725-728, 1928.

[65] For a full discussion, see Meinzer, O. E., An outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, pp. 50-53, 1923. Bryan, Kirk, Classification of springs: Jour. Geology, vol. 27, pp. 522-561, 1919.

not primarily the result of fracturing. The distinctions between these three classes are wholly arbitrary, and all classes grade into one another.

SEEPAGE SPRINGS

Most of the springs in the region are seepage springs, the common type being the contact spring, which issues from permeable material just above the outcrop of some relatively impermeable material. In springs of this type the impermeable material retards or prevents the downward percolation of ground water and consequently deflects it to the surface. These conditions are satisfied in four general cases, each of which is associated with a characteristic type of spring performance. First, the water-bearing material may be a rock, such as sandstone, which is permeable in its unweathered state, and the underlying retaining bed a stratum of shale or other impermeable rock. The storage capacity of such a permeable bed is relatively large, so that the discharge of the spring is not likely to be highly variable, even though it may not be large. Second, the water-bearing material may be a stratum that has been rendered permeable by weathering, and the underlying retaining bed a material that is not affected by weathering to an appreciable degree. Third, the permeable material may be the weathered portion of a massive stratum, and the retaining bed the underlying fresh rock. In these two cases the volume of permeable material that supplies each spring may be small, so that both the storage capacity for ground water and the discharge of the spring during the dry season may also be small. Finally, the water-bearing material may be transported detritus, and the retaining bed the underlying solid rock. The storage capacity and permeability of the detritus vary between wide limits, although under favorable conditions both may be large; hence the discharge of such a spring may be large and relatively invariable. The optimum condition favoring contact springs exists in a terrane of steep slopes, and hence such springs are especially abundant along the Highland Rim escarpment, which bounds the Nashville Basin. They are somewhat less numerous on the valley slopes throughout the region and are not common on the Highland Rim plateau or the Nashville Basin peneplain.

Many contact springs issue from minute joints and bedding-plane crevices in the uppermost part of the Chattanooga shale along the Highland Rim escarpment, although their water is probably derived in part from the weathered zone of the overlying limestone. Typical examples, which are entered in the table of spring data, are Nos. 273 and 278 of Davidson County (pp. 138–139) and Nos. 358 and 395 of Williamson County (pp. 218–219). Each of these springs has a small area of influence and issues from material of low permeability, and hence the discharge is generally very small. Other contact springs issue from beds of permeable sandstone near the top of the Fort Payne formation, which are known to exist only locally along the Highland Rim escarpment in Williamson County, on the west side of the Nashville Basin. Several of the springs that constitute the municipal supply of Franklin (Nos. 366, 380, 383, and 384, pp. 218–219) are typical of the springs that issue from this horizon. Except at these two horizons, contact springs are not especially numerous at the outcrop of any one stratigraphic member, although many springs issue just above clay beds that separate layers of limestone and near the base of the zone of weathering in rocks of all types. Except within very small areas, however, the stratigraphic horizon of these springs is largely a matter of local variations in the texture of the rocks.

The seepage springs of north-central Tennessee are generally small, and many are intermittent. Few of those that issue from the Chattanooga shale yield more than 1 gallon a minute in dry seasons, and most of those that issue from other rocks do not yield more than 25 gallons a minute. Moreover, their yield is likely to vary from season to season, perhaps greatly, although the change in discharge is gradual. Under favorable conditions the discharge of several such springs may be combined into a reliable supply of considerable magnitude, such as the municipal supply of Franklin, Williamson County. This supply comprises 34 springs on the Highland Rim escarpment about 12 miles west of the city, the smallest of which discharges about 3 gallons a minute in dry seasons and the largest about 28 gallons a minute.

The springs that issue from alluvium or coarse hill wash above bedrock constitute a reliable source of water throughout the dissected portions of the Highland Rim plateau, especially along the eastern slope of the Tennessee River Valley. The largest of these generally issue from extensive beds of coarse detritus that have been deposited by the intermittent streams where their gradients flatten at the base of the dissected upland. Typical springs of this class are Nos. 161 and 174 of Humphreys County (pp. 161–162), No. 224 of Dickson County (p. 147), and No. 252 of Cheatham County (pp. 129–130). If the alluvium is well assorted its permeability is high, so that, given an adequate volume of stored water, a spring may have a relatively large and only moderately variable yield. Many discharge more than 25 gallons a minute in dry seasons and some more than 100 gallons a minute.

The water that supplies the seepage springs does not, as a rule, penetrate far below the surface, so that it is nonthermal, and usually its temperature is approximately equal to the mean annual air temperature of the district. In north-central Tennessee the mean annual temperature is between 58° and 60° F. In a spring of very small yield, however, the temperature of the water is likely to be variable and to follow the diurnal variations in air temperature.

The seepage springs differ greatly in the chemical character of their water. Those that issue from thoroughly weathered and leached material and those that have a large discharge generally yield water that contains little dissolved matter, but those that issue by slow percolation from partly leached rock yield water that is relatively highly concentrated. These relations are brought out by Plate 8 and by the corresponding chemical analyses, which are tabulated on pages 110–119. The concentration and chemical character of the water may vary somewhat from season to season, although the change is not likely to be either large or rapid. Moreover, the water usually contains very little suspended matter as it issues from the water-bearing bed. Hence, in case it is desirable to soften the water for use, it will probably not be necessary to modify the treatment process from season to season in order to produce satisfactory results.

FRACTURE SPRINGS

A great many springs issue from fractured rocks in north-central Tennessee and probably owe their origin to the circulaton of ground water along crevices, although most of the rocks are appreciably soluble, so that the crevices have been more or less enlarged by solution. Hence the springs that issue from these rocks are tubular springs rather than fracture springs. However, the Lower Ordovician rocks that crop out in the Wells Creek Basin of southeastern Stewart County (see pp. 190–193) are very closely jointed and are much less soluble than the younger rocks, at least in part. In this locality, therefore, numerous fracture springs occur, which for the most part yield less than 5 gallons a minute and are subjeet to wide seasonal fluctuations.

TUBULAR SPRINGS

The largest and most reliable of the perennial springs of north-central Tennessee are those that issue from tubelike solution channels in the limestone. A tubular spring usually falls into one of three classes. First, it may be the outlet of a subsurface drainage channel into the surface stream to which it is adjusted, such as No. 416, in Rutherford County. (See pl. 9, *A*.) Second, it may be the outlet of a portion of a subsurface drainage system that has been captured by a surface stream during a period of downcutting. The subsurface drainage in the limestones of north-central Tennessee has cut down to an equilibrium surface of solution over extensive areas during the later stages of each cycle of peneplanation. (See pp. 18–23 and 78–82.) Hence, when such an underground drainage system is breached during a later cycle of surface erosion, the tubular springs produced tend, within a given district, to occur at approximately the same distance below the related peneplain. Such a relation seems to exist in the dissected portion of the Highland Rim plateau in the western part of the region. Finally, a tubular spring may be a portion of an underground stream that is exposed when the roof above its channel is breached by collapse or by solution. (See pl. 5, *B*.) Tubular springs representative of each of these classes are very numerous in most parts of the region, and many typical examples are described in the tabulated data and the county reports (pp. 124–233).

The discharge of tubular springs in north-central Tennessee ranges from one gallon or less to many thousand gallons a minute. No springs of the first magnitude—discharging 100 cubic feet a second (45,000 gallons a minute)—are known to exist within the region, but on September 10, 1927, Hurricane Rock Spring, in Humphreys County (No. 181, pp. 161–162), discharged at the approximate rate of 60 cubic feet a second (27,000 gallons a minute). This spring may attain first magnitude during periods of maximum discharge. Of the springs that were visited by the writer during July, August, and September, 1927, 57 discharged more than 100 gallons a minute each, and 12 discharged more than 1,000 gallons a minute. However, most tubular springs fluctuate greatly in yield, the maximum observed discharge of one of these springs during the four months of the field investigation being about twenty times the minimum observed discharge. The discharge of certain springs—presumably those that are fed by solution channels of steep gradient or small storage capacity and those whose source is largely in local intermittent run-off—increases to several times the normal flow in the course of a few hours after a heavy rain and may decline with almost equal rapidity. The discharge of other springs—presumably those that issue from solution channels of flat gradient and large storage capacity as well as those whose source is not primarliy from local run-off—is relatively uniform from day to day, although it may vary considerably from season to season. All the springs of an area may not attain their maximum rate of discharge at the same time, so that the relative magnitude of two or more springs can not be determined accurately if the discharge of each is measured only once, even if the measurements are taken at approximately the same time. The true average discharge of the variable springs can be determined only from a continuous and accurate record of discharge extending over a period of several years. At many localities tubular springs constitute the only source of large water supplies for municipal or industrial purposes. In view of their variability, however, these springs should not be developed as a source of supply without trustworthy information as to the quantity of water that may be available from them in dry seasons.

The tubular springs in north-central Tennessee differ noticeably in the temperature of their water. In springs whose discharge is moderate and not highly variable the temperature is relatively constant and is approximately equal to the mean annual temperature of the region, 58° to 60° F. Springs derived from bodies of surface water at no great distance, however, tend to vary in temperature with the surface streams, and springs whose discharge increases and diminishes with the rainfall may vary several degrees in the course of a few hours. Hence, if the water from such springs is used for cooling, the efficiency of the process may vary noticeably.

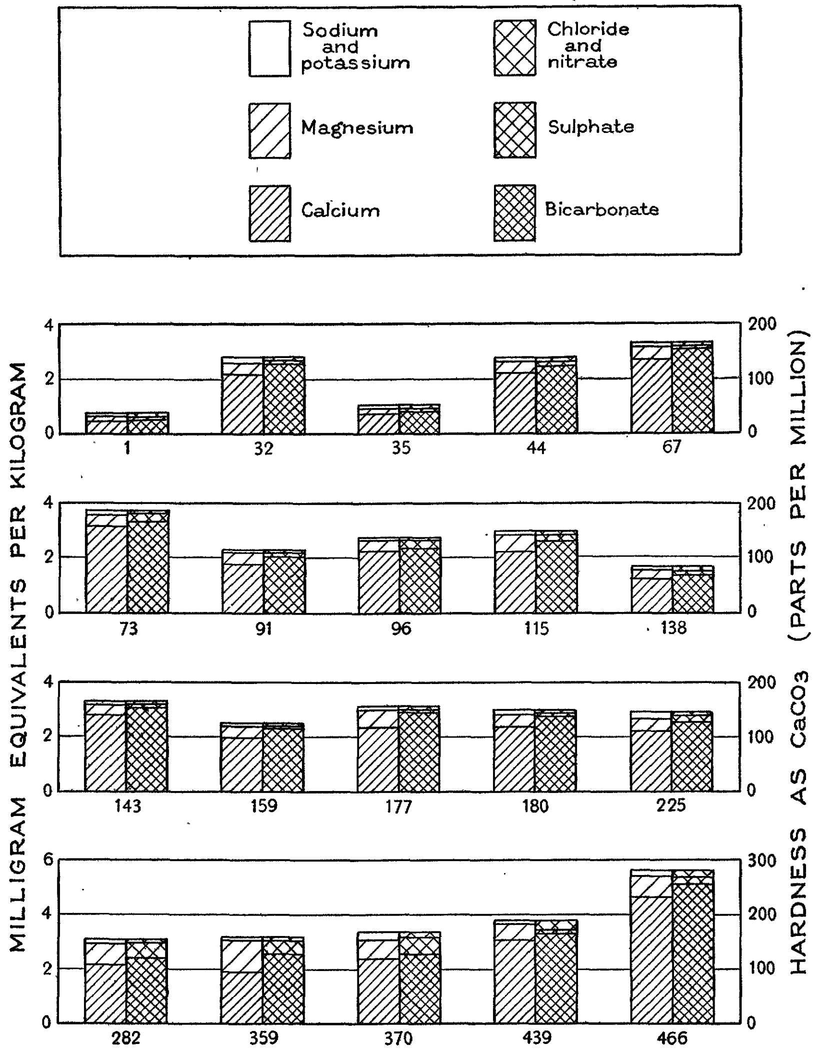


FIGURE 5.—Chemical character of water from representative tubular springs in north-central Tennessee

The quality of the water that issues from the tubular springs is also a critical factor in its utilization, particularly in the content of suspended matter and of organic waste, which may be a carrier of disease. The spring water is derived in the first place from the surface, and in many places surface drainage probably reaches the water-bearing channel very close to the spring outlet. Hence every tubular spring is liable to permanent or intermittent pollution, so that the water of each one that is used for municipal supply should be sterilized thoroughly at all times, as a precaution against the transmission of disease. The liability to pollution is quite independent of the turbidity of the water discharged by the spring. Many of the tubular springs yield clear water at all times, even though the discharge is large and the source is known to be in a body of turbid surface water. The system of solution channels that feeds such a spring has so large a storage capacity and so low a gradient that the water flows slowly and all its suspended matter is deposited. Tubular springs whose flow responds quickly to local rainfall become extremely turbid at high stages and may remain turbid for several days after the peak of the storm discharge has passed. The system of solution channels that feeds such a spring has little storage capacity, so that the suspended matter does not settle from the water. Naturally every possible gradation exists between these two extremes. In order to condition it for municipal and for many industrial uses, the turbid spring water must be passed through a sedimentation basin, the capacity of which should be based upon trustworthy information as to the maximum possible turbidity of the spring water.

The water of the tubular springs is not highly concentrated in dissolved mineral matter and is generally of the calcium-magnesium bicarbonate type. This is brought out by the accompanying diagram (fig. 5) and by the corresponding analyses, which are summarized in the following table and are tabulated on pages 110–119.

Average, minimum, and maximum quantities of mineral constituents in water from tubular springs in north-central Tennessee [a]

[Parts per million]

	Average	Minimum	Maximum		Average	Minimum	Maximum
Silica (SiO_2)	11	2.2	21	Bicarbonate (HCO_3)	155	31	308
Iron (Fe)	.6	.02	4.6	Sulphate (SO_4)	10.9	3.7	31
Calcium (Ca)	49	8.6	93	Chloride (Cl)	2.0	.9	5.5
Magnesium (Mg)	6.3	4.0	14	Nitrate (NO_3)	1.9	.2	8.0
Sodium (Na)	2.0	1.0	6.0	Total dissolved solids	161	50	300
Potassium (K)	.7	.4	1.2	Total hardness as $CaCO_3$	139	31	272
Carbonate (CO_3)	-------	-------	-------				

[a] Based upon analyses of water from 20 tubular springs which issue from Ordovician, Silurian, and Mississippian limestones. Samples taken at low or medium stage of spring flow.

The spring water is only slightly or moderately hard and contains very little dissolved iron, so that it is suitable for most ordinary purposes without softening. For some uses, however, softening may be desirable. The water from the springs that vary in discharge probably varies somewhat in hardness and in its content of dissolved solids, so that the amount of reagents necessary to soften the water will probably vary also.

ARTESIAN SPRINGS

A very few of the springs in north-central Tennessee seem to be artesian springs—that is, they seem to issue under artesian pressure above the usual ground-water level. Such springs probably exist only where an underground solution channel becomes dammed or obstructed by slumping of the roof beds or by accumulation of silt so that water is trapped above the obstruction under hydrostatic pressure. Hence, artesian springs are most erratic in location, and the artesian area is wholly problematic. Big Spring (pl. 9, *B*; No. 329, p. 233), 6½ miles west of Lebanon, Wilson County, may be an artesian spring.

ARTESIAN CONDITIONS

Although the lithologic character and geologic structure of the rocks in north-central Tennessee are not favorable for artesian conditions over any extensive area, ground water under artesian head occurs in several districts. All these districts are below the level of the Highland Rim plateau, and most of them are on or below the Nashville Basin peneplain. Most of the known wells which overflow at the surface or in which water stands at the level of the surface are listed in the following table:

Wells in north-central Tennessee that show artesian head

County	No. on Plate 4	Water-bearing formation	Approximate static altitude of water (feet above sea level)
Davidson	[a] 275	Catheys formation (?)	490
	295	St. Peter (?) sandstone	490
	298	do	495±
	299	do	465 (?)
	303	do	510
Dickson	198-A	Fort Payne formation	550
	206	Chattanooga shale (top)	495
	216	do	715
	220	do	725
Robertson	74		470
	108	Fort Payne formation	510
Sumner	120	Chattanooga shale (top ?)	730
	131	Leipers (?) formation	480
Williamson	[a] 365	Ridley (?) limestone	645
Wilson	328	Lebanon (?) limestone	465

[a] Flows during winter or spring only.

In the vicinity of Nashville water under hydrostatic artesian head occurs in the St. Peter (?) sandstone (see pp. 61, 134) between 1,100 and 1,490 feet below the surface in wells 295, 299, and 303. (See pl. 4, also pp. 135–137). The same stratum is probably the water-bearing bed in well 298, although its exact depth below the surface is not known. The static level of the water in these wells ranges from about 465 to 510 feet above sea level; hence the area within which flowing wells may be expected is limited to bottom lands and low terraces along the Cumberland River and its tributaries in the vicinity of Nashville. However, the exact altitude and inclination of the pressure-indicating surface (the imaginary surface to which the ground water would rise in a well) are not known, so that this area can not be bounded specifically. It probably extends several miles both upstream and downstream from Nashville. As is shown by analyses of samples from wells 295 and 298 (pp. 114–115), the water from the St. Peter (?) sandstone in this district is rather highly concentrated in dissolved mineral matter and contains considerable hydrogen sulphide gas in solution. The chemical character of much of the water renders it undesirable for domestic consumption and many other purposes. Futhermore, the specific capacity of the wells that enter this stratum or strata seems to be relatively small, being less than 10 gallons a minute for each foot of drawdown, although the casings are in poor condition, so that data adequate to determine the specific capacity exactly are not obtainable. Hence, large yields may not be obtainable from the St. Peter (?) sandstone even by pumping. The St. Peter (?) sandstone seems to thin rapidly toward the southeast, for its horizon in the Franklin Oil & Fuel Co.'s test well at Murfreesboro, Rutherford County, seems to be represented by calcareous and magnesian sandstone about 10 feet thick (p. 60). Furthermore, it becomes impermeable in the same direction. The horizon of the St. Peter (?) sandstone is not known to be reached by wells in other directions from Nashville, so that its water-yielding capacity and the static level of its water are unknown. Although this stratum may hold water under sufficient head to overflow at the surface in other parts of north-central Tennessee, its depth below the surface increases radially outward from the apex of the Nashville dome (pp. 62–63); hence the cost of drilling wells to the stratum will increase accordingly. This fact, coupled with the chemical character of the water and the small specific capacity of the wells at Nashville, will probably make it uneconomical to develop this water-bearing formation for many purposes.

Water under artesian head also occurs on the flanks of the White Bluff dome of Dickson County (pp. 140–142), as in wells 206, 216, 220 (pp. 144–146), and several other deep wells of that locality. It is reported by drillers and others that the water occurs in the uppermost layers of the Chattanooga shale, although that formation is generally quite impermeable where it is not weathered. It is more probable that the water-bearing stratum is a permeable sandstone or a channeled limestone that overlies or underlies the Chattanooga shale. The water contains only a moderate amount of dissolved mineral matter and a slight amount of hydrogen sulphide, although its noncarbonate or permanent hardness is rather high and renders the water objectionable as a soap consumer and scale former. (See pp. 103–106.) Analysis 220 (pp. 114–115) is typical. Again, the static level of the ground water and the shape of its pressure-indicating surface are not known exactly. Also, the artesian head may be due in part to the presence of gas. Consequently the areas of flowing wells can not be bounded definitely, although it is known that they are limited to the bottoms of branches of Turnbull and Jones Creeks in the vicinity of White Bluff. Obviously the artesian condition is local, for the horizon of the water-bearing bed seems to be represented by impermeable material in the outcrops to the north, east, and south. (See pl. 4.) To the west, the Highland Rim plateau rises far above the static level of the ground water, and therefore flowing wells are not to be expected. Artesian conditions also exist locally in a stratum at the same stratigraphic horizon in the vicinity of a minor structural dome in northeastern Sumner County. Well 120 (pp. 204–205) is the only one in this district known to overflow at the surface by artesian pressure. The water contains so much dissolved mineral matter and hydrogen sulphide (see analysis 120, pp. 112–113) that it is wholly unfit for all ordinary uses. The artesian head is small and is doubtless due in part to the hydrogen sulphide gas in the water.

Well 328 (pl. 4 and pp. 230–231), in northeastern Wilson County, finds water confined in the Lebanon (?) limestone under so much head that it rises to the surface in the well but does not overflow. The water-bearing bed tapped by this well may be part of a zone of channeling that seems to cut across several limestone formations and yields water copiously to nonartesian wells at Lebanon, about 9 miles southwest. The possible extent and water-yielding capacity of this zone are discussed on pages 222–227.

Artesian conditions exist locally at several points in north-central Tennessee where small solution openings occur at shallow depth in inclined thin-bedded limestone between shaly retaining beds. The artesian head and yield at these places are usually very small. Wells 131 and 198-A (pp. 204, 144) typify this condition, which does not depend upon regional structure but may occur in shaly limestone at any place where its inclination is slightly more than that of the topographic surface. Artesian conditions also exist in channeled limestone above points at which the solution channels are obstructed by clay or other débris, as represented by wells 275 and 365 (pp. 135, 215). Under these conditions the static level of the ground water may fluctuate according to the season, and the wells may overflow at the surface only when the water table is in its highest position.

QUALITY OF GROUND WATER

The chemical character of the ground waters of north-central Tennessee is shown by the analytical data tabulated on pages 110–119. These data cover the analyses of 101 samples collected in 1927 by the writer from representative wells and springs, at sampling points distributed as uniformly as possible within the region and from top to bottom of the geologic column. Approximately half these analyses were made by Margaret D. Foster in the water-resources laboratory of the United States Geological Survey, and half by D. F. Farrar in the laboratory of the Tennessee Geological Survey. All the analyses were made after the methods outlined by Collins.[66]

CHEMICAL CONSTITUENTS IN RELATION TO USE[67]

Total dissolved solids.—The residue from complete evaporation of a natural water consists mainly of the rock substances discussed below, with which may be included a small quantity of organic matter and some water of crystallization. Most waters containing less than 500 parts per million of dissolved solids are satisfactory for domestic and common industrial uses, except for the difficulties resulting from hardness and occasional excessive iron or more rarely corrosive properties. Waters with much more than 1,000 parts per million of dissolved solids are likely to contain enough of certain constituents to impart a noticeable taste to the water. However, some waters that contain more than 1,000 parts per million are satisfactory for domestic use and for some industrial purposes.

The ground waters from most springs and wells of shallow or moderate depth in north-central Tennessee range in concentration from about 50 to 500 parts per million and are satisfactory for all ordinary uses if not polluted by organic waste (pp. 108–109). The waters from most of the deep wells and from some shallow sources, however, are highly concentrated, and some contain as much as 25,000 parts per million of dissolved solids.

Ground water that percolates slowly through permeable rocks is likely to be relatively invariable in concentration throughout the year. However, much of the ground water of north-central Tennessee circulates in solution conduits in limestone and is likely to be subject to seasonal variations in concentration that are comparable to seasonal variations in the discharge of the system of conduits. Most of the representative samples were collected during the season of minimum ground-water discharge. Hence, their concentration probably approximates the seasonal maximum. The magnitude of the average seasonal variations in concentration of the ground water is unknown

[66] Collins, W. D., Notes on practical water analysis: U. S. Geol. Survey Water-Supply Paper 596, pp. 235–261, 1928.

[67] Adapted from Collins, W. D., Chemical character of waters of Florida: U. S. Geol. Survey Water Supply Paper 596, pp. 181–186, 1928.

and can be determined for a given source only by sampling and analyzing the water periodically for several years.

Silica.—A small amount of silica (SiO_2) is carried in solution by most ground waters, even by those that issue from relatively pure limestone. The dissolved silica in a water may be deposited wholly or in part as a constituent of the hard scale formed in boilers, but otherwise it has no effect on the use of the water for domestic or most industrial uses. In the representative ground waters from north-central Tennessee the dissolved silica ranges between 2.2 and 45 parts per million; it is more than 15 parts per million in about two-thirds of the samples analyzed.

Iron.—The iron (Fe) contained by ground waters is derived from pyrite and other iron-bearing minerals. As these minerals are usually distributed very unevenly through the water-bearing rocks, the iron content of ground waters, even those from the same geologic formation, may differ materially from place to place. Although a relatively large amount of iron may be taken into solution by ground water, if much more than 0.1 part per million is present the excess is likely to separate out as a reddish-brown gelatinous sediment after the water has been pumped and allowed to stand in contact with the air. If this sediment be formed in large volume it may obstruct pipes. If the iron content be several parts per million, the water is likely to produce stains on linen during laundering and on enamel-ware and porcelain-ware utensils and plumbing fixtures. Even a very small quantity of dissolved iron renders a water unfit for some industrial chemical uses. In waters that contain hydrogen sulphide (H_2S), such as many of the ground waters of north-central Tennessee, an excess of dissolved iron may separate out as a suspension of the black ferrous sulphide (FeS). Such are the so-called black sulphur waters of this region. The excess iron may be removed from most waters by aeration—as by pumping through spray nozzles—and filtration, although some waters require the addition of lime or other precipitating agent.

The iron content of the representative ground waters from north-central Tennessee ranges from 0.02 to 29 parts per million but is less than 0.5 part per million in half the waters and less than 1.0 part per million in three-fourths of them. In most of the waters iron is present in sufficient quantity to be troublesome for some purposes.

Calcium.—Calcium (Ca) may be taken into solution as the bicarbonate by the reaction of natural waters containing carbon dioxide or natural acids with calcium carbonate, which is the essential constituent of limestone and a minor constituent of many other rocks. Calcium is the most abundant of the bases in nearly all the slightly and moderately concentrated ground waters of north-central Tennessee. In those waters which contain less than 500 parts per million of dissolved solids it ranges from 8.6 to 163 parts per million but is generally between 50 and 100 parts per million. Calcium is also relatively abundant in the highly concentrated brines and other modified connate waters that occur at depth in the marine sedimentary rocks of this region. The greatest concentration of calcium in any of the representative waters is 625 parts per million. (See analysis 260, pp. 114–115.)

Calcium is the principal soap-consuming and scale-forming constituent of the ground waters of north-central Tennessee. Except for the difficulties arising from these properties, whoever, calcium has little or no effect upon the suitability of the water for ordinary uses.

Magnesium.—Magnesium (Mg) is usually taken into solution as the bicarbonate by the reaction of waters containing carbon dioxide or some natural acid with magnesium carbonate, which is present in most of the rocks of north-central Tennessee, especially in the more magnesian limestones. In most natural waters magnesium is much less abundant than calcium, although in five of the samples analyzed —Nos 316, 326, 352, 427, and 433—magnesium exceeds calcium in reacting value. In the moderately concentrated ground waters from north-central Tennessee magnesium is commonly from one-third to one-fifteenth as abundant as calcium. It ranges from about 2.5 to about 50 parts per million but in more than half the samples does not exceed 10 parts per million. Like calcium, magnesium occurs in large quantity in the modified connate waters of this region. The greatest concentration of magnesium in any of the representative waters is 533 parts per million (No. 352, pp. 116–117).

Magnesium is the only element other than calcium that causes any appreciable amount of hardness in natural waters. If a water contains several hundred parts per million of magnesium as the sulphate or chloride, like some of the more concentrated waters of north-central Tennessee, it may be undesirable for drinking.

Sodium and potassium.—Sodium (Na) and potassium (K) are dissolved in small quantities from practically all rocks but where present in considerable amounts are derived chiefly from salts or concentrated brines associated with rocks of marine origin. Potassium is generally much less abundant than sodium. These elements constitute only a small portion of the dissolved mineral matter in most of the ground waters of north-central Tennessee and generally range from 1 to about 50 parts per million. They amount to less than 5 parts per million in two-thirds of the samples. In the highly concentrated ground waters, however, sodium and potassium may be the most abundant metallic elements and may sum up to several thousand parts per million, as in analyses 260 and 352 (pp. 114–117).

Moderate quantities of sodium and potassium have little effect on the suitability of a water for ordinary household use, inasmuch as the salts of these elements do not impart hardness to the water. If these constituents sum up to much more than 100 parts per million, a water is likely to foam if used in a steam boiler unless it is conditioned to prevent this reaction. Most of the ground water of north-central Tennessee will cause little or no trouble in this way. More than 400 parts per million of sodium and potassium in a water make it practically useless as boiler feed without preliminary conditioning. Some natural waters contain so large quantities of sodium salts that they are injurious to vegetation to which they may be applied, the quantity that will be injurious depending upon the species of vegetation, the type of soil, and the drainage. The connate ground waters of north-central Tennessee are generally so concentrated in sodium and potassium as to be toxic to vegetation and hence can not be used for watering crops and sprinkling lawns.

Carbonate and bicarbonate.—The carbonate (CO_3) and bicarbonate (HCO_3) in natural waters are derived by the solution of rock-forming carbonate minerals largely through the action of carbon dioxide or natural acids in the waters. Carbonate is not present in appreciable quantities in most natural waters. All the rocks of north-central Tennessee contain carbonate minerals in abundance, and the associated ground waters are generally rather concentrated in bicarbonate. Those of the representative samples that are moderately concentrated contain from 30 to 400 or more parts per million of bicarbonate; approximately half of them contain between 150 and 250 parts per million. The bicarbonate as such has little effect on the use of a water.

Sulphate.—Sulphate (SO_4) in ground waters may be derived from gypsum (calcium sulphate) associated with limestone and other rocks, from the oxidation products of pyrite (iron disulphide) and other sulphides, or from concentrated or desiccated brines inclosed by marine sediments. The ground waters of north-central Tennessee appear to have acquired sulphate from each of these sources. In the moderately concentrated waters of this region sulphate is generally less abundant than bicarbonate, its approximate range being from 2.5 to 350 parts per million; in two-thirds of them it is less than 25 parts per million. In most of the highly concentrated waters, however, sulphate is more abundant than bicarbonate and may be several thousand parts per million, as in analyses 260, 294, 311, 326, and 390 (pp. 114–117).

The sulphates of sodium or magnesium if present in sufficient quantity impart a bitter taste to water and may render it otherwise unfit for domestic use. Several of the more concentrated waters of north-central Tennessee are of this class. Sulphate in a hard water may increase the cost of softening, and it makes the scale formed in a steam boiler "hard" and therefore much more troublesome. This is particularly true if the calcium plus magnesium in a water is much more than equivalent to the bicarbonate.

Chloride.—Chloride (Cl), which is generally not abundant in moderately concentrated ground waters from shallow sources, may be derived by solution of rock-forming minerals or by contamination of the water with sewage. However, the possible sources of chloride are so many that an abnormally large amount of this constituent in a natural water is not at all a definite indication of pollution. In most of the moderately concentrated ground waters of north-central Tennessee chloride is less than 5 parts per million, although its range is roughly from 1 to 50 parts per million. The waters associated with the Bigby limestone contain notably more chloride than most of the waters associated with the other stratigraphic units of the region. Some ground waters from deep sources are relatively concentrated in chloride, which is derived for the most part from connate brines associated with marine sediments. Such highly concentrated waters are common in north-central Tennessee, and the maximum chloride content shown by the representative analyses is 15,700 parts per million (No. 352, pp. 116–117).

Chloride has little effect on the suitability of water for domestic purposes unless it is so concentrated as to impart a saline taste. Waters that contain several hundred parts per million of chloride may be corrosive when used in steam boilers, unless this action is restrained by suitable treatment.

Nitrate.—Nitrate (NO_3) in natural waters is generally considered a final oxidation product of nitrogenous organic matter. Hence its presence in more than nominal quantity in a ground water implies that the well or spring from which it issues may contain harmful bacteria derived from cultivated fields or other places where oxidized nitrogenous matter is common. Most of the ground waters from the region covered by this report contain less than 1 part per million of nitrate.

Hardness.—Hardness in a natural water is caused almost exclusively by the salts of calcium and magnesium. It is commonly recognized by the excessive amount of soap necessary to lather a hard water and by the curdy precipitate that forms before a permanent lather results. The constituents that cause hardness are also the active agents in the formation of the greater part of the scale formed in steam boilers and in other vessels in which water is heated or evaporated.

In order that hardness may be expressed in a standard unit it is customarily reported as parts per million of calcium carbonate

($CaCO_3$) equivalent to all the calcium and magnesium. This quantity is the so-called "total hardness" of the water. It is calculated by the formula

$$\text{Total hardness} = 2.5\ \text{Ca} + 4.1\ \text{Mg}$$

in which all quantities are expressed in parts per million. Hardness is caused both by the bicarbonates and by the sulphates of calcium and magnesium. The hardness due to sulphates—the so-called "noncarbonate hardness" or "permanent hardness"—may be calculated from the formula

$$\text{Noncarbonate hardness} = 2.5\ \text{Ca} + 4.1\ \text{Mg} - 0.82\ \text{HCO}_3.$$

Water with a total hardness less than 50 parts per million is generally considered soft, and under most circumstances its treatment to remove hardness is not justified on the score of economy. Hardness between 50 and 150 parts per million does not render the water unsatisfactory for most purposes, but it does increase the consumption of soap slightly. Hence, it is profitable for laundries and other industries that use large quantities of soap to soften such a water to remove calcium and magnesium. Hardness exceeding 150 parts per million is objectionable in common household uses of water, and if the hardness is 200 or 300 parts per million it is common practice to soften the water or to install cisterns and rain catches. When an entire municipal supply is softened, the hardness is generally reduced to about 100 parts per million, as the additional improvement from further softening is not deemed an economy. If the hardness is much more than 100 parts per million, the water must generally be treated for the prevention of scale formation before it can be used successfully in steam boilers. The cost and difficulty of adequate softening for this purpose are likely to be increased materially if the noncarbonate hardness is large.

Very few of the ground waters of north-central Tennessee contain less than 50 parts per million total hardness, and many are so hard that they should be softened to make them suitable for general use. In some of the waters the noncarbonate hardness also is relatively large.

There are two processes for softening water in general use—the lime and soda process and the exchange silicate or so-called "zeolite" or "permutite" process, which has been developed in recent years.

In the lime and soda process the noncarbonate hardness, if present in the raw water, is converted to carbonate hardness by the addition of enough soda (sodium carbonate) to react with the sulphates of calcium and magnesium to form the bicarbonates of calcium and magnesium and sodium sulphate. All the products of this reaction are soluble. The total carbonate hardness is removed by adding enough slaked lime (calcium hydroxide) to combine with the free carbon dioxide and the bicarbonate to transform the calcium and magnesium naturally present in the water—as well as the calcium added in the form of lime—into calcium carbonate and magnesium hydroxide. These products, being essentially insoluble, form a solid precipitate, the flocculation and settling of which may be accelerated by adding a small quantity of alum or other coagulant with the lime and soda. Small amounts of calcium carbonate and magnesium hydroxide remain in solution, however, so that the treated water has a small residual hardness. Water softened by the lime and soda process contains less dissolved mineral matter by the amount of calcium bicarbonate and magnesium bicarbonate precipitated from the untreated water less the excess of soda used. All the sodium of the soda used in the process remains in the treated water, as all its products are soluble. Hence, some natural waters that contain much noncarbonate hardness can not be conditioned by this process for successful use in steam boilers, because the treated water contains so much sodium that it would foam prohibitively. Besides lime and soda, many other substances have been proposed and used successfully as softening agents, but many of them are too costly if a large volume of water must be treated. Sodium aluminate has been used successfully with lime and soda to minimize the total dissolved solids in softened water used in locomotive boilers.[68]

The lime and soda process is generally less costly than the exchange silicate method of softening waters that contain only carbonate hardness. On the other hand, it is more costly if much noncarbonate hardness must be removed. With the lime and soda process great care must be exercised to avoid an excess of the chemicals added to the water and to insure complete precipitation of sludge before the water is put to use. Hence, close technical control is necessary. Moreover, if a large volume of water must be treated, difficult problems of sludge disposal may arise.

In the exchange silicate process the active softening agent is the so-called "zeolite" or "permutite," an insoluble hydrous sodium-aluminum silicate which has the property of exchanging its sodium with the calcium, magnesium, iron, and manganese of the hard water. The exchange silicate, which may be natural or artificial, is marketed under several trade names. In practice, the hard water is filtered through a bed of granular exchange silicate and in passing gives up to the silicate its soap-consuming and scale-forming constituents and

[68] Grime, E. M., Water treatment and railroad efficiency: Am. Water Works Assoc. Jour., vol. 18, No. 4, pp. 440-441, 1927.

takes from the silicate an equivalent amount of sodium. In this way the filtered water is completely softened, although the total quantity of dissolved mineral matter is not decreased, and the quantity of sodium may be so increased as to induce foaming to a troublesome degree. When all its exchangeable sodium has been replaced the silicate becomes inert. If, however, a concentrated solution of common salt is passed through the inert silicate, the exchange reaction is reversed, sodium from the salt displaces the calcium and magnesium, and the silicate is reactivated. After it has been flushed with soft water the exchange silicate can again be used as a softening agent.

The exchange silicate process softens water more completely than the lime and soda process, although it does not reduce the total quantity of dissolved solids. It is likely to be somewhat more costly than the lime and soda process if the water to be treated has only carbonate hardness. On the other hand, it is generally less costly if the water contains much noncarbonate hardness and if salt for reactivating the silicate is not unduly expensive. The principal advantages of the exchange silicate process are that the water can be completely softened if desired and that close technical control is not essential. During recent years this process has been successfully adapted to treating as much as 5,000,000 gallons of water daily, as at McKees Rocks, Pa.; it has also been adapted to the needs of the single household in units of small capacity that can be operated with nominal attention.

Hydrogen sulphide.—Hydrogen sulphide (H_2S) is a gas that gives the characteristic odor to sulphur waters, the same odor that is associated with the decomposition of eggs and other organic substances that contain considerable sulphur. It is easily detected by its characteristic odor in concentrations as slight as 1 part per million or less, although it is difficult to determine quantitatively if the concentratio is much less than 5 parts per million. Hydrogen sulphide is quickly dissipated or is oxidized to sulphate when a sulphur water is allowed to stand in contact with air, so that it must be precipitated as an insoluble sulphide, usually cadmium sulphide, when a sample for quantitative analysis is taken. It is generally held that hydrogen sulphide in ground waters of meteoric origin is formed by the reduction of sulphates, as is brought out by a review of the literature cited by Renick.[69]

Hydrogen sulphide, if present in large quantities, imparts to a water a decidedly disagreeable odor and taste that makes the water unfit for domestic uses. In the presence of air it combines with the dissolved iron to form the black ferrous sulphide, which generally

[69] Renick, B. C., Some geochemical relations of ground water and associated natural gas in the Lance formation, Montana: Jour. Geology, vol. 32, pp. 668–684, 1924.

remains in suspension in the water, gives the water an intense color, and stains utensils. In the partly oxidized condition a concentrated hydrogen sulphide water may corrode tanks, pipes, and other metallic objects. Hydrogen sulphide may be removed from a water by aeration, as in the treatment for the removal of iron, the products of oxidation being finely divided sulphur and sulphate.

Many of the ground waters of north-central Tennessee, particularly those that issue from the Chattanooga shale and from shaly facies of certain limestones, contain small quantities of hydrogen sulphide. Relatively little of the water, however, contains more than 5 parts per million—the smallest amount that can be determined quantitatively. Those of the representative samples that contain determinable quantities of hydrogen sulphide are for the most part highly concentrated waters in which the amount of sulphate is several times the amount of bicarbonate and in which the magnesium:calcium ratio is relatively large. On the other hand, some of the moderately concentrated bicarbonate waters contain appreciable amounts of hydrogen sulphide. The greatest concentration of hydrogen sulphide in any of the representative samples is 379 parts per million. (See analysis 120, pp. 112–113.)

Color.—Ground waters are generally colorless, whereas surface waters are likely to be noticeably colored even when quite free from suspended matter. The organic matter that imparts this color is of itself harmless, but decolorizing is one of the primary functions of all plants for the purification of water for a public supply. Consumers are generally more concerned over the slight color that may be perceptible in water than over the unseen disease-bearing bacteria that may be present in dangerous abundance.

The water that issues from some of the tubular springs and wells in north-central Tennessee has a perceptible bluish opalescence, the color probably being derived from decaying vegetation and other organic matter with which the water was in contact before passing underground into the limestone solution channels. Generally, however, the color is not so intense that it is considered objectionable.

Suspended matter.—Ground water that issues from porous rocks is generally free from suspended matter, although an iron-bearing water in contact with air may become turbid by formation of a reddish-brown suspended precipitate of iron hydroxide. Sulphur waters may become turbid by separation of sulphur through oxidation of the hydrogen sulphide by the air or, if iron bearing, by separation of black iron sulphide. Water of each of these classes is common in north-central Tennessee, and the characteristic precipitates give rise to the local designations "red sulphur water," "white sulphur water," and "black sulphur water."

Many springs and wells that issue from tubular solution channels in the limestone of north-central Tennessee at times discharge turbid water containing much suspended clay and silt. This suspended matter is derived from soil and rock waste that is carried through sink holes into the underground drainage system, so that the underground streams, like surface streams, carry more suspended matter after periods of heavy precipitation and vigorous run-off. The amount of suspended matter in the water, the duration of the periods of high turbidity, and the lag between precipitation and increase of turbidity may vary greatly and are generally very different at different springs. The regimen of any spring can not be known even approximately unless its load of suspended matter is determined systematically at different rates of discharge and over a long period.

Suspended matter in a water may not be deleterious for some uses, but it must be thoroughly removed to make the water satisfactory for a municipal supply or for most industrial purposes. Many of the tubular springs of north-central Tennessee offer difficult problems in the removal of suspended matter to adapt them to use. In order to be successful, a clarifying plant must have a large overload capacity to care for periods when the turbidity of the water is high.

SANITARY CONSIDERATIONS

The analyses of the representative ground waters and the statements that have been made in regard to the suitability of the waters for domestic use consider only the effects of the dissolved mineral constituents. They do not consider the presence or absence of disease-bearing bacteria, which is generally the critical factor in determining the suitability of a public supply. The number of bacteria in the water from a given source is not likely to be constant, so that a single determination of the sanitary character of a water may be grossly misleading.

Scrupulous care should be exercised to protect each well and spring used for domestic supply from pollution by organic waste carried by surface drainage, by seepage through the soil, by stock, or on the shoes and clothing of people. Every well should be so located as not to receive drainage from the vicinity of any building, sewer, cesspool, or privy and should be tightly closed at the top in a sanitary manner. Springs should be surrounded by sturdy stock barricades and protected from surface drainage by suitable dikes, cut-off walls, or other structures. In a region underlain by limestone, such as north-central Tennessee, ground water that is circulating in solution channels may be polluted over extensive areas. Hence the sanitary character of the water from all tubular springs and wells that enter solution channels is subject to distrust unless it is shown to be free from undesirable bacteria by periodic sanitary analyses. All ground water that issues from channeled limestone, if used as municipal supply, should preferably be sterilized by a suitable chlorinating apparatus as a routine precaution against pollution. Under most conditions such sterilization does not impart taste or odor to the water if the operation is properly controlled.

ANALYTICAL

Analyses of representative ground

[Margaret D. Foster, U. S. Geological Survey,

No. on Plate 4	Location and description	Temperature (° F.)	Analyst
	STEWART COUNTY		
1	Model, 5½ miles west of. Cedar Spring, water from Fort Payne formation; owned by W. C. Outland. Sampled Oct. 5, 1927.	54	Foster
6	Bumpus Mills, ¾ mile south of. Drilled well 6 inches in diameter and 48 feet deep; water from chert residuum above St. Louis or Warsaw limestone; owned by W. P. Luten. Sampled Oct. 5, 1927.	64	do
19	Dover, 5¾ miles northwest of. Drilled well 6 inches in diameter and 75 feet deep; water from gravel (weathered chert nodules); owned by B. F. Riggins. Sampled Oct. 5, 1927.	60	do
24	Indian Mound, 4½ miles north of. Drilled well 5⅝ inches in diameter and 164 feet deep; water from St. Louis or Warsaw limestone; owned by estate of Mrs. Bert Smith. Sampled Oct. 4, 1927.	58	do
27	Indian Mound. Drilled well 55 feet deep; water from St. Louis or Warsaw limestone; owned by C. K. Keatts. Sampled Oct. 4, 1927.	58	do
32	Mobley, 3¾ miles northwest of. Wofford Spring; water from Fort Payne formation; owned by J. W. Wofford. Sampled Oct. 5, 1927.	56	do
35	Mobley, 4½ miles east of. Unnamed spring from Fort Payne formation; owned by estate of W. H. Cox. Sampled Oct. 5, 1927.	54	do
	MONTGOMERY COUNTY		
42	Woodlawn, 5 miles northwest of. Drilled well 5⅝ inches in diameter and 136 feet deep; water from St. Louis or Warsaw limestone; owned by E. B. Ingraham. Sampled Oct. 4, 1927.	59	do
44	Woodlawn, 5½ miles northeast of. Britton Spring; water from St. Louis or Warsaw limestone; owned by H. E. Killebrew. Sampled Oct. 4, 1927.	60	do
54	St. Bethlehem, 2¼ miles southwest of. Idaho Spring; water from alluvium overlying St. Louis or Warsaw limestone; owned by J. H. Unseld. Sampled Oct. 4, 1927.	60	do
57	Clarksville, 4¼ miles east of. Drilled well 6 inches in diameter and 162 feet deep; water from St. Louis or Warsaw limestone, leased by W. R. Corlew. Sampled Oct. 4, 1927.	58	do
64	Hackberry. Drilled well 6 inches in diameter and 50 feet deep; water from St. Louis or Warsaw limestone; owned by Henry Yarber and James Broom. Sampled Oct. 4, 1927.	60	do
67	Louise, 4 miles southwest of. Unnamed spring from St. Louis or Warsaw limestone; owned by George W. Bryant. Sampled Oct. 4, 1927.	59	do
68	Louise, 5 miles southeast of. Drilled well 5 inches in diameter and 65 feet deep; water from Fort Payne formation; owned by C. D. Batson. Sampled Oct. 4, 1927.		do
71	Hickory Point, 6½ miles northeast of. Dug well 4 feet in diameter and about 60 feet deep; water from chert residuum above St. Louis or Warsaw limestone; owned by George Watson. Sampled Oct. 4, 1927.	59	do
	ROBERTSON COUNTY		
73	Adams, 3½ miles northwest of. Mint Spring; in basal St. Louis limestone; owned by Joel Fort. Sampled Oct. 9, 1927.	57	Farrar.
81	Springfield, 10 miles north of. Drilled well 5⅝ inches in diameter and 71 feet deep; water from St. Louis or Warsaw limestone; owned by Elmore Marshall. Sampled Oct. 9, 1927.	58	Farrar and Foster.[a]
87	Orlinda, 4¾ miles southwest of. Drilled well 5⅝ inches in diameter and 54 feet deep; water from St. Louis or Warsaw limestone; owned by S. R. Russell. Sampled Oct. 9, 1927.	57	Farrar
91	Orlinda, 6½ miles east of. Unnamed spring from St. Louis or Warsaw limestone; owned by James Payne. Sampled Oct. 9, 1927.	57	do
96	Springfield, 3 miles west of. Unnamed spring from St. Louis or Warsaw limestone; owned by Will Powell. Sampled Oct. 9, 1927.	58	do
104	Cedar Hill, 9¼ miles south of. Drilled well 5⅝ inches in diameter and 119 feet deep; water from St. Louis or Warsaw limestone; owned by J. F. Browning. Sampled Oct. 9, 1927.	57	do
112	Greenbrier, 1¾ miles southeast of. Drilled well about 100 feet deep at Hygeia Springs resort; water from Fort Payne formation; owned by B. B. Beal. Sampled Oct. 9, 1927.	56	do

[a] Includes iron precipitated at time of analysis.
[b] Carbonate radicle (CO_3) not present.

DATA

waters in north-central Tennessee

and D. F. Farrar, Tennessee Geological Survey, analysts]

Analyses (quantities in parts per million)													No. on Plate 4
Total dissolved solids at 180° C.	Silica (SiO_2)	Iron (Fe)[a]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)[b]	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hydrogen sulphide (H_2S)	Total hardness as $CaCO_3$[c]	
50	12	0.36	8.6	2.4	1.2	0.9	31	4.7	1.5	2.0	-------	31	1
132	7.9	.10	24	9.1	14	1.6	147	5.8	2.8	.23	-------	97	6
198	12	.30	61	7.4	2.1	.4	219	2.8	1.1	3.8	-------	183	19
196	12	.21	62	4.8	3.1	.4	208	6.0	2.9	.88	-------	175	24
220	11	.76	74	2.4	1.6	.4	222	2.5	3.7	10	-------	195	27
143	9.4	.02	44	5.3	2.2	.4	158	4.0	1.0	.20	-------	132	32
71	13	.44	15	2.5	1.3	.8	50	5.0	1.0	2.8	-------	48	35
262	8.4	.06	54	23	3.8	.6	230	43	2.9	1.8	-------	229	42
148	9.1	.15	44	5.2	1.9	.7	150	6.8	1.6	3.6	-------	131	44
2,970	8.0	.38	366	173	294	10	400	1,474	295	.10	116	1,624	54
1,948	14	6.89	382	132	3.6	1.3	228	1,224	2.2	.21	-------	1,496	57
336	15	1.5	110	8.4	3.0	.4	344	8.6	4.1	15	-------	309	64
174	11	.07	54	5.7	2.0	.4	192	4.7	1.6	1.2	-------	158	67
1,238	13	2.8	163	95	75	5.1	190	771	2.3	.07	11	797	68
318	13	.15	114	8.6	2.6	.3	374	4.2	2.7	8.3	-------	320	71
[d] 2,202	10	1.5	64	5.0	3.0		202	16	2.0	.2	-------	180	73
[d] 2,101	19	1.3	353	135	92		225	1,307	82	1.2	20	1,436	81
[d] 362	15	1.1	96	20	5		308	67	4	2.2	-------	321	87
[d] 132	13	2.5	36	6.0	1.0		127	8	1.0	.4	-------	115	91
146	9.6	4.6	46	5.0	2.0		147	15	1.5	1.0	-------	135	96
1,158	19	1.8	282	39	9.0		293	611	3.5	3.2	-------	864	104
230	10	.6	70	14	2.0		273	7.5	3.0	.3	-------	232	112

[c] Calculated.
[d] Total by summation of constituents.
[e] Determinations of H_2S and SO_4 by Margaret D. Foster.

Analyses of representative ground waters

No. on Plate 4	Location and description	Temperature (° F.)	Analyst
	SUMNER COUNTY		
115	Portland, 2 miles northeast of. Cold Spring; in St. Louis or Warsaw limestone; owned by John Baskerville; municipal supply of Portland. Sampled Oct. 19, 1927.	58	Farrar
120	Westmoreland, 5 miles west of. Oil test well 5⅝ inches in diameter and 100 feet deep; water from bed just above or below Chattanooga shale; owned by R. C. Troutt. Sampled Oct. 19, 1927.	56.5	Foster
121	Westmoreland, ½ mile east of. Drilled well 5⅝ inches in diameter and 65 feet deep; water from chert residuum above Fort Payne formation; owned by Sumner County High School. Sampled Oct. 18, 1927.	57	Farrar
126	White House, 2¾ miles south of. Tyree Spring; water from weathered zone of Fort Payne formation; owned by Mrs. Cartwright. Sampled Oct. 20, 1927.	58	Farrar and Foster.[a]
127	Cottontown. Drilled well about 60 feet deep; water from Leipers (?) formation; owned by G. W. Mitchell. Sampled Oct. 20, 1927.	58	Farrar
131	Saundersville, 2½ miles northwest of. Drilled well 20 feet deep; water from shaly facies of Leipers (?) formation; owned by John Mirs. Sampled Oct. 20, 1927.	62	Farrar and Foster.[c]
132	Saundersville. Drilled well 50 feet deep; water from Leipers (?) formation; owned by J. R. Durham. Sampled Oct. 20, 1927.	58	Farrar
135	Gallatin. Drilled well 8 inches in diameter and 300 feet deep; water from Bigby (?) limestone at approximate depth of 200 feet; owned by Louisville & Nashville R. R. Sampled Oct. 18, 1927.	58	do
137	Castalian Springs post office. Castalian Spring; water from Bigby limestone or upper part of Hermitage formation; owned by G. W. Wynne. Sampled Oct. 18, 1927.	60	Farrar and Foster.[a]
	HOUSTON COUNTY		
138	Stewart, 1 mile west of. Unnamed spring from St. Louis or Warsaw limestone; owned by Largent Bros. Sampled Oct. 6, 1927.	56	Foster
143	Erin, 0.6 mile west of. Unnamed spring from St. Louis limestone; owned by A. J. Mitchum; municipal supply of Erin. Sampled Oct. 6, 1927.	57	do
149	Erin, 6½ miles southwest of. Well 6 inches in diameter and about 160 feet deep; water from Fort Payne formation; owned by Steve Batson. Sampled Oct. 6, 1927.	57	do
151	Erin, 9¼ miles southeast of. Drilled well 6 inches in diameter and 64 feet deep; water from Fort Payne (?) formation; owned by Yellow Creek High School. Sampled Oct. 7, 1927.	58	do
	HUMPHREYS COUNTY		
159	Waverly, 6¼ miles north of. Unnamed spring from St. Louis limestone; owned by Milton Petty. Sampled Oct. 6, 1927.	56	do
161	Denver, 1½ miles north of. Critchlow Spring; water from weathered chert gravel; owned by Luther Haygood. Sampled Oct. 7, 1927.	58	Farrar
164	McEwen, ½ mile northeast of. Drilled well 8 inches in diameter and 217 feet deep; water from chert residuum above St. Louis or Warsaw limestone at depth of 80 feet; owned by McEwen School. Sampled Oct. 7, 1927.	58	do
167	Waverly, 1 mile northeast of. Drilled well 8 inches in diameter and 32 feet deep; water from weathered St. Louis or Warsaw limestone; owned by Nashville, Chattanooga & St. Louis Ry., municipal supply for Waverly. Sampled Oct. 6, 1927.	61	Foster
171	Johnsonville, ½ mile north of. Drilled well 6 inches in diameter and 92 feet deep; water from chert residuum above Fort Payne formation; owned by J. M. C. Young. Sampled Oct. 7, 1927.	57	Farrar
173	Denver, 4¾ miles east of. Cold Spring; water from Fort Payne formation; owned by L. L. Shipp. Sampled Oct. 7, 1927.	58	Foster
177	Bold Springs post office. Bold Spring; water from St. Louis (?) limestone; owned by J. R. James. Sampled Oct. 6, 1927.	57	do
180	Denver, 4¼ miles south of. Sulphur Spring; water from Silurian (?) limestone; owned by D. M. McCrary. Sampled Oct. 7, 1927.	60	do
	DICKSON COUNTY		
190	Stayton, 2¾ miles north of. Drilled well 5 inches in diameter and 65 feet deep; water from Fort Payne formation; owned by John Freeman. Sampled Oct. 8, 1927.	56	Farrar
191	Stayton, 3 miles north of. Drilled well 6 inches in diameter and about 40 feet deep; water from Fort Payne formation; J. L. Tilley, renter. Sampled Oct. 8, 1927.	58	Farrar and Foster.[a]
198-A	Vanleer, 5 miles west of. Drilled well 5⅝ inches in diameter and 65 feet deep; water from Fort Payne formation (?); W. R. Berry, owner. Sampled Oct. 7, 1927.	59	do.[a]

[a] Includes iron precipitated at time of analysis. [b] Carbonate radicle (CO_3) not present. [c] Calculated

in north-central Tennessee—Continued

Analyses (quantities in parts per million)													
Total dissolved solids at 180° C.	Silica (SiO_2)	Iron (Fe)[a]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)[b]	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hydrogen sulphide (H_2S)	Total hardness as $CaCO_3$[c]	No. on Plate 4
162	8.9	.4	45	8.0	2.0		161	11	3.0	.2	-------	145	115
4,502	25	.0	505	148	699	24	700	2,282	336	.10	379	1,869	120
214	12	1.0	47	20	3.0		205	31	3.0	.3	-------	200	121
2,236	24	1.5	479	90	16		180	1,353	28	2.1	20	1,565	126
292	12	.8	75	16	5.0		245	49	8.5	.3	-------	253	127
385	9.2	.8	71	31	16		254	98	19	.6	5.5	304	131
628	19	1.4	163	18	26		312	198	48	.5	-------	481	132
262	15	1.6	80	8.0	6.0		276	5.0	7.8	.2	-------	232	135
[d]3,497	18	1.5	484	65	631	16	298	1,128	1,005	3.8	31	1,475	137
97	9.5	.21	26	4.0	1.0	.4	86	7.2	1.2	2.2	-------	81	138
186	18	.09	57	4.3	2.7	.4	188	5.0	2.0	1.7	-------	160	143
172	10	.40	50	11	1.7	.4	202	2.2	1.0	1.1	-------	170	149
226	11	.32	76	5.5	1.9	.5	251	3.0	2.4	.78	-------	213	151
140	15	.12	40	5.3	1.6	.5	144	3.7	0.9	.83	-------	122	159
168	11	.6	46	9.0	2.0		176	8.0	2.5	.3	-------	152	161
166	13	.6	64	3.8	1.2		174	26	4.0	.01	-------	175	164
151	14	.07	39	6.7	3.3	1.7	141	8.3	3.8	3.2	-------	125	167
155	13	1.0	44	6.0	5.0		157	6.0	7.0	.5	-------	135	171
160	25	.09	46	4.3	2.0	.4	156	3.7	1.2	.15	-------	133	173
156	9.9	.07	48	7.9	2.2	.6	173	3.9	2.0	1.3	-------	152	177
160	12	.05	48	5.5	2.9	.8	168	6.0	1.8	.53	-------	143	180
222	14	.3	65	10	2.5		213	23	3.5	1.2	-------	204	190
2,505	26	2.0	603	60	45		152	1,644	14	1.1	22	1,754	191
3,195	2.4	29	496	208	82	6.2	184	1,988	31	4.0	31	2,093	198–A

[d] Total by summation of constituents.
[e] Determinations of H_2S and SO_4 by Margaret D. Foster.

Analyses of representative ground waters

No. on Plate 4	Location and description	Temperature (° F.)	Analyst
	DICKSON COUNTY—continued		
198-B	Vanleer, 5 miles west of. Drilled well 5⅝ inches in diameter and 32 feet deep; water from St Louis or Warsaw limestone; W. R. Berry, owner. Sampled Oct. 7, 1927.	58	Farrar
218	White Bluff, ½ mile west of. Drilled well 5⅝ inches in diameter and 75 feet deep; water from St. Louis or Warsaw limestone; owned by Jesse Gill. Sampled Oct. 8, 1927.	61	do
219	White Bluff. Drilled well 4 inches in diameter and 61 feet deep; water from St. Louis or Warsaw limestone; owned by Nashville, Chattanooga & St. Louis Ry. Sampled Oct. 8, 1927.	58	do
220	White Bluff, ½ mile south of. Drilled well 8¼ inches in diameter and 1,383 feet deep; water from top of Chattanooga shale at depth of 246 feet; owned by White Bluff Canning Co. Sampled Oct. 8, 1927.	58	do
225	Dickson, 1¼ miles southwest of. Baker Cave Spring; water from St. Louis or Warsaw limestone; owned by city of Dickson; municipal supply. Sampled Oct. 8, 1927.	58	do
229	Dickson. Drilled well 5⅝ inches in diameter and 427 feet deep; water from St. Louis or Warsaw limestone at depth of 75 feet; owned by Dickson Ice Co. Sampled Oct. 8, 1927.	58	do
	CHEATHAM COUNTY		
243	Neptune, 1¾ miles northeast of. Drilled well 6 inches in diameter and 165 feet deep; water from St. Louis limestone; owned by R. P. Frazier. Sampled Oct. 10, 1927.	58	do
258	Ashland City. Drilled well 6 inches in diameter and 69 feet deep; water from Chattanooga shale; owned by T. F. Chambliss. Sampled Oct. 10, 1927.	58	Farrar and Foster.[a]
259	Ashland City, 2¼ miles south of. Dug and drilled well 25 feet deep at former site of Sulphur Spring; water from Fort Payne formation; owned by Cheatham County. Sampled Oct. 10, 1927.	59.5	do.[a]
260	Ashland City, 1¾ miles south of. Drilled well 5 inches in diameter and 120 feet deep; water from Fort Payne (?) formation; owned by E. F. Allen and others; locally known as Sunrise Spring. Sampled Oct. 10, 1927.	60	Farrar
265	Ashland City, 7½ miles southwest of. Drilled well 6 inches in diameter and 45 feet deep; water from St. Louis limestone; owned by Idlewild School, Petway community. Sampled Oct. 10, 1927.	57	do
268	Kingston Spring post office, ½ mile south of. Kingston Spring; water from Fort Payne formation; owned by W. C. West. Sampled Oct. 10, 1927.	61	Farrar and Foster.[a]
269	Pegram, ½ mile north of. Drilled well 6 inches in diameter and 79 feet deep; water from Silurian limestone; owned by W. L. Palmore. Sampled Oct. 12, 1927.	58	Foster
	DAVIDSON COUNTY		
277	Whites Creek, 3 miles northwest of. Drilled well 6 inches in diameter and 158 feet deep; water from Fort Payne formation; owned by E. B. Hart. Sampled Sept. 14, 1927.	58	do
278	Whites Creek, 2¼ miles west of. Carney's Spring; water from Chattanooga shale; owned by Mrs. George Carney. Sampled Sept. 14, 1927.		do
279	Whites Creek, 3¾ miles southwest of. Drilled well 6 inches in diameter and 23 feet deep; water from Chattanooga shale; owned by J. D. Carrington. Sampled Sept. 14, 1927.	59	do
282	Ashland City, 8 miles southwest of. Young's Spring; water from Silurian limestone; owned by C. R. Rohrer. Sampled Sept. 13, 1927.	60	do
286	Whites Creek, 2 miles south of. Drilled well 6 inches in diameter and 63 feet deep; water from Leipers or Catheys formation; owned by J. C. Smith. Sampled Sept. 14, 1927.	64	do
292	Nashville, 10½ miles northwest of. Drilled well 6 inches in diameter and 97 feet deep; water from Catheys (?) formation; owned by Henry Farmer. Sampled Sept. 13, 1927.	62	do
294	Nashville, 4¾ miles northwest of. Drilled well 6¼ inches in diameter and 94 feet deep; water from Hermitage formation; owned by G. W. Bolin. Sampled Sept. 14, 1927.	62	do
295	Nashville, 4¼ miles northwest of. Drilled well 8⅝ inches in diameter and 1,491 feet deep; water from St. Peter (?) sandstone at depth of 1,165 feet probably mixed with water from Hermitage formation and Lebanon limestone; owned by Arthur Stevens. Sampled Sept. 14, 1927.	66	do
297	Nashville, Buena Vista Ave. "Black sulphur" spring; water from Bigby limestone; owned by Buena Vista Springs Co. Sampled Sept. 14, 1927.	60	do
298	Nashville, 1400 Eighth Ave. N. Drilled well 2,965 (?) feet deep; water probably from St. Peter (?) sandstone; owned by Morgan & Hamilton Co. Sampled Oct. 10, 1927.	68	Farrar and Foster.[a]

[a] Includes iron precipitated at time of analysis.
[b] Carbonate radicle (CO_3) not present.

in north-central Tennessee—Continued

Analyses (quantities in parts per million)													No. on Plate 4
Total dissolved solids at 180° C.	Silica (SiO_2)	Iron (Fe)[a]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)[b]	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hydrogen sulphide (H_2S)	Total hardness as $CaCO_3$[c]	
441	17	.35	80	33	3.6		223	148	4.5	.2	-------	335	198-B
213	3.2	2.2	72	11	2.0		252	20	3.5	2.5	-------	225	218
258	3.4	.4	67	24	2.7		294	26	10	3.2	-------	265	219
503	10.2	.4	101	33	3.7		232	215	3.5	.6	-------	387	220
145	2.2	.2	42	5.4	5.0		162	14	3.0	.2	-------	127	225
256	24	.4	61	12	14		224	29	14	1.2	-------	201	229
274	10	1.0	75	24	2.0		308	24	1.0	.5	-------	286	243
285	8.4	.7	62	26	9.2		292	21	9.0	.3	10	261	258
514	28	.9	121	32	15		433	87	7.0	.6	18	433	259
10,688	19	3.2	625	221	2,996	7.0	153	3,652	3,425	.5	-------	2,468	260
280	9.8	.6	74	19	3.0		284	27	4.0	.4	-------	263	265
401	26	.8	51	18	75		253	74	54	2.2	5.2	201	268
70	12	.08	17	2.9	2.1	1.0	60	3.8	1.8	2.6	-------	54	269
168	15	.22	39	15	2.6	0.6	181	5.7	5.1	1.6	-------	159	277
844	23	.04	156	51	32	32	351	359	10	.0	-------	599	278
295	17	.42	57	19	31	1.7	322	21	4.4	.05	-------	220	279
178	21	.06	43	9.9	2.4	1.2	144	27	1.2	3.0	-------	148	282
412	10	.12	93	23	5.7	1.8	237	111	22	.33	-------	327	286
2,160	9.7	1.4	139	62	459	16	270	1,174	131	.0	-------	602	292
4,372	18	.32	423	169	695	21	332	2,268	424	.10	34	1,750	294
979	11	.13	58	30	252	14	255	147	316	.12	10	268	295
714	12	.28	110	20	103	9.8	285	135	146	10	Tr.	357	297
4,306	45	1.5	382	117	1,066	52	298	585	2,085	8.0	22	1,435	298

[c] Calculated.
• Determinations of H_2S and SO_4 by Margaret D. Foster.

Analyses of representative ground waters

No on Plate 4	Location and description	Temperature (° F.)	Analyst
	DAVIDSON COUNTY—continued		
302	Nashville, 916 Fourth Ave. N. Drilled well 12 inches in diameter and 300 feet deep; water from Lebanon (?) limestone at depth of 128 feet; owned by Atlantic Ice & Coal Co. Sampled Sept. 14, 1927.	63	Foster
305	Nashville, Rosebank Ave. Pioneer Spring; water from upper Hermitage formation; owned by Pioneer Water Co. Sampled Sept. 14, 1927.	62	do
311	Belleview, 1¼ miles west of. Drilled well 6 inches in diameter and 144 feet deep; water from Catheys formation; owned by N. M. Morton. Sampled Sept. 13, 1927.	60	do
312	Belleview. Drilled well 6 inches in diameter and 143 feet deep; water from Bigby (?) limestone; owned by Nashville, Chattanooga & St. Louis Ry. Sampled Sept. 13, 1927.	59	do
316	Nashville, 4½ miles south of. Drilled well 6 inches in diameter and 125 feet deep; water from Lowville (?) limestone; owned by G. W. Luetzeler. Sampled Sept. 13, 1927.	58	do
317	Woodbine, 3 miles west of. Drilled well 6 inches in diameter and 65 feet deep; water from Catheys formation (?); owned by Robertson Academy. Sampled Sept. 13, 1927.	60	do
	WILSON COUNTY		
326	Hornsprings post office. Horn Spring (No. 2); water from Hermitage formation; owned by J. A. Horn. Sampled Oct. 16, 1927.	63	do
328	Lebanon, 9 miles northeast of. Drilled well 5 inches in diameter and 118 feet deep; water from Lebanon (?) limestone; owned by Mrs. Alice Murrey. Sampled Oct. 14, 1927.	60	Farrar
330	Mount Juliet. Drilled well 6 inches in diameter and 47 feet deep; water from Lowville (?) limestone; owned by Mount Juliet School. Sampled Oct. 15, 1930.	60	do
333	Lebanon, municipal well No. 1. Drilled well 10 inches in diameter and 205 feet deep; water from Ridley (?) limestone; owned by Lebanon Light & Water Co. Sample Oct. 13, 1927.	58	Foster
344	Gladeville, ¾ mile east of. Drilled well 6 inches in diameter and 28 feet deep; water from Lebanon (?) limestone; owned by T. H. Phillips. Sampled Oct. 15, 1927.	62	Farrar
347	Watertown, ½ mile west of. Two drilled wells 6 inches in diameter and 251 feet deep; water from Ridley (?) limestone; owned by city of Watertown; municipal supply. Sampled Oct. 13, 1927.		do
348	Watertown. Drilled well 6 inches in diameter and 76 feet deep; water from Lebanon (?) limestone; owned by Watertown Grain & Feed Co. Sampled Oct. 13, 1927.	59	do
352	Norene, 5½ miles south of. Drilled well 6 inches in diameter and 152 feet deep; water from Lebanon (?) limestone; owned by Mrs. Bessie Hayes. Sampled Oct. 14, 1927.	56	Foster
353	Norene, 5¾ miles south of. Drilled well 6 inches in diameter and 80 feet deep; water from top of Lebanon (?) limestone; owned by Clark Hill. Sampled Oct. 14, 1927.	58	Farrar
	WILLIAMSON COUNTY		
359	Jingo, 5½ miles southeast of. Cold Spring; water from Fernvale formation; owned by estate of W. P. Bruce. Sampled Oct. 11, 1927.	59	Farrar
365	Nolensville. Well 8 inches in diameter and 160 feet deep; water from Ridley (?) limestone; owned by W. M. Owen. Sampled Oct. 11, 1921.		do
366	Boston, 6¼ miles north of. Stillhouse Spring; water from sandstone near top of Fort Payne formation; owned by city of Franklin; municipal supply (in part). Sampled Oct. 11, 1927.	57	do
370	Franklin, 1 mile south of. Winder Spring; water from Hermitage formation; owned by C. H. Kinnard. Sampled Oct. 11, 1927.	62	do
376	Arrington, 5¾ miles northwest of. Drilled well 6 inches in diameter and 132 feet deep; water from Ridley limestone; owned by John N. Boxley. Sampled Oct. 11, 1927.	58	do
387	Boston, 2¼ miles west of. Dug well 4 feet in diameter and 54 feet deep; water from residual chert débris above St. Louis or Warsaw limestone; owned by Sid Wall. Sampled Oct. 11, 1927.	58	do
390	Boston, 5 miles east of. Drilled well 6 inches in diameter and 45 feet deep; water from Cannon or Bigby limestone; owned by Mrs. Lulu Gordon. Sampled Oct. 11, 1927.	61	Farrar and Foster.[a]
394	Boston, 4¾ miles southeast of. Drilled well 6 inches in diameter and 105 feet deep; water from Catheys (?) formation; owned by Mrs. J. C. Sparkman. Sampled Oct. 11, 1927.	62	Farrar
395	Thompson's Station, 3½ miles northwest of. Cayces Spring; water from Chattanooga shale; owned by Douglas Martin. Sampled Oct. 11, 1927.		do

[a] Includes iron precipitated at time of analysis.
[b] Carbonate radicle (CO_3) not present.
[c] Calculated.

in north-central Tennessee—Continued

Analyses (quantities in parts per million)													
Total dissolved solids at 180° C.	Silica (SiO_2)	Iron (Fe)[a]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)[b]	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hydrogen sulphide (H_2S)	Total hardness as $CaCO_3$[c]	No. on Plate 4
796	11	.25	160	17	79	7.4	278	191	131	37	-------	470	302
282	15	.04	70	7.2	5.4	1.4	146	40	12	43	-------	204	305
6,474	26	1.05	497	219	1,231	22	371	3,426	694	.15	60	2,140	311
312	13	.13	90	8.2	8.2	1.8	246	48	18	5.6	-------	259	312
469	8.4	.64	44	28	74	6.4	204	197	18	1.4	-------	225	316
469	20	.25	92	43	7.1	2.2	364	113	2.9	.05	-------	406	317
3,880	16	.53	487	306	207	16	541	2,348	37	.20	-------	2,472	326
382	8.8	.9	89	20	35		357	13	48	1.0	-------	305	328
312	12	1.0	88	15	7.0		302	35	6.5	.6	-------	281	330
379	18	.27	92	14	19	2.9	294	46	27	2.4	-------	287	333
1,152	18	1.9	62	19	290	2.0	211	70	431	2.0	-------	232	344
319	11	.5	86	21	11		335	28	12	1.0	-------	301	347
280	10	.7	92	16	14		334	22	17	.8	-------	295	348
[f]26,410	13	2.34	580	533	8,785	133	383	118	15,700	0	86	3,600	352
1,048	16	16	252	48	12		535	377	1.0	1.3	-------	826	353
241	8.4	.5	39	14	1.6		154	25	1.5	.4	-------	155	359
342	11.4	.8	118	8.2	3.4		357	34	5.0	1.2	-------	328	365
168	3.2	.2	45	12	2.0		169	21	3.0	.3	-------	162	366
192	9.8	.9	48	8.2	6.0		156	31	5.5	.4	-------	154	370
481	14	.9	99	20	42		220	133	70	1.0	-------	329	376
77	3.4	.4	21	2.0	1.0		46	11	8.0	-------	-------	60	387
10,920	9.6	1.3	354	208	3,008	42	286	4,459	2,375	4.1	40	1,738	390
2,296	10.2	.8	518	95	26		220	1,275	174	3.0	-------	1,683	394
238	3.4	2.4	62	16	7.0		228	37	7.0	.3	-------	220	395

[e] Determinations of H_2S and SO_4 by Margaret D. Foster.
[f] Also contains 35 parts per million free carbon dioxide (CO_2) and 216 parts per million of hydrosulphide radicle (HS); the carbonate radicle (CO_3) is not present.

Analyses of representative ground waters

No. on Plate 4	Location and description	Temperature (° F.)	Analyst
	RUTHERFORD COUNTY		
427	Murfreesboro, 1½ miles north of. Oil test well 10 inches in diameter and 1,930 feet deep (October, 1927); water from Murfreesboro limestone at depth of 70 feet and possibly from other strata at unknown depth; owned by G. M. Alsup. Sampled Sept. 15, 1927.	62	Foster
431	Murfreesboro, 5½ miles west of. Drilled well 5⅝ inches in diameter and 51 feet deep; water from Pierce or Murfreesboro limestone; owned by J. M. Free. Sampled Sept. 15, 1927.	60	do
432	Murfreesboro, 2½ miles west of. Drilled well 5⅝ inches in diameter and 175 feet deep; water from Murfreesboro limestone; owned by T. F. Lane. Sampled Sept. 15, 1927.	60	do
433	Murfreesboro, ¾ mile northwest of. Drilled well 10 inches in diameter and 650 feet deep; water from Murfreesboro limestone at depth of 80 feet, also from unnamed limestone at depth of 350 feet; well No. 4 of Carnation Milk Products Co. Sampled Sept. 15, 1927.	60	do
435	Murfreesboro, ¾ mile northwest of. Drilled well 10 inches in diameter and 217 feet deep; water from Murfreesboro limestone at depth of 50 to 65 feet; well No. 2 of Carnation Milk Products Co. Sampled Sept. 13, 1927.	60	do
439	Murfreesboro. Murfreesboro City Spring; water from Murfreesboro limestone; municipal supply; owned by city of Murfreesboro. Sampled Sept. 15, 1927.		do
462	Eagleville, 2 miles east of. Spring (head of Harpeth River); water from alluvial silt overlying Lebanon limestone; owned by R. S. Brown, jr. Sampled Oct. 11, 1927.	59	Farrar
466	Christiana, 9 miles west of. Big Spring; water from Lebanon limestone; owned by W. H. Robinson. Sampled Sept. 15, 1927.	62	Foster

[a] Includes iron precipitated at time of analysis.
[b] Carbonate radicle (CO_3) not present.

in north-central Tennessee—Continued

Analyses (quantities in parts per million)													
Total dissolved solids at 180° C.	Silica (SiO_2)	Iron (Fe)[a]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)[b]	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hydrogen sulphide (H_2S)	Total hardness as $CaCO_3$[c]	No. on Plate 4
322	23	.06	33	29	43	5.6	258	29	40	.07	-------	201	427
282	13	.39	57	28	3.9	1.9	232	57	9.0	.25	-------	257	431
1,240	11	.21	106	28	322	8.4	588	26	406	.0	75	380	432
514	16	2.0	40	26	105	9.9	264	138	55	.35	-------	207	433
356	18	.32	78	22	19	2.5	292	44	29	1.6	-------	285	435
204	11	.44	61	6.9	1.2	.9	198	6.0	4.4	8.0	-------	181	439
256	10.1	.7	59	24	8.0		290	15	1.5	1.2	-------	246	462
300	17	.12	93	9.7	3.0	.9	308	13	1.6	7.0	-------	272	466

[c] Calculated.

RELATION TO STRATIGRAPHY

As is brought out in the following paragraph, the analyses of representative ground waters tabulated above do not disclose any outstanding relation between the chemical character of the ground waters and the stratigraphic horizon of the water-bearing beds. In general most of the waters fall into one of three classes—first, slightly and moderately concentrated calcium bicarbonate waters having moderate carbonate hardness; second, highly concentrated calcium or calcium-magnesium sulphate waters with considerable noncarbonate hardness; third, highly concentrated brines or sodium chloride-sulphate waters. All members of the geologic column contain waters that fall into these three classes and have about the same range in concentration. The waters of the first class are those that circulate freely through permeable beds and channeled limestone at shallow or moderate depth and issue from most of the springs and from wells less than 200 feet deep. Most of them contain from 150 to 400 parts per million of dissolved mineral matter and from 125 to 325 parts per million of carbonate hardness. Usually they are essentially free from iron and hydrogen sulphide. Hence they are suitable for all ordinary purposes if softened. The waters of the second and third classes, which can not be sharply discriminated, occur at greater depth in permeable beds or at moderate depth in beds of low permeability. The brines are probably connate or modified connate waters originating in an epoch of marine sedimentation. The calcium sulphate waters owe their high concentration to slow percolation or stagnation in strata containing soluble sulphates or possibly to reaction on limestone of sulphuric acid formed by oxidation and hydrolysis of pyrite. These highly concentrated waters issue from a few springs and from some wells less than 50 feet deep, though generally they occur in strata more than 100 feet below the surface. So far as is known, the water in all strata more than 350 feet below the surface is highly concentrated and is not entirely satisfactory for most ordinary uses, especially for domestic consumption.

The general character of the ground water associated with different stratigraphic units in north-central Tennessee is shown by the accompanying table of average, minimum, and maximum quantities of mineral constituents, which is based only on the 101 representative analyses. The accuracy of the relations suggested by this table is limited by several factors. It is impossible to tell the precise stratigraphic horizon of the water-bearing bed of some wells, because complete records of the strata penetrated are not available. This table shows the absolute minimum and maximum of each constituent without reference to any other constituent. All the minima are not necessarily derived from the same analysis; neither are all the maxima necessarily derived from a single analysis. Some wells penetrate more than one water-bearing bed, so that the sample may not be quite representative of the principal bed. Other wells may not be adequately cased, or the casing may have deteriorated, so that water from the surface or from a shallow water-bearing stratum may be entering the well. Any particular stratigraphic unit may have considerable lateral and vertical variations in the mineral character of its component beds, so that the ground waters associated with it at different depths and places may differ considerably in chemical character. Wells that draw upon intensely channeled limestone may yield water of different chemical character at different seasons.

100144—32——9

Average, minimum, and maximum quantities of mineral constituents in waters from stratigraphic units in north-central Tennessee

[Parts per million]

Stratigraphic unit	Number of analyses included in average	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Total dissolved solids	Total hardness as $CaCO_3$ (calculated)	Hydrogen sulphide (H_2S)
St. Louis limestone and Warsaw formation:													
Waters containing less than 1,000 parts per million dissolved solids (analyses 6, 24, 27, 42, 44, 64, 67, 71, 73, 87, 91, 96, 115, 138, 143, 159, 164, 167, 177, 198–B, 218, 219, 225, 229, 243, 265, 387)—													
Average	27	11.0	0.73	59	10	[a] 3.7	204	20	3.5	[b] 2.4	209	189	------
Minimum	------	2.2	.06	21	2.0	1.0	46	2.5	.9	.01	77	81	------
Maximum	------	24	4.6	114	33	15.6	374	148	14	15	441	335	([c])
Waters containing more than 1,000 parts per million dissolved solids (analyses 54, 57, 81, 104)—													
Average	4	15	2.6	346	120	102	286	1,154	96	1.2	2,044	1,355	([d])
Minimum	------	8.0	.38	282	39	4.9	225	611	2.2	.10	1,158	864	[e] 20
Maximum	------	19	6.9	382	173	304	400	1,474	295	3.2	2,970	1,624	[e] 116
Fort Payne formation:													
Waters containing less than 1,000 parts per million dissolved solids (analyses 1, 32, 35, 112, 121, 149, 151, 171, 173, 190, 259, 268, 277, 366)—													
Average	14	14.4	.47	52	11	[f] 8.7	195	20	[g] 6.7	1.0	207	175	([d])
Minimum	------	3.2	.02	8.6	2.4	2.0	31	2.2	1.0	.15	50	31	[e] 5.2
Maximum	------	28	1.0	121	32	75	433	87	54	2.8	514	433	[e] 18
Waters containing more than 1,000 parts per million dissolved solids (analyses 68, 126, 191, 198–A, 260)—													
Average	5	17	7.5	591	135	[h] 646	173	1,883	[i] 700	1.6	3,970	1,735	[j] 21
Minimum	------	2.4	1.5	163	60	16	152	771	2.3	.07	1,238	797	11
Maximum	------	26	29	625	221	3,003	190	3,652	3,425	4.0	10,688	2,468	31
Chattanooga shale (analyses 220, 258, 278, 279, 395)—													
Average	5	12	.78	88	29	18	285	131	6.7	.25	433	337	------
Minimum	------	3.4	.04	57	16	1.7	228	21	3.5	.0	238	220	------
Maximum	------	23	2.4	156	51	32	351	359	10	.6	844	599	10
Silurian limestones (analyses 180, 269, 282, 359)—													
Average	4	13	.17	37	8.1	3.0	131	15	1.6	1.6	162	125	------
Minimum	------	8.4	.05	17	2.9	1.6	60	3.8	1.2	.4	70	54	------
Maximum	------	21	.5	48	14	3.7	168	27	1.8	3.0	241	155	([c])

Leipers and Catheys formations:													
Waters containing less than 1,000 parts per million dissolved solids (analyses 127, 131, 132, 286, 317)—													
Average	5	14	.67	99	26	13	282	114	20	.35	437	354	------
Minimum	------	9.2	.12	71	16	5.0	237	49	2.9	.05	292	253	------
Maximum	------	20	1.4	163	43	26	364	198	48	.6	628	481	[k] 5.5
Waters containing more than 1,000 parts per million dissolved solids (analyses 292, 311, 394 [d])—													
Minimum	------	9.7	.8	139	62	26	220	1,174	131	.0	2,160	602	------
Maximum	------	26	1.4	518	219	1,253	371	3,426	694	3.0	6,474	2,140	[l] 60
Bigby limestone (analyses 135, 297-A, 297-B, 297-C, 312)—													
Average	[m] 5	[n] 13	[n] .67	78	10.8	79	276	56	79	16	470	240	------
Minimum	------	12	.13	54	4.8	6.0	222	5.0	7.8	.2	262	155	------
Maximum	------	15	1.6	110	20	113	350	135	204	58	722	357	------
Hermitage formation and Lowville limestone (analyses 305, 316, 330, 370)—													
Average	[o] 4	11	.64	63	15	25	202	76	11	11	314	216	------
Minimum	------	8.4	.04	44	7.2	6.0	146	31	5.5	.4	192	154	------
Maximum	------	15	1.0	88	28	81	302	197	18	43	469	281	------
Stones River group:													
Waters containing less than 1,000 parts per million dissolved solids (analyses 302, 328, 333, 347, 348, 365, 376, 427, 431, 433, 435, 439, 466)—													
Average	13	14	.59	84	18	32	287	58	[p] 35	4.7	[q] 381	286	------
Minimum	------	8.8	.06	33	6.9	2.1	198	6	1.6	.07	204	181	------
Maximum	------	23	2.0	160	29	115	357	191	131	37	796	470	([c])
Waters containing more than 1,000 parts per million dissolved solids (analyses 344, 352, 353, 432)—													
Average	[r] 4	15	5.1	250	157	2,388	429	148	4,134	.82	7,462	1,259	------
Minimum	------	11	.21	62	19	12	211	26	1.0	.0	1,048	232	------
Maximum	------	18	16	580	533	8,918	588	377	15,700	2.0	26,410	3,600	[s] 86

[a] Average is 2.8 if analyses 219 and 229 are excluded from the mean.
[b] Based on 26 determinations.
[c] Quantity indeterminate.
[d] Average not computed unless more than three determinations available.
[e] Determinate in two samples only.
[f] Average is 2.6 if analyses 259 and 268 are excluded from the mean.
[g] Average is 3.0 if analysis 268 is excluded from the mean.
[h] Average is 57 if analysis 260 is excluded from the mean.
[i] Average is 19 if analysis 260 is excluded from the mean.
[j] Based on 4 determinations.
[k] Determinate in sample 131 only.
[l] Determinate in sample 311 only.
[m] Analyses 137 and 390, which contain more than 1,000 parts per million dissolved solids, excluded from the mean. Nos. 137 and 390 are H_2S-bearing sodium and calcium sulphate waters.
[n] Based on 3 determinations.
[o] Analyses 294 and 326, which contain more than 1,000 parts per million dissolved solids, excluded from the mean. No. 294 is an H_2S-bearing sodium and calcium sulphate water; No. 326 is a magnesium and calcium sulphate water.
[p] Average is 27 if analysis 302 is excluded from the mean.
[q] Average is 347 if analysis 302 is excluded from the mean.
[r] Averages weak because of great concentration of sample 352.
[s] Determinate in samples 352 and 432 only.

In general, the ground water associated with the Chattanooga shale near its outcrop is "black sulphur" water, iron being taken into solution as the sulphate from oxidized portions of the pyritiferous shale and the sulphate being reduced by the carbonaceous matter of the shale. Generally the water contains less than 500 parts per million of dissolved mineral matter and the hydrogen sulphide is less than 10 parts per million. The water associated with the crystalline Silurian limestones has the least average content of dissolved solids, is relatively soft, and has little noncarbonate hardness; hence it is suitable for many uses without any preliminary treatment. The water that issues from the Bigby limestone generally contains more matter in solution and appreciably more sodium and potassium than the water carried at similar depth by other stratigraphic units of the same water-yielding capacity. At several localities, especially in the vicinity of Nashville, the dense limestone beds of the Cannon and Bigby limestones contain blebs of petroliferous material, and some of the associated ground water contains sufficient oil in the emulsified state to impart a disagreeable taste and a pronounced opalescence. Other than these general relations, however, little correlation can be made between chemical character of the ground water and the stratigraphic horizon of the water-bearing bed.

SUMMARY DESCRIPTIONS BY COUNTIES

CHEATHAM COUNTY

[Area, 314 square miles. Population, 9,025 [70]]

GENERAL FEATURES

Cheatham County lies in the geographic center of the area covered by this report and is bounded on the north by Montgomery and Robertson Counties, on the east by Davidson County, on the south by Williamson County, and on the west by Dickson County. The area is wholly rural. The county seat and largest community, Ashland City (population, 712) is situated in the valley of the Cumberland River on the Tennessee Central Railroad.

Cheatham County includes the stream gaps by which the Nashville Basin drains northwestward across the Highland Rim Plateau (see pp. 16–18) and hence has a rather rugged topography. From the Cumberland River northward the surface is a dissected plateau comprising flat and gently rolling interstream tracts whose altitude ranges from 700 to 780 feet above sea level and closely spaced subparallel youthful drains adjusted to the Cumberland River at 350 feet above sea level. Sink-hole topography exists locally on these interstream plateau tracts but is not characteristic of them within Cheatham County. The topography of the central and southern parts of the county,

[70] Figures for population from 1930 census.

which are traversed by the Cumberland and Harpeth Rivers, is somewhat more diverse, the summit flats being less extensive and some of the slopes along the major streams having submature profiles. The youthful tributary drains in the southern part of the county are adjusted to the Harpeth River, which at Kingston Springs is about 440 feet above sea level.

The interstream flats of Cheatham County are underlain by 20 to 60 feet or more of cherty residual soil and clay resting upon the massive subcrystalline beds of the St. Louis limestone and Warsaw formation. The underlying Fort Payne formation, which in this area consists of interbedded strata of dense bluish cherty limestone and calcareous shale 1 to 3 feet thick, crops out on the slopes of the tributary drains throughout the county. (See pl. 4.) The Chattanooga shale crops out as a narrow band slightly above stream level along the Cumberland River and some of its larger tributaries from Ashland City eastward and intermittently along the Harpeth River entirely across the county. Beneath this well-known horizon marker limestones of Devonian and Silurian age crop out over the valley floors. The Leipers formation, of Upper Ordovician age, and some of the uppermost beds of the Middle Ordovician are exposed at stream level along the Cumberland River eastward from a point near Ashland City. The general character and succession of these strata are described on pages 33–53, and their areal extent is shown by Plate 4.

GROUND-WATER CONDITIONS

On the interstream plateau remnants most rural water supplies are obtained from dug wells 25 to 50 feet deep, which tap the loose cherty débris or partly disintegrated limestone at or just above the contact of the residual clay that rests on the St. Louis limestone. Many such wells are inadequate for a single household during the summer in years of subnormal rainfall. Hence each farmstead usually has a cistern for storing rain water. Water for stock is generally impounded in small pools by damming one or more ephemeral drains and conserving storm run-off. The few drilled wells on these upland tracts obtain water in channeled zones of the St. Louis limestone between 90 and 160 feet below the surface. To judge from the records of several deep wells that have been drilled in Cheatham and adjoining counties in search of oil, it does not seem likely that potable water will be found by drilling to depths exceeding 200 feet in the upland tracts.

On the slopes of the youthful drains that dissect the Highland Rim plateau many small tubular springs issue at several altitudes from jointed and channeled limestone, and seepage springs from the cherty residuum of the weathered rocks. Many rural dwellings are located adjacent to perennial springs of this sort. Drilling for water on these slopes is exceedingly uncertain, although successful wells from 35 to

60 feet deep have been drilled in several places. These wells encounter water at the upper surface of the Chattanooga shale and at random horizons in shaly facies of the overlying Fort Payne formation.

Shaly and channeled beds of the Devonian, Silurian, and Ordovician limestones supply drilled wells from 70 to 125 feet deep on and near the bottom lands of the Cumberland River Valley, where the water-bearing zone is approximately 300 to 350 feet above sea level. In the Harpeth River Valley of the southern part of the county wells from 50 to 75 feet deep in the Silurian and Devonian limestones find relatively soft water about 450 feet above sea level. The extent and lateral persistence of the channeled zones that supply these wells can not be inferred from the well data at hand.

The conditions under which ground water occurs in limestone are discussed on pages 69–89. Analyses of representative ground waters from Cheatham County are tabulated on pages 114–115.

Typical wells in Cheatham County, Tenn.

[All drilled wells]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
238	Thomasville, 1½ miles NE	H. J. Pace	Ridge crest	640	100	6	
240	Thomasville, ½ mile NW	William Harris	Valley terrace	595	100	6	30
243	Neptune, 1¾ miles NE	R. P. Frazier, M. D	Ridge crest	620	165	6	
244	Neptune, 1 mile E	R. O. Davis	Hillside	575	800		
246	Fox Bluff, 2½ miles NE	C. W. Clifton	Ridge crest	650	895		
248	Pleasant View, 3½ miles S	Millard Williams	Plateau	615	120	6	40
251	Ashland City, 5 miles NE	Y. M. C. A. camp	Valley	445	50±	6	
253	Joelton, 7 miles W	R. F. Biggs	Upland	755	89	6	
254	Joelton, 6½ miles W	J. F. Krantz	do	760	96	6¼	
255	Chapmansboro, 3¼ miles S	Albert Dozier	Valley	415	45		
257	Ashland City, ½ mile NW	Standard Oil Co	River terrace	410	30	8	
258	Ashland City	T. F. Chambliss	do	430	69	6	To rock.
260	do	E. F. Allen, M. D., and others	do	390	120	5	
261	Ashland City, 4¼ miles SE	G. H. Kessler	Valley	410	35	6	
262	Ashland City, 5¼ miles SE		do	425±	80	8	30
263	Ashland City, 6½ miles SE	Grace Chester	River terrace	425	130	6	72
264	Ashland City, 8 miles SW	O. E. Williams	Hilltop	500	100	6	
265	Ashland City, 7½ miles SW	Idlewild School	Ridge crest	445	45		
267	Kingston Springs	John Greer	Valley	495	50	6	
269	Pegram, ½ mile N	W. L. Palmore	do	525	79	6	15
270	Kingston Springs, 2 miles S	Cheatham County	Upland	625	150	8	40

[Table continued on pp. 128–129]

Typical wells in Cheatham County, Tenn.—Continued

[All drilled wells]

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
238	95±	Limestone	St. Louis limestone.		Electric force pump			Domestic, stock	All ridgetop residents of vicinity have cisterns; several drilled wells of which this is typical.
240	72	Small crevice	do	−48	Hand pump	3–5	61	Domestic	Emergency supply only; pumped dry in 30 minutes when first drilled.
[a] 243	160	Dense limestone	do	−75	do	3	58	do	Other wells of community 60 to 70 feet deep; many cisterns used by upland residents.
244	200±		St. Louis (?) limestone.					None	Abandoned test well by Sewanee Oil & Gas Co. No water below depth of 200 feet. Chattanooga shale at depth of 700± feet.
246	200±		St. Louis limestone.			Large.		do	Abandoned test well by Sewanee Oil & Gas Co. Small amount of water at depth of 35–40 feet. None below 200 feet.
248	120	Limestone	do	−40	Gasoline force pump	10±		Domestic, stock	Could not be bailed dry by driller. Cisterns and rain catches are usual source of water in vicinity; a few supplemental wells in chert residuum.
251	45±	Shale and cherty limestone.	Fort Payne formation.		do	5		Domestic	Ample for summer camp of 100 persons.
253	85±	Crevice	St. Louis limestone.	−40	Bucket and rope		59	do	Drawdown reported as 6 inches when bailing 20 gallons a minute.
254	95±	Cherty limestone	Fort Payne formation.	−65	do		59	do	Water too hard for laundering.
255	40±		do		do			Domestic, stock	Most household water supplies of community come from cisterns.
257	30	Inclined crevice	do	−20		1±		Drinking	
[a] 258	65±	Shale	Chattanooga shale.	−35	Bucket and rope		58	Domestic	So-called sulphur water.
[a] 260		Shale (?)	Fort Payne formation.	−20	do		60	Medicinal	Well known as "Sunrise Spring."
261	35	Shale	Chattanooga shale.	−25	do			Domestic	Ultimate capacity about 10 gallons an hour.
262	70	do	Silurian	−50	Force pump			Sawmill	Well abandoned. Adequate for 25-horsepower boiler and for drinking.
263	120±	Limestone	Leipers (?) formation.	−65	Hand pump	3		Domestic	Cased through solution cavity, which probably communicated with the Cumberland River.
264	Near bottom.	do	Fort Payne (?) formation.		Bucket and rope			do	

[a] 265		do	St. Louis limestone.		Hand pump	3	57	Drinking	In village of Petway. Most other supplies of the vicinity from dug wells about 25 feet deep.
267	Near bottom.	Solution crevice	Fort Payne formation.	−25		1±		Domestic	
[a] 269	70	Bedding-plane crevice.	Silurian limestone.	−40	Bucket and rope		58	do	Tested at 20 gallons a minute with bailer when drilled.
270	144	Solution channel filled by silt.	Fort Payne (?) formation.	−125		1±		Drinking	Pumped several cubic yards of silt and sand from well in development; ultimate capacity about 1 gallon a minute

[a] See analysis, pp. 114–115.

Typical springs in Cheatham County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
239	Thomasville, 2 miles NE	H. O. Knox		Hillside	595	St. Louis or Warsaw limestone.
241	Thomasville, ¼ mile SW	A. T. Stewart		Valley	550	Do.
242	Pleasantview, ¼ mile SW	J. W. Cage & Co.	Mill Spring	Plateau	660	Do.
245	Neptune, 2¼ miles E			Valley	500	Do.
247	Chapmansboro, 5 miles NE	Tom Nichols	Big Spring	do	460	Do.
249	Pleasantview, 3¼ miles S	Brinkley Bros.	George Payne Spring	do	505	Fort Payne (?) formation.
250	Ashland City, 4 miles N	Perry Jackson		Hillside	435	Fort Payne formation.
252	Ashland City, 7½ miles NE	Mary B. Thomas	Blue Spring	Valley	625	Detritus from Fort Payne formation.
256	Ashland City, 2¾ miles W	H. W. Blackenslip	Miles Spring	Hillside	425±	Fort Payne formation.
259	Ashland City, 2¼ miles S	Cheatham County	Sulphur Spring	Valley	395	Do.
266	Kingston Springs, 7 miles N	J. Morris heirs	Deep Spring	do	535	Do.
268	Kingston Springs, ½ mile S	W. C. West	Kingston Spring	do	510	Do.

[Table continued on p. 130]

Typical springs in Cheatham County, Tenn.—Continued

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
239	1	Natural well leading to underground channel.				Domestic		
241	1	Bedding-plane channel	25	Aug. 21	Erratic		59	Yield increases and water becomes turbid about 12 hours after rain to the south.
242	1	do	20	Aug. 20	Seasonal	Domestic	58	Perennial spring.
245	1	do	1-2	Aug. 21	do	Drinking, stock	59	Roadside spring and watering trough.
247	1	do	100	Aug. 20	do	Domestic	58	Turbid after several days' continuous rain. Emergency supply for Ashland city. Reported minimum discharge 100 gallons a minute.
249	1	do	50	do	Probably seasonal	Domestic, stock	58	
250	1	Concealed	1±	do	Seasonal	Domestic	59	Perennial spring.
252	1	Seepage	10	do	do	Domestic, stock	57	Do.
256	Many.	Joint and bedding-plane channels.	5±	Aug. 22	do	do	58	
[a] 259	1	Concealed	No flow.			Drinking	59	Used locally as medicinal water.
266	1	Slumped roof of underground channel.	5-8	Aug. 22	Seasonal		57	Discharge may percolate through creek gravel in large part.
[a] 268	2	Concealed	½±	do		Drinking	61	Medicinal sulphur spring. So-called freestone spring near by has its source in weathered zone of rock.

[a] See analysis, pp. 114-115.

DAVIDSON COUNTY

[Area, 511 square miles. Population, 222,854]

GENERAL FEATURES

Davidson County, which adjoins Cheatham County on the east, occupies the east-central part of the region covered by this report. (See pl. 1.) Its county seat, Nashville (population, 153,866), is also the capital and second largest city of the State; it is situated on the Cumberland River about at the geometric center of the county. Old Hickory (estimated population, 3,050), about 10 miles northeast of Nashville, is an industrial city devoted to the manufacture of rayon products. With the exception of these urban districts, the county is for the most part a fertile rural area.

The greater part of Davidson County is drained by the Cumberland River, which follows a meandering westward course through Nashville and gathers the tributary drainage of Mansker, Whites, and Little Marrowbone Creeks from the north and of the Stone River and Mill Creek from the south. The Harpeth River crosses the extreme southwestern part of the county at Belleview and drains a small area in the county.

Davidson County embraces approximately equal areas in two physiographic districts, the northwestern quadrant of the Nashville Basin (p. 18) and the contiguous encircling escarpment of the Highland Rim plateau (pp. 16–17). Its extreme topographic relief is about 525 feet, the highest point being about 900 feet above sea level on the divide between Sycamore and Mansker Creeks, in the vicinity of Ridgetop, and the lowest about 375 feet above sea level, where the Cumberland River crosses the western boundary of the county. From the meander belt of the Cumberland River as it was in the Nashville Basin erosion cycle the Highland Rim escarpment rises northward about 300 feet to the plateau that extends northward beyond the county. The face of this erosion escarpment is trenched by closely spaced subparallel youthful drains several miles in length. The extreme northwestern part of the county, in the vicinity of Joelton, lies upon the gently undulating peneplain that constitutes the Highland Rim plateau. A salient of the plateau, now reduced to a group of mature hills, extends eastward into the county to and beyond Nashville and forms the divide between the Cumberland and Harpeth Rivers. The portion of the county that lies south and east of the escarpment is gently rolling, the product of submature dissection of the Nashville Basin peneplain by streams adjusted to the Cumberland River in its present cycle. The accordant summits—peneplain remnants—are about 600 feet above sea level. Sink holes are locally abundant in the limestones that underlie this physiographic district, particularly between the limbs of river meanders and in the acute angle between converging streams in the vicinity of their confluence.

Davidson County lies on the northwest flank of the Nashville dome (see pp. 62–63), so that at any particular altitude successively older strata appear toward the southeast. The exposed rocks constitute nearly a full section from the St. Louis limestone, of Mississippian age, down to the Ridley limestone, of Lower Ordovician age. (See pp. 33–55.) The massive subcrystalline St. Louis limestone crops out only in the Highland Rim plateau northwestward from Joelton, where it is overlain by a thick mantle of cherty residual soil. The underlying Fort Payne formation, which in this county is generally thin-bedded earthy cherty limestone, crops out in all the upper slopes of the Highland Rim escarpment and forms the divide between the Cumberland and Harpeth Rivers. The New Providence and Ridgetop shales, which are stratigraphically beneath the Fort Payne formation, crop out in an area several miles across northwest of Nashville but are not widespread elsewhere. The Chattanooga shale crops out as a narrow band following the lower slope of the Highland Rim escarpment and inclosing erosion outliers of the plateau as far east as Nashville. Heavy-bedded dense and crystalline limestones of Devonian and Silurian age crop out along the base of the escarpment and of the outliers of the plateau and in the valley of the Harpeth River below Belleview. The stratigraphic relations of the formations of these two systems, which lap eastward over the underlying strata, have not been traced in detail. The earthy and dense pure limestones of Upper and Middle Ordovician age cover most of the rolling terrane of the Nashville Basin north and west of Nashville. The massive compact Carters limestone member of the Lowville limestone is exposed by the Cumberland River in the southeastern part of Nashville and crops out extensively farther southeast. The Lebanon and Ridley limestones of the Stones River group appear successively in the lower parts of the county and cover larger and larger areas toward the southeast. The areas within which the several stratigraphic units crop out are shown on Plate 4.

GROUND-WATER CONDITIONS

The water-bearing properties of the rocks in Davidson County differ greatly from place to place and for the most part can not be foretold from stratigraphic position alone. Rather, the ability of any particular stratum to transmit water is generally limited by the number and size of solution channels and hence is dependent upon the solubility of the rock, the number and persistence of joints, and the position of the stratum with relation to present and past equilibrium profiles of underground drainage. (See pp. 78–82.) Thus in several parts of the county a water-bearing zone occurs in the limestone at about the same depth below the surface even though at different stratigraphic horizons. On the other hand, a few of the formations have the same water-bearing properties wherever they occur. For example, the outcrop of the Chattanooga shale is everywhere accompanied by perennial sulphur springs of rather small discharge, although the same stratum may not be water bearing beneath deep continuous cover. The Leipers and Catheys formations, which are for the most part very impure earthy limestone and calcareous shale, are generally poor water bearers throughout the county.

On the Highland Rim plateau, in the northwestern part of the county, the mantle of residual cherty soil supplies dug wells of household magnitude, though many such wells prove inadequate during long dry periods. Drilled wells 75 to 160 feet deep encounter water in the coarse cherty débris at the bottom of the residual soil mantle or in the weathered and channeled limestone just below, 700 to 750 feet above sea level. On the slopes of the escarpment that bounds the plateau on the southeast many tubular springs occur at the same altitude. This water-bearing zone is probably more nearly constant in water-yielding capacity than any other within the county.

On the Highland Rim escarpment and among the near-by outlying hills, which constitute the more rugged parts of the county, erosion has been comparatively rapid, and there has been no fixed equilibrium profile to which solution channels in the limestone could adjust themselves. Hence in this area water-bearing channeled zones are very erratic in altitude and extent. Under such conditions drilled wells in the limestone are very uncertain as sources of water, and the likelihood of finding water decreases greatly as the depth exceeds 50 or 100 feet, as in well 315 (pp. 135, 137). Also, dry holes are not uncommon, such as well 320. Wells that reach the Chattanooga shale in the vicinity of its outcrop, however, generally obtain enough sulphur water to supply individual dwellings. In terranes of this sort springs are a relatively certain source of water, particularly the perennial tubular springs (pp. 92–95), which drain large areas of channeled limestone. The pure subcrystalline Silurian limestones supply many of the larger tubular springs along the base of the Highland Rim escarpment. In most of the rugged tracts enough such springs exist to meet the present and probable future requirements for water.

In the part of the county that lies in the Nashville Basin, drilled wells from 60 to 200 feet deep generally find ample water for household purposes in channeled limestone. The water-bearing zones of most of these wells fall into one of two groups—one from 300 to 350 feet above sea level and the other from 400 to 450 feet above sea level. The tested capacities of these wells range from a fraction of 1 gallon to 228 gallons a minute, although most of the wells have not been proved for drafts exceeding 10 gallons a minute. Dry holes have been drilled in several localities, as in the blocks bounded by deeply cut meanders of the Cumberland River and in the earthy beds of the

Leipers and Catheys formations. Some perennial tubular springs also exist in the limestones of this part of the county, particularly in the Hermitage formation in the vicinity of Nashville. Most of these springs, however, discharge only a few gallons of water a minute in the dry season and in general are much less reliable than the springs of the Highland Rim escarpment. No potable water has been found at depths exceeding 200 feet except in a very few wells, and hence deep drilling for water is not generally advisable. In well 313, for example, no water-bearing beds were penetrated below a depth of 101 feet to a depth of 409 feet, even though the well is on the crest of a ridge about 300 feet high. The few deep wells that have been drilled—Nos. 295, 298, 299, and 303—pass through the deepest beds that carry fresh water less than 200 feet below the surface; below these beds they penetrate only dense limestone to the St. Peter (?) sandstone at a depth of about 1,100 feet. The St. Peter (?) sandstone, however, contains water that is too highly concentrated to be satisfactory for many uses, as is shown by analyses 295 and 298 (pp. 114–115).

The static level of the water carried by the St. Peter (?) sandstone is about 510 feet above sea level in the vicinity of Nashville, so that flowing wells, such as Nos. 295 and 298, can be obtained in the lower land along the Cumberland River. However, the specific capacity of the wells seems to be rather small.

Descriptive data for typical wells and springs in Davidson County are tabulated on the following pages, and the driller's record of the strata penetrated by well 295 is given on page 59. The chemical character of the ground waters is shown by representative analyses tabulated on pages 114–117.

Typical wells in Davidson County, Tenn.

[All drilled wells]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
272	Joelton, 1 mile NW	Joelton High School	Plateau	825	85	6	
275	Madison, 2 miles NE	Louisville & Nashville R. R.	Plain	490	60	6	
276	Old Hickory, 3¾ miles NW	E. I. du Pont de Nemours & Co.	Valley	435	195	6	
277	Whites Creek, 3 miles NW	E. B. Hart	Plateau	855	158	6	60
279	Whites Creek, 3¾ miles SW	J. D. Carrington	Valley	700	23	6	18
280	Whites Creek, 4 miles SW	W. B. Holt	do	670	120	6	
281	Ashland City, 8 miles SE	C. R. Rohrer	do	450	76	6	
284	Whites Creek, 5 miles SW	N. S. Walker	do	455	45±	6¼	
285	Whites Creek, 3¾ miles S	Ralph Drake	do	505	90+	6	10
286	Whites Creek, 2 miles S	J. C. Smith	do	475	63	6	13
287	Madison, 1¾ miles S	J. T. Benson	River terrace	490	176	6	18
289	Old Hickory, 2¼ miles SW	William Tate	do	465	100-125	6	
290	Old Hickory, 1¼ miles SE	Paul Gamble	do	475	168	8	
291	Old Hickory, 1½ miles SE	William Gore	do	470	61	6¼	
292	Nashville, 10½ miles NW	Henry Farmer	Valley	475	97	6	
293	Nashville, 10¾ miles W	W. T. Pearson	Hillside	415	47	6¼	
294	Nashville, 4¾ miles NW	G. W. Bolin	River terrace	485	94	6¼	
295	Nashville, 4¼ miles NW	Arthur Stevens	do	485	1,481	10	
296	Nashville, 3½ miles NW	Aleck Ackenbaurer, jr	Valley	450	111	6	40
298	Nashville	Morgan & Hamilton Co	do	420	2,965(?)		
299	Nashville	Phillips-Buttorff Manufacturing Co	do	455	1,535	6⅝	
300	Nashville	Noel & Co	do	445	100±	8	
302	Nashville	Atlantic Ice & Coal Co	do	420	300	12	62
303	Nashville	Maxwell House	Hillside	510	2,400±		1,100
307	Old Hickory, 5¾ miles SW	G. I. Waddey	River terrace	560	200	6	
309	Pegram, 3½ miles E	Nashville, Chattanooga & St. Louis Ry	Valley	575	236	8	43
310	Belleview, 4¼ miles NW	do	do	565	106	8	
311	Belleview, 1¼ miles W	N. M. Morton	River terrace	565	144	6	11
312	Belleview	Nashville, Chattanooga & St. Louis Ry	Valley	595	143	6	63
313	Belleview, 3½ miles NE	Sunrise Auto Club	Ridge crest	800	409	8	70
314	Belleview, 3¼ miles E	Nashville, Chattanooga & St. Louis Ry	Wind gap	710	210	8	
315	Nashville, 5¾ miles SW	E. B. Stahlman	Hilltop	575	250	8	
316	Nashville, 4½ miles S	G. W. Luetzeler	Plain	560	125	6	
317	Woodbine, 3 miles W	Robertson Academy	Valley	640	65	6	
318	Woodbine, 4 miles NE	Central State Hospital	Plain	590	200	6	
319	Donelson, 4¼ miles SE	A. F. Ganier	Dissected plain	500	135	5	
320	Brentwood, 2½ miles W	B. B. Woodroff	Hillside	735	125	6¼	10
321	Brentwood, ½ mile N	F. H. Benjamin	do	750	135		
322	La Vergne, 2¾ miles N	George Seet	Plain	540	100	8	18

[Table continued on pp. 136-137]

Typical wells in Davidson County, Tenn.—Continued

[All drilled wells]

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
272	75	Sandstone	Top of Fort Payne formation.	−40	Automatic electric pump.	12±		Domestic	
275	Near bottom.	Limestone	Catheys (?) formation.	−15	Hand pump	3–5	60	Drinking	Public well at Amqui station. Reported to flow in wet seasons.
276	185	do	Bigby (?) limestone.						One of several wells at abandoned explosives plant.
[a] 277	155±	Cherty limestone	Fort Payne formation.	−125	Bucket and windlass		58	Domestic	Supply ample in extreme drought.
[a] 279	20	Shale	Chattanooga shale	−6	Hand pump	3–5	59	do	
280	30	do	Silurian limestone	−20		⅕		do	Well at new residence on east side of Eaton Creek.
281		Cherty limestone	do	−40	Gasoline force pump	5		Stock	Water too hard for laundering.
284	40±	Shale	Leipers (?) formation.	−15	Hand pump	3–5	60	Domestic, stock	In Gordonia community.
285	90	do	Bigby (?) limestone.		Gasoline force pump	5±		do	
[a] 286	59	Bedding-plane crevice.	Leipers or Catheys formation.	−30	do	8	64	Domestic	Reported tested at 18 gallons a minute without notable drawdown.
287	160	Limestone	Hermitage (?) formation.	−50		2±		do	
289	100±	Shaly limestone	do	−50				do	
290	92	Limestone	Lowville (?) limestone.	−35	None			None	Well abandoned because of pollution by oil waste from near-by garage.
291	Near bottom.	do	Hermitage (?) formation.		Hand pump	3	60	Domestic	Ample for 3 families in extreme drought.
[a] 292	do	Bedding-plane crevice.	Catheys (?) formation.	−20	Bucket and rope		62	Stock	
293		Limestone	Leipers formation		Hand pump		58	do	Ultimate capacity about 2 gallons a minute.
[a] 294	90	do	Hermitage formation.	−60	Bucket and rope		62	Medicinal	
[a] 295	1,165	Sandy limestone	St. Peter (?) sandstone.	+3½	Artesian flow	35	66	None	Fresh water at 85 feet in Hermitage formation; sulphur water at 195 feet in Lebanon (?) limestone. Casing pulled and water probably from several beds.
296	100	Solution crevice	Hermitage formation.	−45	Electric pump	20		Garden irrigation	

[a]298			St. Peter (?) sandstone.	+75 (?)	Artesian flow	5	68	Drinking	At 1400 Eighth Ave. N.
299	1,100 (?)		do	+8	Artesian flow and air lift.	15	62	Drinking, foundry	At foundry, 217 Third Ave. N. Maximum consumption 10,000 gallons a day. A second well near by is 500 feet deep.
300			Bigby limestone or Hermitage formation.						At 607 Tenth Ave. N. Three wells drilled and sprung with 200 sticks dynamite each to open crevices to buried spring.
[a]302	128 289	Solution channels filled with sand.	Lebanon (?) limestone. Ridley (?) limestone.	−28 −60	Deep-well turbine	228	63	Cooling	At 916 Fourth Ave. N. Maximum capacity of well tested at 228 gallons a minute.
303	1,100±		St. Peter (?) sandstone.	+Slight	None	Less than 2		None	At Fourth Ave. and Church St. Ultimate capacity tested at 100 gallons an hour and well abandoned.
307						None		do	Dry hole in divide between meanders of Cumberland River.
309	195	Limestone	Leipers formation.	−60	Hand pump	3–5		Domestic	Well at Newsom section houses. Capacity tested by bailer at 20 gallons a minute; water-bearing crevices of small yield at depth of 60 and 95 feet.
310	90	do	do	−45	do	3		Drinking	Public well at Newsom station.
[a]311	52	do	Catheys formation.	−10	Bucket and rope		60	Medicinal	
[a]312	136	Bedding-plane crevice.	Bigby (?) limestone.		Hand pump	3–5	60	Drinking	Public well at Belleview station.
313	101	Small solution crevice.	Leipers (?) formation.	−101	Automatic electric pump.	5		Domestic	No water-bearing beds below 103 feet.
314	200	Limestone	Bigby (?) limestone.	−136	Hand pump	3	60	do	Well at Vaughns Gap section houses; supplies 9 families.
315	98	do	Hermitage (?) formation.			1/3		do	No water-bearing beds below 98 feet.
[a]316	Near bottom.	do	Lowville (?) limestone.		Hand pump	3	58		Water contains oily material in emulsion.
[a]317	50	do	Catheys (?) formation.		do	3	60	Drinking	Other wells in this vicinity which reach same horizon yield 1/4 to 2 gallons a minute.
318									Five test wells each yielded enough for a household supply; inadequate for hospital needs.
319	100	Bedding-plane crevice.	Lebanon (?) limestone.	−100	Bucket and rope		58	Domestic	Water-bearing channel at same altitude as bed of Stone River.
320						None.		None	Dry hole; bottom in Hermitage formation.±
321	120	Shale	Hermitage formation.	−85		2		Domestic	
322	90	do	Lebanon limestone.	−60				do	

[a] See analysis, pp. 114–117.

Typical springs in Davidson County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
271	Joelton, 3¼ miles NW	Jay John	Craighead Spring	Creek head	760	Fort Payne formation.
273	Joelton, 3 miles NE	A. Kirshner	Crocker Spring	Valley	570	Chattanooga shale.
274	Whites Creek, 4½ miles NE		Cool Spring	do	550	Leipers (?) formation.
278	Whites Creek, 2¼ miles W	Mrs. George Carney	Carney Spring	do	545	Chattanooga shale.
282	Ashland City, 8 miles SE	C. R. Rohrer	Young Spring	do	435	Silurian limestone.
283	Whites Creek, 5½ miles SW	Ben Carr	Cave Spring	do	575	Fernvale formation.
288	Madison, 2½ miles S	E. H. Fletcher		Hillside	490	Cannon limestone.
297	Nashville, 1½ miles NW	Buena Vista Springs Co.	Black Sulphur Spring	Valley	435	Bigby limestone, upper part.
301	Nashville	Fred B. Cassety Coal Co.	French Lick Spring	do	420	Hermitage formation.
304	Nashville, 4½ miles E	Howe Water Co.	Lockeland Spring	do	500	Do.
305	Nashville, 5 miles E	Pioneer Water Co.	Pioneer Spring	do	510	Hermitage formation, upper part.
306	Nashville, 5½ miles E	Frank Legler		Hillside	505	Hermitage formation.
308	Hermitage, 3 miles NW	D. B. De Bow		do	430	Do.
	Nashville, 5 miles SE	D. C. Buell				
	do	do				

[Table continued on p. 139]

Typical springs in Davidson County, Tenn.—Continued

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
271	1	Concealed	20	July 31	Probably seasonal	Domestic	58	Does not become turbid after rain.
273	Several	Joints	None	Aug. 3		Formerly medicinal.		Springs failed after a well had been drilled in each orifice in an attempt to increase the yield.
274	1	Bedding-plane solution channel.	½	do	Seasonal	Domestic	56	
[a] 278	1	Joint and bedding-plane crevices.	Trickle	do		Drinking		Probably seasonal fluctuation.
[a] 282	1	Solution channel along joint	100 Less than 5.	do Sept. 13	Perennial	Domestic, stock	60	Water slightly turbid after protracted rains. Young Spring on south side of valley; springs on north side of valley are less reliable.
283	1	Bedding-plane solution channel.	5	July 27	Seasonal	Stock	56	
288	1	Solution channel	1½	July 31	Erratic	Domestic	60	Yield increases greatly during rainy months.
[a] 297	1	Concealed	5±	Aug. 2	Permanent	Drinking, bottling	59	Spring is pumped as much as 400 gallons an hour.
301								Former spring, now buried by fill. Reported to have yielded concentrated sulphur water.
304	1	Bedding-plane channel	1½	July 26	Permanent	Bottling	58	Yield probably fluctuates with season.
[a] 305	1	do	2	July 28	Seasonal	do	62	Yield in winter is several times as much as in summer; minimum yield reported about 1 gallon a minute.
306	2	do	15	Aug. 2	do	Domestic, stock	58	Yield increases after protracted rain; water never highly turbid.
308	1	Joint crevice	2	Aug. 3	do	Domestic	64	Perennial spring.
			13½			Municipal		Spring No. 1.
			10			do		Spring No. 2.

[a] See analysis, pp. 114–117.

DICKSON COUNTY

GENERAL FEATURES

[Area, 549 square miles. Population, 18,4911

Dickson County lies in the southwestern part of the region covered by this report (pl. 1) and is bounded on the north by Montgomery County, on the east by Cheatham and Williamson Counties, on the south by Hickman County, and on the west by Humphreys and Houston Counties. The county seat, Charlotte, is a town of 291 inhabitants approximately at the center of the county. The chief commercial center, however, is Dickson (population 2,902), which is on the Nashville, Chattanooga & St. Louis Railway in the south-central part of the county. The county is wholly rural.

Dickson County lies entirely within the Highland Rim plateau (pp. 16–18), and is drained for the most part by the Cumberland and Harpeth Rivers, which constitute parts of its northern and eastern boundaries. A small area in the southwestern part of the county, however, is drained by the Piney and Duck Rivers into the Tennessee River. In general, the county is a dissected plain, the summits of the main ridges being remnants of the Highland Rim plateau and having the slightly undulating surface characteristic of it. The most extensive plateau remnants occur in the southwestern quadrant of the county along the divide between the Cumberland and Tennessee Rivers. The stream valleys have mature profiles near their heads and youthful profiles in their lower reaches; the mature profiles of dissection are adjusted to the Nashville Basin stage of the Cumberland River (pp. 20–22), and the youthful profiles are correlative with the present stage of downcutting by the river. The largest of these streams are Turnbull, Jones, Barton, and Yellow Creeks, which are tributaries of the Cumberland and Harpeth Rivers, and Piney River and its tributary, Garner Creek. The surface relief of the county is about 550 feet. The highest points, which are on the Highland Rim plateau in the southwestern part of the county, are about 900 feet above sea level; the lowest points, about 350 feet above sea level, are on the Cumberland River at the northeast corner of the county.

Dickson County lies on the western flank of the Nashville dome (pp. 62–63), so that in general the rock strata constitute a monocline dipping slightly westward or northwestward. This regional structure is modified, however, by a superposed dome whose apex is in the vicinity of White Bluff, in the central-eastern part of the county (p. 65), and probably by other secondary folds.

The rocks that crop out in Dickson County range in age from Upper Cretaceous to the Chattanooga shale (Mississippian or Upper Devonian). The youngest stratigraphic unit is the Tuscaloosa formation, a coastal-plain gravel deposit that covers several square miles of the Highland Rim plateau in the vicinity of Tennessee City. The massive subcrystalline limestones of the St. Louis limestone and Warsaw formation underlie the surface throughout the western half of the county and cap the interstream tracts as far eastward as the county boundary. These rocks do not appear at the surface on any of the remnants of the Highland Rim plateau, however, being covered by a mantle of cherty residual clay soil as much as 80 feet thick. The thin-bedded earthy and cherty limestone of the Fort Payne formation, which underlies the Warsaw formation, forms the lower slopes of the valleys throughout the eastern half of the county. The underlying Chattanooga shale is known to crop out in only two small areas near the eastern boundary of the county, one in the bed of Jones Creek Valley about 4 miles above its mouth and the other in Turnbull Creek Valley between Beaverdam and Nails Creeks. The lithology and stratigraphy of these rocks has been discussed on pages 31–41; their distribution is shown on Plate 4.

GROUND-WATER CONDITIONS

As is generally true in an area underlain by limestone, the ground-water conditions in Dickson County vary considerably from place to place and for the most part are not related to the stratigraphy. Rather, the ability of a stratum to transmit water is dependent upon the number and size of solution channels and hence is indirectly dependent upon the solubility of the limestone, the number and persistence of joints, and the position of the stratum with respect to past and present equilibrium profiles of solution channeling. If, as in Dickson County, the strata do not differ materially in solubility, the water-bearing properties of the rocks are determined by factors that are largely independent of stratigraphy and are relatively constant for a given physiographic district. (See pp. 78–82.)

Dug and drilled wells in the residual clay that overlies the limestone on the Highland Rim plateau generally obtain sufficient water for the needs of a single household from coarse chert débris, especially just above the underlying rock. In some places, however, the residual material is not water bearing or its permeability is so slight that the wells are inadequate during long dry periods. The depth of wells in this material ranges from 25 to 80 feet or more. Drilled wells that pass through the residual soil find water in channeled zones either in the uppermost part of the limestone or at greater depth. Such wells are generally less than 200 feet deep. Many of the dwellings on these plateau tracts derive their water from rain catches and cisterns.

In the mature and youthful terrane at lower altitudes than the Highland Rim plateau channeled zones in the limestone are not likely to be persistent at any one level or depth below the surface; hence ground-water conditions are exceedingly erratic, and drilling for water is very uncertain. In general, however, wells must be drilled somewhat below the level of the near-by perennial drains in order to assure an adequate water supply. On the other hand, the likelihood of entering a water-bearing channeled zone seems to become materially less as a well is drilled much more than 75 feet below the perennial surface streams. In these comparatively rugged sections of the county springs are a relatively important source of water, especially the perennial tubular springs, which drain large volumes of channeled limestone. (See pp. 92–95.) The discharge of such a spring may vary widely during the year, however, so that its reliability can be determined only by periodic measurements of discharge over a period of several years.

In the southern and eastern parts of the county several relatively deep wells have encountered a water-bearing stratum just above the Chattanooga shale, possibly in the lower part of the Fort Payne formation. Among the wells that have tapped this stratum are Nos. 194, 206, 216, 220, and 226 (pp. 144–146), of which Nos. 206 and 220 overflow at the surface by artesian pressure. However, the static level of the water confined in this bed is about 700 to 725 feet above sea level, so that the area within which flowing wells may be expected is not extensive and is limited to parts of the lower reaches of Turnbull and Jones Creeks. The specific capacity of wells that tap this stratum is relatively small, that of well 226, for example, being about 0.4 gallon a minute for each foot of drawdown. This water-bearing stratum seems to be discontinuous, for it was not found in wells 193, 205, and 222, and a permeable bed is not known farther east where the strata at this horizon crop out in Cheatham County. Hence, the reliability of this stratum as a source of water throughout the region is limited. The chemical analysis of a sample from well 220 (pp. 114–115) shows that the water from this stratum, although rather hard, is not highly concentrated and is essentially free from sodium chloride (common salt).

A few wells have been drilled into the beds that underlie the Chattanooga shale in Dickson County, such as Nos. 194, 205, 207, 209, and 222. Of these, well 222 reaches the lowest stratigraphic horizon, about 1,260 feet below the Chattanooga shale. All such wells find these beds to be dry or to contain relatively small amounts of highly concentrated brine, as in well 194. Hence, deep drilling for water is not likely to be successful in this area.

The chemical character of the ground waters of Dickson County is shown by the representative analyses tabulated on pages 112–115. It is noteworthy that the waters associated with the Fort Payne formation have a wide range in chemical composition, even in adjacent wells that reach approximately the same stratigraphic horizon, such as Nos. 190 and 191. Of these two wells, No. 190 yields a moderately hard calcium bicarbonate water containing 222 parts per million of dissolved mineral matter, whereas No. 191 yields a calcium sulphate water which is so hard and so highly concentrated as to be unfit for ordinary uses.

MUNICIPAL GROUND-WATER SUPPLIES

Dickson.—The municipal water supply of Dickson, the largest town of the county, is derived from two springs near the head of the East Fork of the Piney River. The collecting and distributing works are the property of the town. The upper spring, which is known as Payne Spring No. 1 (No. 224, p. 147), is about a mile northwest of the town and constitutes the perennial head of the East Fork. It is a seepage spring supplied by underflow in chert gravel and sand, and its catchment area comprises about 185 acres of timbered land and 15 acres of tilled ground. The improved orifice is a concrete-walled pit about 20 by 25 feet in plan, sunk to the water-bearing gravel and roofed over. The yield varies with the seasons, but the estimated minimum is about 50 gallons a minute. This spring, about 765 feet above sea level, discharges by gravity into a 404,000-gallon reservoir about 20 feet lower. The second spring, known as Baker Cave Spring (No. 225), is a tubular spring that issues from limestone in the west bank of the East Fork about 300 yards south of the Centerville and Dickson pike and about a mile southwest of Dickson. The orifice is about 700 feet above sea level. The maximum and minimum discharge of the spring are not known, although it is reported that the minimum yield exceeds the present draft, which is approximately 85 gallons a minute. The water from this spring is raised to the reservoir by a 3-stage centrifugal pump having a rated capacity of 250 gallons a minute. From the reservoir the water is pumped directly into the distributing mains by high-pressure pumps, including one single-stage centrifugal pump with a capacity of 300 gallons a minute, a similar pump with a capacity of 600 gallons a minute, and a 2-stage centrifugal fire pump with a capacity of 750 gallons a minute. All the pumps are operated by electric motors. The chemical character of the water from Baker Cave Spring is shown by analysis 225 (pp. 114–115). The approximate temperature of the water is 56° F.

Typical wells in Dickson County, Tenn.

[All drilled wells]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
189	Slayden, 3½ miles NW	Mrs. Ada Burrell	Ridge crest	695	192	6	65
190	Stayton, 2¾ miles N	J. M. Freeman	Hillside	470	65	5	15
191	Stayton, 3 miles N	J. L. Tilley	do	455	40±	6	20
192	Stayton, 2 miles NW	Samuel Hartley	Valley	475	29	6	6
196	Cumberland Furnace, ¾ mile S	M. M. Brown	Hillside	530	125	5⅝	
197	do	Floyd Brown	do	530	60	5	20
198-A	Vanleer, 5 miles W	W. R. Berry	Valley	550	65	5⅝	35
198-B	do	do	do	550	32	5⅝	
199	Vanleer, 6½ miles SW	Jerry Nesbit	do	515	39	5	21
200	Charlotte, 2½ miles NW	A. L. Miller	Hillside	675	150±	5⅝	65
201	Charlotte, 2¾ miles N	J. W. Edmundson	Ridge crest	810	80	5	72
202	Charlotte, ½ mile SW	W. A. Nicks	Valley	645	27	5	11
205	Charlotte, 5 miles E	Mrs. J. A. Gilliam	do	525	1,060		
206	Charlotte, 5¼ miles E	S. V. Pack	do	495	636	10	
207	White Bluff, 7½ miles N	Will Williams	do	560	1,001		
208	White Bluff, 5¼ miles N	R. Messier	Plateau	800	198	5⅝	91
209	Charlotte, 4¾ miles SE	Dickson County Farm	Valley	550	1,000±	8¼	
210	White Bluff, 3¾ miles N	Elmer Cox	Plateau	800	91	5⅝	38
212	Tennessee City	Nashville, Chattanooga & St. Louis Ry.	do	810	145	6	83
214	Dickson, 3¼ miles NE	James Purdue	Hillside	770	150±	5⅝	
215	Dickson 1¾ miles N	Martin Butterey	do	745	50	5	38
216	White Bluff, 1½ miles NW	W. M. Adcock	Valley	715	535		
218	White Bluff, ½ mile W	Jesse Gill	Plateau	805	75	5⅝	60
219	White Bluff	Nashville, Chattanooga & St. Louis Ry.	Hillside	810	61	4	52
220	White Bluff, ½ mile S	White Bluffs Canning Co.	do	725	1,383	8¼	
221	White Bluff, 2¼ miles NE	Howard Jensen	Valley	580	165	5	60
222	White Bluff, 2½ miles NE	Henry and Elijah Taylor	do	570	1,378		
223	Dickson, 5 miles SW	Eno School	do	645	50	5	20
226	Dickson, 1 mile NW	City of Dickson	Plateau	745	600	8	45
228	Dickson, ½ mile E	Crowell heirs	Hilltop	800	216	5⅝	62
229	Dickson	Dickson Ice Co.	Plateau	775	427	5⅝	70±
230	Dickson, ½ mile E	Nashville, Chattanooga & St. Louis Ry.	do	790	115	8	80
232	Burns, ¼ mile S	Burns Motor Co.	do	790	206	5⅝	60
233	Burns, 1¾ miles E	Moody Johnson	do	790	91	5⅝	41
234	Burns, 3¾ miles SW	J. T. Lewis	Ridge crest	825	80	4	72
235	Dickson, 6¼ miles S	Albert Dudley	Valley	680	50	6¼	
236	Burns, 4 miles SW	W. O. Hake	Plateau	870	85	5⅝	50
237	Burns, 8½ miles SE	H. L. Lamply	Ridge crest	750	87	5⅝	35

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remarks
	Depth below surface (feet)	Character of material	Geologic horizon						
189	Near bottom.	Limestone	Fort Payne (?) formation.		Bucket and windlass			Domestic	
[a] 190	60	do	Fort Payne formation.	−40	Hand pump	1		do	
[a] 191	38	do	do	−20	do	Small	58		Too concentrated for domestic use.
192	29	Solution crevice	Fort Payne (?) formation.	−1½	Bucket and rope			Domestic	
196	Near bottom.	Limestone	Fort Payne formation.		Hand pump	3		do	Residual clay 80 feet thick.
197	55	do	St. Louis (?) limestone.	−25	do	1½		do	Residual clay 20 feet thick.
[a] 198–A	65	Shaly limestone	Fort Payne (?) formation.	+0.5	Artesian flow	⅛	59	Drinking	Water-bearing bed at depth of 30 feet cased off.
[a] 198–B	30±		St. Louis or Warsaw limestone.	−12	Bucket and rope		58		2 feet from No. 198–A.
199	21		Base of chert residuum above St. Louis limestone.	−21	Hand pump	2–3		Domestic	Barely adequate in summer.
200		Limestone	St. Louis (?) limestone.		Gasoline force pump	12		Stock	
201	70		Chert residuum above St. Louis limestone.	−65	Bucket and rope	3½		Domestic	Residual clay 70 feet thick.
202	18	Limestone	St. Louis or Warsaw limestone.	−10	do	½		do	
205						None		None	Dry hole. Top of Chattanooga shale 75 feet below casing head.
206	75±		Top of Chattanooga shale.	+0.3	Artesian flow	Trickle		do	
207						None		do	Dry hole. Top of Chattanooga shale about 10 feet below casing head.
208	175	Limestone	Fort Payne formation.	−168	Gasoline force pump			Domestic, stock	
209	30	do	do					None	No water-bearing beds below depth of 50 feet. Top of Chattanooga shale 156 feet below casing head.
210	75	Bedding-plane crevice.	St. Louis or Warsaw limestone.	−60	Bucket and windlass			Domestic	
212	135	Solution channel	do	−65	Hand pump	3–5		do	At Tennessee City section houses.
214	Near bottom.	Bedding-plane crevice.	do		do			do	

[a] See analysis, pp. 112–115.

Typical wells in Dickson County, Tenn.—Continued

[All drilled wells]

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remarks
215	42	Limestone	do	−25	Bucket and rope	10±		do	Residual clay 37 feet thick; some water at base.
216	225		Top of Chattanooga shale.	At casing head.				None	No water-bearing beds below Chattanooga shale.
[a] 218	Near bottom.	Bedding-plane crevice.	St. Louis or Warsaw limestone.	−15	Bucket and rope		61	Domestic	
[a] 219	58	Bedding-plane crevice (?)	do	−45	Hand pump	3	58	Drinking	Public well at White Bluff station.
[a] 220	246		Top of Chattanooga shale.	+2±	Artesian flow	5–8	58	do	Dry crevices in limestone above Chattanooga shale; no water-bearing beds below.
221	125	Bedding-plane crevice.	Fort Payne (?) formation.	−60	Bucket and rope	1/30		None	Well abandoned as inadequate. Residual clay 60 feet thick.
222	1,373	Limestone						do	Salt water. No other water-bearing beds except at shallow depths.
223	20		Residual chert above St. Louis or Warsaw limestone.	−20	Hand pump	4	57	Drinking	Residual clay 20 feet thick.
226	400		Top of Chattanooga shale.	−35	Steam force pump	75		None	Former municipal supply. Drawdown reported 200 feet while pumping 75 gallons a minute.
228	81	Bedding-plane crevice.	St. Louis or Warsaw limestone.	−75	Force pump	½		Domestic, stock	Residual clay 60 feet thick.
[a] 229	75±	Limestone	do		Steam force pump	25	58	Boiler feed	Pumped steadily at about 25 gallons a minute in summer. No water-bearing beds below 100 feet.
230	110	Solution channel	do	−50	Hand pump			Domestic	At Dickson section houses.
232	200	Limestone	Fort Payne (?) formation.	−80	Automatic electric pump.	½		Garage	Water-bearing bed at depth of 65 feet yielded about 1 gallon an hour.
233	71	Bedding-plane crevice.	St. Louis or Warsaw limestone.	−40				Domestic	
234	76	do	do	−65	Bucket and rope	8		do	
235	50	Limestone	do	−5	Hand pump	1/20		Domestic, stock	
236	65	Solution channel	do	−40	Automatic electric pump.			Domestic	Residual clay 50 feet thick; some water at base.
237	Near bottom.	Limestone	do		Hand pump			do	

[a] See analysis, pp. 114–115.

Typical springs in Dickson County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
188	Slayden, 3½ miles NW	Edgar Organ	Cave Spring	Valley	510	St. Louis or Warsaw limestone.
195	Cumberland Furnace, 1 mile SW	Warner Iron Co.	Pond Spring	do	500	Do.
203	Charlotte, 2 miles E	Joseph McMillan	McMillan Spring	do	550	Base of St. Louis limestone.
204	Charlotte, 1¾ miles SE	W. W. Larkins		do	615	St. Louis limestone.
211	Ruskin, ¼ mile W	Gladys Dick	Ruskin Cave	do	540	Do.
213	Dickson, 4 miles N	Boker heirs	Schmitto Spring	do	685	St. Louis or Warsaw limestone.
217	White Bluff, 1 mile N	William Adler	Buck Spring	do	725	Do.
224	Dickson, 1 mile NW	City of Dickson	Payne Spring No. 1	do	765	Residuum from St. Louis limestone.
225	Dickson, 1¼ miles SW	do	Baker Cave Spring	do	700	St. Louis or Warsaw limestone.
227	Dickson, ¾ mile NE	Nashville, Chattanooga & St. Louis Ry.	McFarland Spring	do	720	Do.
231	Burns, 1½ miles SW	do		do	745	Alluvium.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (°F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
188	1	Bedding-plane solution channel.	75±	Sept. 6	Seasonal	Domestic, stock	55	
195	1	Submerged	100±	Sept. 2	Probably seasonal	None		Former supply for blast furnace.
203	1	Bedding-plane channel	35±	Sept. 1	Seasonal	Domestic, stock	64	Outlet channel cress-grown; estimate of flow inaccurate; minimum flow reported about 25 gallons a minute.
204	1	Large solution channel	40-50	do	do	do	57	Yield increases and water becomes very turbid after rain.
211	1	do	400	Aug. 31	do	Drinking		Yield increases 2 to 3 days after heavy rains to the southwest.
213	1	Bedding-plane channel	25+	Sept. 2	do	Stock	57	Perennial spring.
217	1	do	5	Sept. 1	do	Domestic, stock	59	Do.
224	1	Underflow conduit	50±	Aug. 29	do	Municipal	56	
[a] 225	1	Solution channel	95	do		do	58	Large seasonal fluctuation in yield; minimum yield reported about 90 gallons a minute.
227	1	do			Seasonal	Railroad		Pumped 150 gallons a minute about 10 hours daily.
231	1	Underflow conduit	5	Aug. 29	do	None	60	Formerly pumped to Colesburg water station.

[a] See analysis, pp. 114-115.

Driller's partial log of Cumberland Furnace well No. 1, on Mrs. Emma Wall's property

[No. 193, pl. 4. Well drilled by Tuxbury Oil Co. in April, 1919. Diameter at top, 10 inches; at bottom, 6½ inches. Total depth, 1,142 feet; no water-bearing beds below 320 feet]

	Feet
Cherty residual soil	0–52
Limestone, white, large yield of water at 150 feet	52–162
Sandstone, gray, medium hard, water bearing; static level of water 125 feet below casing head	315–320
Shale, black (Chattanooga shale)	445–522

Driller's partial log of Cumberland Furnace well No. 2, on Mr. Stark's property

[No. 194, pl. 4. Well drilled in December, 1919. Diameter at top, 12½ inches; bottom, at 6¼ inches. Total depth, 1,166 feet]

	Feet
Cherty residual soil	0–11
Limestone, bluish gray; casing set at bottom to shut out water	11–131
Limestone and shale, water bearing	278–285
Shale, black (Chattanooga shale)	300–342
Shale, brown	342–369
Sandstone (?), fine grained, white, contains salt water	525–554

Driller's partial log of Henry and Elijah Taylor's well

[No. 222, pl. 4. Well drilled by Tennessee Central Oil Co. in 1920. Diameter at bottom, 5⅝ inches; total depth, 1,378 feet; approximate altitude of casing head, 570 feet above sea level]

	Feet
Soil	0–10
Limestone, gray, cherty	10–109
Shale, black (Chattanooga shale)	109–114
Limestone, pink	114–264
Limestone, bluish gray	264–315
Limestone and shale, gray	315–440
Shale, gray	440–490
Limestone, sandy, dense	490–547
Limestone, hard	547–563
Limestone	563–700
Shale, gray	700–750
Limestone, hard, brown to gray	750–925
Limestone, cherty	925–953
Limestone, dark olive-green; contains salt water	1, 373–1, 378

HOUSTON COUNTY

[Area, 197 square miles. Population, 5,555]

GENERAL FEATURES

Houston County is a rather sparsely settled rural area that lies in the west-central part of the region described in this report. (See pl. 1, p. 24.) Its county seat, Erin (population 819), is on the Louisville & Nashville Railroad near the west edge of the Wells Creek Valley.

Houston County is a part of the Highland Rim plateau (pp. 16–18), although its surface has been so intricately and so deeply dissected by tributaries of the Cumberland and Tennessee Rivers as to bear little superficial relation to a plain. The flat summit tracts of the divide between the two rivers, however, are remnants of the plateau, about 775 to 800 feet above sea level. By far the greater part of the county lies below the plateau level, having been eroded to a submature stage in the Nashville Basin cycle (pp. 20–22) and subsequently trenched by youthful streams imperfectly adjusted to the present stage of the master streams. The total relief is about 475 feet.

The consolidated rocks of Houston County include only the upper part of the Mississippian series (pp. 33–39). The interstream remnants of the Highland Rim plateau and most of the lower country in the eastern half of the county are cut from the massive limestone beds of the St. Louis limestone and Warsaw formation. The underlying Fort Payne formation, which in this county is made up of dense thin-bedded, extremely cherty limestone, crops out in the lower half of the Wells Creek Basin and forms the valley slopes of Whiteoak, Cane, and Hurricane Creeks, in the western half of the county. The Tennessee River has cut approximately to the horizon of the Chattanooga shale along the western boundary of the county, but neither the shale nor any of the underlying limestones are known to crop out in that area. On the remnants of the Highland Rim plateau the consolidated rocks are overlain by a mantle of cherty residual clay and soil, which at Tennessee Ridge has been penetrated to a depth of 112 feet by a drilled well. Along the Tennessee River the consolidated rocks are overlain by clay, sand, and gravel deposited by the stream.

GROUND-WATER CONDITIONS

In Houston County, as in many other parts of the Highland Rim plateau in north-central Tennessee, most domestic water supplies are obtained from dug wells and cisterns in the unconsolidated rocks or from springs. The dug wells in the cherty clay of the plateau are generally about 20 or 25 feet deep but range from 15 to 50 feet. Many of these wells are inadequate during periods of drought, so that rain water is stored in cisterns as a supplemental or major part of the supply. A few drilled wells on the plateau tracts find water in beds of coarse chert débris just above the limestone or in channeled zones just below the top of the limestone. On the alluvial plains of the Tennessee River practically all water supplies are derived from dug wells that pass through a clay hardpan and tap beds of sand and gravel approximately at the level of the river.

Inasmuch as Houston County is so deeply dissected, the channeled zones of the limestone have probably been drained in many places, so that drilling for water is especially uncertain. In general the prospect of finding water is notably less in beds that lie very far below the level of the perennial streams, and it is unlikely that any water other than concentrated brines will be obtained at depths exceeding 300 feet.

Probably the most reliable sources of ground water in the county are the tubular springs that issue from solution channels of the limestone at many points in the lower parts of the area. The discharge of such a spring, however, is likely to vary widely from season to season and must be determined periodically over a term of several years to establish the minimum discharge and probable safe draft. Moreover, all such springs are liable to permanent or intermittent pollution by organic waste (pp. 108–109), so that the water should be adequately sterilized if it is to be used for municipal supply.

The conditions under which ground water occurs in limestone are discussed on pages 69–89. Typical wells and springs of Houston County are described by the tabulated data on pages 151–152. The chemical character of the ground water from certain of these typical wells and springs is shown by the analyses on pages 112–113.

MUNICIPAL GROUND-WATER SUPPLIES

Erin.—The one community ground-water supply in Houston County is that at Erin, which supplies about 50 residences and a 10-ton artificial-ice plant from a tubular spring in the St. Louis limestone (No. 143, p. 152) at the west edge of the town. The water from this spring is raised to a small reservoir on a hilltop north of the town and distributed by gravity. The spring and distribution system are owned and operated by A. J. Mitchum, of Erin. The minimum discharge of the spring is less than 10 gallons a minute, so that the capacity of the system is correspondingly small, although adequate for the present demand. A reserve capacity several times that of the present system is afforded by other springs of the vicinity.

Typical wells in Houston County, Tenn.

[No. 139 dug and drilled; others drilled]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
139	Stewart	Louisville & Nashville R. R.	Valley	493	57	4	30
140	Tennessee Ridge, ½ mile S.	Tennessee Ridge School	Plateau	730	112	4	112
144	Erin, ¾ mile SW.	A. B. Bell	Valley	425	1,001	8	
145	Erin, 4 miles E.	Garner Harris	do	515	565		
149	Erin, 6½ miles SW.	Steve Batson	Hillside	610	160(?)	6	
151	Erin, 9¼ miles SE.	Yellow Creek High School	Valley	525	64	6	
153	Erin, 10¼ miles SE.	J. H. Stokes	do	500	93	6	6

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remarks
139	Near bottom.	Limestone	St. Louis (?) limestone.	−30	Hand pump	3	60	Drinking	Public well at Stewart station. Dug well 6 feet in diameter and 30 feet deep to top of rock, with drilled hole 4 inches in diameter drilled to total depth, 57 feet. Fails in extreme drought.
140	do		Cherty residuum above St. Louis limestone.		do	3–5	58	do	Other supplies of community are obtained from cisterns and dug wells about 20 feet deep.
144	177	Solution crevice	Fort Payne formation.	−20	None			None	Test well by Erin Oil & Gas Co. Small yield of water at depth of 14 feet; no water-bearing beds below depth of 177 feet.
145	300±		do		do			do	Sulphur water. Top of Chattanooga shale at depth of 370 feet.
[a] 149		Limestone	do		Hand pump	3	57	Domestic, stock	
[a] 151	48	Bedding-plane crevice.	Fort Payne (?) formation.		do	3–5	58	Drinking	
153	23	do	Fort Payne formation.	−20	Bucket and windlass		62	Domestic	No water-bearing beds below depth of 23 feet.

[a] See analysis, pp. 112–113.

Typical springs in Houston County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
138	Stewart, 1 mile W	Largent Bros.		Valley	460	St. Louis or Warsaw limestone.
141	Tennessee Ridge, 1¼ miles S.	Theodore Bass		do	530	Do.
143	Erin, ¾ mile W	A. J. Mitchum		Hillside	455	St. Louis limestone.
146	McKinnon, 4¾ miles SE	W. J. Ederd	McAskill Spring	Valley	415	Fort Payne formation.
147	Stewart, 5¾ miles S.	R. E. Crosswell		do	450	Do.
148	Tennessee Ridge, 5¼ miles S.	Dewey Petty		do	515	Do.
150	Erin, 5 miles SE	A. W. Averitt		Valley head	555	St. Louis or Warsaw limestone.
152	Slayden, 7 miles SW	W. M. Adkins		Valley	495	Fort Payne (?) formation.

No. on Plate 4	Openings: Number	Openings: Character	Approximate yield: Gallons a minute	Approximate yield: Date of measurement (1927)	Variability	Use	Temperature (°F.)	Remarks
[a] 138	1	Bedding-plane solution channel.	625	Sept. 19	Seasonal	Domestic, stock	56	
141	4	Bedding-plane and joint channels.	100±	do	do	do	56	Main orifice yielded 50 gallons a minute Sept. 19, 1927.
[a] 143	1	Bedding-plane solution channel.	Less than 10.	do	do	Municipal	57	Perennial spring. Spring from same stratum at Southland Lime Co.'s quarry, ½ mile west, yields 100 gallons a minute.
146	Several.	Bedding-plane channels	50	Sept. 18	do	Domestic, stock	58	Westernmost perennial spring in Whiteoak Creek Valley.
147	1	Concealed; probably joint channel.	45	do	do	do	56	
148	1	Bedding-plane solution channel.	10	do	do	Domestic	56	Perennial spring.
150	1	Concealed	120	Sept. 19	do	Domestic, stock	56	Perennial head of Wells Creek.
152	Several.	Concealed by alluvium	125	do	do	do	58	

[a] See analysis, pp. 112–113.

HUMPHREYS COUNTY

[Area, 451 square miles. Population, 12,039]

GENERAL FEATURES

Humphreys County, which adjoins Houston County on the south, occupies the southwest corner of the region covered by this report (pl. 1) and embraces the greater part of the most sparsely populated area in north-central Tennessee. Waverly and McEwen, with populations of 1,152 and 620, respectively, are its two largest towns; Waverly is also the seat of the county government.

Humphreys County lies wholly within the Highland Rim plateau (pp. 16–18), and extensive tracts along the divide between the Tennessee and Cumberland Rivers in its eastern part present the gently undulating plain characteristic of that physiographic feature. In this part of the county the plain attains a maximum altitude of about 825 feet above sea level. Toward the west, however, the interstream tracts that represent portions of the once continuous plateau become somewhat lower and are about 675 to 725 feet above sea level near the Tennessee River. The western part of the county is deeply and intricately dissected by the Tennessee and Duck Rivers and their subparallel tributaries, which head in mature valleys correlative with the Nashville Basin peneplain and in their lower reaches occupy youthful trenches imperfectly adjusted to the present stage of stream erosion. The relief in this part of the county is of the order of 400 feet.

The consolidated rocks exposed in Humphreys County are of Mississippian, Devonian, and possibly Silurian age and in general dip nearly westward about 10 to 15 feet to the mile. The youngest or uppermost of these rocks are the massive subcrystalline beds of the St. Louis limestone and Warsaw formation, which cap all the interstream plateau tracts. The underlying Fort Payne formation comprises in this county thin beds of dense and extremely cherty limestone; it forms the valley slopes of the larger streams and of the lower reaches of the tributaries. Neither the New Providence shale nor the Ridgetop shale, which appear in the complete stratigraphic section (pp. 26–29), is known to be present within the county, and the Fort Payne formation rests directly upon the Chattanooga shale. Although the Tennessee, Duck, and Buffalo Rivers have cut down to the approximate horizon of the Chattanooga shale throughout the county, it is known to crop out only in a few small separated areas. It is possible, however, that this shale crops out much more extensively in the county than these discontinuous areas indicate. The Pegram limestone, of upper Middle Devonian age, is not known in Humphreys County, but the underlying Camden chert, also of Middle Devonian age, crops out directly beneath the Chattanooga shale at the "whirl" on the Buffalo River and probably also at Hurricane Rock Spring, on the Duck River (No. 181, pp. 161–162). It is likely that this formation also crops out at other places along the lower reaches of the Duck and Buffalo Rivers, but the limits of its outcrop have not been traced in detail. Some of the limestone that underlies the Chattanooga shale in this same area resembles beds of Silurian age in Davidson County, but its exact position in the stratigraphic section is not known. These formations are described on pages 33–45; their areal distribution is shown on Plate 4.

The youngest unconsolidated rocks of the county are the clay, sand, and gravel that form the present flood plains of the major streams—plains which are nearly continuous and locally extensive along the Tennessee River and the lower reaches of its tributary, the Duck River. Similar stream deposits also form extensive terraces above the flood plains on the east bank of the Tennessee River and locally along the Duck and Buffalo Rivers on the convex banks of meanders. The oldest of the unconsolidated rocks is the Tuscaloosa formation, an earthy gravel deposit of coastal-plain origin, of which an erosion remnant covers a relatively extensive area along the divide between the Cumberland and Tennessee Rivers in the eastern part of the county. These unconsolidated deposits are described on pages 30–33, and the more extensive areas covered by them are shown on Plate 4.

GROUND-WATER CONDITIONS

In Humphreys County, as in other parts of north-central Tennessee, the water-bearing properties of any particular limestone bed are not related to its stratigraphic position alone but rather are dependent upon its solubility, the number and persistence of joints and the position of the bed with relation to present and past equilibrium profiles of solution channeling (pp. 78–82). Hence, the ground-water conditions in any stratum are likely to vary greatly from place to place but may be relatively uniform in any one physiographic district. None of the field relations suggest that there exists in Humphreys County any large body of limestone that has been depressed with relation to the water table after it had been rendered permeable by channeling. Hence the principal channeled zones generally do not contain water under hydrostatic pressure, and their water-yielding capacity is correspondingly limited.

In the present stage of economic development in Humphreys County most of the water used for domestic purposes is derived from dug wells or springs. On the high interstream tracts the wells range in depth from 12 to 65 feet and derive their supply from cherty zones in the residual clay and soil that overlie the limestone or from beds of sand and gravel in the Tuscaloosa formation. In some places an adequate supply can not be obtained without digging to great depth, and elsewhere the dug wells prove inadequate in periods of drought. In these localities cisterns for the storage of rain water are the usual source of domestic supply. A few wells have been drilled through the residual chert and find water at the top of the solid rock or in channeled limestone just below. The maximum draft upon any of these wells, however, has been only about 20 gallons a minute. Several wells in the vicinity of McEwen—Nos. 163, 164, 165 and 166 (pp. 159-160)—are reported to pass through 200 to 230 feet of unconsolidated gravel or residual chert before reaching solid rock. This unconsolidated material is water-bearing in well 164 and may yield some water to wells 163, 165, and 166. It is not known whether the water-bearing beds are gravel that belongs to the Tuscaloosa formation (see pp. 31–33) or whether they are composed of residual chert.

In the more rugged parts of the county most domestic water supplies are derived from springs, although some are derived from dug wells and a few from drilled wells. In these areas, however, the water-bearing zones in the limestone are likely to be extremely discontinuous so that drilling for water is uncertain. To judge from the experience in other counties, drilling may be unsuccessful if water is not found within 50 or 75 feet below near-by perennial streams. Tubular springs of relatively large discharge are numerous and constitute an adequate water supply to meet the probable future needs of most of these rugged areas. Tubular springs (pp. 92–95) are especially numerous in the southwestern part of the county, in the vicinity of the confluence of Tennessee, Duck, and Buffalo Rivers, where the limestone has been channeled by subsurface drains adjusted to the surface streams. Some of the subsurface channels cut across stream meanders or join converging surface streams above the point of confluence. Such channels have been formed during several stages of the dissection of the Highland Rim plateau. The largest of the tubular springs in this part of the county, and the largest spring known to exist in the region covered by this report, is Hurricane Rock Spring (No. 181, pl. 4 and p. 161). This spring is on the east bank of the Duck River about half a mile upstream from the mouth of Beech Creek and 4 miles from the Tennessee River. It issues from a single solution conduit about 15 feet wide and 5 feet high in the Camden chert. The conduit is adjusted to the present stage of the Duck River, and its orifice is submerged during periods of high water. When observed by the writer, on September 9, 1927, the discharge of the spring was about 60 cubic feet a second (27,000 gallons a minute), and the water was essentially free from suspended matter and had a temperature of 62 °F. This discharge presumably is approximately the seasonal minimum, although the maximum discharge and the variability of the spring over a long period are not known. The source of the spring is generally ascribed locally to the "whirl," a persistent and strong eddy in the

Buffalo River about 2 miles upstream from the confluence of the Buffalo and Duck Rivers and about 4 miles S. 60° E. from the spring. The only adequate source for the large amount of water flowing from the spring during the period of minimum ground-water discharge is the Duck River or the Buffalo River from some point or points upstream from the orifice of the spring. However, the water can not flow directly from the intake area to the orifice, for although both the Buffalo and Duck Rivers were extremely turbid when observed by the writer, the effluent from the spring was clear, even though its velocity at the orifice was much greater than that of the surface streams. Hence the system of solution channels intervening between intake and orifice must store enough water to permit all the suspended matter to settle, even though the average gradient of the channels is presumably at least as steep as the gradient of the surface streams. Consequently, the zone of cavernous limestone drained by the spring must be relatively extensive, and the "whirl" may be only one of several points at which water enters the zone.

Other typical springs and wells of Humphreys County are described by the tabulated data on pages 159–163, and the chemical character of the ground water is represented by the analyses given on pages 112–113.

MUNICIPAL GROUND-WATER SUPPLIES

Waverly.—The town of Waverly derives its municipal water supply from a drilled well (No. 167), owned by the Nashville, Chattanooga & St. Louis Railway and leased to the Tennessee Utilities Co., of Waverly. The well, which is 8 inches in diameter and 32 feet deep, is on the north bank of Trace Creek and obtains its water from the weathered and channeled St. Louis limestone approximately at the level of the creek. The chemical character of the water is shown by analysis 167 (pp. 112–113). The well is equipped with two electrically driven pumps, each of which has a capacity of 50 gallons a minute, which raise the water to an 18,000-gallon wood-stave pressure tank about 125 feet above the well on a hilltop a quarter of a mile south of the town. The water is sterilized with chlorine as it passes through the pumps. The distribution system embraces about 2½ miles of mains ranging from 1 to 2½ inches in diameter and supplies water by gravity at a maximum pressure of 80 pounds to the square inch. The draft on the system generally ranges from 40,000 to 45,000 gallons a day, a quantity which probably approaches the ultimate capacity of the well during periods of minimum ground-water discharge. Hence some additional source of water will be essential if the demand is increased by future growth of the community.

Several possible sources of ground water to supplement the present supply of Waverly exist; these are (1) drilled wells in the limestone in the vicinity of Waverly; (2) a well or wells in the gravel fill of Trace Creek Valley east of Waverly; (3) springs on Claxton branch of Blue Creek, 2 miles south of Waverly; (4) springs on Mathews branch of Blue Creek, 2 miles southwest of Waverly; (5) Carnell Spring, on Little Richland Creek, 2½ miles north of Waverly.

Drilling wells in the limestone in the vicinity of Waverly is at best uncertain of success, for in view of the conditions of ground-water occurrence in limestone (pp. 69–89) it is impossible to predict the depth or water-yielding capacity of water-bearing beds. Although the cherty débris just above the unweathered limestone generally yields ample water for individual dwellings, it is very likely to prove inadequate as a source of municipal supply throughout the year. A well 300 feet deep drilled some years ago near the pressure tank on the hilltop south of Waverly failed to find a water-bearing bed adequate for the demand of the town and has been abandoned. No deeply buried water-bearing stratum is known to underlie the vicinity. The chief advantages of drilled wells in the limestone would be that the capacity of the source would presumably not show large seasonal variations and that the wells could be located in or near the town, with a consequent saving in capital expenditure for pipe lines. The chief disadvantages would be that the uncertainty of developing wells of adequate yield renders a comprehensive and costly program of exploratory drilling advisable before permanent construction and that a supply adequate for emergencies and for future expansion of the town may not be obtainable.

At Waverly, Trace Creek flows over a rock bed cut on limestone, but farther east its valley embraces a flat alluvial plain underlain by stream gravel. This material supplies several household wells from 11 to 25 feet deep, such as Nos. 168 and 170 (pp. 159–160), although none is known to have a capacity approaching the requirements of a municipal supply. The thickness of gravel that lies below the water table is unknown; moreover, much of the gravel is poorly sorted as to size and contains considerable sand and clay. Hence the permeability of the material is presumably relatively small and the size of the ground-water reservoir is unknown, although the total volume of water in the gravel may be considerable and a thorough test of this potential source is warranted. Test pits or wells should first be dug or drilled systematically over the chosen site to ascertain the depth to bedrock and the thickness of water-bearing gravel below the water table. Second if the gravel is found to be reasonably thick, its water-yielding capacity should be determined from a test well or wells at the point where the greatest thickness of water-bearing gravel exists. This test should be made when the water table is at a a low stage.

If the results of preliminary tests are satisfactory, one or more permanent wells should be excavated to bedrock by digging while using temporary lagging to support the walls of the hole or by sinking a temporary casing by well-drilling methods. It is essential that the well be sunk to bedrock in order that the largest possible yield may be obtained. A permanent casing should then be set axially in the well and extending from the surface to the bottom of the well, with that part of the casing which penetrates the water-bearing beds thoroughly perforated. This casing should be 12 inches or more in diameter; preferably it should be perforated in the shop before being placed in the well. The space between the permanent inner casing and the temporary outer casing should then be filled with well-rounded gravel that has been screened so that all the particles are more than a quarter of an inch but less than half an inch in diameter. As the gravel is inserted the outer temporary casing should be raised and the well pumped vigorously, so as to draw the fine sand from the surrounding stream gravel as completely as possible. The rate of pumping should be increased gradually, and pumping should be continued until the well attains its maximum yield and no more fine material can be drawn into the well. More screened gravel may be added in the space outside the perforated casing until a condition of stability is attained. By properly developing the well in this way an envelope of highly permeable clean gravel is created about the perforated casing, so that for a given draft the water enters the well with the least possible velocity and consequently with the minimum burden of entrained sand and silt. An air-lift pump is especially well suited to developing a well, inasmuch as its yield can be changed easily to suit the water-yielding capacity of the gravel. From the yield of the well determined in this way when the water table was at its lowest stage the number of wells necessary can be determined.

Claxton Branch of Blue Creek, which heads about 2 miles south of Waverly, is fed by a group of tubular springs that issue from earthy cherty limestone beds, probably in the Fort Payne formation. The largest of these springs (No. 175, pp. 161–162) was flowing about 20 gallons a minute on July 19, 1927, whereas the total flow of this spring-fed creek was about 100 gallons a minute just above its confluence with Blue Creek, about 2¾ miles south of the town. The seasonal variation of these springs is unknown. Although Claxton Branch is probably an adequate source for the present requirements of the town, it may prove inadequate for future requirements unless supplemented by the springs on Mathews Branch, about 2 miles southwest of Waverly. Mathews Branch of Blue Creek rises as a seepage spring (No. 174), issuing from coarse chert hill wash overlying the Fort Payne (?) formation. The catchment area tributary to the spring is about 200 acres, most of which is covered with hardwood timber. The discharge of the spring on July 19, 1927, was about 100 gallons a minute. The orifice was unimproved, and the seasonal variation in discharge is unknown. Periodic measurements of the discharge of both Claxton and Mathews Branches should be made, in order to determine their seasonal variation, before plans for their utilization are drawn. To develop these spring-fed streams it would be necessary to install suitable diversion works, pipe lines, and pumps to raise the water about 200 feet above the springs to the crest of the ridge south of Waverly. The cost of such a system would exceed that of a well field in the vicinity of the town, especially if neither stream were adequate of itself.

Carnell Spring (No. 62) is a tubular spring that issues from the St. Louis limestone in the south bank of Little Richland Creek about 2½ miles north of Waverly. The discharge from the main orifice on July 19, 1927, was about 1.5 cubic feet a second (675 gallons a minute, or 975,000 gallons a day); on September 18, when the ground-water discharge of the region was approximately at the minimum for the season, the spring discharge was about 1.1 cubic feet a second (500 gallons a minute, or 700,000 gallons a day). Several smaller openings in a zone extending 200 yards up the creek above the main orifice add considerably to the aggregate discharge. The discharge from the main orifice alone is probably adequate for any prospective requirement of the town, although periodic measurements of the discharge should be made over a term of several years to establish its variability. It is reported by Wade Work, owner of the spring, that when the creek is at its highest stage the main orifice is not submerged, although the water issuing from it is slightly turbid due to suspended matter. If Carnell Spring should be developed for municipal supply, suitable cut-off walls should be put down to bedrock about the orifice in order to prevent seepage of surface waste into the spring, and the orifice itself should be thoroughly cleaned and inclosed. A suitable pipe line and pumps for raising the water about 200 feet above the spring to the crest of the ridge north of Waverly should also be installed. Carnell Spring is half a mile farther from Waverly than the springs on Claxton and Mathews Branches of Blue Creek, but the heads against which water would have to be raised are approximately the same for these two potential sources. Hence, the development of Carnell Spring would be somewhat more costly than that of Claxton Branch or Mathews Branch alone but would be less costly than the development of both Claxton and Mathews Branches.

In any region underlain by limestone, such as the vicinity of Waverly, the ground waters may be polluted permanently or intermittently over extensive areas. Hence, in order that public health may be properly safeguarded, any ground water to be used for municipal supply should be sterilized by the application of chlorine or other adequate sterilizing agent. Chlorination would be required for each of the possible sources of supply for Waverly.

Typical wells in Humphreys County, Tenn.

[Nos. 168, 170, 183, 184, and 186 dug; the others drilled]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
155	Tennessee Ridge, 8¼ miles SE	G. D. Ridings	Valley	500	64	5⅝	18
163	McEwen	McEwen Canning Co.	Plateau	825	350	6	200
164	McEwen, ½ mile NE	McEwen School	do	840	217	8	195
165	McEwen, ½ mile SE	S. W. Taylor	do	810	303	5	167
166	MoEwen, 4 miles E	Nashville, Chattanooga & St Louis Ry.	do	820	232	5⅝	230
167	Waverly, 1 mile NE	do	Valley	545	32	8	32
168	Waverly	P. F. Gould	do	540	23½	24	23
169	Waverly, 1 mile NE	Anderson Coal & Ice Co.	do	540	175		115
170	Waverly, 1¾ miles E	Humphreys County High School	do	545	12½	24	12½
171	Johnsonville, ½ mile N	J. M. C. Young	River terrace	360	92	6	92
172	Waverly, 7 miles SW	M. W. Plant	Valley	370	650±		
178	Bold Springs, ¾ mile NE	B. Y. Rogers	do	545	54(?)	4	
183	Hurricane Mills, 2½ miles SE	Robert Rustin	Ridge crest		160(?)	48	160
184	Bakerville, 2½ miles NW	James Tubbs	Hillside	505	97	36	97
185	Sycamore Landing, 2½ miles NE	J. T. Anderson heirs	Valley	525	2,000	12	
186	Buffalo, 4¼ miles NE	T. O. Perkins	do	380	15	48	15
187	Buffalo, 2½ miles E	James Jones heirs	do	560	270	5⅝	230(?)

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
	Depth below surface (feet)	Character of material	Geologic horizon						
155	60	Limestone	Fort Payne formation.	−20	Hand pump	3-5	58	Domestic, stock	
163	200+	do	St. Louis or Warsaw limestone(?)	−50	Steam force pump	7½—10		Boiler feed, canning.	
[a] 164	80	Gravel or residual chert.	Tuscaloosa (?) formation.		Electric force pump	5	58	Drinking	Cherty residuum or coarse gravel to bottom of well; 80-foot water-bearing bed could not be cased off.

[a] See analysis, pp. 112-113.

Typical wells in Humphreys County, Tenn.—Continued

[Nos. 168, 170, 183, 184, and 186 dug; the others drilled]

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
165	303	Bedding-plane crevice.	St. Louis or Warsaw (?) formation.	−35	Air lift	15–20		Boiler feed	Well at Taylor's planing mill.
166		Gravel or residual chert.	Tuscaloosa (?) formation.	−40	Bucket and rope				Section houses at Fifty Four. Top of solid rock is 230 feet below surface.
[a] 167	Near bottom.	Weathered limestone.	St. Louis or Warsaw limestone.	−12	Electric suction pump	50	61	Municipal	Supply for city of Waverly. Consumption 40,000 to 45,000 gallons a day.
168	do	Chert gravel	Alluvium	−14	Hand pump or bucket	10		Domestic	Maximum draft has been 12 gallons a minute for 35-minute period.
169		Limestone	Fort Payne (?) formation.	−6	Electric suction pump	20±		Condensers	Capacity of pump 35 gallons a minute, exceeds ultimate capacity of well.
170	Bottom	Chert gravel	Alluvium	−9	Bucket and rope			Domestic	At janitor's residence, 200 yards east of school.
[a] 171	Near bottom.		Cherty residuum above Fort Payne formation.	−38	Bucket and windlass		57	do	Large capacity in all seasons. Most other supplies of community from dug wells.
172	400		Upper part of Ordovician system.		None			None	Abandoned oil test well.
178	Near bottom.	Limestone	St. Louis or Warsaw limestone.	−25	Hand pump	3–5	59	Domestic, stock	
183	do		Cherty residuum above Fort Payne formation.	−142	Buckets and pulley			do	
184	do		do	−90±				None	Formerly used for stock watering.
185	1,580	Sandstone (?)	St. Peter (?) sandstone.		None			do	Test well by Tennessee Central Oil Co. Salt water struck at depths of 1,580, 1,700, and 1,940 feet.
186	Near bottom.	Chert gravel	Alluvium		Hand pump	3–5	71	Domestic	
187	50±		Gravel residuum from Fort Payne formation.	−40±				None	Abandoned well at former sawmill. Residual clay and chert rubble extends to depth of 235 feet, or approximately to level of Tennessee River.

[a] See analysis, pp. 112–113.

Typical springs in Humphreys County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
154	Tennessee Ridge, 6¾ miles S	Alvin Daniel	Daniel Spring	Valley	545	St. Louis limestone.
156	Erin, 8 miles S	Bank of McEwen	Blowing Spring	do	505	Do.
157	Gorman, 7¾ miles N	E. Wanamaker		do	600	St. Louis or Warsaw limestone.
158	McEwen, 7¾ miles NW	J. R. Patterson		do	560	Do.
159	Waverly, 6¼ miles N	Milton Petty	Petty Spring	do	450	St. Louis limestone.
160	Gorman, 3¼ miles NE	Philip Bradley	Brown's Mill Spring	do		St. Louis or Warsaw limestone.
161	Denver, 1½ miles N	Luther Haygood	Critchlow Spring	do	370	Alluvium.
162	Waverly, 3¼ miles NW	Wade Work	Carnell Spring	do	545	St. Louis limestone.
173	Denver, 4¾ miles E	L. L. Shipp	Cold Spring	do	385	Fort Payne formation.
174	Waverly, 2¼ miles SW	J. H. Mathews		do	460	Alluvium.
175	Waverly, 2 miles S	J. J. Claxton	Claxton Spring	do	475	St. Louis (?) limestone.
176	Bold Springs, 4¼ miles NW	Ezra Joslin		do	485	Fort Payne formation.
177	do	J. R. James	Bold Spring	do	515	St. Louis (?) limestone.
179	Bold Springs, 5¾ miles E	Lee Crowell		do	690	St. Louis or Warsaw limestone.
180	Denver, 4¼ miles S	D. M. McCrary	Sulphur Spring	do	370	Silurian (?) limestone.
181	Denver, 5½ miles S	John Waggoner	Hurricane Rock Spring	do	390	Camden chert (?).
182	Bakerville, 5 miles NE	L. W. Slayden		do	385	Fort Payne formation.

[Table continued on p. 162]

Typical springs in Humphreys County, Tenn.—Continued

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
154	1	Solution channel along joint	20	Sept. 18	Seasonal	Domestic, stock	55	Yield increases 24 to 36 hours after heavy local rain. Eleven perennial springs on 100-acre tract.
156	1	Solution channel along bedding plane.	90	Sept. 11	do	do	55	Water reported never turbid.
157	1	Probably bedding-plane channel.	350	do	do	do	59	Perennial head of Deer Creek.
158	1	Solution channel concealed by chert gravel.	160	do	do	do	58	Reported minimum yield about 150 gallons a minute.
[a] 159	1	Bedding-plane solution channel.	1,750	do	do	do	56	Flow increases and water becomes very turbid 12 to 24 hours after a rain; reported minimum yield about 1,500 gallons a minute.
160	1	Solution channel						Reported maximum yield about 500 gallons a minute.
[a] 161	1	Concealed	250	Sept. 9	Seasonal	Domestic, stock	58	Reported minimum yield about 200 gallons a minute.
162	1	Bedding-plane solution channel.	675 500	July 19 Sept. 18	do	Domestic	57	
[a] 173	Many	Bedding-plane and joint channels.	500±	Sept. 9	do		58	Perennial head of Cold Branch Creek. Many small openings in weathered limestone along zone 100 yards long.
174	do	Seepage pools	100±	July 19	do	Domestic, stock	58–62	Perennial spring.
175	Several	Bedding-plane channels	100	do		Domestic	57	Yield noted is total flow of spring-feed creek, ¼ mil below main orifice.
176	do	do	450±	Sept. 10	Seasonal	Domestic, stock	57	Perennial spring.
[a] 177	2	Solution channel along joint	325	do	do	do	57	Water becomes turbid 24 to 48 hours after protracted rain; reported maximum yield about 1,500 gallons a minute.
179	2	Bedding-plane channels	300±	do	do	do	58	Perennial head of Tumbling Creek.
[a] 180	1	Solution channel concealed by bog.	175	Sept. 9	Slight seasonal fluctuation.	None	60	Reported minimum yield about 175 gallons a minute.
181	1	Large solution channel	27,000	Sept. 10	Seasonal	do	62	Water reported never turbid, even though orifice is submerged by high stages of Duck River; minimum reported yield about 25,000 gallons a minute.
182	3	Solution channels concealed by chert gravel.	100±	Sept. 8	do	Stock	56	Reported minimum yield about 100 gallons a minute.

[a] See analysis, pp. 112–113.

Driller's log of J. T. Anderson well No. 1

[No. 185, pl. 4. Test well drilled by Tennessee Central Oil Co. in 1921. Casing head approximately 525 feet above sea level]

	Feet
Soil	0–5
Limestone, dense, blue	5–30
Shale, black (Chattanooga shale)	30–50
Sandstone (?) hard, gray	50–245
Limestone and shale, dark blue-gray	245–260
Limestone, pink	260–370
Limestone, white	370–375
Limestone and green shale, alternate thin beds	375–400
Limestone, white	400–420
Limestone, pink	420–470
Limestone, brown, dense	470–500
Shale, green, soft	500–504
Shale, brown, hard	504–540
Limestone, gray, cherty	540–590
Limestone, black, sandy and cherty	590–650
Shale, black, soft	650–710
Limestone, brown	710–800
Limestone, gray	800–890
Limestone, gray-brown, very dense	890–1, 470
Limestone, sandy, gray and white	1, 470–1, 575
Sandstone, white; small yield of salt water	1, 575–1, 580
Sandstone and blue shale, alternating layers about 6 feet thick	1, 580–1, 650
Limestone, gray; salt water at bottom	1, 650–1, 700
Limestone, gray, brown	1, 700–1, 800
Limestone, brown, very hard; salt water at 1,940 feet	1, 800–2, 000

MONTGOMERY COUNTY

[Area, 516 square miles. Population, 30,882]

GENERAL FEATURES

Montgomery County, which occupies the north-central part of the region described in this report (pl. 1), lies on the most fertile and thickly populated part of the Highland Rim plateau. The county seat, Clarksville (population 9,242) is the principal commercial center of this upland area. Most of the county is a slightly rolling plain comprising extensive flat tracts of the Highland Rim peneplain (pp. 16–18) and shallow mature drains, which are presumably adjusted to the Nashville Basin stage of planation (pp. 20–22). Many parts of the peneplain remnants, especially in the northeast quadrant of the county, drain into sink holes in the limestone or into small intermittent and perennial ponds at the bottom of shallow undrained depressions. These ponds occur at all altitudes and most of them are far above the general level of the ground water. Some are probably caused by the filling of sink holes or natural wells by impermeable débris; others are probably due merely to unequal depth of chemical weathering of the limestone. The peneplain remnants range from about 575 to 700 feet above sea level. The south half of the county is traversed by the somewhat meandering youthful valley of the Cumberland River, which at Clarksville is about 350 feet above sea level. Hence the total relief within the county is about 350 feet.

The massive crystalline beds of the St. Louis limestone and Warsaw formation, of Mississippian age, cover the greater part of the county, although there are few visible exposures of these rocks except in the youthful stream valleys. In the interstream areas bedrock is mantled by as much as 125 feet of clay and soil, which are residual from the chemical weathering of the limestone. Montgomery County is unlike areas in which the cherty Fort Payne formation underlies the surface in that this residual clay contains comparatively few chert fragments. The Fort Payne formation, which crops out in the valleys of the Cumberland River and of Barton and Little Barton Creeks, in the southeast corner of the county, consists of thin beds of cherty and earthy limestone. The geologic map (pl. 4) shows the outcrop areas of these formations; the discussion of stratigraphy (pp. 33–37) treats of their lithologic character.

GROUND-WATER CONDITIONS

Most of the residents of the upland areas rely upon cisterns as a source of water, inasmuch as the residuum from the weathering of the limestone is generally not water bearing and dug wells are generally unsuccessful. Water for stock is generally impounded in natural or artificial ponds. Comparatively few tubular wells have been drilled, although they generally obtain sufficient water for domestic purposes. Most of the drilled wells are between 100 and 160 feet deep, and all derive their water from channeled zones in the limestone. (See pp. 69–89.) A few wells, such as Nos. 49, 50, and 55 (pp. 166–167), have been drilled more than 200 feet deep in search of water, and several relatively deep holes have been drilled in search of oil or gas. So far as is known, however, the deepest water-bearing stratum disclosed in any of the upland tracts by these wells is 187 feet below the surface. If the experience of drilling in adjacent parts of the Highland Rim plateau is a sound basis for judgment, it seems likely that potable water will not be found more than 200 feet below the upland areas of Montgomery County. In the more deeply dissected parts of the county ground-water conditions are relatively erratic, although many wells from 50 to 100 feet deep yield sufficient water for domestic supply. Several wells in and near Clarksville, such as No. 52, are reported to find water about 300 feet below the surface in a sandstone or sandy limestone that occurs approximately at the horizon of the sandstone member of the Pegram limestone (pp. 41–43). However, there is no sound basis for making a definite correlation. This stratum is not water bearing in some wells that reach its horizon, as in well No. 55, and most of the wells heretofore drilled to it for industrial water supply have been abandoned as inadequate. Hence it does not constitute a promising source of water in other parts of the county.

The most reliable sources of water in many parts of the county are the tubular springs (pp. 92–95), which issue from solution channels in the limestone. Such springs are especially numerous in the north-central part of the county, in the vicinity of the converging forks of the Red River and of the meandering portion of the course of the Cumberland River. The largest and least variable of the springs issue from channels that are approximately adjusted to the present erosion stage of the principal streams and are essentially tributaries of the regional drainage system. Some issue from channels that probably join converging tributaries or the limbs of stream meanders and hence they may have a large and relatively invariable discharge, even though they do not drain large bodies of limestone. Two springs in Montgomery County, Nos. 43 and 44 (p. 168), are known to discharge more than 1,000 gallons a minute and many others discharge 100 gallons a minute or more. The discharge from a tubular spring may fluctuate greatly, so that the maximum safe draft can be determined only by periodic measurements during several years.

Most of the ground waters from the St. Louis limestone and Warsaw formation in Montgomery County are only moderately concentrated and, except for moderate carbonate hardness, are satisfactory for all ordinary uses. A few of the waters from these formations and others from the underlying Fort Payne formation, however, are highly concentrated, have much noncarbonate hardness, and are unsatisfactory for some purposes. Analyses of representative ground waters are tabulated on pages 110–111.

Typical wells in Montgomery County, Tenn.

[No. 71 dug, the others drilled]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
38	Woodlawn, 8 miles NW	Ernest Payne	Plateau	535	120	6	100
39	Woodlawn, 6 miles NW	T. H. Batson	Hillside	470	100±	5⅝	
42	Woodlawn, 5 miles NW	E. B. Ingraham	Plateau	505	136	5⅝	90
45	Clarksville, 7½ miles NW	C. R. Nichols	Hilltop	425	142	6	35
46	Clarksville, 7 miles NW	R. D. Fort	Plateau	450	114	6	
48	Clarkvsille, 3½ miles NW	Mrs. Ernest Whitfield	Plain	465	160±	6	
49	Clarksville, 2¾ miles N	I. R. Peterson	Hillside	405	273	5⅝	
50	St. Bethlehem, 2 miles W	Mrs. Lucy Merriweather	Plain	460	275	6¼	45
51	Clarksville, 1½ miles W	T. S. Phipps	Valley	365	900+	8	
52	Clarksville	Clarksville Ice & Coal Co	do	420	300±	8	70
55	Clarksville, 2 miles SE	Greenwood Cemetery Co	Plain	475	675±		
56	Clarksville, 2 miles SE	B. H. Shearon	Plateau	525	160	6	
57	Clarksville, 4¼ miles E	W. R. Corlew	do	520	162	6	
60	St. Bethlehem, 5½ miles E	Will Kroutch	Hilltop	445	156	6	
61	Woodford, 2 miles W	Sango School	Plateau	580	145	6	
63	Sailors Rest, 2 miles S	George Fort	Ridge crest	530	225	6	
64	Hackberry	Henry Yarber and James Brown	Hillside	405	50	6	14
66	Palmyra, 6¼ miles S	J. S. Chambers	do	485	101	6	
68	Louise, 5 miles SE	C. D. Batson	do	425	65	5	15
70	Southside, 2¼ miles S	C. E. Appleton	Valley		100	6	
71	Hickory Point, 6½ miles NE	George Watson	Plateau	625	60±	48	60

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
	Depth below surface (feet)	Character of material	Geologic horizon						
38	115	Limestone	St. Louis or Warsaw limestone.	−80	Hand pump	3–5	60	Domestic, stock	Water too hard for laundering. Many cisterns in vicinity.
39	Near bottom.	Bedding-plane crevice.	do	−20	Bucket and rope		58	Cooling	Water too hard for laundering.
[a] 42	do	Limestone	do	−85	Hand pump	3–5	59	Domestic	Water-bearing bed at approximately same altitude as Cumberland River.

45	135	Bedding-plane crevice.	do	−110 (?)	do	3–5	60	Domestic, stock	Maximum consumption 1,200 gallons a day.
46	Near bottom.	Limestone	do		Air lift			Domestic	Two dug wells about 25 feet deep in neighborhood; other water supplies from cisterns.
48	do	do	do		Electric force pump	5±		do	
49		do	do	−90		½		do	
50	187	Bedding-plane crevice.	Fort Payne (?) formation.	−245	Bucket and rope		60		Ultimate capacity 75 to 100 gallons a day of highly concentrated water. Residual clay 42 feet thick.
51	130	Limestone	do	−15 (?)	None			None	No water-bearing beds below depth of 130 feet. Test well by Simmons Oil Co.
52	60–70 Near bottom.	Solution channel. White sandstone.	St. Louis or Warsaw limestone. Pegram limestone (?).	−30	Air lift	35	59	Cooling	Solution channel filled with sand; drawdown about 95 feet pumping 30 to 35 gallons a minute. Similar wells at plants of Dunlop Milling Co. and American Snuff Co. abandoned because of small yields and trouble with sand.
55	50±	Bedding-plane crevice.	St. Louis or Warsaw limestone.		None			None	Ultimate capacity 2,000 gallons a day. No water-bearing beds below depth of 50 feet.
56		Bedding-plane crevices.	Fort Payne (?) formation.	−130	Bucket and windlass			Domestic	
[a] 57		Limestone	St. Louis or Warsaw limestone.	−120 (?)	Hand pump	3–5	58	do	Other plateau residents of the vicinity rely upon cisterns.
60		do	do		do	3–5		do	
61		do	do	−125 (?)	do	3–5	59	Drinking	
63		do	do					None	Well abandoned.
[a] 64	Near bottom.	do	do	−38	Hand pump	3–5	60	Domestic	Other drilled wells of community are 35 to 80 feet deep; some inadequate in dry seasons.
66	80±	do	do	−30	do	3–5		Domestic, stock	All supplies of Shiloh community derived from cisterns.
68	62	do	Fort Payne formation.	−25	Bucket and rope	⅛	64	Domestic	
70	70		Cherty residuum from Fort Payne (?) formation.		None			None	Ultimate capacity only 2 gallons an hour. Well abandoned.
[a] 71			Cherty residuum from St. Louis or Warsaw limestone.	−47	Bucket and windlass		59	Domestic	Most supplies of Fredonia community are derived from cisterns and rain catches.

[a] See analysis, pp. 110–111.

Typical springs in Montgomery County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
40	Woodlawn, 4½ miles NW	Mrs. T. J. Shelby	Jordan Spring	Valley	490	Alluvium.
41	Woodlawn, 4¼ miles NW	T. H. Batson		do	485±	St. Louis or Warsaw limestone.
43	Woodlawn, 6¼ miles N	E. B. Trahern	Boiling Spring	do	405	Do.
44	Woodlawn, 5½ miles NE	H. E. Killebrew	Britton Spring	do	340	Do.
47	Clarksville, 4 miles W	T. M. Adkins	Donelson Spring	Gulch head	305	Do.
53	St. Bethlehem, 2 miles SW	J. H. Unseld	Dunbar Cave	Valley	305	Do.
54	St. Bethlehem, 2¼ miles SW	do	Idaho Spring	do	295	Alluvium above St. Louis or Warsaw limestone.
58	Clarksville, 3¾ miles SE	H. J. Hiett	Hiett Spring	Hillside	445	St. Louis or Warsaw limestone.
59	Hampton Station, ½ mile E	Mrs. Mary Fort	Hampton Spring	Valley	450	Do.
62	Sailors Rest, 6¾ miles N	Mrs. L. F. Thomas	Thomas Spring	do	395	Do.
65	Louise, 3¾ miles NW	Joe Baggett		do	525	Do.
67	Louise, 4 miles SW	George W. Bryant		do	570	Do.
69	Louise, 5½ miles SE	Montgomery County	Blackwell Spring	do	415	Do.
72	Hickory Point, 5 miles NE	Mrs. Richard Swift	Blue Spring	do	485	Do.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
40	1	Concealed	15	Sept. 5	Seasonal	Domestic, stock	56	
41	Several	Bedding-plane channels	575	do	do	Stock	57	Water emerges from several openings in a zone 75 yards long.
43	1	Concealed, probably large solution channel.	3,350	do	do	None	57	Water in spring was approximately 1 foot higher than Little West Fork of Red River, 25 yards away, Sept. 5, 1927.
a 44	1	Bedding-plane solution channel.	1,900	do	do	Stock	60	Maximum yield reported several times that on Sept. 5, 1927.
47	1	Bedding-plane channel	350	Sept. 6	do	do	58	Large perennial flow.
53	1	Large solution channel	750±	Sept. 3	do	Swimming pool		Yield increases and water becomes very turbid 12 to 24 hours after rains to the east and northeast.
a 54	6	Concealed; probably small bedding-plane channels.				Medicinal	60	Sample from so-called white sulphur spring. No natural flow on Sept. 4, 1927.

	--------	Bedding-plane channel	30	Sept. 4	Seasonal	Domestic, greenhouses.	58	Maximum yield several times that noted on Sept. 4, 1927; reported minimum yield about 25 gallons a minute.
59	1	Concealed, though undoubtedly solution channel.	75	Sept. 3	do	Stock	58	Slight turbidity Sept. 3, 1927.
62	1	Large solution channel	100±	Sept. 5	do	Domestic, stock	56	Perennial spring; largest in valley of Blooming Grove Creek.
65	1	Bedding-plane channel	10±	Sept. 6	do	do	56	Perennial spring.
[a] 67	1	Large solution channel	125	do	do	do	59	
69	1	Bedding-plane channel	20±	Sept. 4	do		58	Do.
72	1	Slump conduit leading to solution channel.	125	Aug. 21	do		58	Perennial head of Blue Creek.

[a] See analysis, pp. 110–111.

ROBERTSON COUNTY

[Area 455 square miles. Population, 28,191]

GENERAL FEATURES

Like Montgomery County, which it adjoins on the east (pl. 1), Robertson County lies in the most densely populated and fertile part of the Highland Rim plateau in north-central Tennessee. It comprises extensive slightly undulating interstream tracts with a local relief of 25 to 50 feet, which are remnants of the Highland Rim peneplain (pp. 19–20), and mature and youthful drains, which trench the plain to a maximum depth of about 250 feet. The peneplain remnants range from about 875 feet above sea level at Ridgetop, at the crest of the Highland Rim escarpment in the southeastern part of the county, to about 625 feet along the northern boundary of the county. The peneplain remnants also include many small undrained depressions, of which a large number contain perennial ponds. These water bodies occur at all altitudes, and most of them are derived wholly from surface run-off; a few such ponds, which are generally in the lower parts of the surface, may be supplied by ground water through one or more submerged solution channels. All but a very small part of the county is drained by tributaries of the Red River, which head in relatively shallow mature drains along the crest of the Highland Rim escarpment and flow northwestward and westward. In their lower reaches these tributaries occupy youthful valleys 100 feet or more deep. A strip several miles wide along the southern boundary of the county from Ridgetop westward is drained by Sycamore and Half Pone Creeks.

Robertson County lies on the northwest flank of the Nashville dome (pp. 62–63), so that the primary structure of the rocks is that of a monocline dipping very gently northwestward. In all the upland tracts the bedrock is the massive limestone that composes the St. Louis limestone and Warsaw formation, although there are few outcrops of these formations away from the youthful stream valleys. In the peneplain tracts the bedrock is concealed by a mantle of residual clay and soil, usually between 15 and 50 feet thick but in some places 100 feet thick. Over most of the county this material contains very few chert fragments, unlike the residuum that overlies the Fort Payne formation in other counties. In Robertson County the Fort Payne formation is composed chiefly of thin-bedded earthy cherty limestone, calcareous shale, and impure sandstone. It crops out only in the valleys of the tributaries of the Red River south and east of Springfield and in the valley of Sycamore Creek from Ridgetop westward. The stratigraphic relations of these rock formations are discussed on pages 33–37. Their areal extent is shown on Plate 4.

GROUND-WATER CONDITIONS

As in other parts of the Highland Rim plateau that are underlain by the St. Louis limestone, most of those who reside in interstream tracts of Robertson County derive their domestic water supplies from cisterns. This condition is chiefly due to the absence of water-bearing zones in the residual clay that mantles the plateau, so that dug wells are generally inadequate. Relatively few tubular wells have been drilled in the county, although such wells generally obtain adequate domestic supplies in channeled zones in the limestone (see pp. 173–175) from 30 to 105 feet below the surface. A few wells obtain potable water in the limestone as much as 175 feet below the surface, but on the other hand some deep wells have found no water-bearing strata more than 100 feet below the surface. One typical well, No. 92 (pp. 173–174), found a small amount of water 20 feet beneath the surface in cherty débris at the top of the solid rock but did not penetrate any other water-bearing strata even though drilled to a depth of 311 feet. Several relatively deep wells, such as Nos. 78, 93, 94, 99, and 108 which have been drilled in search of oil or gas, have either been dry holes below a depth of 100 to 200 feet or have encountered only highly concentrated brine. No extensive permeable stratum is known to exist beneath the county. So far as is known, none of the tubular wells have been pumped more than 5 gallons a minute, and the total capacity of some is much less than 5 gallons a minute.

In those parts of the county which are deeply trenched by the streams ground-water conditions in the limestone differ greatly from place to place; generally water-bearing beds are not found far below the level of the perennial streams. Some of the beds in the upper part of the Fort Payne formation, which crops out in the deeper valleys south of Springfield, are sandy and appreciably permeable, but their water-yielding capacity is not known. In these parts of the county both seepage and tubular springs (pp. 90–95) are numerous, and many of the domestic water supplies are derived from them. Some of the tubular springs have relatively constant discharge and are by far the most reliable sources of water in the county. Three of the typical springs (p. 176) discharge 100 gallons a minute or more each, and the discharge from one (No. 80) was about 725 gallons a minute on August 26, 1927, when the ground-water discharge was nearly at its seasonal minimum.

Most of the ground waters of Robertson County are moderately concentrated and moderately hard calcium bicarbonate waters that are suitable for any ordinary use, especially after they have been softened. In a few places the water associated with the St. Louis limestone and Warsaw formation is highly concentrated and very high in noncarbonate hardness; it may also contain considerable hydrogen sulphide. In other places, as in well 76, the ground water is accompanied by enough petroleum to render it unfit for domestic use or for watering stock. The deep-seated waters are very highly concentrated brines. Analyses of representative ground waters are tabulated on pages 110–111.

MUNICIPAL GROUND-WATER SUPPLIES

Orlinda.—The only town in Robertson County that derives a municipal water supply from an underground source is Orlinda (estimated population, 515), on the Highland Rim plateau in the northeastern part of the county. The principal source is a tubular spring (No. 89) that issues from a solution channel in the wall of a sink hole about half a mile east of the town. It is reported that the discharge ranges from 12,000 to 15,000 gallons a day and that it is sufficient for the needs of the town even in periods of extreme drought. From the spring a pump with a capacity of 35 gallons a minute raises the water to a 10,000-gallon wooden standpipe near the center of the town, whence it is distributed by gravity. A drilled well (No. 88) 4 inches in diameter and 80 feet deep constitutes an emergency source; it is equipped with a deep-well pump having a capacity of 5 gallons a minute. The water from both the spring and the well is sterilized with chlorine before use.

Typical wells in Robertson County, Tenn.

[All drilled wells]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
74	Sadlersville, 3¼ miles NE	Hugh Head	Valley	470	800		
75	Cedar Hill, 9¾ miles NE	Walter Taylor heirs	Plateau	555	1,440	12	
76	do	do	do	555	185	6	22
77	Cedar Hill, 4¾ miles NE	S. R. Russell	do	625	106	5⅝	40
78	Cedar Hill, 5 miles NE	T. R. Woodward	Valley	505	775	8	
81	Springfield, 10 miles N	Elmore Marshall	Plateau	645	71	5⅝	15
82	Springfield, 8¼ miles N	J. A. Barricks	do	680	80	5⅝	40
83	Springfield, 9 miles N	I. D. Elliott	do	650	33	5⅝	
84	Orlinda, 2¾ miles W	Melvin Barry	Hilltop	670	84	5⅝	
85	Orlinda, 3¼ miles SW	J. C. Barber	Hillside	615	52	5⅝	13
86	Orlinda, 3½ miles SW	E. G. Brewer	do	625	105	5⅝	27
87	Orlinda, 4¾ miles SW	S. R. Russell	Plateau	700	54	5⅝	
88	Orlinda, ¾ mile E	City of Orlinda	do	730	80	4	60
92	Cedar Hill, 4¼ miles SW	Felix Ewing	Valley		311	6	
93	do	Felix Ewing No. 1	do		675		
94	do	Felix Ewing No. 2	do		1,022	8	
95	Cedar Hill, 6¼ miles SE	Flewellyn School	Plateau	695	96	5⅝	
98	Springfield	John Porter	Valley	705	54	5⅝	27
99	Springfield, ½ mile SE	William DeBerry	do		390		
101	Springfield, 2 miles SE	E. B. Long	Hilltop	755	71	5⅝	
102	Springfield, 6¼ miles E	Henry Orand	Plateau	705	99	5⅝	
103	Springfield, 6½ miles E	Joe Armstrong	do	715	106	5⅝	46
104	Cedar Hill, 9¼ miles S	J. F. Browning	do	695	119	5⅝	
106	Springfield, 5½ miles SE	Lee Jones	Hilltop	800	74	5⅝	45
107	Greenbrier, 8½ miles W	Lester Clinnard	Plateau	770	52	5⅝	32
108	Pleasant View, 4¼ miles SE	T. O. McMahan	Hillside	510	500	8	165
109	Pleasant View, 7¼ miles E	Bailey Pratt	Plateau	700	96	5⅝	
110	Greenbrier, 6¼ miles SW	Callie Walker	do	765	97	5⅝	
112	Greenbrier, 1¾ miles SE	R. B. Beal	do	800±		6±	
113	Ridgetop	J. B. Ransom and others	Plateau edge	890	160	8	20

[Table continued on pp. 174–175]

Typical wells in Robertson County, Tenn.—Continued

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remarks
	Depth below surface (feet)	Character of material	Geologic horizon						
74					None			None	Static level reported to be at casing head in wet season.
75	85	Limestone	St. Louis or Warsaw limestone (?)		do			do	Test well for petroleum; 85-foot water-bearing bed yields about 50 gallons a day.
76	85	do	do		Hand pump	⅕		do	Well yielded crude oil in small quantity at depth of 90 feet.
77	102	Solution crevice	do	−78	Bucket and windlass		58	Domestic	
78	100±	Limestone	do	−50	None			None	Test well for petroleum. Top of Chattanooga shale at about 500 feet; concentrated salt water at 600 feet; no water-bearing beds between 100 and 600 feet.
[a]81	Near bottom.	do	do	−55	Bucket and rope		58	Stock	
82	do	Bedding-plane crevice.	St. Louis or Warsaw limestone.	−41		⅛±		Domestic	
83	do	Limestone	do		Hand pump	3–5		do	
84	80	Bedding-plane crevice.	St. Louis or Warsaw limestone (?).	−50				do	
85	Near bottom.	Limestone	do	−25	Hand pump	1		do	
86	102	Bedding-plane crevice.	do	−40±				do	Ultimate capacity 150 gallons a day.
[a]87	Near bottom.	Solution crevice	do	−30	Hand pump	5	57	do	
88	do	Bedding-plane crevice.	do	−30	Electric force pump	5		Municipal	Part of Orlinda municipal supply.
92	20		Bottom of residual chert.					None	No water-bearing beds below depth of 20 feet. Gas at about 250 feet.
93	100±	Limestone	St. Louis or Warsaw limestone.					do	Test well for petroleum. No water-bearing beds below depth of 100 feet. Top of Chattanooga shale at about 560 feet.
94	100±	do	do					do	Do.
95	91	do	St. Louis or Warsaw limestone (?).	−30				Drinking	Residual chert and clay 90 feet thick.
98	50	Bedding-plane crevice.	St. Louis or Warsaw limestone.	−30	Hand pump	3–5		Domestic	Wells within a radius of 5 miles from Springfield are 23 to 144 feet deep; most are about 65 feet.
99								None	Very little water found. Natural gas encountered.

101	Near bottom.	Bedding-plane crevice.	St. Louis or Warsaw limestone (?).					Stock	Water turbid.
102	do	do	do	−60	Gasoline and hand pump.	5±		Domestic, stock	Yields less than capacity of pump.
103	do	do	do		do	5±			Two water-bearing crevices penetrated at depth of less than 100 feet had very small yield.
[a]104	115	do	St. Louis or Warsaw limestone.	−52	Hand pump	1–2	57	Drinking, stock	Maximum draft 1,250 gallons in 24 hours.
106	Near bottom.	do	St. Louis or Warsaw limestone (?).					Domestic, stock	
107	do	Limestone	do			Small		Stock	
108	125	do	Fort Payne (?) formation.	+1	Artesian flow	Trickle	64	None	Test well for petroleum; string of tools fast in bottom; top of Chattanooga shale at 165 feet. No water-bearing beds below 165 feet.
109	Near bottom.	Bedding-plane crevice.	Fort Payne formation.	35	Bucket and rope		68	Domestic	Residual clay 48 feet thick.
110	95±	Limestone	Fort Payne (?) formation.	−79	Hand pump	3–5		do	
[a]112			Fort Payne formation.		do	3–5	56	Drinking	In grounds of Hygeia Springs resort.
113	155	Solution crevice	Base of Fort Payne formation.	−150		Small		Domestic	Replaces former well, which was drained when Louisville & Nashville R. R. tunnel was driven at Ridgetop. Drainage by tunnel has lowered ground-water level 75 feet in vicinity.

[a] See analysis, p. 110–111.

Typical springs in Robertson County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
73	Adams, 3½ miles NW	Joel Fort	Mint Spring	Valley	400	St. Louis limestone.
79	Cedar Hill, 3¼ miles NE	John Sneed	Sneed Spring	do	575	St. Louis or Warsaw limestone.
80	Cedar Hill, 4¾ miles NE	W. M. Gossett		do	495	Do.
89	Orlinda, 1 mile SE	City of Orlinda		Plateau	700	Do.
90	Orlinda, 1¾ miles S	J. W. Drake	Mill Cave	Valley	605	Do.
91	Orlinda, 6½ miles E	James Payne		Hillside	655	Do.
96	Springfield, 3 miles W	Will Powell		do	575	Do.
97	Springfield, 2½ miles N	Arthur Powell	McIntosh Spring	do	590	Do.
100	Springfield, 1 mile S	J. H. Perry	Perry's Park Spring	Valley	630	Do.
105	Springfield, 5 miles SE		Worsham Spring	Plateau	700	Fort Payne (?) formation.
111	Greenbrier, 1½ miles SE	R. B. Beal	Hygeia Spring	do	780	Fort Payne formation.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (°F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
[a] 73	1	Bedding-plane channel	100	Aug. 26	Seasonal	Domestic	58	Flow increases and water becomes turbid after protracted rain.
79	5	do	25	do	do	Domestic, stock	59	Yield noted is total from 5 openings in a zone 200 yards long.
80	1	Large solution channel	725	do	do	Stock	59	Yield noted 150 yards below spring outlet.
89	1	Small bedding-plane channel	10±	Aug. 27	do	Municipal	60	In wall of sink hole on Highland Rim plateau.
90	1	Large solution channel	50±	do	do		57	Flow increases and water becomes turbid 3 hours or more after heavy rain.
[a] 91	1	do	30 50	do Oct. 8	do	Domestic	57	Flow increases and water becomes turbid after long rain.
[a] 96	1	Bedding-plane solution channel.	75 175	Aug. 24 Oct. 9	do	Domestic, stock	58	Do.
97	1	Solution channel	50±	Aug. 4	do	do	58	
100	1		½	Aug. 25		Drinking		
105	1	Joint-plane channel				None	64	Formerly had considerable yield. Spring failed after heavy blasting in near-by quarry.
111	1	Joint fracture	Trickle	Aug. 25	Seasonal (?)	Medicinal formerly.	63	

[a] See analysis, pp. 110–111.

RUTHERFORD COUNTY

[Area, 614 square miles. Population, 32,286]

GENERAL FEATURES

Rutherford County lies in the southeast corner of the region described in this report (pl. 1), approximately at the geographic center of the State. Its county seat and principal town, Murfreesboro, has a population of 7,993.

The county occupies the southeastern part of the northern lobe of the Nashville Basin (p. 18) and is roughly a natural physiographic unit in that its eastern, southern, and western boundaries follow approximately the divide surrounding the basin of the Stone River. Extensive tracts in its central and western parts lie on the Nashville Basin peneplain (pp. 20–22), a nearly featureless plain that slopes northwestward and is from 550 to 700 feet above sea level. On this plain sink holes, undrained depressions, and "glades"—essentially flat areas of limestone with little or no soil—are numerous. This plain is surrounded by a nearly continuous belt of hills along the boundaries of the county, the hilly terrane being a product of a mature dissection of outlying remnants of the Highland Rim plateau. The largest of these remnants is a branching ridge about 4 miles long near the southeast corner of the county. Its summit, 1,352 feet above sea level, is the highest point in the county and in the entire region covered by this report.

The county is drained northwestward by the Stone River, whose principal branches occupy trenches cut 25 to 100 feet below the Nashville Basin peneplain. Many extensive tracts on this peneplain, however, have no surface drains, and their run-off is carried by solution conduits, which discharge as perennial springs. The larger of these subsurface drains are adjusted to the surface streams.

Rutherford County lies on the apex of the Nashville dome (pp. 62–63), the rock strata dipping radially away from a point near Fosterville, south of Murfreesboro. Hence the oldest rocks exposed by that dome, of Lower Ordovician age, crop out in the central part of the county and are surrounded by concentric bands of the younger formations. The youngest strata exposed in the county, which belong to the lower part of the Fort Payne formation, include earthy cherty limestone and sandy shale; they cap several of the highest ridges in the southeastern and southwestern parts of the county. These beds are underlain by the Chattanooga shale, which is generally accompanied at its base by the Hardin sandstone member. This shale is underlain unconformably by rocks of Ordovician age, the Devonian and Silurian systems and the upper part of the Ordovician system being absent. The rocks of Upper Ordovician age that are present are the Leipers limestone. Those of Middle Ordovician age are, from the top downward, the Catheys, Cannon, and Bigby limestones, the Hermitage formation, and the Lowville limestone, including the Carters member. The Upper and Middle Ordovician formations crop out only as narrow bands on the upper and middle slopes of the hilly country along the boundaries of the county. The Hermitage formation comprises earthy limestone, calcareous shale, and calcareous sandstone associated with thin-bedded limestone; the other formations are composed wholly of limestone. The Middle Ordovician strata are underlain successively by the Lebanon, Ridley, Pierce, and Murfreesboro limestones, of Lower Ordovician age. The thin-bedded Lebanon limestone usually underlies the lower part of the hill slopes along the boundaries of the county but also crops out over extensive tracts along the edges of the central peneplain, especially in the southern half of the county. The dense massive beds of the underlying Ridley limestone are the surface rocks over the greater part of the central peneplain, the outcrop area of this formation being slightly more than half the area of the county. The Pierce and Murfreesboro limestones crop out in several relatively small areas on the apexes of minor structural domes within 9 miles of Murfreesboro. These two formations are the oldest rocks that crop out in the Nashville Basin and are not known to be exposed anywhere in central Tennessee outside of Rutherford County. The lithologic character and stratigraphic relations of these rocks are discussed on pages 35–38; their areal distribution is shown on Plate 4. The nature of the rocks that lie beneath the Murfreesboro limestone and do not crop out within the county are shown by the record of the Franklin Oil & Fuel Co.'s well (No. 427, pl. 4 and pp. 60–61).

GROUND-WATER CONDITIONS

The rocks that underlie the Nashville Basin peneplain in the central part of the county, being all limestones, are not generally permeable and carry water only in solution channels, bedding planes, or joints (pp. 69–89). Hence the water-bearing properties of any one stratum may differ greatly from place to place, as the number and size of solution channels are dependent chiefly upon the solubility of the rock, the number and continuity of joints, and the position of the stratum with respect to present and past equilibrium profiles of erosion. In general water-bearing openings are much fewer in the massive, thick-bedded rocks such as the Ridley and Murfreesboro limestones than in the thin-bedded and less competent rocks such as the Hermitage formation and the Lebanon and Pierce limestones. However, some of the largest solution conduits of the district occur in the more massive facies of the limestones. So far as is known, there are no water-bearing channels related to the unconformities nor any bodies of limestone that have been depressed with relation to the water table after channeling. Consequently, there seem to be no extensive systems of solution channels underlying those which are adjusted to the present surface streams, and thus the limestones are generally not water bearing where they lie at more than moderate depth.

Over much of the peneplain the unweathered rock lies very close to the surface, so that dug wells do not furnish adequate supplies of water. At most places, however, drilled wells obtain sufficient water for domestic purposes and for stock. The water-bearing beds range from 40 to 135 feet below the surface, though generally from 60 to 100 feet. The depth of water-bearing beds may differ greatly in wells which are close together. Some wells, such as Nos. 432, 434, 437, 440, and 441 (pp. 184–186), penetrate water-bearing beds from 175 to 250 feet below the surface, but others of similar depth are dry holes. Well 423, for example, did not reach a water-bearing bed, though drilled to a depth of 446 feet. In the vicinity of Murfreesboro wells 434, 440, and 441 seem to obtain water at about the same stratigraphic horizon, from a bed of soft granular limestone 200 to 245 feet below the surface and about 350 to 375 feet above sea level. This bed seems to differ greatly in water-yielding capacity from place to place, however, so that it can not be assumed to be water bearing in all parts of the county. Most of the drilled wells are used for domestic purposes only; hence they are pumped intermittently and lightly, and their total capacity is not known. In fact, relatively few of the wells have proved capacities of more than 5 gallons a minute. On the other hand, wells 435, 440, 441, and some others that chance to enter large solution channels yield 100 gallons a minute or more, although the capacity of such wells is likely to vary greatly from season to season or even to vary with local precipitation. These wells are drilled in cavernous limestone at or near the orifices of large tubular springs.

The St. Peter (?) sandstone (p. 61) has been considered a potential water bearer throughout north-central Tennessee. It seems to correspond with sandy beds that were entered about 610 feet below the surface in the Franklin Oil & Fuel Co.'s test well near Murfreesboro (No. 427, pp. 60–61), and its projected horizon is penetrated by well 4 of the Carnation Milk Products Co.'s plant (No. 433, p. 184). However, neither of these wells is reported to have found an appreciable amount of water at this horizon. It is probably inadvisable, therefore, to drill to this formation for ground water in other parts of the county.

In general, it is not to be expected that large yields of water can be obtained in Rutherford County from wells. For example, of four wells drilled in 1927 at the plant of the Carnation Milk Products Co., near Murfreesboro, only one was moderately successful. This well, No. 435, which is about 200 feet southeast of the boiler room, derives most of its water from a cavernous zone in the Murfreesboro limestone between 50 and 65 feet below the surface, although several water-bearing beds of small capacity were penetrated between this cavernous zone and the bottom of the well, at a depth of 217 feet. The well is pumped by air lift. It is reported by the driller that when first tested in May, 1927, the well yielded about 400 gallons a minute for 24 hours, the drawdown indicated by the difference between starting and running pressures in the air line being approximately 70 feet. Hence the specific capacity is rather small—about 6 gallons a minute for each foot of drawdown. During this first test at least 1 cubic yard of fine silt and corroded fragments of limestone as large as 2 inches in diameter were discharged from the well, indicating that the solution channels that transmit the water are partly clogged with such débris. During the period July to September, 1927, the well was pumped almost continuously, and its yield ranged approximately between 75 and 150 gallons a minute. A part of this variation was perhaps due to changes in the efficiency of the air-lift pump as the water level declined, but most of the variation was presumably due to seasonal fluctuations in the ground-water supply. This presumption is strengthened by the fact that the yield of the well increases about 24 hours after a heavy local rain. It is noteworthy that this well is approximately on the projected trace of prominent joints that cut the Murfreesboro limestone at the orifice of the Murfreesboro city spring (No. 439, p. 187), about a mile to the southeast. Another well (No. 434), about 150 feet northwest of No. 435, passed through the same water-bearing zones; its ultimate capacity is only about 5 gallons a minute. A third well (No. 433), which is 650 feet deep, penetrates a small water-bearing channel in the Murfreesboro limestone at a depth of 80 feet; a small amount of water may also be derived from a depth of about 350 feet. The rocks at the projected horizon of the St. Peter (?) sandstone were probably penetrated, although little if any water was found in them. The total capacity of this well, when pumped continuously, is about 12 gallons a minute, with a drawdown of about 180 feet. A fourth well (No. 436) comprises a sump 18 feet in diameter and 23 feet deep and an 8-inch drilled hole extending 63 feet below the bottom of the sump. Water-bearing zones in the limestone were penetrated 46 and 55 feet below the surface. Even after the well had been shot with dynamite at the bottom, its total capacity was only about 10 or 15 gallons a minute, of which about 5 gallons seeped from fractures in the walls of the sump and presumably originated in a near-by perennial creek. In general, the greatest likelihood of wells of large capacity exists where the course of a cavernous zone in the limestone is indicated at the surface by a linear arrangement of sink holes or along a line parallel to master joints and passing through proved wells or springs. Obviously, however, the uncertainty of finding water increases with the distance from the proved sites and is very great under even the most favorable circumstances.

In many if not most parts of the peneplain that covers the central part of the county springs constitute the most reliable source of water where perennial streams are absent. The largest of these are tubular springs whose water is gathered by systems of solution channels in the limestone (pp. 92–95). Some such springs return to the surface the water drained from large or small bodies of channeled limestone and constitute the perennial heads of surface streams. Typical examples are the city spring at Murfreesboro (No. 439, pl. 4) and Ward Spring (No. 428). In other springs of this type a subsurface stream is exposed for a short distance where the roof of its channel has collapsed or has been pierced by a natural well or subvertical solution channel, as in the Love Davis cave (No. 413, see also pl. 5, *B*), the Blue Sink (No. 450), and the Snail Shell cave (No. 455). Springs 416, 417, and 418, about 5 miles southeast of Smyrna (pl. 4), mark the course of a rather well-defined subsurface drain. The aggregate discharge from the tubular springs of this district constitutes the subsurface drainage that is tributary to the surface streams. Moreover, this ground-water discharge is subject to seasonal fluctuations comparable in magnitude to the fluctuations of the surface run-off, although the variability of all springs is not likely to be the same. Hence, the average or minimum discharge of a given spring can be determined only by measuring the flow at regular intervals over a long period.

In the hilly parts of the county ground-water conditions are likely to differ greatly from place to place, so that drilling is a most uncertain method of obtaining ground water. In general, few water-bearing beds probably occur very far below the level of near-by perennial streams. In many places dug wells derive adequate supplies from the surficial mantle of rock waste. Both tubular and seepage springs (pp. 90–95) are common and constitute an adequate source of water for domestic purposes and for stock in most of these sparsely populated districts.

Usually the ground water from springs and wells of shallow or moderate depth in Rutherford County is a moderately concentrated calcium-magnesium bicarbonate water of moderate hardness, such as is shown by analyses 431, 439, and 466 on pages 118–119. These waters are suitable for most ordinary uses after softening. Not all the ground waters, however, are of this type. Drillers in Rutherford County have noted that water of poor quality is usually encountered in wells from 60 to 150 feet deep in a zone about 1 mile wide that trends approximately N. 30° E. through a point about 3 miles west of Murfreesboro. This zone also passes through Sulphur Spring (No. 425, pl. 4), about 4 miles north of Murfreesboro. The water, which is derived from the upper part of the Murfreesboro limestone, is relatively concentrated in sodium, sulphate, and chloride and usually contains hydrogen sulphide. Analyses 432 and 433 are representative. Analyses 427 and 435 represent more dilute waters, which are

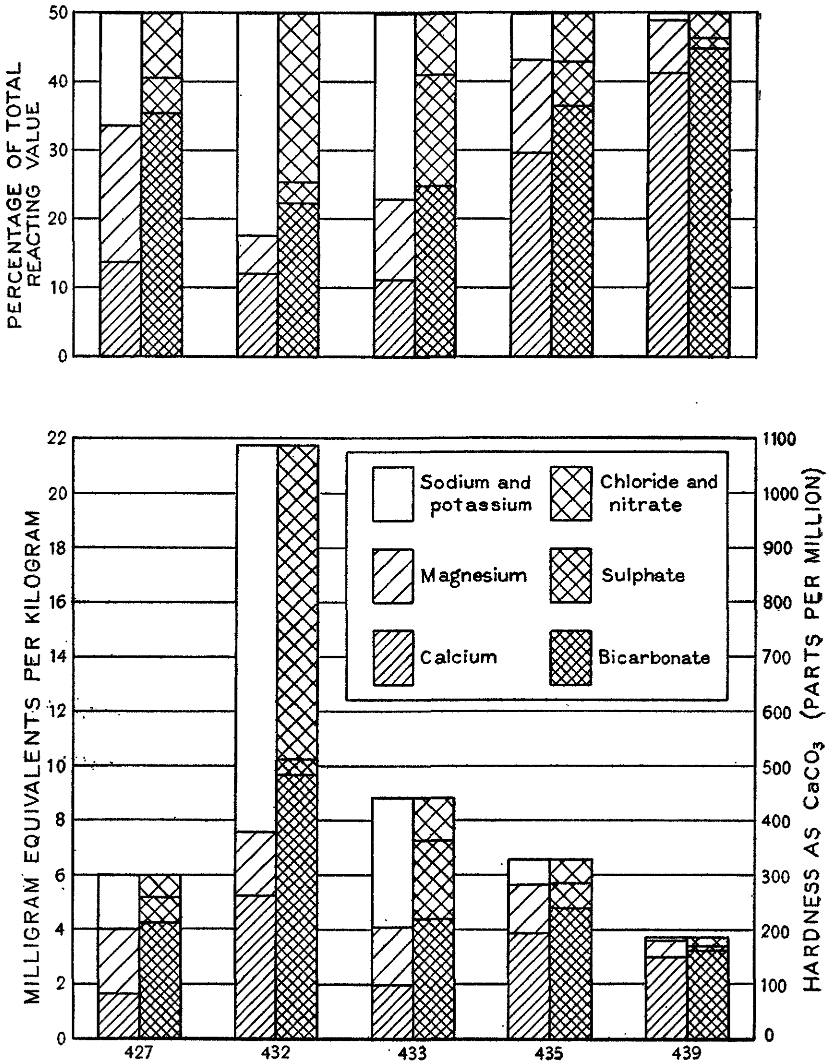


FIGURE 6.—Chemical character of representative ground waters from the Murfreesboro limestone.

presumably a mixture of the calcium-magnesium bicarbonate and sodium bicarbonate-sulphate waters. The chemical character of these representative waters is also shown graphically by Figure 6. The water from some wells and springs in this zone contains a relatively large quantity of iron, which in the presence of air is precipitated as the black iron sulphide; it is known locally as "black sulphur" water. Comparatively few wells derive water from the Murfreesboro limestone in other parts of the county, so that it is uncertain whether or not the water from this formation is everywhere of similar chemical character. Unfortunately, in many places water of satisfactory quality can not be obtained above or below the beds that yield the sodium bicarbonate-sulphate waters.

MUNICIPAL GROUND-WATER SUPPLIES

Murfreesboro.—The municipal water supply of the county seat, Murfreesboro, is derived from a tubular spring (No. 439, pl. 4 and p. 187), which issues from several openings along a cavernous zone in the Murfreesboro limestone near the southeast corner of the city. The cavernous zone follows a set of persistent joints striking N. 55° W. From the downstream orifice, which is protected by concrete cut-off walls sunk to the bedrock, the water is pumped to sedimentation tanks, chlorinated, and then pumped to a 700,000-gallon steel tank at the south edge of the town. Distribution is effected by gravity. The average daily consumption is reported to be about 700,000 gallons; the maximum about 1,000,000 gallons. Usually the discharge of the spring is adequate for the total consumption, although in the summer of 1925, a year of extreme drought, it reached a minimum of 300,000 gallons a day. Furthermore, the discharge increases greatly and the water becomes turbid from 6 to 12 hours after heavy rains in the vicinity of the spring and along the belt of hills to the southeast. The chemical character of the water is shown by the analysis tabulated on page 118 and graphically by Figure 6.

During periods of drought the municipal supply is pumped from a gang of six wells (No. 440) drilled in the cavernous limestone near the spring orifice, the ground-water level being so depressed by pumping that the spring ceases to flow. Of these wells one is 147 feet deep, and the other five from 200 to 211 feet. Each is equipped with an air-lift pump. During the drought of 1925 two of these wells (then 100 feet deep) were pumped continuously for six weeks, and the yield of each declined gradually from 300 to about 250 gallons a minute, with a drawdown of about 45 feet. Hence their specific capacity is moderate—about 6 gallons a minute for each foot of drawdown. In 1927, which was also a dry year, the yield of the six wells was found to be more than the consumption, although the total capacity of the gang was not determined.

Typical wells in Rutherford County, Tenn.

[Nos. 436 and 459 dug and drilled; No. 451 bored; No. 465 dug; all others drilled]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
405	Smyrna, 4½ miles NE	E. V. Mattocks estate	Plain	535	60	5	6
407	Smyrna, 5 miles E	Mrs. Milbury Wrather	River bluff	535	86	5½	
408	Smyrna, 7 miles E	J. H. Short	Plain	535	101	5½	
409	Walter Hill, 3½ miles N	Mrs. J. E. Wrather	Hillside	610	100±	5½	
410	Smyrna	John Tucker	Plain	510±	100±	5½	
412	Smyrna, 4¼ miles SW	H. A Lee	do	595	86	5½	48
414	Florence, 6¾ miles W	Guy Lawrence	do	660	66	5½	6
415	Florence, 2½ miles NW	Hermitage Portland Cement Co	do	595	200	8	
419	Walter Hill, ½ mile N	Riley Barry	do	535	116	5½	
420	Walter Hill, ½ mile S	Murfreesboro Light Co	do	535	75	4½	62
421	Lascassas, 2 miles SW	Charles Dunaway	Hillside	590	125	5⅝	52
422	Lascassas, 1½ miles S	Lefel Brown	Plain	575±	135	5⅝	16
423	Florence, 8¾ miles W	William Webb estate	Hillside	745±	446	6	
424	Murfreesboro, 5 miles NW	—— School	Plain	565	60	5⅝	2
426	Murfreesboro, 3 miles N	James Butler	do	580	115	5⅝	
427	Murfreesboro, 1½ miles N	G. M. Alsup	do	595	1,930+	10	
429	Milton, 5½ miles S	B. A. Taber	Hillside	610	43	5⅝	
430	Overall, 3 miles NW	Kingwood School	Plain		115	6	15
431	Overall, 3¼ miles N	J. M. Free	do	600	51	5⅝	
432	Murfreesboro, 2½ miles W	T. F. Lane	do	565	175	5⅝	12
433	Murfreesboro, ¾ mile NW	Carnation Milk Products Co	do	585	650	10	20
434	do	do	do	585	240	8	20
435	do	do	do	587	217	10	20
436	do	do	do	580	86		
437	Murfreesboro	Sunshine Hosiery Co	Plain	600	262	6	
440	do	City of Murfreesboro	Creek bed	580	147–211	8	18–24
441	do	Cristy & Huggins Co	Plain	590	487	8¼	28
442	Murfreesboro, 1¼ miles SE	A. L. Todd	do	645	95	6	
445	Murfreesboro, 3½ miles SE	—— Jackson	do	650	100±	5⅝	
447	Rockvale, 7¼ miles NW	Patterson School	Valley	655	32	5	
448	Rockvale, 6½ miles NW	Henry Pate	Hillside	655	126	5	
451	Overall	Mrs. Norris	Hilltop	630	60	4	
452	Overall, ½ mile E	William Riggs	Plain	640	48	5	
453	Overall, 2 miles NE	Jessie Beasley	do	610±	114	5⅝	6
456	Rockvale, ½ mile NE	C. E. Yeargan	do	750	101	6	5
457	Rucker, 3¾ miles W	Thomas Stokes	do	650±	53	5	
458	Rucker, 2¾ miles W	Roy Moulton	do	645	149	5	
459	Rucker, ¼ mile N	Nashville, Chattanooga & St. Louis Ry	do	665	22–55	Minimum 6	

460	Rucker, 4½ miles E		do		20-100	6±	
463	Eagleville, 3¾ miles E	Puckett's store	do	735	50	5½±	
464	Rockvale, 2½ miles SW	Walter Ferris	Ridge crest	780	103	5	
465	Christiana, ¼ mile S	Nashville, Chattanooga & St. Louis Ry	Plain	690	18	48	18
467	Fosterville, ½ mile N	do	Hillside	830	118	5	32

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
405	60	Solution channel	Ridley limestone	-54		3½			Water turbid after general rain.
407	66	Cherty limestone	do	-48	Bucket and rope	1/20		Domestic	
408	100	Bedding-plane crevice.	Ridley (?) limestone.	-50	do	2		Domestic, stock	
409	Near bottom.	Shale	do	-70	do	2		Domestic	
410	90	Shaly bed	Murfreesboro limestone.	-65	Gasoline force pump	3½		do	Drawdown reported as 15 feet pumping about 7 gallons a minute.
412	85	do	Ridley (?) limestone.	-40	Bucket and rope	3½		do	Cased through dry solution cavity.
414	60	Shale	Ridley limestone	-44	Gasoline force pump	3½		Stock	Drawdown reported as 18 feet pumping about 7 gallons a minute.
415	100, 135	Limestone	Murfreesboro limestone.		None	6		None	Ultimate capacity about 6 gallons a minute or less in each of three wells.
419	115	Shale	do	-26	Bucket and rope	4		Domestic, stock	Drawdown reported as 70 feet pumping about 4 gallons a minute.
420	75	Solution crevice	do	-40	Hand pump			Drinking	
421	95	Bedding-plane crevice.	do	-60	do	⅕		Domestic	
422	135	Solution crevice	do	-40	do	3		Stock	
423								None	Dry hole; casing head in Hermitage formation; bottom reaches Murfreesboro limestone.
424	Near bottom.	Limestone	do	-35	do	3		Drinking	
426	105		do	-40	None			None	Very highly concentrated water. Small yield of water also obtained at depth of 90 feet.
[a] 427	70	Limestone	do	-3	do		62	do	Test well by Franklin Oil & Fuel Co. Depth in October, 1927, with drilling in progress.
429	43	Solution crevice	Ridley limestone	-32				Stock	
430	110±	Limestone	Murfreesboro limestone.	-60	Hand pump	5		Drinking	Drawdown reported as less than 20 feet pumping 5 gallons a minute.
[a] 431	Near bottom.	Bedding-plane crevice.	Pierce or Murfreesboro limestone.	-17	do	3-5	60	Domestic	

[a] See analysis, pp. 118-119.

Typical wells in Rutherford County, Tenn.—Continued

[Nos. 436 and 459 dug and drilled; No. 451 bored; No. 465 dug; all others drilled]

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
[a] 432	Near bottom.	Bedding-plane crevice	Murfreesboro limestone.	−60	Bucket and windlass		60	Domestic	Yielded so-called black sulphur water for about 2 years after drilling, but water is now clear, though highly charged with hydrogen sulphide.
[a] 433	80	Solution channel	do	−10	Air lift	10–12	60	Cooling	Well No. 4. A minor water-bearing bed possibly exists at depth of 350 feet.
434	65–70	do	do	−10	None	5		None	Ultimate capacity 5 gallons a minute. Some water from soft limestone at 220 feet.
[a] 435	50, 65	Solution channels	do	−30	Air lift	75–300	60	Cooling	Well No. 2. Capacity increases and becomes turbid after heavy rains.
436	46, 55	Soft limestone	do		None	10		None	Open well 18 feet in diameter and 23 feet deep, with drilled hole 8 inches in diameter in bottom to total depth of 86 feet.
437	240	Limestone	Below Murfreesboro limestone (?).	−30	Air lift	Limited		do	Pumps dry in a few minutes.
440	60–75	Solution channels	Murfreesboro limestone.	−10	do	250 ea	60	Municipal	Group of 5 stand-by wells; several water-bearing beds between 60 and 200 feet in depth. Drawdown reported as 40 feet pumping 250 gallons a minute from each well.
441	237	Limestone	Not named	−17	do	200	60	Ice plant	Drawdown reported 48 feet pumping about 200 gallons a minute.
442	95	Solution crevice	Murfreesboro limestone.	−60	Electric force pump			Domestic, stock	
445	Near bottom.	Bedding-plane crevice.	do	−30				Domestic	
447	32	Solution channel	Lebanon limestone	−25				Drinking	Solution channel clogged with silt.
448	Near bottom.	Bedding-plane channel.	Ridley limestone	−45	Bucket and rope	5±		Stock	
451	do	Solution crevice	Ridley (?) limestone.	−40±	Hand pump	3		Domestic	Other wells of the vicinity are 30 to 75 feet deep.
452	do	Solution channel	do	−25±		5			
453	110	do	Murfreesboro limestone.	−10	None			None	Water very salty and unusable.
456	100	Bedding-plane crevice.	Ridley (?) limestone.	−35	Steam force pump	5–10		Abandoned	Formerly used for boiler feed at pencil mill.
457	Near bottom.	Solution channel	Murfreesboro limestone.	−10	Bucket and rope			Domestic	

458	138		do							Very small yield.
459	Near bottom.	Limestone	Ridley limestone		Buckets				Domestic	Group of 16 wells at Rucker section houses, of which 12 wells failed in drought of 1925.
460		do	do		do				do	Miscellaneous wells in and near village of Gum. Usually adequate for domestic supply.
463	45	Bedding-plane crevice.	do	−20	Bucket and rope	½			do	
464	102	do	do	−75	do	½			Domestic, stock	
465	Near bottom.	Gravelly soil	Alluvium		Steam and hand pumps.				Domestic, railroad	Wells at Christiana station. One well 7 feet square and 18 feet deep, used as auxiliary locomotive-boiler feed.
467	106	Limestone	Ridley limestone	−84		10			Domestic	Well at Fosterville section foreman's dwelling. Drawdown 22 feet pumping 10 gallons a minute for 2 hours.

[a] See analysis, pp. 118–119.

Typical springs in Rutherford County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
404	Lavergne, ½ mile NW	Nashville, Chattanooga, & St. Louis Ry.		Plain		
406	Smyrna, 4½ miles NE	J. J. Anderson	Jefferson Spring	Valley	475	Ridley limestone.
411	Smyrna, 6 miles SW	W. D. Wood	Rock Spring	Hillside	680	Carters limestone member.
413	Smyrna, 3¾ miles SW	H. A. Lee	Love Davis Cave	Plain	645	Ridley limestone.
416	Florence, 2¾ miles NE			River trench	495	Do.
417	Florence, 2½ miles NE			Plain	500	Do.
418	Florence, 2¼ miles NE			do	505	Do.
425	Murfreesboro, 5 miles N		Sulphur Spring	do	560	Do.
428	Murfreesboro, 4 miles NE	D. Dement	Ward Spring	do	595	Do.
438	Murfreesboro	D. James	Sand Spring	do	580	Murfreesboro limestone.
439	do	City of Murfreesboro		do	580	Do.
443	Murfreesboro, 3¼ miles NE		Shiloh Caves	do	585	Ridley limestone.
444	Murfreesboro, 3½ miles E	William Dill	Double Spring	do	620	Do.
446	Murfreesboro, 6¼ miles E			Hillside	655	Lebanon limestone.
449	Rockvale, 4 miles N	Sam Hendricks		Plain	620	Ridley limestone.
450	Rockvale, 3½ miles N	James Jarrett	Blue Sink	do	620	Do.
454	Murfreesboro, 5 miles SE	Robert Harrell	Fox Camp Spring	do	620	Do.
455	Rockvale, 1½ miles W	James Ferris	Snail Shell Cave	do	665	Do.
461	Rucker, 5¼ miles SE	Wilson Aubury		do	670	Lebanon limestone.
462	Eagleville, 2 miles E	R. S. Brown, jr		do	720	Alluvium above Lebanon limestone.
466	Christiana, 9 miles E	W. H. Robinson	Big Spring	Valley	710	Lebanon limestone.

[Table continued on pp. 188–189]

Typical springs in Rutherford County, Tenn.—Continued

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
404	1	Sink-hole conduit to large solution channel.			Seasonal	Railroad		Pumped about 100 gallons a minute for periods of several hours; perennial spring.
406	2	Joint crevices	1	Aug. 7		Drinking, medicinal.	62	Submerged by high stages of Stone River. Water has slight content of hydrogen sulphide.
411	2	Bedding-plane channels	¼	Aug. 10	Seasonal	Domestic	61	Perennial spring.
413	1	Sink-hole conduit to large solution channel.	50	do	do	Stock	62	Yield increases and water becomes very turbid after heavy rain; direction of flow N. 70° E.
416	1	Bedding-plane solution channel.	1,000±	Aug. 7	Probably seasonal			Water turbid. Probably underground cut-off across river meander. (416, 417, 418)
417	1	Sink hole 75 yards long, 20 yards wide, 20 feet deep.	do	do	do			
418	1	Sink hole 50 feet in diameter and 15 feet deep.	do	do	do		60	
425	1	Concealed	Very small	do		Formerly medicinal.		Water contains small amount of hydrogen sulphide.
428	1	Large bedding-plane solution channel.	2,500± 5,000+	do Aug. 11	Seasonal			Permanent head of Bushnell Creek. Yield increases and water becomes very turbid after long local rain.
438	1	Joint-plane channel	100 None	Aug. 9 Sept. 15	do	None	60.5	Yield and turbidity vary less abruptly than in No. 539.
[a] 439	2	Solution channels along joints	200–700		do	Municipal		Tabulated yield is pumpage. Natural flow of spring increases and water becomes very turbid after heavy rain. Reported maximum yield 700 gallons a minute; reported minimum 200 gallons a minute.
443	4	Solution channels with roof collapsed along joints.	No flow visible.	Aug. 7	Probably seasonal			
444	2	Bedding-plane channels	100	do	Seasonal	Domestic, stock	61	Perennial spring. Water becomes turbid after rain to the southeast.
446	1		15	Aug. 9	Seasonal, probably intermittent.	None		Drains radially into large sink hole.
449	1	Bedding-plane solution channels.	6,000±	Aug. 11	Flashy, seasonal	Stock	61	Yield increases and water becomes very turbid a few hours after heavy rains.
450	1	Sink hole 75 yards wide, 200 yards long, 50 feet deep.	No flow visible.	do	Seasonal	None		
454	1	Sink-hole pool 75 yards in diameter.	250	Aug. 8	do	Stock		Large seasonal fluctuation. During drought of 1925 spring was pumped by city of Murfreesboro 2,250 gallons a minute with drawdown of 18 feet in 3 hours.

455	1	Large solution channel exposed by collapse of roof along joint.	125± 10±	Aug. 11 Sept. 25	do	None	58	
461	1	Joint and bedding-plane channels.	25	Aug. 9	do	Stock	62	Water extremely turbid after heavy rain.
[a] 462	1	Concealed	725 25	Aug. 11 Oct. 11	do		59	Perennial head of Harpeth River.
[a] 466	1	Bedding-plane channel	100 20	Aug. 9 Sept. 15	do	Domestic, stock	62	Yield increases after long rain.

[a] See analysis, pp. 118-119.

Driller's log of well on William Webb estate

[No. 423, pl. 4]

Limestone, soft, dark	0– 90
Limestone, gray, dense	90–107
Limestone, dark, soft	107–130
Flint [chert?]	130–133
Limestone, soft	133–142
Limestone	142–154
Limestone, reddish gray, with layers of white chert 3 feet apart	154–192
Limestone	192–204
Limestone, dark, soft	204–212
Limestone, buff, with black chert	212–292
Limestone, white, thin bedded	292–322
Shale, black	332–400
Limestone, cherty at top	400–440
Limestone, bluish black, earthy	440–446

STEWART COUNTY

[Area, 449 square miles. Population, 13,278]

GENERAL FEATURES

Stewart County, which occupies the northwest corner of the region described in this report (pl. 1), is bounded on the west by the Tennessee River, on the north by Kentucky, on the east by Montgomery County, and on the south by Houston County. Its density of population, as in the other counties along the east side of the Tennessee River Valley, is less than in other parts of north-central Tennessee. The county seat, Dover (estimated population, 406), is on the south bank of the Cumberland River near the geographic center of the county.

Although the county lies in the physiographic district known as the Highland Rim plateau (pp. 16–18), only a part of its northeastern quadrant shows any extensive level tracts such as are characteristic of that peneplain. Most of the county is deeply dissected by the subparallel tributaries of the Tennessee River and of the Cumberland River, which traverses the county from southeast to northwest. Even in this dissected area, however, the crest of the divide between the Tennessee and Cumberland Rivers and the crests of many of the subordinate ridges have not been reduced below the peneplain level. These peneplain remnants rise southward from an altitude of about 525 to 600 feet above sea level along the northern boundary of the county to nearly 750 feet above sea level along its southern boundary. The master streams are about 300 to 335 feet above sea level, so that the total relief in the county is about 450 feet. A part of this relief is expressed in open mature valleys at the heads of tributary streams, but by far the greater part in narrow youthful trenches of the master streams and of the lower reaches of the tributaries.

In addition to recent alluvial deposits along the major streams, Stewart County embraces both unconsolidated and consolidated rocks, which range in age from Upper Cretaceous to Lower Ordovician, although the full stratigraphic sequence of the Nashville Basin is not recognized. The unconsolidated deposits include the fine micaceous sands of the Eutaw formation and the underlying chert gravel of the Tuscaloosa formation, which cover an extensive tract on the divide between the Tennessee and Cumberland Rivers in the northwest corner of the county. (See pl. 4.) The Tuscaloosa formation also occurs in a small area on the crest of the ridge west of Bear Spring. The youngest of the consolidated rocks are the massive and medium-bedded St. Louis limestone and Warsaw formation, which constitute the bedrock over the greater part of the county. Visible exposures of these beds are uncommon, however, except in the youthful stream trenches, for on all the remnants of the Highland Rim peneplain the bedrock is covered by 50 to 75 feet of residual clayey débris. The underlying Fort Payne formation, which in this county is a dense thin-bedded and extremely cherty limestone, crops out over the lower valley slopes of the Tennessee River and its tributaries in the western part of the county, also in the lower part of the Wells Creek Basin, near the southeast corner of the county. The carbonaceous Chattanooga shale underlies the Fort Payne formation and crops out just above stream level in the Tennessee River Valley at the mouth of Standing Rock Creek and farther north. It also crops out as a peripheral band surrounding the Wells Creek uplift and elsewhere in the Wells Creek Basin. The uppermost of the pre-Chattanooga rocks, which crop out only in the Wells Creek Basin, include the Linden formation, of Lower Devonian age, and a rather full sequence of Silurian limestones. These are in turn underlain by the Hermitage formation and the Lowville limestone, both of lower Middle Ordovician age, all Upper Ordovician strata and the upper part of the Middle Ordovician being absent. The Lowville is underlain directly by limestone of earliest Ordovician (Beekmantown?) age, which is the oldest rock cropping out in north-central Tennessee. The general character and stratigraphic relations of both the unconsolidated and consolidated rocks are discussed on pages 24–58, and their areal distribution is shown on Plate 4. However, the stratigraphic relations within the Wells Creek Basin are known only approximately.

Stewart County lies on the flank of the Nashville dome, so that in general the strata constitute a monocline dipping very slightly northwestward. In the extreme southeast corner of the county, however, this regional structure is modified by the Wells Creek uplift (pp. 65–67), within which the strata are steeply upturned, locally folded, and complexly faulted.

Small steeply tilted blocks also occur about 2 miles east of Cumberland City, although the structural conditions are not fully known and can not be delineated on the scale of Plate 4.

GROUND-WATER CONDITIONS

In Stewart County, as in other parts of the Highland Rim plateau where the bedrock consists of the St. Louis limestone, the residual clay mantle on the upland tracts contains little coarse material and generally yields very little ground water. Hence, most residents of the upland store rain water in cisterns for domestic supply and impound storm run-off in small artificial ponds for watering stock. On the other hand, a few derive water from rather deep dug wells or from drilled wells that enter the limestone. No wells are known to find potable water more than 175 feet below the surface or water of any character more than 350 feet below the surface, as in well 34 (pl. 4 and pp. 194–195), which is 1,636 feet deep. On the plateau remnants in the deeply dissected western part of the county the channeled zones in the upper part of the limestone may be drained, so that it is impossible to obtain an adequate water supply even for domestic purposes by drilling. The Eutaw and Tuscaloosa formations, which underlie a part of the plateau (pl. 4), contain beds of permeable material that should yield water freely where they are not drained by the valleys of tributary streams. However, the part of the plateau that is underlain by these formations is in general very sparsely populated and is covered with a dense growth of timber, so that nothing is known of the actual water-bearing conditions.

In the stream valleys and on the lower slopes of the dissected areas many dug wells derive water from alluvium or from hill wash. Ground-water conditions in the underlying limestone differ greatly from place to place, although drilled wells usually find water less than 100 feet below the surface. In general, however, water-bearing beds are not likely to be found far below the level of the near-by perennial streams. Probably the most reliable sources of ground water in the dissected parts of the county are the tubular springs that issue from the limestone (pp. 92–95), many of which are used for domestic supplies and for stock. The discharge of some of these springs is relatively invariable; that of others may vary greatly from season to season, even though the minimum discharge may be large. Hence the reliability of a spring can be determined only by periodic measurements of its discharge over a term of several years. Large springs of this sort seem to be especially numerous at two levels—on the lower reaches of the tributary streams from 25 to 50 feet above the Tennessee and Cumberland Rivers, and near the heads of the tributaries not far below the remnants of the Highland Rim plateau. Many seepage springs (pp. 90–92) of relatively small discharge also issue from the hill wash and weathered rocks in the lower parts of the dissected areas, especially in the closely jointed cherty limestones of the Wells Creek Basin. Some of these springs are perennial and constitute reliable sources of water for domestic purposes.

Most of the ground waters of Stewart County are moderately concentrated and moderately hard calcium bicarbonate waters such as those whose analyses are tabulated on pages 110–111. Waters associated with the Chattanooga shale in the vicinity of its outcrop, however, are likely to be rather high in iron and to contain appreciable quantities of hydrogen sulphide. Here, as in other parts of north-central Tennessee, ground water that occurs in the Mississippian limestone at moderate depth may be rather high in noncarbonate hardness and may contain considerable hydrogen sulphide.

Typical wells in Stewart County, Tenn.

[Nos. 11, 14, and 15 dug; all others drilled]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Depth to which well is cased (feet)	Diameter of well (inches)
6	Bumpus Mills, ¾ mile S	W. P. Luten	Hillside	425	48	38	5⅝
8	Big Rock	V. N. Lee	Valley	515	28		6
10	Weaver's store, 2¼ miles NW	W. W. Outlaw	Plateau	510	188	80±	6
11	Weaver's store, 1½ miles W	Will Norflitt	do	515	100±		48
12	Weaver's store, 2 miles S	Steve Hester	do	510	65±		
14	Tharpe	R. L. Whitford	Valley	385	30	30	28
15	Tharpe, 3½ miles SW	—— Herndon	Ridge crest		78		
19	Dover, 5¾ miles NW	B. F. Riggins	Valley	405	75	60	6
20	Dover, 4¼ miles NW	W. T. Crisp	do	485	72	50	5⅝
22	Dover, ¾ mile W	U. S. National Cemetery	Ridge crest	490	200–300±		
23	Dover	Aleck Morgan	Hillside	390	90		
24	Indian Mound, 4½ miles N	Mrs. Bert Smith estate	Upland	670	164	132	5⅝
26	Indian Mound, 3 miles W	J. A. Keatts	Ridge crest		275±		
27	Indian Mound	C. K. Keatts	Valley	355	55	20	
33	Mobley, 2¾ miles NW	J. A. Gray	do	380	548	65	12
34	Mobley, 3 miles E	Marvin Milton	do	430	1,636		

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remarks
	Depth below surface (feet)	Character of material	Geologic horizon						
[a] 6	48		Chert residuum above St. Louis or Warsaw limestone.	−10	Bucket and rope			Domestic	
8	12–18	Solution channel	do	− 7±	Hand pump	3–5	62	do	Other wells of vicinity range between 10 and 60 feet deep; all supplied by solution crevices.
10	85	Bedding-plane crevice.	St. Louis or Warsaw limestone (?).	−90	Hand and gasoline pump.	½			In Trigg County, Ky.
11	Near bottom.		Cherty residuum above St. Louis or Warsaw limestone.	−75±	Bucket and rope		57	Domestic	Many cisterns used in vicinity.

12			St. Louis or Warsaw limestone.		Hand pump			do	
14	Near bottom.		Cherty residuum above St. Louis or Warsaw limestone.	−10–25	Bucket and rope			do	Maximum draft 50 to 75 gallons a day.
15			Weathered St. Louis or Warsaw limestone.		None			None	Very little water.
[a] 19	75	Gravel	Alluvium or chert residuum above limestone.	−10	Hand pump		60	Stock	Reported to flow during seasons of high precipitation.
20	50±	Cherty limestone	St. Louis or Warsaw limestone.		do	3–5	58	do	
22			St. Louis or Warsaw limestone(?).			Very small		Abandoned	
23			St. Louis or Warsaw limestone.					Domestic	
[a] 24	162	Bedding-plane crevice.	do	−144	Bucket and rope		58	do	Water hard for laundering.
26	Near bottom.	do	do						
[a] 27	do	do	do	−20	Hand pump	3	58	Domestic	
33								None	Test well for petroleum. No water-bearing beds below Chattanooga shale, base of which is 60 feet below surface.
34	239	Limestone	Not known		None			do	Test well for petroleum by Midwest Tennessee Oil Co. Top of Chattanooga shale at depth of 164 feet; no water-bearing beds below 350 feet.

[a] See analysis, pp. 110–111.

Typical springs in Stewart County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
1	Model, 5½ miles W	W. C. Outland	Cedar Spring	Valley	375	Fort Payne formation.
2	Model, 2½ miles N	J. H. Hicks	Hicks Spring	do	395	Chert detritus above St. Louis or Warsaw limestone.
3	Model, ¼ mile SE	A. D. Russell, M. D.		do	460	St. Louis or Warsaw limestone.
4	Tobaccoport, 1½ miles NE	Mrs. Nannie Wallace	Shelby Spring	do	340	Do.
5	Bumpus Mills, ½ mile NW	Roy Hargis		do	335	Do.
7	Bumpus Mills, 2¾ miles NE	Byrd Scott		do	345	Do.
9	Big Rock, 1¾ miles SE	M. F. Brandon	Brown Spring	do	395	Do.
13	Tharpe, 7 miles W	J. W. Tishell	Maynard Spring	do	390	Fort Payne formation.
16	Tharpe, 2¼ miles SE	George Brannon	Brannon or Gatling Spring	do	360	St. Louis or Warsaw limestone.
17	Tharpe, 4½ miles SE	A. H. Wallace	Brandon Spring	do	325	St. Louis limestone.
18	Fort Henry, 3½ miles NE	B. C. Rowlett	Blue Spring	do	375	Fort Payne formation.
21	Dover, 3½ miles NW	J. M. Fitzhugh		do	410	St. Louis or Warsaw limestone.
25	Indian Mound, 3¾ miles N	Claude Johnson	Cold Smith Spring	do	445	Do.
28	Indian Mound, ½ mile N	T. W. Seay	Seay Spring	do	355	Do.
29	Indian Mound, 5 miles NE	Robert Halliday	Blue Spring	do	505	Do.
30	Bear Spring	H. B. Howard	Bear Spring	do	420	Do.
31	Bear Spring, 2¾ miles NE	G. E. Halliday	Lee or Stall Spring	do	330	Do.
32	Mobley, 3¾ miles NW	J. W. Wofford	Wofford Spring	do	360	Fort Payne formation.
35	Mobley, 4½ miles E	W. H. Cox Estate		do	460	Do.
36	Bear Spring, 3¼ miles S	Dover Iron Co	Carlisle Spring	do	390	St. Louis or Warsaw limestone.
37	Cumberland City, 1 mile E	Wallace Bros	Lewis Spring	Valley plain	355	Alluvium above St. Louis or Warsaw limestone.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
[a] 1	1	Bedding-plane channel	500±	Sept. 23	Seasonal	None	54	Perennial head of Rushing Creek.
2	1	Concealed; probably joint channel.	25	do	do	Domestic, stock	56	Perennial head of Pryors Creek.
3	1	Large solution channel	3-5	do	do	do	58	Perennial spring.
4	1	Concealed; probably solution channel.	900	Sept. 22	do	None	57	Perennial head of creek.
5	1	Joint-plane channel	5	Sept. 21	do	Domestic, stock	58	Perennial spring.
7	1	Bedding-plane channel	2,000	do	do		58	
9	1	do	225	do	do		58	Perennial head of creek.
13	1	Concealed; probably bedding-plane channel.	15	Sept. 23	do	None	58	Yield increases and water becomes turbid during rainy periods.
16	3	Bedding-plane channels	300	do	do	do	56	Perennial head of creek.
17	1	Concealed; probably solution channel.	525	Sept. 22	Probably seasonal	Sawmill boiler	56	Reported minimum yield about 500 gallons a minute.
18	1	Bedding-plane channel	1,200	Sept. 23	Seasonal	None	56	Perennial head of Panther Creek. Becomes turbid after protracted regional rain.
21	1	do	2	do	do	Domestic	63	
25	3	Bedding-plane and joint channels.	200	Sept. 21	do		56	Perennial head of creek.
28	1	Bedding-plane channel	25±	do	do	Domestic, stock	60	
29	1	do	5-8	do	do	Stock	56	Perennial spring.
30	1	do	1	Sept. 20	do	Domestic, stock	58	Perennial spring. Water turbid after very heavy rain.
31	1	do	350	Sept. 21	do	do	56	
[a] 32	2	Concealed; probably bedding-plane channels.	200	Sept. 24	do	do	56	Water reported never turbid; reported minimum yield about 200 gallons a minute.
[a] 35	1	Bedding-plane channel	150	Sept. 22	do	do	54	Perennial head of creek.
36	1	do	5	Sept. 20	do	Domestic	55	Perennial spring.
37	1	Concealed	125	do	do	do	58	Do.

[a] See analysis, pp. 110-111.

Driller's partial log of Midwest Tennessee Oil Co.'s well on Marvin Milton property

[No. 34, pl. 4. So-called Standing Rock Well; casing head about 430 feet above sea level; total depth, 1,636 feet]

	Feet
Soil	0–30
Chert, dense	30–164
Shale, black (Chattanooga shale)	164–239
Limestone, white and brown, water bearing	239–375
Limestone, petroliferous	375–380
Limestone, dense, brown	380–495
Shale, blue	495–597
Limestone, white	597–602
Limestone, gray	602–608
Limestone, brown	608–612
Limestone, red	612–670
Limestone, white	670–696
Shale, green	696–706
Limestone and shale, brown	706–742
Limestone, red	742–904
Limestone, white	904–924
Limestone, dark blue	924–1,129
Limestone, gray	1,129–1,220

SUMNER COUNTY

[Area, 558 square miles. Population, 28,622]

GENERAL FEATURES

Sumner County, which occupies the northeast corner of the region covered by this report (pl. 1), is bounded on the west by Robertson County, on the southwest by Davidson County, and on the south by Wilson County. Its county seat and principal commercial center is Gallatin (population, 3,050).

Sumner County is divided into two physiographic districts of nearly equal area by the Highland Rim escarpment; to the north lies the Highland Rim plateau; to the south lies the northern lobe of the Nashville Basin (pp. 16–18). In this county the Highland Rim plateau is a very gently undulating plain which slopes northward from an altitude of about 900 feet above sea level along its southern edge to about 775 to 880 feet in the northwestern part of the county. This plain is drained northwestward by subparallel mature valleys tributary to the Red and Green Rivers, branches of the Cumberland and Ohio Rivers, respectively. (See pl. 3.) Undrained depressions and sink holes are common in many parts of the plain. The Highland Rim escarpment is a southward-facing dissected scarp from 350 to 400 feet high which embraces a belt of rugged topography from 4 to 7½ miles wide produced by the northward advance of Mansker, Drake, Station Camp, and Bledsoe Creeks, subparallel tributaries of the Cumberland River. Its general trend within the county as defined by a line tangent to the points of protruding spurs is approximately N. 70° E. The Nashville Basin, which lies south of the escarpment, is a rolling terrane whose summits—level tracts from 550 to 600 feet above the sea—are remnants of the Nashville Basin peneplain and whose drains are youthful to submature valleys adjusted to the present stage of the Cumberland River, about 400 feet above sea level. Numerous sink holes and undrained depressions occur along the southern edge of the county in the meander belt of the Cumberland River.

The unconsolidated rocks of Sumner County include clay, sand, and gravel deposited by the Cumberland River and its larger tributaries during recent erosion cycles, also the mantle of residual clay and chert fragments, at least 60 feet in maximum thickness, which covers the bedrock of the Highland Rim peneplain.

Inasmuch as the county lies on the north flank of the Nashville dome (pp. 62–63), its consolidated rocks constitute a monocline dipping very slightly toward the north-northwest. Its geologic column embraces strata that range in age from Mississippian to probably Lower Ordovician. The youngest of these, the massive and somewhat cherty St. Louis limestone, constitutes the bedrock beneath the Highland Rim plateau in the extreme northwestern part of the county, although its visible exposures are limited to the steeper valley slopes. This limestone is underlain successively by the Warsaw formation, which comprises clay shale, calcareous shale, and thin beds of cherty limestone near the top and bottom of its section, and by the Fort Payne formation, which in this county consists of thin-bedded limestone containing much nodular and tabular chert, with some sandy beds. The Fort Payne formation is the bedrock of the Highland Rim plateau in the northeastern quadrant of the county; it also crops out in the deeper valleys farther west and on the uppermost slopes of the Highland Rim escarpment. In the middle slopes of the escarpment this formation is underlain in succession by the interbedded limestone and calcareous shale that constitute the New Providence shale, by the carbonaceous Chattanooga shale, and possibly by the Pegram limestone (Middle Devonian) or other rocks of Devonian age. The Chattanooga shale—or the Middle or Lower Devonian if present in Sumner County—is underlain by Silurian limestone, earthy limestone, and shale, which constitute a full sequence from the Lobelville limestone down to and including the Brassfield limestone. Of this sequence the Lobelville and Laurel limestones both contain sandy beds that should be permeable to water. The Brassfield limestone is underlain in turn by clay and shale and by massive gray limestone, which may represent the Fernvale and Arnheim formations, respectively, of latest Upper Ordovician (Richmond) age. These beds crop out along the base of the Highland Rim escarpment. Farther south, on the Nashville Basin peneplain, the Arnheim is underlain by limestones of Upper (?) and Middle Ordovician age, the older rocks cropping out successively toward the south. The oldest rocks of the county, which crop out along the Cumberland River, may belong to the uppermost part of the Stones River group, of Lower Ordovician age, although the stratigraphy of the Ordovician rocks in that part of the county has not been traced. The general character and stratigraphic relations of the consolidated rocks that are exposed in Sumner County are discussed on pages 33–58, and their areal distribution is shown on Plate 4.

GROUND-WATER CONDITIONS

Of the rocks that lie within reach of the drill in Sumner County, only the sandy beds associated with the Pegram, Lobelville, and Laurel limestones are likely to be permeable over extensive areas. These beds, which lie just below the Chattanooga shale, crop out along the Highland Rim escarpment and are potential water bearers only on the plateau farther north. The few wells that reach their horizons, however, either find the beds to be impermeable or to yield highly concentrated salt water with hydrogen sulphide. The overlying Chattanooga shale is also reported to contain salt water at many places, as in wells 117, 118, and 120 (pl. 4 and pp. 204–205). In the other rocks, all of which are limestones, the only water-bearing openings are bedding planes, joints, and solution channels, whose number and transmission capacity are not at all uniform within any one stratum but are rather related to physiographic environment (pp. 78–82).

On the Highland Rim plateau the residual clay that overlies the St. Louis limestone in the northwestern part of the county contains very little coarse material and in general is not a source of ground water. Farther east, however, where the Fort Payne formation constitutes the bedrock, the residual material contains many chert fragments, and some of it yields sufficient water to dug wells and a few drilled wells for household supplies and for stock. The most permeable zone is usually just above the bedrock. Some of the shallower dug wells are inadequate in periods of extreme drought, so that water is drawn from cisterns. Comparatively few wells have been drilled into the limestone that underlies the residual material, although some of them find sufficient water for domestic purposes between 50 and 100 feet below the surface. Others, however, are inadequate for household use, and a few have failed to find water-bearing beds. The ground water from the residual clay and from the uppermost beds of the underlying limestone is generally satisfactory for any ordinary purpose, containing a moderate amount of dissolved mineral matter and being only moderately hard. Analyses 115 and 121 (pp. 112–113) are representative. However, some of the ground water that occurs in the limestone less than 100 feet below the surface and much of that at greater depth is high in noncarbonate hardness and in hydrogen sulphide and contains so much dissolved matter as to be unfit for most purposes. To judge from conditions in other parts of the Highland Rim plateau it is likely that all strata underlying the Chattanooga shale or much more than 200 feet below the surface are dry or contain only highly concentrated brine such as that represented by analysis 120. Hence in the upland areas deep drilling for water is generally inadvisable.

Along the Highland Rim escarpment and in other deeply dissected parts of the county ground-water conditions are most variable, for channeled zones in the limestone have not adjusted themselves to the present erosion cycle. Hence water-bearing zones are discontinuous and are not likely to occur far below the level of the perennial streams. Most successful drilled wells in these areas are less than 50 feet deep. Fortunately, perennial seepage and tubular springs (pp. 90–95) are numerous and constitute an adequate and reliable source of water in many places. Seepage springs are especially abundant along the weathered outcrops of extremely cherty members in the Fort Payne formation and at the top of the Chattanooga shale, an impermeable stratum that prevents downward percolation of ground water. The larger of the tubular springs generally occur at the perennial heads of the tributary streams, about 75 or 100 feet below the Highland Rim peneplain, such as No. 115 (p. 206). The aggregate discharge from such springs constitutes the ground-water drainage from the peneplain tracts. Generally, the water from the intermittent springs and from those perennial springs that discharge several gallons a minute or more is suitable for any ordinary use. On the other hand, the water from some of the smaller seepage springs is unsuitable for many uses, that which issues from the Chattanooga shale being generally high in iron and in hydrogen sulphide. Furthermore, the water that issues from some of the earthy beds of the Fort Payne formation is extremely high in noncarbonate or permanent hardness and contains appreciable quantities of hydrogen sulphide, as is represented by analysis 126. In some places along the lower slopes of the Highland Rim escarpment and near its base the Silurian and Ordovician rocks contain hard hydrogen sulphide water or highly concentrated brine only 50 feet below stream level, so that potable water may not be obtainable from drilled wells. In the vicinity of Bethpage, for example, well 123 derives water of good quality from the Leipers limestone or the Catheys formation 38 feet below the surface. Of two wells on the D. Beard property, a quarter of a mile southwest of well 123, one encounters "black sulphur" water and the other "white sulphur" water—waters containing hydrogen sulphide with and without an appreciable quantity of iron, respectively. In the same vicinity wells more than 50 feet deep generally encounter concentrated salt water in the Ordovician rocks, from which brine was formerly pumped and evaporated to obtain salt for household use. In some wells the salty water contains a small amount of oil. In the hilly area southeast of Cottontown drilled wells encounter but little water, and that is inferior in quality and is associated with natural gas; hence it is in some places difficult or impossible to develop adequate household water supplies. Unfortunately, strata bearing fresh water are not likely to occur below those from which the salty and oil-bearing waters are obtained.

In the rolling country of the Nashville Basin, which constitutes the southernmost part of the county, ground-water conditions differ so greatly from place to place that it is impossible to predict the depth and water-yielding capacity of the permeable zones. In the interstream tracts many domestic water supplies are derived from drilled wells, most of which are between 25 and 50 feet deep. However, not all such wells obtain adequate supplies, and some are dry. Neither is this shallow ground water satisfactory in chemical character at all places, for it is generally high in noncarbonate hardness and may contain an appreciable quantity of hydrogen sulphide. Analyses 131 and 132 (pp. 112–113) are representative. In a few places the water is extremely concentrated in sulphate, chloride, and hydrogen sulphide, like that from Castalian Spring (analysis 137), and is quite unfit for all ordinary uses. Seemingly the earthy Middle Ordovician limestones that occupy much of this area have never been extensively channeled, and such permeable rocks as exist have been largely drained by the tributaries of the Cumberland River. Several relatively deep wells in Gallatin, such as Nos. 134, 135, and 136, reach a water-bearing zone from 124 to about 200 feet below the surface, at approximately the same altitude as the Cumberland River. The tested capacity of these wells, which is reported as 80 to 150 gallons a minute, is much greater than the capacity of any other known wells within the county. Furthermore, the water is only moderately concentrated, has only a very little noncarbonate hardness, and is suitable for all ordinary purposes if softened. Within the meander belt of the Cumberland River along the southern edge of the county the limestone is extremely cavernous and contains many sink holes into which the water is reported to rise from below when the river is in flood, the water level fluctuating with the stage of the river. Hence there are in this area systems of solution channels adjusted to the level of the river in its present erosion cycle, and it is possible that the deep wells at Gallatin tap a channeled zone that is tributary to one of these systems. If such is the case, it may be that ground water of satisfactory chemical character can be obtained at many other places south of the Highland Rim escarpment by drilling to or slightly below the level of the Cumberland River. However, no other wells as deep as those at

Gallatin are known to exist in the adjacent parts of the county, so that the water-yielding capacity of the rocks at the level of the river is not known.

MUNICIPAL GROUND-WATER SUPPLIES

Portland.—The only municipal ground-water supply in Sumner County is that of Portland (population 1,030), which derives its water from Cold Spring (No. 115, p. 206) and from another tubular spring about a quarter of a mile to the east. These springs, which are about 2 miles northeast of Portland and about 100 feet below the level of the Highland Rim peneplain in that vicinity, issue from solution channels along bedding planes in the St. Louis limestone or the Warsaw formation. Other springs and solution channels at approximately the same altitude indicate that the conduits of the municipal springs are parts of a system of channels that probably drains a rather extensive area of the peneplain. The discharge of the two springs in October, 1927, when the ground-water discharge was approximately the minimum for the season, was about 150,000 gallons a day; the maximum discharge of the springs is not known. At each orifice are a covered cut-off trench lined with concrete, suitable collecting mains, and a pump with a capacity of 100 gallons a minute. These pumps force the water directly into the distribution mains, in which the pressure is equalized by a 150,000-gallon elevated steel tank near the center of the town.

Typical wells in Sumner County, Tenn.

[All drilled wells]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
114	Portland, 1½ miles NE	W. M. Davis	Plateau	815	165	6	
117	Westmoreland, 7¼ miles N	Jake Miller No. 1	Hillside	770	257		
118	do	Jake Miller No. 2	do	760	255		
120	Westmoreland, 5 miles W	R. C. Troutt	Plateau	725	100	5⅝	
121	Westmoreland, ½ mile E	Sumner County High School	Ridge crest	980	65±	5⅝	35±
122	South Tunnel, 1½ miles NW	Oakland High School	Plateau	915	60±	6	
123	Bethpage, 3½ miles NE	L. G. Howard	Valley	595	38±	6	
125	White House, 3¾ miles S	Stewart & Terrell No. 2	do	630	203		
127	Cottontown	G. W. Mitchell	Hilltop	585	50-60	6	
128	Rogana, ¼ mile SE	H. M. Senter	Valley	540	30±	6	
130	Saundersville, 5½ miles NW		do	510	25-40	6	
131	Saundersville, 2½ miles NW	John Mirs	do	480	20	6±	
132	Saundersville	J. R. Durham	Plain	585	50	6	10
133	Saundersville, ½ mile E	Louisville & Nashville R. R.	do	555	41	6	
134	Gallatin	Gallatin Ice & Coal Co	do	525	168	8	15
135	do	Louisville & Nashville R. R.	do	520	300	8	8
136	do	do	do	520	227	8	

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
	Depth below surface (feet)	Character of material	Geologic horizon						
114	100	Bedding-plane crevice.	Warsaw limestone	−75(?)	Hand pump			Stock	Maximum draft about 150 gallons a day. Two near-by drilled wells 50 and 60 feet deep are inadequate for household use. Dug wells 40 to 60 feet deep in vicinity yield moderate supplies at base of zone of weathering.
117	80	Limestone	Fort Payne formation.		None			None	Test well for petroleum. Salt water from Chattanooga shale, whose top is 160 feet below surface.

118	84	do	do	do	do			do	Do.
[a] 120	60		Chattanooga shale (?).	+3 or more	Artesian flow	5	58	do	Most domestic supplies of vicinity come from hillside springs.
[a] 121	Near bottom.		Cherty residuum above Fort Payne formation.	−43			57	Drinking	Most wells of vicinity 40 to 50 feet deep and derive water from bottom of weathered zone.
[a] 122	do		Warsaw limestone	−20	Hand pump	3	58	do	
123		Limestone	Leipers limestone or Catheys formation.	−25–30				Domestic	Most wells of vicinity that are more than 50 feet deep encounter salt water.
[a] 125	115		Silurian system		None			None	Test well for petroleum. Top of Chattanooga shale 26 feet below surface.
[a] 127	Near bottom.	Limestone	Leipers (?) limestone.		Hand pump	3	58	Domestic	
128	do	Bedding-plane crevice.	Bigby (?) limestone.	−10	Gasoline force pump	3–5		Domestic, stock	
130	do	Limestone	Leipers limestone or Catheys formation.					Domestic	Miscellaneous wells in Worsham community.
131	20	Shale bed	Leipers (?) formation.	±0	Artesian flow	Trickle	62	Stock	
[a] 132	30	Bedding-plane crevice.	do	−30	Hand pump		58	Domestic	
133	Near bottom.		do					Abandoned	Former well at Avondale station; inadequate and polluted.
134	124	Flinty limestone	Cannon (?) limestone.	−35	Steam force pump	150	60		Two wells. Reported capacity 150 gallons a minute each.
[a] 135	200±		Bigby (?) limestone.	−50–100	do	80	58	Railroad	Gallatin water station. Consumption 80,000 to 200,000 gallons a day from wells 135 and 136.
136	200±		do		do	80	58	do	Ultimate capacity less than that of well 135.

[a] See analysis, pp. 112–113.

Typical springs in Sumner County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
115	Portland, 2 miles NE	J. Baskerville	Cold Spring	Valley	685	St. Louis or Warsaw limestone.
116	Portland, 7½ miles NE	Boiling Springs Church	Boiling Spring	Plateau	755	do.
119	Westmoreland, 4 miles N	Mrs. Carey Carter		Hillside	740	Fort Payne formation.
124	Bethpage, 3 miles NE	L. G. Howard	Tank Spring	do	705	Silurian system.
126	Whitehouse, 2¾ miles S	Mrs. Cartwright	Tyree Spring	Valley	685	Fort Payne formation.
129	Rogana, 2½ miles E	Charles Rogan		Plain	570	Bigby (?) limestone.
137	Castalian Springs	G. W. Wynne	Castalian Spring	Valley	505	Bigby limestone or uppermost Hermitage formation.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (°F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
[a] 115	1	Bedding-plane channel	100	Oct. 19	Seasonal	Municipal	58	Water turbid after rains.
116	1	Bedding-plane crevices	10	do	do	Domestic, stock	57	Perennial spring.
119	1	Bedding-plane channel	2	do	do	do	56	
124	Several.	Bedding-plane crevices	7	Oct. 18	do	Railroad	55	Perennial spring; supplies Louisville & Nashville R. R. watering station at Bransford.
[a] 126	1	Concealed	Trickle.	Oct. 20		Formerly medicinal.	58	So-called white sulphur water.
129	2	do	15	Oct. 18	Seasonal	Stock	58	Perennial head of creek.
[a] 137	1	Concealed; probably bedding-plane channel.	⅛	do		Medicinal	60	

[a] See analysis, pp. 112–113.

Driller's log of well No. 1 on Jake Miller property

[No. 117, pl. 4]

	Feet
Soil	0–3
Limestone; fresh water at 80 feet	3–121
Shale, green	121–160
Shale, black (Chattanooga shale); salt water	160–200
"Cap rock"	200–220
Sandstone	220–228
Limestone, white	228–239
Cavity	239–241
Sandstone	241–255
Limestone	255–257

Driller's log of well No. 2 on Jake Miller property

[No. 118, pl. 4]

	Feet
Soil	0–8
Limestone; fresh water at 84 feet	8–115
Shale, green	115–155
Limestone, earthy	155–160
Shale, black (Chattanooga shale); salt water	160–200
"Cap rock"	200–206
Shale, brown	206–221
Limestone, white; 6-inch cavity at 228 feet	221–245
Sandstone	245–255

Driller's partial log of Stewart & Terrell well No. 2

[No. 125, pl. 4]

	Feet
Soil.	
Limestone	?–58
Shale, black (Chattanooga shale)	58–84
Limestone, blue-gray	84–104
Limestone, light brown, sandy near bottom	104–114
Limestone, bluish-gray, sandy	114–117
Limestone, bluish-gray	117–147
Limestone, gray, sandy	147–153

WILLIAMSON COUNTY

[Area, 586 square miles. Population, 22,845]

GENERAL FEATURES

Williamson County, which occupies the south-central part of the region covered by this report (pl. 1), is bounded on the north by Cheatham and Davidson Counties, on the east by Rutherford County, and on the northwest by Dickson County. Its county seat, Franklin (population, 3,377), lies about 20 miles south of Nashville on the Louisville & Nashville Railroad.

Like Sumner County, Williamson County is divided into two physiographic districts of approximately equal area by the Highland Rim escarpment, which trends nearly due south through its center. The western half of the county, most of which is drained northward by the South Fork and other branches of the Harpeth River, is a part of the Highland Rim plateau (pp. 16–18). Its major ridge crests, remnants of the Highland Rim peneplain, increase in altitude from about 800 feet above sea level in the northwestern part of the county to 1,020 feet in its southwest corner. None of these remnants are extensive, however, for the peneplain has been dissected by the closely spaced youthful valleys of a dendritic drainage pattern. Hence the topography is rather rugged, especially along the southern boundary of the county, where the Harpeth and Duck Rivers are striving for drainage mastery. The eastern half of the county, which constitutes a part of the northern lobe of the Nashville Basin (p. 18), is drained northward by the Harpeth and West Harpeth Rivers. In their lower reaches these streams have planed laterally and have cut valley floors half a mile to 3 miles wide at 620 to 670 feet above sea level, a stage which is correlative with the much more extensive planation by the Stone River in Rutherford County. Furthermore, they have reduced the interstream tracts to groups of submature hills and branching ridges, the highest of which are in the south-central part of the county and range from 1,165 to 1,250 feet above sea level. These hilly tracts are outliers of the Highland Rim plateau.

The rocks that crop out in Williamson County constitute a rather full stratigraphic sequence from the St. Louis and Warsaw limestones of Mississippian age, to the Lebanon limestone, of Lower Ordovician age (pp. 33–54). The youngest stratigraphic unit, which comprises the St. Louis and Warsaw limestones, is made up of thick-bedded, somewhat cherty limestone and crops out over an extensive tract along the western boundary of the county. It also caps the higher ridges as far eastward as the Highland Rim escarpment but is not known at any point east of the West Harpeth River. (See pl. 4.) However, visible exposures of the rock generally occur only on the slopes of youthful valleys, for on the remnants of the Highland Rim peneplain it is overlain by residual clay and chert as much as 60 feet thick. The Warsaw limestone is underlain everywhere by the Fort Payne formation, which comprises thin beds of extremely cherty limestone and shale, sandy limestone, calcareous shale, and clay shale. These beds also cap outliers of the plateau in the north-central and south-central parts of the county as well as the highest summits of the ridge that trends southeastward across the county between the Harpeth and West Harpeth Rivers. In a few places, as on the slopes of Sugar Ridge, in the south-central part of the county, these beds are underlain by the New Providence shale, which consists of clay, shale, and lenses of massive crinoidal limestone. The Fort Payne formation, or the New Providence shale where that formation is present, is underlain in all parts of the county by the carbonaceous Chattanooga shale. This stratigraphic horizon marker crops out as a narrow band in the lower part of the Highland Rim escarpment and its many reentrants, also in the middle or upper part of the hill slopes farther east. It rests unconformably upon rocks that range in age from lower middle Silurian to Middle Ordovician, the pre-Chattanooga Devonian rocks being absent in all parts of the county and the Silurian and Upper Ordovician being absent east of Franklin. In a few places—particularly in the valleys of tributaries of Leipers Creek, a branch of the Duck River, near the southwest corner of the county; in the valley of the South Harpeth River near the northern boundary of the county; also between the West Harpeth River and Murphy Fork about 2½ miles east-southeast of Hillsboro—the Chattanooga shale rests upon the Osgood limestone or possibly upon younger beds of middle Silurian (Niagaran) age. In the same localities the Chattanooga shale, or the Osgood limestone where that formation is present, is underlain in turn by the soft green or chocolate-colored shale with associated bands of crystalline limestone and granular crystalline limestone that constitute the Fernvale and Arnheim formations, of Richmond age. The Leipers formation, which in this county comprises knotty earthy limestone and shale or granular crystalline limestone without shale, crops out at its proper stratigraphic horizon along the base of the Highland Rim escarpment, also in the lower and middle slopes of Sugar Ridge and of the hilly tract between Franklin and Brentwood. However, the formation thins eastward, both by unconformity at its top and by overlap at its base, and is not known to crop out south and east of Franklin. The Leipers formation, or the Chattanooga shale where the Leipers is absent, rests upon knotty earthy limestone and shale with associated thick beds of impure limestone. These beds, which constitute the Catheys formation, do not crop out anywhere in the county west of the Highland Rim escarpment. Together with the underlying massive Cannon limestone and the granular, crystalline, laminated Bigby limestone, the Catheys formation crops out on the lower slopes and about the flanks of the hilly tracts of the eastern half of the county. Stratigraphically beneath the Bigby limestone is the Hermitage formation, which in the central part of the county comprises sandy, granular, phosphatic limestone at the top and even-bedded shale and sandy limestone below, but which along the east edge of the county is largely thin-bedded sandy limestone. This formation crops out extensively along the flanks of the ridge that divides the Harpeth and West Harpeth Rivers in the central part of the county and on the middle and upper slopes of the hilly areas in the eastern part of the county. It is underlain successively by the massive compact cherty beds of the Lowville limestone and by the thin-bedded compact Lebanon limestone, of which the most extensive outcrop covers the floor and lower slopes of the Harpeth River Valley from the vicinity of Franklin eastward to and beyond the boundary of the county. The Lowville limestone is also exposed in an area about 3½ miles long in the West Harpeth River Valley between the Columbia and Lewisburg pikes. Both the Lowville and Lebanon limestones crop out in small areas in the south-central part of the county near the heads of the forks of Rutherford Creek, a branch of the Duck River. No rocks older than the Lebanon limestone are known to crop out within Williamson County.

Inasmuch as Williamson County lies on the western flank of the Nashville dome (pp. 62–63), its strata are generally inclined very slightly westward. However, they do not constitute a true monocline but are deformed by secondary open folds of small amplitude.

GROUND-WATER CONDITIONS

In Williamson County, as in other parts of north-central Tennessee, none of the unweathered rocks are permeable, so that ground water does not circulate in them except along joints or bedding planes or through tubular solution channels in the limestone. The number and size of the water-bearing openings of this sort are not uniform in all parts of the same stratum but are related to the geomorphologic history of the region (pp. 78–82). Hence ground-water conditions are in large measure the same throughout any one physiographic district.

On the remnants of the Highland Rim peneplain, in the western part of the county, water supplies large enough for domestic purposes are generally obtained from layers of chert débris in the residual material that overlies the bedrock, as in wells 355 and 387 (pl. 4, also pp. 215–217), or in the uppermost part of the bedrock itself. So far as is known the wells on the peneplain remnants are between 30 and 95 feet deep, and all yield adequate supplies for household use. One well (No. 386) that was drilled on the plateau in search of oil is reported to be 1,060 feet deep and to have passed through water-bearing beds at 33, 67, and 189 feet below the surface. It is reported further that the yield from the upper two water-bearing beds was less than could be removed with a 20-gallon bailer, whereas the yield from the 189-foot bed was much greater, and that no water-bearing beds were penetrated between 189 and 1,060 feet below the surface. The chemical character of the water from the 189-foot bed is unknown, although in other parts of north-central Tennessee the water associated with these rocks at such a depth is so highly concentrated that it is wholly unfit for most uses. Some perennial seepage springs also issue from the residual material in the heads of the minor drains. Generally the residual clay and chert have been thoroughly leached, so that the ground water associated with them is only slightly or moderately concentrated and relatively soft, as is shown by analysis 387 (pp. 116–117).

On the Highland Rim escarpment and other slopes of the dissected parts of the plateau practically all water supplies are derived from perennial springs, most of which are seepage springs issuing from the weathered rocks. Such springs are especially numerous along the outcrops of some beds of earthy and sandy limestone in the Fort Payne formation, many of which are rendered permeable when the calcareous matrix is leached out during weathering, although they may be quite impermeable if unweathered. In fact, the outcrops of some of the more sandy limestone beds resemble a coarse and somewhat friable sandstone, such as that from which Stillhouse Spring (No. 366, pl. 4; also pp. 218–219) issues near the head of Dobbins Branch of Leipers Fork, as well as springs 380 and 384, on other tributaries of that stream. Although they are generally variable and some are intermittent, the minimum annual discharge of the perennial seepage springs ranges from a few gallons to about 30 gallons a minute. The water from these leached outcrops is generally slightly or moderately concentrated in calcium bicarbonate (analysis 366, pp. 116–117), and is satisfactory for most uses. As elsewhere, many springs, such as Nos. 358 and 395, issue from the uppermost part of the Chattanooga shale along its outcrop, although generally the minimum annual discharge is less than 1 gallon a minute, and the water contains so much iron and hydrogen sulphide that it is unsatisfactory for many purposes. Analysis 395 is representative. None of these strata that are permeable in the outcrop zone are known to be water-bearing where they are far below the surface and unweathered. Other perennial springs in the dissected tracts issue from jointed beds in the St. Louis and Warsaw limestones or in the massive limestone facies of the Fort Payne formation. Although some of these issue from small solution channels that follow joints or bedding planes, all are rather variable and presumably derive their water largely from the zone of weathering. The discharge from any one spring is generally less than 25 gallons a minute, as in Nos. 379, 381, 382, 383, and 385. However, the aggregate discharge from several springs of this sort may constitute a reliable supply of considerable magnitude, such as the municipal supply of Franklin (pp. 213–214). The massive crystalline limestones of the Silurian system, which crop out locally just below the Chattanooga shale, seem to be relatively much more soluble than the overlying Mississippian limestones, so that under favorable conditions they may be rendered cavernous by solution. Cold Spring (No. 359), which issues from a solution channel in these rocks, is the largest known spring in the west half of the county. Its water contains only a moderate quantity of dissolved mineral matter and has moderate carbonate hardness, as is shown by analysis 359 (pp. 116–117); hence it is wholly satisfactory for most purposes, especially if softened.

In the east half of Williamson County both the quantity and the chemical character of the ground water differ greatly from place to place, especially in the hilly areas. In a few places the limestone is rather cavernous, as at Whitehurst Cave (No. 361, pl. 4), about 4 miles northeast of Franklin, and along the crest of the ridge crossed by the Murfreesboro pike between 4 and 5 miles east-southeast of Franklin. These cavernous zones, which occur approximately from 100 to 200 feet above the major valleys, were clearly formed before the Nashville Basin stage of stream planation (pp. 20–22), for they have been cut through by streams adjusted to that stage and generally are completely drained. That along the Murfreesboro pike, however, constitutes a natural reservoir and impounds water, which is exposed in several sink holes about 740 feet above sea level, such as Armstrong's Pond (No. 374), and is discharged by several perennial springs between 700 and 740 feet above sea level about the periphery of the hilly tract. Presumably the principal outlets of this cavernous zone are wholly or partly clogged with débris, else water could not be impounded in it. In these same hilly tracts some drilled wells penetrate water-bearing beds between 40 and 200 feet below the surface, although most wells are between 60 and 100 feet deep. Some wells that are close together find water at different depths. Generally the water associated with beds 100 feet or less below the surface contains only a moderate amount of dissolved calcium bicarbonate and other mineral matter and is not unduly hard. On the other hand, the water associated with the shallower beds in a few places and with the deeper water-bearing beds at most places is likely to be so highly concentrated in sulphate or chloride and to have so much noncarbonate or permanent hardness that it is quite unsuited for general use. Analysis 394 (pp. 116–117) is typical of the calcium sulphate waters. Furthermore, some of the waters are reported to contain hydrogen sulphide, as in well 378, or appreciable amounts of petroleum or natural gas, as in wells 399 and 401. Both potable and highly mineralized nonpotable water are encountered by well 373 in beds that are approximately 40 feet and 200 feet, respectively, below the surface. The water from this well is usable for domestic purposes only in the wet season, when the static level of the ground water in the 40-foot bed is at its highest and is considerably above that of the 200-foot bed. Furthermore, many wells in the hilly tracts, such as Nos. 357, 363, 388, and 396, do not find any water-bearing beds even though they range from 40 to 225 feet or more in depth. Well 389 passed through a water-bearing bed that yielded 15 gallons a day about 40 feet below the surface but found no other water-bearing beds to a depth of 300 feet. Among the most reliable sources of water in the hilly areas are perennial springs, such as Nos. 362 and 364, although none are known whose minimum annual discharge is much more than 25 gallons a minute.

In the valleys of the east half of the county ground-water conditions also differ greatly from place to place. In general the wells may be divided into two groups—those which obtain moderately concentrated calcium bicarbonate water in beds from 30 to about 75 feet below the surface and those which find more highly mineralized waters containing sulphate, with or without hydrogen sulphide, generally in beds between 100 and 135 feet below the surface. However, some wells more than 100 feet deep yield calcium bicarbonate water of satisfactory quality, and some others less than 50 feet deep yield water that is much too highly concentrated to be fit for any ordinary use. Analyses 365, 370, 376, and 390 (pp. 116–117) are typical. Highly mineralized water that is unfit for most uses is found in a relatively large proportion of the wells drilled in the Lowville and Lebanon limestones on the upper reaches of the Harpeth and West Harpeth Rivers. (See pl. 4.) Furthermore, adjacent wells may differ greatly in depth to water-bearing beds and in the chemical character of the water, and not all wells are successful. None have a reported tested capacity exceeding 20 gallons a minute, and the ultimate capacity of several is less than 1 gallon a minute. The water-bearing properties of the deeply buried rocks are not known but may be inferred to be similar to those disclosed by well 403, which is in Maury County about 5 miles south of Allisona. This well on August 17, 1927, was 870 feet deep. Beds carrying potable water were penetrated at 25 and 60 feet below the surface, but the underlying strata were devoid of water to a depth of 855 feet, where a very small amount of concentrated brine was found at the contact (unconformable?) between two beds of limestone. Hence deep drilling for water in the east half of the county is not likely to be successful. Furthermore, no rocks of large water-yielding capacity are known to occur here at any depth.

It is reported that well 365 discharges by artesian pressure during the winter from a solution crevice or unconformity 160 feet below the surface. Presumably the artesian condition is local and due to trapping of ground water above an obstruction in a solution channel or in a discontinuous cavernous zone associated with an inclined unconformity.

MUNICIPAL GROUND-WATER SUPPLIES

Franklin.—The city of Franklin derives its municipal water supply from 36 springs along the eastern base of Duck River Ridge, from 9 to 13 miles west and southwest of the city (Nos. 366, 379 to 385). The estimated minimum annual discharge of these springs, as reported to the city officials by B. H. Klyce, consulting engineer, of Nashville, is shown by the following table.

Estimated minimum daily discharge of springs constituting municipal water supply at Franklin, Tenn.

No. on Plate 4	Name	Location	Daily discharge (gallons)
366	Stillhouse Spring	Dobbins Branch of Leipers Fork	25,000
-------	Stillhouse group, not including Stillhouse Spring (11 springs).	do	40,000
379	McNeill-Pewett group (3 springs)	Garrison Branch of Leipers Fork, north branch of.	21,000
380	1,100-foot Hollow, including Foster and Poyner Springs (3 springs).	do	16,000
381	Tom Anderson Springs (2 springs)	do	16,000
-------	Hargrove Spring	do	3,000
382	Black group (3 springs)	do	12,000
-------	Tears Spring	do	8,000
-------	Skinner Spring	do	5,000
-------	Green Spring	do	8,000
-------	Berry Anderson Spring	do	4,000
383	Goodjine Spring	Garrison Branch of Leipers Fork, south branch of.	21,000
384	Maple Springs (2 openings)	do	53,000
384	Far Gambill Spring	do	8,000
384	Silver Spring	do	4,000
385	Tohrner and Cannon Springs (2 openings)	do	29,000
			273,000

This estimate, however, seems to be based upon measurements made in only one season, 1922, in which the surface-water and ground-water discharge in central Tennessee were much more than the average. For example, the run-off from the Cumberland River Basin above Nashville in the year ending September 30, 1922, was 28.37 inches, whereas the average run-off in the 20-year period ending September 30, 1924, was 22.68 inches and the minimum run-off in the same period only 12.40 inches.[71] Hence, the estimates tabulated above may be more than twice the minimum discharge of the springs in an unduly dry year.

Each of the 36 springs that constitute the source is provided with a suitable cut-off box and discharge pipe connecting with an 8-inch cast-iron pipe which discharges by gravity into a 100,000-gallon steel standpipe and a 500,000-gallon covered concrete reservoir on a hillside about 2¼ miles southwest of Franklin and 130 feet above it. Distribution is effected by gravity, the maximum domestic pressure being about 50 pounds to the square inch. The average daily consumption is reported to be about 125,000 gallons, to supply which the entire discharge of the source is utilized during the summer and autumn of unduly dry years. Hence, some addition to the supply will perhaps become imperative in dry years if the population of the city should increase. In view of the small tested capacities of wells drilled in the limestone in the vicinity of Franklin and of the inferior quality of the deeper ground water, it is not certain that a material addition to the supply can be obtained by drilling wells. Rather, such an addition should be sought first in other springs along the flank of Duck River Ridge and second in surface water from the Harpeth River or some of its tributaries.

Hillsboro.—Most of the residents of Hillsboro (formerly Leipers Fork; estimated population 375) derive their domestic water supplies from individual dug wells. One group of eight dwellings, however, is supplied from a small perennial spring through a distribution system owned and operated in cooperation by the residents.

[71] King, W. R., Water resources of Tennessee: Tennessee Div. Geology Bull. 34, pp. 129-132, 1925.

Typical wells in Williamson County, Tenn.

[No. 387 dug; all others drilled]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
354	Brentwood, ½ mile S	Louisville & Nashville R. R	Valley	745	60	6	
355	Jingo, 3 miles E	P. E. Cox	Ridge crest	845	60±	6	40±
356	Franklin, 7 miles N	Ned Warren	Hillside	670	115	6	6
357	Brentwood, 4½ miles SW	Tennessee Baptist Orphans' Home	Valley	755	100–225		
360	Franklin, 5¾ miles NW	H. P. Cochrane, M. D	Hillside	665	80	6	
363	Franklin, 6 miles NE	Charles Cook	do	840	100–170		
365	Nolensville	W. M. Owen	do	645	160	8	10
367	Franklin, 7½ miles W	W. L. Henry	Valley	655	70–80	6	5
368	Franklin	Andrew Ewing	do	635±	56	6	20
369	do	Louisville & Nashville R. R	do	640	80±	6	
371	Franklin, 2¾ miles E	Jack Mullins	Hillside	720	70, 120	6	
372	Franklin, 7½ miles E	S. J. Wilson	Valley	725	45	6	
373	Franklin, 7½ miles SE	John Crunk	Hillside	720	207	6	5
375	Franklin, 7 miles SE	Lindsey Stevens	Hilltop	760	149		
376	Arrington, 5¾ miles NW	J. N. Boxley	Valley	660	132	6	45
377	Nolensville, 3 miles S	J. M. Waters			150	6	10
378	Arrington, 6 miles NE	Mrs. Bessie Allen	Hilltop	850	170	6	
386	Boston, 2¾ miles W	Sid Wall	Hillside	935	1,060	6	
387	Boston, 2¼ miles W	do	Plateau	985	54	48	50
388	Franklin, 7½ miles SW	James Carr	Hillside	740	50–140	6	
389	Franklin, 5½ miles SW	Fullerton Lilley	Hilltop	725	300	6	
390	Boston, 5 miles E	Mrs. Lulu Gordon	Valley	675	45	6	6
391	Arrington, ¼ mile W	Louisville & Nashville R. R	do		50	6	
392	Arrington, 3¼ miles SW	Smithson & Akin	do	730	40	6	
393	Arrington, 3¼ miles SE	Walter Pollard	do	750	107	6	10
394	Boston, 4¾ miles SE	Mrs. J. C. Sparkman	Hillside	825	105	6	
396	Thompsons Station, ¾ mile NE	H. A. Laws, M. D	Ridge crest	845	100+		
397	Thompsons Station	Gus Watson	Valley	820±	70	6	
398	Thompsons Station, 2 miles SE	Benjamin Gary	Hilltop	800±	133	6	
399	Thompsons Station, 4 miles SW	Lucien Brown	Valley	775	30		
400	Thompsons Station, 7½ miles SE	Duplex School	do		70	6	15
401	Allisona, 6 miles W	Charles Trice	do	900±	60	6	
402	Allisona, 1 mile S	Louisville & Nashville R. R	do	830	51	6	
403	Allisona, 5 miles S	Albert Mainer No. 1	do	800±	870+	6	

[Table continued on pp. 216–217]

Typical wells in Williamson County, Tenn.—Continued

[No. 387 dug; all others drilled]

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remarks
354			Bigby limestone or Hermitage formation.	−30	Hand pump	Very small.		Domestic	At Brentwood section houses.
355	40–50	Residual chert	St. Louis or Warsaw limestone.	−30–45		1/10		do	Representative of group of 17 wells in the community.
356	100	Bedding-plane crevice.	Cannon limestone	−75	Gasoline force pump			do	
357	None								4 wells, all dry holes, in Cannon and Bigby (?) limestones.
360	70	Limestone	Cannon limestone	−40	Bucket and rope			Domestic	Maximum capacity about 500 gallons a minute.
363	None							None	8 or 10 dry holes at house; well at barn, 60 feet deep, yields salty water; other domestic wells of neighborhood are 45 to 100 feet deep.
[a] 365	160	Solution crevice	Ridley (?) limestone.		Hand pump			Domestic, stock	Well flows by artesian pressure in winter. Most wells of vicinity about 60 feet deep.
367	60	Limestone	Cannon limestone	−40	Bucket and rope			Domestic	Ultimate yield 500 gallons a day
368	50	Bedding-plane crevice.	Hermitage formation.	−22	do			do	Ultimate yield 300 gallons a day.
369	Near bottom.	Limestone	Lowville limestone or Hermitage formation.	−40	Hand pump			do	At Franklin section foreman's residence.
371	None								Dry holes in Bigby limestone and Hermitage formation.
372	Near bottom.	Bedding-plane crevice.	Lowville limestone	−20	Hand pump	20		Domestic	Reported drawdown 25 feet pumping 20 gallons a minute for 1 hour.
373	200	Limestone	Ridley limestone		Bucket and rope	Small		do	Highly mineralized water from 200-foot water-bearing bed; another bed at depth of 40 feet supplies potable water in wet season.
375				−75	do			do	Well reaches top of Lebanon limestone at depth of 75 feet.
[a] 376	132	Limestone	Ridley limestone	−50	Hand pump		58	do	Well on Johnson property, which adjoins Boxley, entered solution cavity 4 feet high at 139 feet.
377	75	Bedding-plane crevice.	Lowville (?) limestone.	−60	Bucket and rope	Very small.		do	Ultimate capacity reported as 25 gallons a day.

378	Near bottom.	Shale	Chattanooga shale.	−130					Highly mineralized water, unfit for domestic use.
386	189	Solution channel	Fort Payne formation.	−3 (?)	None			None	Test well for petroleum. No water-bearing beds found below depth of 189 feet.
[a] 387	Near bottom.		Residual chert above St. Louis or Warsaw limestone.	−35	Bucket and rope		58	Domestic	
388	None							None	Several wells, all dry holes in Catheys formation and Cannon limestone.
389	40		Bigby limestone of Hermitage formation.		None	Very small.		do	No water-bearing beds below depth of 40 feet. Ultimate capacity about 15 gallons a day. Well abandoned.
[a] 390	Near bottom.	Bedding-plane crevice.	Cannon or Bigby limestone.	−20	Bucket and rope		61	Drinking	A second well 400 yards east found only salt water at depth of 100 feet; a third well 100 yards from No. 390 is 45 feet deep and finds fresh water at base of zone of weathering.
391	do	Limestone	Lebanon (?) limestone.	−20	Hand pump			do	At Arrington station.
392	do	do	Lowville limestone.	−15	Bucket and rope	5+			Another well near by 70 feet deep to water-bearing bed, ultimate capacity 150 gallons a day. Static level 40 feet below surface.
393	90	Bedding-plane crevice.	Lebanon (?) limestone.	−40	do			Domestic	Most wells of vicinity are 50 to 60 feet deep; no solution channels penetrated.
[a] 394	Near bottom.	do	Catheys (?) formation.	−75	do		62	Domestic, stock	
396	None								Several wells, all dry holes in Cannon or Bigby limestone.
397	60	Bedding-plane crevice.	Bigby limestone	−40	Automatic electric pump.	3+			
398	40±	Limestone	Hermitage formation.	−20		Small			Ultimate capacity reported as 3½ gallons an hour.
399			Cannon or Bigby limestone.		None			None	In Maury County. Small quantity of petroleum with water; well abandoned.
400	60	Bedding-plane crevice.	Lebanon (?) limestone.	−50	Hand pump			Domestic	
401	Near bottom.	Limestone	Hermitage formation.	−4					Water contains natural gas, unfit for domestic use.
402		do	Hermitage (?) formation.	−22	Hand pump			Drinking	At Allisona station.
403	25, 60	do	Hermitage formation or Lowville limestone.	−25	None	1–2		None	In Maury County at Holts Corner. Test well for petroleum 870 feet deep on August 17, 1927, while drilling. Dry hole from 60 to 855 feet; small yield of highly mineralized water at 855 feet at top of gray magnesian (?) limestone.

[a] See analysis, pp. 116–117.

Typical springs in Williamson County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
358	Jingo, 5¼ miles SE		Fernvale Spring	Valley	700	Chattanooga shale.
359	Jingo, 5½ miles SE	W. P. Bruce estate	Cold Spring	do	610	Fernvale formation.
361	Franklin, 5½ miles NE	Gentry Hughes	Whitehurst Cave	Hillside	835	Catheys formation.
362	Franklin, 7½ miles NE	J. H. Womack	Boiling Spring	Valley	710	Hermitage formation.
364	Nolensville, 5½ miles W	W. N. Skinner	Stracker Spring	do	765	Cannon limestone.
366	Boston, 6¼ miles N	City of Franklin	Stillhouse Spring	Hillside	790	Fort Payne formation.
370	Franklin, 1 mile S	C. H. Kinnard	Winder Spring	Plain	640	Hermitage formation.
374	Franklin, 6 miles SE	J. W. Haye	Armstrong's Pond	Hillside	740	Lowville limestone.
379	Boston, 4¼ miles NW	City of Franklin	McNeil-Pewett group	Valley	850	Fort Payne formation.
380	Boston, 3¾ miles NW	do	1,100-foot Hollow	do	835	Do.
381	do	do	Tom Anderson Spring	do	884	Base of St. Louis limestone.
382	Boston, 3½ miles NW	do	Black Spring group	do	884	Fort Payne formation.
383	Boston, 2¾ miles NW	do	Goodjine Spring	do	805	Do.
384	Boston, 3½ miles W	do	Maple Spring group	do	850	Do.
385	Boston, 3 miles W	do	Tohrner & Cannon Spring	do	875	Do.
395	Thompsons Station, 3½ miles NW	Douglas Martin	Cayces Spring	do	730	Chattanooga shale.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (° F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
358	1	Joint and bedding-plane crevices.	Very small	Aug. 18		Formerly medicinal.		So-called sulphur spring.
[a]359	1	Bedding-plane channel	270	do	Seasonal	Domestic, stock	59	Perennial spring.
361	1	Large solution channel along joints.	Less than 1	Aug. 17	do	Stock		Remnant of high-level solution channel system.
362	1	Joint and bedding-plane channel.	25	Aug. 15	do	Domestic, stock	59	Perennial spring.
364	1	Concealed; probably solution channel.	10	do	do	do	58	Reported minimum yield 10 gallons a minute.
366	1	Porous stratum	17	Aug. 13	Little fluctuation	Municipal	57	
370	1	Bedding plane	20	Aug. 16	Seasonal	Swimming pool	62	Reported minimum yield about 5 gallons a minute.
374	1	Sink hole leading to solution channel.	No flow noted.	Aug. 17	Probably seasonal	Stock		Small springs on hillside near by at altitude of 700 to 740 feet are fed from the same channel system.
379	3	Joint and bedding-plane crevices.	15		Seasonal	Municipal	59	Noted yield is total for 3 openings. Minimum yield about 15 gallons a minute.
380	3	do	10		do	do	58	Minimum yield about 10 gallons a minute.
381	1	Joint and bedding-plane channel.	8½		do	do		Minimum yield about 8½ gallons a minute.
382	3	Joint and bedding-plane crevices.	8½		do	do	60	Do.
383	1	Porous stratum	19		do	do	60	Minimum yield about 19 gallons a minute.
384	4	do	47		do	do	57	Noted yield is total for 4 openings; principal opening yields 28 gallons a minute.
385	2	Joint and bedding-plane crevices.	26		do	do	59	Minimum yield about 26 gallons a minute.
[a]395	3	do	½	Aug. 16		Formerly medicinal.	69	So-called sulphur spring.

[a] See analysis, pp. 116–117.

WILSON COUNTY

[Area, 613 square miles. Population, 23,929]

GENERAL FEATURES

Wilson County, which occupies the east-central part of the region covered by this report (pl. 1), is bounded on the north by Sumner County, on the south by Rutherford County, and on the west by Davidson County. Its principal cities are the county seat, Lebanon (population 4,656), and Watertown (population 928), both of which are on the main line of the Tennessee Central Railroad.

This county, which lies near the center of the northern lobe of the Nashville Basin, lies for the most part on a dissected plain, the Nashville Basin peneplain (pp. 20–22), whose interstream flats slope gently northwestward and generally are between 625 and 700 feet above sea level. Its drains, which are adjusted to the present stage of the Cumberland River, about 400 feet above sea level, radiate from the southeastern quadrant of the county to the Cumberland River on the north, the Stone River on the southwest, and Caney Fork of the Cumberland River on the east. Near these major streams the surface has been so deeply dissected by the closely spaced branches of the dendritic tributaries that it bears little semblance to the original peneplain. Away from the major streams, however, and especially along the divide between the Cumberland and Stone Rivers, the peneplain extends undissected for many miles. Not all of this district is drained by the surface streams, for there are many small sinkholes and some closed depressions covering 1 square mile or more that drain radially inward and discharge into solution channels in the limestone. The origin of some of these features is related to that of the Nashville Basin peneplain, that of others to the older of the two partial erosion cycles by which the peneplain was dissected. In contrast to this extensive dissected plain, the southeastern quadrant of the county is a hilly and moderately rugged area of which only the floors of the major valleys are correlative with the surrounding peneplain. Its hills and ridges, the highest of which are in the vicinity of Greenvale and reach 1,300 feet above sea level, are maturely eroded outliers of the Highland Rim plateau (pp. 16–18), which covers extensive areas in the adjoining counties.

Inasmuch as Wilson County lies on the axis and northwest flank of the Nashville dome (pp. 62–63), its rock strata dip radially northward and westward from its southeast corner, although this regional dip is modified somewhat by open secondary folds. The rocks that crop out embrace the lowest part of the Fort Payne formation and the underlying Chattanooga shale, the latter of Upper Devonian or early Mississippian age, as well as a nearly complete sequence of Ordovician formations down to the Ridley limestone (pp. 35–55). The entire Middle and Lower Devonian and the Silurian are absent throughout the county, being cut out by overlap upon the Ordovician and by the major disconformity that marks the base of the Chattanooga shale. The Fort Payne formation and the Chattanooga shale cap the highest hills and ridges in the vicinity of Greenvale, Statesville, and Watertown, in the southeastern quadrant of the county, as is shown by Plate 4, but do not crop out elsewhere. In a few places the Chattanooga shale is underlain by the nodular earthy limestone and shale that constitute the Leipers and Catheys formations, but in many others the Leipers and Catheys are missing and the Chattanooga rests directly upon the Cannon limestone. This formation, which comprises gray and blue argillaceous cherty limestone at the top and massive dove-colored limestone in its lower part, crops out extensively on the middle slopes of the hilly areas and on some of the peneplain remnants farther north and west. The Hermitage formation, which underlies it and comprises thin-bedded argillaceous limestone, clay shale, and phosphatic shale, crops out on the middle and lower slopes of the hills in the southeastern part of the county and is widespread on the peneplain tract to the north and west. Beneath the Hermitage are compact massive and thin-bedded dove-colored cherty limestones, which constitute the Lowville, Lebanon, and Ridley limestones in succession from the top downward. The Lowville limestone crops out on the lower slopes of some of the hills and on the valley floors in the southeastern quadrant of the county and on much of the higher ground farther west; the Lebanon and Ridley limestones are the most widespread formations on the dissected plain of the southwestern quadrant. So far as is known, the lowest beds of the Ridley limestone and all underlying strata are not exposed at any place within the county.

GROUND-WATER CONDITIONS

In Wilson County, as in other parts of the Nashville Basin, the amount and chemical character of the ground water differ widely from place to place. Most of the ground water is of meteoric origin and circulates along joints, bedding planes, or other solution channels of the limestone, the permeability of the rocks depending wholly upon the frequency and size of these openings. In many places, however, bodies of connate and other highly concentrated water are trapped above or below impermeable shaly beds, in deeply buried permeable strata, or perhaps in permeable zones related to unconformities. In some of the interstream areas the channeled zones in the limestone above the level of the streams have been drained, the rocks below stream level are not water bearing, and domestic water supplies must be derived from cisterns. Furthermore, at many places on the peneplain remnants, bedrock is only a few feet below the surface, so that wood or steel tanks are used to store rain water. In these same areas storm run-off is generally impounded in small natural or artificial ponds for the watering of stock.

Among the most reliable sources of ground water in the county are the perennial tubular springs (pp. 92–95), such as those which issue at the heads of the perennial creeks (Nos. 323, 329, and 342, p. 233), and the underground streams that are exposed where the roof of a large solution channel has collapsed (Nos. 331 and 338). The course of one such underground stream from 15 to 25 feet or more below the surface is indicated in a general way by a belt of sink holes that trends northwestward through Blindfish Cave (No. 338); through Cave Spring, which is on the fair grounds at the western edge of Lebanon; and through the unused City Spring, in the public square at Lebanon. The solution channel through which this stream flows is a part of what seems to have been an extensive system of channels draining much of the Nashville Basin peneplain before its dissection. Hence, some of the tubular springs that issue from channels of this system may drain large bodies of limestone and be correspondingly less variable in discharge than those whose catchment area is small. The discharge of most of the tubular springs is extremely variable, increasing notably a few hours after a heavy rain and decreasing greatly in the summer. Consequently, the reliability of any spring can be determined only by periodic measurements of the discharge during several years.

The drilled wells from which domestic water supplies are drawn on the Nashville Basin peneplain of Wilson County range in depth from 22 feet to about 200 feet, although most of them are between 50 and 75 feet deep. Generally, the portions of the strata that are permeable are not continuous, for wells at adjacent sites may be drilled to very different depths in order to find water. Generally the tested capacities of the wells are not more than 5 gallons a minute, and for some the capacities are less than 1 gallon a minute. A few wells, such as No. 348 (pl. 4, also pp. 230–232), have tested capacities exceeding 10 gallons a minute, but unsuccessful wells have been drilled at many places, especially on the crests of the ridges. The difficulties that are encountered in obtaining a large amount of water from drilled wells are shown by conditions at Horn Springs (No. 326), where 30 or more wells have been drilled in an effort to obtain an adequate water supply for a resort hotel with outdoor swimming pool. It is reported that each of these wells would have yielded enough water for a single household, although the chemical character of some of the ground water obtained was unsatisfactory, and all but four of the wells have been abandoned as inadequate. Several wells that were drilled near the hotel within 200 yards of Horn Spring No. 2 (No. 326), about 570 feet above sea level, range from 35 to 95 feet in depth; all found rather highly concentrated water at depths between 17 and 35 feet but no water below. The chemical character of the water from these wells, which have been abandoned, is presumably similar to that represented by analysis 326 (pp. 116–117). In a well 292 feet deep, which is about 425 yards northwest of the hotel, near the swimming pool, on the crest of a ridge about 615 feet above sea level, at least five water-bearing beds were penetrated. The uppermost of these was 17 feet below the surface. It is reported that the static level of the ground water was 15 feet below the surface and that the drawdown was about 65 feet with a yield somewhat less than 10 gallons a minute. Hence, the specific capacity of the well is low, between 0.2 and 0.1 gallon a minute for each foot of drawdown. About 250 yards northwest of this well and 590 feet above sea level is another well 252 feet deep (No. 325), in which at least three water-bearing beds were penetrated, the uppermost and principal one 160 feet below the surface. The static level of the ground water is reported to be about 30 feet below the surface. In a capacity pumping test made soon after it was completed, in September, 1927, the well yielded about 15 gallons a minute for 8 hours, but the correlative drawdown is unknown. About 100 yards northeast of well 325 and about 25 feet lower in altitude is a group of three wells about 20 yards apart and 56, 170, and 168 feet deep. The 56-foot well is unused. The tested capacity of one of the deeper wells is about 20 gallons a minute and that of the other somewhat less, and the specific capacity is about 0.3 gallon a minute for each foot of drawdown. It is not known whether or not the beds that yield water in these wells are also water bearing in the vicinity of the hotel, where they underlie the strata that contain the highly concentrated sulphate water.

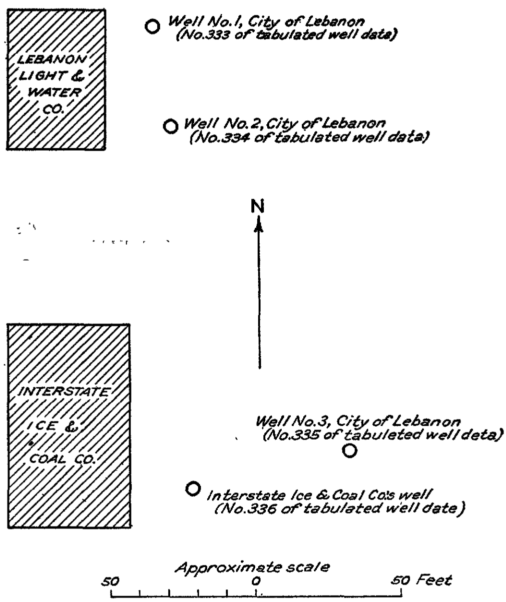


FIGURE 7.—Sketch plan showing location of wells in Lebanon that yield more than 100 gallons a minute

Several wells in Wilson County have capacities between 50 and 200 gallons or more a minute, including Nos. 333, 334, and 335, owned by the city of Lebanon; No. 336, owned by the Interstate Ice & Coal Co., of Lebanon; and No. 347 (two wells), owned by the city of Watertown. Figure 7 shows the approximate plan of the wells at

Lebanon, all of which tap a common water-bearing bed. Wells 333 and 334 (Nos. 1 and 2, respectively, city of Lebanon) are 205 and 196 feet deep and 10 and 8 inches in diameter. They are about 75 yards east of the Lebanon station of the Tennessee Central Railroad. Both of these wells obtain water from the Ridley (?) limestone about 185 feet below the surface (about 345 feet above sea level); the static level in the wet months is 64 feet below the surface (about 465 feet above sea level), or about 25 feet below the near-by Sinking Creek. Presumably the water was obtained in solution channels. Well 335 (No. 3, city of Lebanon), which was originally about 200 feet deep, was deepened to 351 feet in 1924 without finding any water-bearing beds below that which is about 185 feet below the surface. These wells are pumped by air lifts. Two of the three wells are generally operated 10 hours or more each day, and the yield of each ranges from about 100 to more than 200 gallons a minute, varying with the season. The specific capacity is relatively large for north-central Tennessee and ranges between 5 and 10 gallons a minute for each foot of drawdown. In 1927 wells 334 and 335 were pumped steadily from September 16 until October 12, and the combined yield decreased gradually in that period from 325 to 200 gallons a minute. About 8 a. m. October 12, about 10 hours after the start of a long heavy rain on the adjacent region, the yield began to increase, and on October 13 it reached a maximum of about 450 gallons a minute. Most of the increase in yield was probably due to rise in static level of the ground water in response to the rainfall, although a part of it may have been due to greater efficiency of the air-lift pumps as their submergence increased with rising static level. Furthermore, it is reported that the discharge from well 335 is slightly turbid after rainfall in the vicinity, even though it is cased from the surface to the water-bearing bed. If this report is correct it follows that the changes in static level induced by rainfall are not merely hydrostatic effects but represent actual saturation of permeable rock. Furthermore, as the changes take place so promptly after rainfall, the water-bearing bed tapped by the municipal wells must communicate rather directly with the surface by solution channels or other openings which can transmit water rapidly. Well 336, which is owned by the Interstate Ice & Coal Co., derives most of its water from an open channel or cellular zone of the limestone about 18 inches thick and about 185 feet below the surface. Another water-bearing bed was penetrated at a depth of 85 feet, but none was found below the 185-foot bed, although the well is 304 feet deep. Like the Lebanon municipal wells, well 336 is pumped by an air lift whose capacity is about 150 gallons a minute. It also interferes with the municipal wells, whose yield is reported to drop 50 or 75 gallons a minute within 15 minutes after the pump on well 336 is started. The two wells (No. 347) that constitute the source of municipal water at Watertown, about 12 miles southeast of Lebanon, are 250 and 251 feet deep and 6 inches in diameter. Both tap a water-bearing bed in the Ridley (?) limestone more than 200 feet below the surface and hence not more than 455 feet above sea level. The static level of the ground water is reported as about 40 feet below the surface. Each well is equipped with an electrically driven double-acting deep-well pump with a rated capacity of 60 gallons a minute. When the wells were first placed in service, in October, 1925, one was pumped at full capacity for 36 hours and both were pumped concurrently at full capacity for 12 hours in order to fill the 200,000-gallon municipal standpipe. Since that time they have been pumped about four hours each day. The drawdown under ordinary operating conditions is reported as 19 feet, which corresponds to a specific capacity of 3 gallons a minute for each foot of drawdown.

It is perhaps noteworthy that the water-bearing beds in the municipal wells both at Lebanon and at Watertown occur in the Ridley (?) limestone. Furthermore, at Lebanon the water-bearing bed is about 50 feet below the level of the Cumberland River, whereas at Watertown it is about 50 feet above the level of the river. The static level of the ground water at Lebanon is about 465 feet above sea level and at Watertown about 625 feet above sea level, or about 65 and 225 feet, respectively, above the Cumberland River. Big Spring (No. 329), which is about 7 miles northeast of Lebanon and whose altitude is about 520 feet above sea level, discharges by artesian head from the Hermitage formation or Lowville limestone. Also, the static level of ground water in well 328, about 3½ miles northwest of Big Spring, is approximately level with the ground surface, or about 465 feet above sea level. This well finds water confined under artesian head in the upper part of the Stones River group (pp. 54–57) about 118 feet below the surface (350 feet above sea level). These static levels seem to define a pressure-indicating surface which is approximately a true plane sloping northwestward about 13 feet in each mile and intersecting the water surface of the Cumberland River approximately due north of Horn Springs. Such a hydraulic gradient is quite compatible with the assumption that the water-bearing beds at Lebanon, Watertown, well 328, and Big Spring are connected by moderately permeable material. Even on this assumption, however, the conditions that maintain artesian head remain somewhat uncertain. Clearly, the water-bearing beds do not constitute a stratigraphic unit nor a channeled zone related to an unconformity, for they occur at several stratigraphic horizons. Furthermore, the relation between rainfall and static level of the ground water in the 185-foot bed at Lebanon, together with the chemical character of the water from both the Lebanon and Watertown municipal wells (see analyses 333 and 347, pp. 116–117), indicate that the water is of meteoric origin and that it circulates rather freely. Hence, if the water-bearing beds at these several places are actually connected, the water-bearing openings probably constitute a system of solution channels that receives water by percolation from the surface and discharges it into the Cumberland River. Such a system might comprise either a few branching ground-water arteries or many braided small channels. Ground water might be maintained under artesian head in such a system of channels by the hydrostatic pressure of water in the Cumberland River if the openings through which discharge was effected were few and small or if they were partly clogged by impermeable material such as silt and clay. It follows, therefore, that the limestone in the northern part of Wilson County may be rather extensively channeled and water bearing at a depth somewhat greater than that attained by most wells but generally more than 350 feet above sea level. Furthermore, the wells of the Louisville & Nashville Railroad at Gallatin, Sumner County (Nos. 135 and 136, pp. 204–205), which tap a water-bearing bed in the Bigby (?) limestone about 320 feet above sea level, may indicate an extension of this channeled zone toward the north. The static level of the ground water in these wells is reported to be between 50 and 100 feet below the surface, or 420 to 470 feet above sea level. If, however, the water-bearing beds of the wells at Lebanon and Watertown, well 328, and Big Spring are not connected, the artesian head existing in well 328 must be local and due to obstruction of its water-bearing channel. Unfortunately, no other deep wells are known to have been drilled in northern Wilson County, so that adqeuate data for analyzing the true hydrologic condition are not obtainable.

Although at least one deep well (No. 327) has been drilled in Wilson County in search of oil, no satisfactory records of the lithologic character or water-bearing properties of the deeper strata are available. It seems probable, however, that potable ground water of meteoric origin does not circulate in the limestones much lower than a plane about 300 feet above sea level, and that water-bearing beds which may occur at greater depth contain only highly concentrated water of inferior chemical character.

In the hilly country which constitutes the southeastern quadrant of Wilson County reliable ground-water supplies are generally derived from perennial springs or from drilled wells that do not extend much more than 50 feet below the level of the perennial streams. On the middle and upper slopes of the hills some wells either do not find any permeable beds, as in well 350, or encounter only highly concentrated nonpotable brine, as in well 352.

The chemical character of the ground waters of Wilson County differs greatly. The water that issues from most of the perennial springs, especially from those of the tubular type, and that which is associated with the more permeable strata 200 feet or less below the surface, is generally satisfactory for most purposes. Those represented by analyses 328, 330, 333, 347, and 348 (pp. 116–117) are typical. These are moderately concentrated calcium bicarbonate waters that have moderate carbonate hardness and some noncarbonate hardness, so that they are somewhat objectionable as scale formers and soap consumers unless softened. The waters of this type that are associated with the deeper beds are usually higher in noncarbonate hardness. Some, such as No. 353, are much too hard for satisfactory use in laundering or as boiler feed water and even if softened are likely to be unsuitable for certain purposes. In contrast with waters of this type are the highly concentrated sulphate and chloride waters, of which analyses 326, 344, and 352 are representative. They may occur at slight depth in such thin-bedded and shaly formations as the Hermitage formation and Lebanon limestone or at moderate depth in any of the rock formations, especially in the hilly areas and the contiguous parts of the peneplain in the southeastern quadrant of the county. These are the areas in which underground drainage has not been completely established in the present erosion cycle. The sulphate and chloride waters are of two general classes—those, such as No. 344, which contain much more sodium than other bases and hence are moderately soft unless very highly concentrated and those which contain large amounts of calcium and magnesium and have much noncarbonate hardness. The waters of the first class may be used for domestic and some other purposes if they do not contain much more than 1,000 parts per million of dissolved mineral matter, although they are somewhat objectionable. Those of the second class are generally unfit for any ordinary use. A considerable proportion of the sulphate and chloride waters contain appreciable amounts of hydrogen sulphide and objectionable amounts of iron, which, in the presence of air, form a suspended precipitate of black ferrous sulphide. In the vicinity of Norene and possibly elsewhere in the southeastern quadrant of the county some of the ground water contains moderate quantities of hydrocarbon gases. It is reported that for about two years gas issued from one well in Norene, about 60 feet deep, in sufficient quantity to illuminate a store. The water from well 352 (pp. 230–232) is unusual in that most of the combined sulphur occurs as the hydrosulphide radicle (HS). In general, highly concentrated waters of these types are likely to be found in any part of the county in beds more than 100 feet below the surface and, so far as is known, in all beds much more than 200 feet below the surface. Furthermore, it is not known that potable ground water exists at any place in beds underlying those which contain the highly concentrated sulphate or chloride water.

MUNICIPAL GROUND-WATER SUPPLIES

Lebanon.—Lebanon, the county seat of Wilson County, derives its municipal supply from three drilled wells about 75 yards east of the Tennessee Central Railroad station, on the west bank of Sinking Creek. These wells, which are 205, 196, and 351 feet deep, are described on pages 230–232. The chemical character of the water is shown by analysis 333 (pp. 116–117). Water is raised from the wells by air-lift pumps, chlorinated, and pumped into a 450,000-gallon elevated steel standpipe by two horizontal centrifugal pumps with capacities of 750 and 500 gallons a minute. These pumps are driven by directly connected electric motors. Distribution is effected by gravity, and the average domestic pressure is about 45 pounds to the square inch. The aggregate capacity of the three wells ranges from about 200 gallons a minute during long dry periods to 750 gallons a minute during the winter and spring. The maximum daily consumption, which is measured by an automatic recording flow meter, is about 450,000 gallons, and the average consumption about 326,000 gallons. Hence the present source is barely adequate to supply the demand in the dry periods.

Foxhill, a suburb of Lebanon, derives an auxiliary water supply from a fourth well (No. 337) about a mile northeast of the three already described. This well, which is about 250 feet deep and 6 inches in diameter, probably also taps the Ridley limestone. It is equipped with an electrically driven deep-well pump with a rated capacity of 100 gallons a minute, but its actual yield and specific capacity are unknown. This well is used only during periods of extreme drought or other emergency.

Two possible sources from which additional water can be obtained by the city of Lebanon are other wells drilled to the 185-foot water-bearing bed and surface water from the Cumberland River, which is about 9 miles north of the city at the nearest accessible point. The capacity of the 185-foot bed depends upon the cross-sectional area of the belt of channeled limestone that forms it, which can be determined only by drilling. If this bed is a small ground-water artery, the capacity of the present wells may be as large as its transmission capacity. On the other hand, if it comprises several or many braided channels, a considerable additional amount of water may be obtainable. If other wells are drilled, they should be located several hundred yards from those now in use and should be tested carefully to determine the degree to which they interfere with the present wells, especially during the summer and autumn. If they show considerable interference the aggregate capacity of the system may not be increased appreciably. On the other hand, an adequate supply can be diverted from the Cumberland River at all times, although the cost of the necessary pipe line, filtration plant, and diversion structures would be rather large, The sum of the static and friction heads against which water would have to be pumped from the river would be greater than from wells. Moreover, the water from the river would require filtration as well as chlorination, whereas the ground water does not need to be filtered. Hence, both construction and operating costs for diverting water from the river would be much larger than for operation and maintenance of wells. However, the capacity of the source may outweigh comparative costs in determining which source of additional water is the more practicable.

Watertown.—The municipal water supply of Watertown is drawn from two wells (No. 347) 250 and 251 feet deep, south of the Tennessee Central Railroad near the southwest corner of the city. Reference to these wells has been made on pages 223–225, and the chemical character of the water is shown by analysis 347 (pp. 116–117). Each well is equipped with a Chippewa double-acting deep-well pump, with a rated capacity of 60 gallons a minute, by which water is raised to a 200,000-gallon steel tank on a hillside at the northwest corner of the town. Each pump is driven through a suitable gear train and pump jack by a 5-horsepower electric motor. The water is distributed by gravity, and the average domestic pressure is approximately 46 pounds to the square inch. The daily consumption is reported to be about 18,000 gallons, and approximately half the population is served. The wells were pumped continuously at full capacity for 36 hours without depletion when they were first placed in service, in October, 1925, whereas the present demand is met by pumping four hours or less each day. Hence the capacity of the source is adequate to care for a considerable increase in demand.

Typical wells in Wilson County, Tenn.

[All drilled wells]

No. on Plate 4	Location with reference to nearest post office	Owner or lessee	Topographic situation	Approximate altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)	Depth to which well is cased (feet)
324	Horn Springs, 2 miles NW	Joy Brothers	Valley	575±	100±		
325	Horn Springs, 1 mile NW	J. A. Horn	Hillside	590	252	6	8
327	Lebanon, 6¾ miles NE	Meacham Chambers	Hill slope		1,490		
328	Lebanon, 9 miles NE	Mrs. Alice Murrey	Plain	465	118	5	
330	Mount Juliet	Mount Juliet School	do	540	47	6	
332	Lebanon, 1 mile W	Castle Heights Academy	do	585	500±	8	
333	Lebanon	City of Lebanon	do	530	205	10	201
334	do	do	do	530	196	8	190
335	do	do	do	530	351	8	
336	do	Interstate Ice & Coal Co	do	530	304	8¼	10
337	Lebanon, 1¾ miles NE	City of Lebanon	do		250 (?)	6	
339	Greenwood, ½ mile NW	Frank Lindsley	do	625	95±	6	9
340	Greenwood	R. H. Beard	do	625	30±	6	
343	Gladeville, 3 miles NW	S. B. Spickard	do	625	22	6	10
344	Gladeville, ¾ mile E	T. H. Phillips	do	620	28	6	6
345	Gladeville, 5½ miles E	R. P. Gentry	do	665	75±	5	10±
347	Watertown, ½ mile W	City of Watertown	do	655	250 and 251	6	200
348	Watertown	Watertown Grain & Feed Co	do	665	76	4	5±
349	Smyrna, 6½ miles NE	R. H. Parker	do	535	48	5½	10
350	Statesville, 3½ miles NE	J. W. Waldon	Hillside	870	77 and 156		
351	Statesville, ½ mile N		Valley	710	30-60		
352	Norene, 5½ miles S	Mrs. Bessie Hayes	Hilltop	785	152	6	10
353	Norene, 5¾ miles S	Clark Hill	Hillside	760	80	6	

No. on Plate 4	Water-bearing beds: Depth below surface (feet)	Water-bearing beds: Character of material	Water-bearing beds: Geologic horizon	Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (° F.)	Use of water	Remarks
324			Lowville or Lebanon limestone (?).		Gasoline force pump			Stock	Salty water, too concentrated for use in summer.
325	160	Bedding plane	do	−70	Belt-driven force pump.	15±		Swimming pool and hotel.	30 or more wells have been drilled near Horn Springs Hotel to develop a water supply for swimming pool and hotel; any of these would have been adequate for a household well, but all but four proved inadequate for the purpose.
327									Several water-bearing beds reported; some shallow, some near bottom of well.
[a] 328	Near bottom.	Bedding-plane crevice.	Lebanon (?) limestone.	±0	Bucket and rope		60	Domestic	Most wells of the community are 60 to 75 feet deep; well on T. J. Lowery property, 2 miles north, 202 feet deep, yields highly mineralized water.
[a] 330	do	do	Lowville (?) limestone.	−25±	Hand pump	3±	60	Drinking	
332			Stones River group						Well abandoned on account of pollution.
[a] 333	185±	Limestone	Ridley (?) limestone.	−64	Air lift		58	Municipal	Well 1. Wells interfere when pumped simultaneously, usually two of the three being pumped at once; total draft from two wells is 200 to 450 gallons a minute; yield of wells increases about 12 hours after heavy regional rain.
334	185±	do	do	−64	do			do	Well 2.
335	165±	do	do	−64±	do			do	Well 3.
336	185	Solution channel	do	−30	do	150		Ice plant	Interferes with Nos. 333, 334, and 335. Minor water-bearing bed at depth of 85 feet.
337			do		Electric force pump	100		Municipal	Well 4, in Fox Hill district.
339	95	Shaly bed	Lowville (?) limestone.	−50	Bucket and rope	Small	60	Domestic, stock	
340	30±	Bedding-plane crevice.	Hermitage (?) formation.	−10	Hand pump	Less than 3.		Domestic	
343	22	do	Lebanon (?) limestone.	−13	Bucket and windlass		63	None	Water highly colored with organic matter.
344	28	do	do	−21	do		62	Domestic	Other wells of the community are between 22 and 100 feet deep, although most are between 40 and 60 feet.
345		do	do	−48	do		60	do	

[a] See analysis, pp. 116–117.

Typical wells in Wilson County, Tenn.—Continued

[All drilled wells]

No. on Plate 4	Water-bearing beds			Water level above or below surface (feet)	Method of lift	Yield (gallons a minute)	Temperature (°F.)	Use of water	Remark
	Depth below surface (feet)	Character of material	Geologic horizon						
347	Below 200		Ridley (?) limestone.	−40±	Electric force pumps	60 each.		Municipal	Two wells. Reported drawdown 19 feet pumping 60 gallons a minute for about 4 hours. Consumption about 18,000 gallons a day.
[a] 348	Near bottom.	Bedding-plane crevice.	Lebanon (?) limestone.	−45	Bucket and windlass	See notes.	59	Domestic	Formerly pumped as much as 26 gallons a minute for community use.
349	do	Limestone	Pierce (?) limestone.	−12		3½		Domestic, stock	
350	None								Two wells, both dry holes, in Hermitage formation and Bigby (?) limestone.
351	Near bottom.		Lebanon (?) limestone.					Domestic	Miscellaneous wells of Statesville community.
[a] 352	152		do	−19	Hand pump		57	None	Very saline water, unfit for any use.
[a] 353	75		do	−55	Bucket and rope		58	Stock	A second well 180 feet deep encountered salt water.

[a] See analysis, pp. 116–117.

Typical springs in Wilson County, Tenn.

No. on Plate 4	Location with reference to nearest post office	Owner	Name	Topographic situation	Approximate altitude above sea level (feet)	Geologic formation
323	Martha, 6 miles N	Ed. Adams		Valley	455	Lebanon (?) limestone.
326	Horn Springs	J. A. Horn	Horn Spring No. 2	Mature hill slope.	570	Hermitage formation.
329	Lebanon, 6½ miles E	Roe Purnell	Big Spring	Plain	520	Hermitage formation or Lowville limestone.
331	Mount Juliet, 2½ miles E	Mrs. Emma Moore	Silver Spring	Valley	540	Hermitage (?) formation.
338	Lebanon, 1½ miles SE	Tennessee Central Railroad	Blind Fish Cave	Plain	560	Lebanon limestone.
341	Shop Spring, 1¼ miles N	R. L. Donald		Hillside	725	Cannon (?) limestone.
342	Shop Spring, ½ mile S	Ed. Griffin	Shop Spring	Plain	665	Bigby (?) limestone.
346	Gladeville, 6½ miles E	Wm. Ingraham	Jackson's Cave	Undulating plain.	625	Lebanon (?) limestone.

No. on Plate 4	Openings		Approximate yield		Variability	Use	Temperature (°F.)	Remarks
	Number	Character	Gallons a minute	Date of measurement (1927)				
323	1	Concealed; probably bedding-plane channel.	150	Oct. 16	Seasonal	Stock	58	Perennial spring.
[a] 326	1	Concealed				Medicinal	63	Yield by pump 3 to 5 gallons a minute; spring is site of former deer lick. Well 8 feet deep dug in orifice.
329	1	Concealed; probably solution channel.	1,800	Oct. 14	Seasonal	Stock	60	Yield increases and water becomes turbid after rains to the south; noted yield is 2 days after heavy rains.
331	1	Natural well 25 feet deep; leads to solution channel.			Probably seasonal	Railroad watering station.		Pumped 75 to 100 gallons a minute about 2 hours daily.
338	1	Vertical slump and solution passage; lead to horizontal subsurface channel.			Seasonal	Railroad (formerly).		Abandoned watering station.
341	1	Bedding-plane crevices	½	Oct. 13	do	Stock	62	Perennial spring.
342	1	Concealed; probably joint and bedding-plane channels.	10	do	do	do	63	Do.
346	1	Large solution channel	None.	Oct. 15	do	None		Flows during wet season and forms intermittent creek head. Locally reported that permanent subsurface stream exists some distance within the cave.

[a] See analysis, pp. 116-117.

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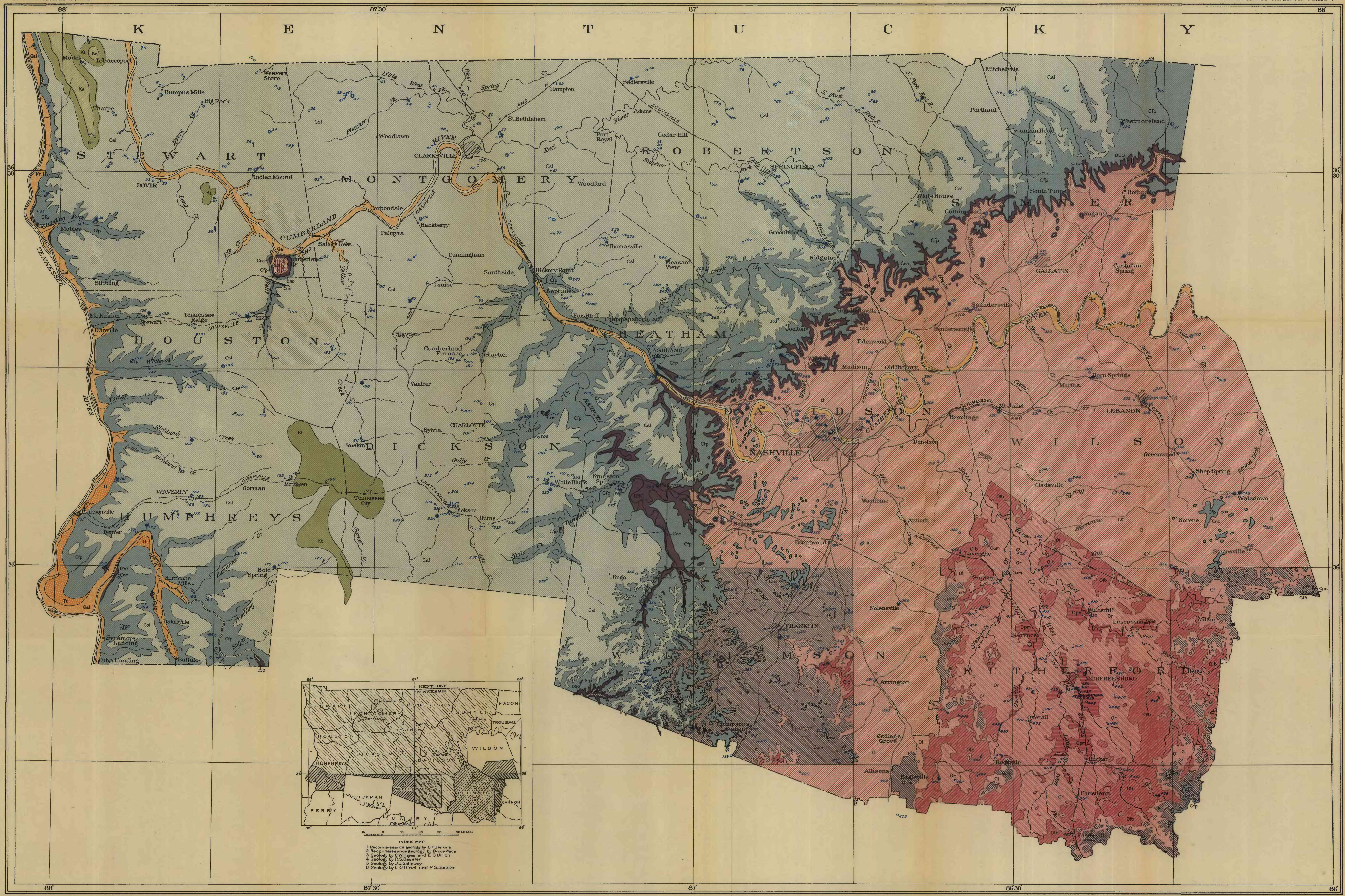

Base enlarged from U. S. Geological Survey base map of Tennessee compiled in 1911 and 1912, with corrections from topographic maps by the U. S. Geolcgical Survey and from county traverse maps by the Tennessee Geological Survey, during the period 1912–1927

GEOLOGIC MAP OF NORTH-CENTRAL TENNESSEE, SHOWING LOCATION OF WELLS AND SPRINGS

Scale $\frac{1}{250,000}$

5 0 5 10 15 MILES

1932

WILLIAMS & HEINTZ CO. WASH. D.C.

Geology compiled by A. M. Piper from detailed geologic maps by R. S. Bassler, J. J. Galloway, C. W. Hayes, and E. O. Ulrich, also from the third edition of the geologic map of Tennessee by the Tennessee Geological Survey, with minor adjustments to the corrected base

EXPLANATION

UNCONSOLIDATED ROCKS

QUATERNARY — Recent

Qal — **Alluvium**
(Gravel, sand, and silt, composing flood plains of major streams; deposits on secondary streams not mapped)

TERTIARY (?) — Pliocene (?)

Tt — **Terrace deposits**
(Rounded to subangular gravel, sand, and silt on river terraces; locally several hundred feet above present stream beds)

CRETACEOUS — Upper Cretaceous

Ke — **Eutaw formation**
(Red micaceous sand with interstratified layers of clay and fossil wood)

Kt — **Tuscaloosa formation**
(Gravel derived from chert of Mississippian rocks, with little sand and clay)

UNCONFORMITY

CONSOLIDATED ROCKS

CARBONIFEROUS — Mississippian

Csl — **St. Louis limestone and Warsaw formation**
(Massive fine-grained gray to blue limestone (St. Louis) above; thick-bedded coarsely crystalline sandy or cherty limestone (Warsaw) below. Both weather to reddish clay with loose chert fragments)

Cfp — **Fort Payne ("Tullahoma") formation**
(Siliceous shale, chert, flint, and cherty crinoidal limestone of extremely variable character; progressively more argillaceous from west to east)

Cnc — **New Providence, Ridgetop, and Chattanooga shales**
(Limestone and greenish clay shale (New Providence and Ridgetop) above and carbonaceous black shale (Chattanooga) below)

UNCONFORMITY

DEVONIAN — Middle Devonian

Pegram limestone
(Thick-bedded light-gray limestone with coarse-grained sandstone at base locally; forms small isolated outcrops)

Camden chert
(Alternating layers of dense bluish-gray limestone and yellowish chert; known at only two localities in southern Humphreys County)

UNCONFORMITY

Lower Devonian

Harriman (?) chert
(White, gray, and buff nonfossiliferous cherty limestone, known only in the Wells Creek Basin, Stewart County)

Birdsong limestone
(Thin-bedded cherty fossiliferous limestone; known only in the Wells Creek Basin)

UNCONFORMITY

SILURIAN

Decatur limestone
(Thick-bedded light-gray relatively pure limestone)

Lobelville formation
(Thin-bedded earthy limestone and variegated shale)

Bob formation
(Massive pure limestone and variegated shale)

Beech River formation
(Calcareous shale and shaly cherty limestone)

Dixon limestone
(Earthy red limestone and red and purple shale)

Lego limestone
(Compact light-gray subcrystalline limestone)

Waldron shale
(Light-gray shaly limestone)

Laurel limestone
(Massive purple and reddish limestone)

Osgood limestone
(Thin-bedded compact light-gray, blue, or reddish earthy limestone)

Brassfield limestone
(White or blue cherty fossiliferous limestone)

ORDOVICIAN — Upper Ordovician

Fernvale formation
(Soft green or chocolate-colored shale with bands of crystalline limestone)

Arnheim formation
(Blue granular crystalline limestone and interbedded shale)

DSO — **Middle and Lower Devonian, Silurian, and Upper Ordovician undifferentiated**

UNCONFORMITY

Leipers limestone
(Knotty earthy limestone and interbedded shale, or granular crystalline limestone without shale)

Middle Ordovician

Catheys limestone
(Knotty earthy limestone and shale with thick bands of impure blue limestone)

Cannon limestone
(Massive pure dove-colored and gray limestone, also argillaceous cherty blue limestone)

Bigby limestone
(Mainly granular crystalline gray or brown laminated and cross-bedded phosphatic limestone)

Hermitage formation
(At western edge of Nashville Basin, chiefly medium-bedded sandy and phosphatic subgranular limestone with local beds of shale. Toward the northeast and east grades into flaggy blue-gray sandy and earthy limestone, calcareous sandstone, and shale)

Oum — **Upper and Middle Ordovician**

Ol — **Lowville limestone**
(Massive compact white or light-blue cherty limestone (Carters limestone member) with thin-bedded dove-colored limestone and yellowish-gray shale at top)

Lower Ordovician — Stone River group

Olb — **Lebanon limestone**
(Thin-bedded compact bluish or dove-colored limestone)

Or — **Ridley limestone**
(Massive fine-grained blue-gray cherty limestone)

Opm — **Pierce and Murfreesboro limestones**
(Thin-bedded blue or drab brittle limestone with local thick beds of bluish-brown coarse crystalline limestone (Pierce) overlying massive brittle drab cherty limestone (Murfreesboro))

O — **Ordovician undifferentiated**

UNCONFORMITY

Ob — **Limestone of Beekmantown age**
(Light-gray fine-grained cherty magnesian limestone)

450 — **Nonflowing well**
(Number refers to description in text and in tabulated well data)

Flowing well

Spring

Well or spring for which water analysis is tabulated in text