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UNDERGROUND WATERS

OF

TENNESSEE AND KENTUCKY WEST OF TENNESSEE RIVER

AND OF

AN ADJACENT AREA IN ILLINOIS

BY

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UNDERGROUND WATERS OF TENNESSEE AND KENTUCKY WEST OF TENNESSEE RIVER AND OF AN ADJACENT AREA IN ILLINOIS.

By L. C. Glenn.

INTRODUCTION.

In this report is described an area in western Tennessee and Kentucky and southern Illinois in which the surface formations are for the most part unconsolidated deposits that were laid down in an embayment of the great sea that once existed in the Mississippi Valley. In Tennessee this embayment area includes the portion of the State between Mississippi and Tennessee rivers with the exception of a narrow strip along the west bank of Tennessee River. In Kentucky it includes all of the State west of Tennessee River with the exception of a narrow strip that extends along the west bank almost to Paducah. In Illinois it includes a large part of Massac, Pulaski, and Alexander counties.

A part of the summer of 1903 was spent in field work, and since that time several trips have been made across various portions of the area. Much information has been obtained by correspondence with owners of wells and springs and with well drillers. The Illinois portion of the area did not receive as much study as the others, but the data obtained are of sufficient value to warrant their inclusion.

SOURCE OF UNDERGROUND WATER.

With the exception of deep underground supplies from porous beds that have received their water where they rise to the surface, perhaps many miles distant, the water supply of any region is abundant or deficient, constant or variable, in accordance with the character of the rainfall. Only a part of the rainfall contributes to the underground water supply. The total precipitation may be divided most conveniently into three portions. One portion runs down the surface slopes and flows into the streams and to the sea. A second portion is absorbed by the soil and fills the pores and cracks in the solid rocks and the interstices in the loose sands and clays, and thus saturates all the strata that are at no great depth beneath the surface. The upper limit of this saturation, or the water table, is not a plane, but a modified reproduction of the actual surface. It rises beneath hills, though not so steeply as the hills, and sinks beneath valleys, though often so much less abruptly that it intersects the valley slope. Where the water table does not lie too far beneath the surface it may be reached by digging wells. Where it intersects the surface it produces springs or marshes. From these springs a part of the absorbed portion of the rainfall flows to the streams in the same manner as the portion that runs off directly during and for a short time after rains, and except this amount furnished by direct run-off, the supply from springs is the sole dependence of the surface streams. A third portion of the rainfall is temporarily absorbed by the earth or held by the covering of leaves and vegetation to be evaporated again by the sun either directly or by transpiration through plant growth.

The water resources of the region discussed in this paper are very largely dependent on its rainfall. The springs and shallow wells derive their supplies exclusively from the rain falling in their immediate vicinity, while the strata from which the deep wells obtain water, though in many cases not reached by the immediately local rainfall, are supplied by rain that falls within the limits of the region or in the region just west of Mississippi River in which Gulf embayment deposits also occur. In only a very few cases do deep wells pierce the hard rocks that lie beneath the soft sands and clays of the embayment deposits and derive their water from rain which has fallen where these hard rocks outcrop, beyond the Gulf embayment area.

ARTESIAN CONDITIONS.

GENERAL STATEMENT.

The requisite conditions for the occurrence of artesian wells in any region are few, simple, and easily understood. It is often difficult, however, to ascertain whether a given region meets all the necessary conditions. In applying the principles of artesian-well occurrence to particular localities numerous subsidiary problems may arise that may greatly modify results and much uncertainty may exist as to the exact geologic conditions present. The requisite conditions have been formulated by T. C. Chamberlin [a] as follows:

1. A pervious stratum to permit the entrance and the passage of the water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
4. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface at the well.

[a] Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 134-135.

WATER-BEARING BEDS.

In close-grained strata like limestones water is found in cracks, fissures, and irregular cavities; in open-grained rocks like sandstones, sands, and gravels it occurs in the pores and interstices between the rock particles. In the region under consideration all the rocks through which waters freely pass are open-grained sands and gravels. The size of the rock particles varies greatly, however, ranging from

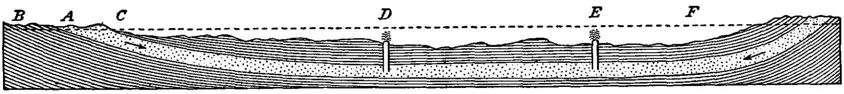


FIG. 1.—Section showing principal requisites of artesian wells. *A*, a porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous beds *A*, or, in other words, height in reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*.

fine silty sands, through which water flows slowly and with difficulty, to very coarse sands, fine gravels, or even cobbles in exceptional cases, which yield their water supplies freely. The loose, porous water-bearing beds of the region are the Lagrange sands, the Ripley sands, and the Eutaw sands, each of which is described in detail. The areal occurrence of each is shown by the geologic map (Pl. I).

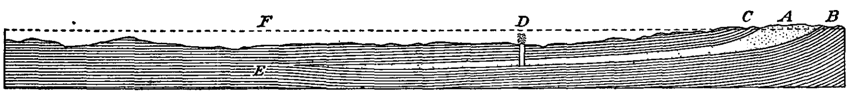


FIG. 2.—Section illustrating thinning out of porous water-bearing bed *A*, inclosed between impervious beds *B*, *C*, thus furnishing conditions for artesian well at *D*, but not at *E*.

As the dips are westward each formation occurs as an underground bed in all of the area west of its outcrop.

Immediately underlying the entire area is a floor of hard, close-grained rocks which in some places are sufficiently seamed and fissured to furnish a supply of artesian water. The drill has pierced these hard beds underlying the loose embayment deposits in only a

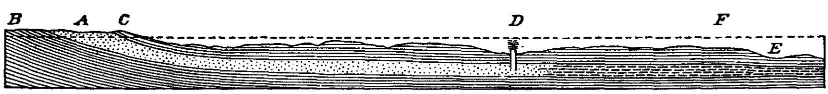


FIG. 3.—Section showing transition from porous to impervious bed. As the bed *A* is inclosed between impervious beds *B* and *C*, an artesian well is obtained at *D*. At *E*, however, *A* is impervious and water can not be obtained.

few places around the edges of the area, where the old rock floor is not deeply covered by the later deposits, as at Corinth, Miss.; Lexington, Tenn.; Paducah and Wickliffe, Ky.; Cairo, Ill.; and Morehouse, Mo. At some of these places the underlying hard beds are fissured and yield water; at others they are without notable fissures and yield little or none.

CONFINING BEDS.

Both above and below the water-bearing bed there must be beds of impervious material that prevent the escape of the water by natural means. The imprisoned water thus accumulates under pressure until the impervious cover is pierced by the drill.

The presence of an impervious bed directly beneath the porous water-bearing stratum is not so important as that of one over it, since, if the underlying bed does permit the passage of water through it, the escape is downward and lower impervious beds are almost sure to be reached in a short distance, so that usually the ultimate escape of the water is prevented.

In the region under discussion the lowest water-bearing bed of the embayment deposits over a considerable though as yet not accurately delimited portion of the area is the Eutaw sand. Beneath it are cherts, limestones, shales, or sandstones of Paleozoic age that at some places are impervious. At other places they are seamed or fissured, but the water received from overlying beds does not escape either along the seams or downward, as is shown by the great rise of the water in wells that enter these fissured beds.

The fine close-grained clays of the Selma clay form an impervious cover above the Eutaw sand and an impervious floor for the overlying Ripley sands. The Porters Creek clays form both an impervious cover for the Ripley sands beneath them and an impervious floor for the pervious Lagrange sands above them.

DIP.

The dip of the Paleozoic floor upon which the embayment sands and clays rest is westward in Tennessee; but to the north, toward the head of the embayment, the dip gradually changes to southwestward in Kentucky, and finally becomes southward in southern Illinois, at the northern margin of the deposits. Farther west, across southeastern Missouri and eastern Arkansas, it is southeastward. The rock floor in the northern part of the embayment is consequently spoon-shaped, with the tip of the spoon extending northward into southern Illinois and its eastern half underlying western Tennessee and Kentucky.

While not much is known of the structure of this Paleozoic floor, because few borings have penetrated it, a study of the borings and of the beveled surface in visible contact with the embayment deposits around their margin indicates that the shape of the floor is not the result of downward folding of one stratum or series of strata, but is due, at least mainly, to erosion which occurred while the Paleozoic rocks formed the actual surface of the region, before the embayment deposits had been laid down. The sands and clays of the northern half of the embayment were deposited in successive strata upon this rock floor. They accordingly dip westward in Tennessee, westward and southwestward in Kentucky, and southward in Illinois, in conformity with the dips of the underlying Paleozoic surface.

The rocks dip somewhat more steeply near their outcropping edges than they do farther out in the embayment area. The dip of the Selma clay from its eastern edge near Tennessee River westward to Selmer, Tenn., is about 25 feet per mile. The westward dip of the Lagrange beds from their eastern edge east of Saulsbury, on the Southern Railway, to Memphis is about 22 feet per mile. The southwestern dip of the Paleozoic floor from Paducah to Hickman, Ky., is about 27 feet per mile, and its southern dip from a point near Ullin to Cairo, Ill., is about 27 feet per mile.

EXPOSURE OF POROUS STRATA.

The porous strata that may furnish artesian water are the Eutaw sand, the Ripley sand, and the Lagrange sand. The Eutaw sand lies immediately on the Paleozoic floor and outcrops along the eastern edge of the area discussed in a belt that varies from less than a mile to about 8 miles in width and extends northward from the Mississippi line about halfway across the State of Tennessee.

The Ripley sands outcrop in a belt that varies from 5 to 15 miles in width. This belt is situated some distance west of and parallel to the outcrop of the Eutaw sand as far north as the Eutaw and the intervening Selma clay extend as surface formations. About halfway across the State of Tennessee the two older formations disappear, and thence northward across western Kentucky and into southern Illinois the Ripley sands rest on the underlying Paleozoic rocks, and consequently outcrop in a belt immediately west of them. In Kentucky this belt averages about 6 miles in width, but it narrows considerably near Paducah before passing into Illinois. In Illinois exposures are poor and rare, so that the width of the Ripley outcrop is difficult to determine, but it would seem to be as great as the average in Kentucky.

Though the Eutaw and Ripley formations outcrop in narrow belts, these belts are wide enough to absorb many times as much water as will be required to supply any prospective demand.

The Lagrange sand forms the surface of more than half the entire area under consideration, so that there can be no question as to the sufficiency of the supply of water absorbed by it. This formation, however, does not conform strictly to the conditions of a porous artesian stratum, as do the two lower formations, the Ripley and

Eutaw, since, except locally in the western part of the area, as at Memphis, it is not overlain by an impervious bed to prevent the upward escape of the water, but forms the surface of the country in the area of its occurrence save for the thin and, as confining beds, unimportant deposits of Lafayette gravel and Columbia loess and loam.

RAINFALL.

As the supply of underground water is dependent on the rainfall, the amount and distribution of the latter is very important. The following table has been prepared from the records of the United

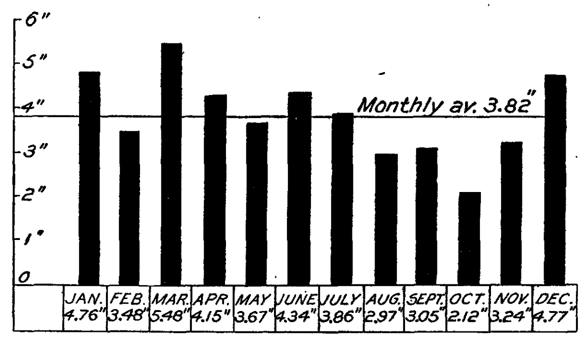


FIG. 4.—Diagram showing graphically the monthly average rainfall in the area discussed.

States Weather Bureau to show the average monthly rainfall at a number of places in and near the area here discussed. The monthly averages are shown graphically in fig. 4.

Monthly rainfall, in inches, at Weather Bureau stations in the embayment area.

Station.	Length of record (years).	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Illinois:													
Cairo	34	3.82	3.89	3.79	3.82	3.78	4.42	4.97	2.83	2.54	2.70	4.10	3.32
Kentucky:													
Blandville	11	4.56	3.12	5.44	3.49	3.70	4.77	4.19	1.82	3.23	2.52	3.22	4.12
Mayfield	....	4.17	2.09	6.48	2.34	2.86	3.83	6.93	3.00	2.89	.84	.57	4.19
Paducah	13	4.08	3.50	4.93	3.92	3.67	5.18	3.94	2.75	3.20	2.32	3.75	3.68
Missouri:													
Caruthersville	5-6	3.99	4.07	5.65	3.20	4.23	4.80	3.60	2.67	3.72	1.53	Trace	4.52
Tennessee:													
Arlington	14-23	......	......	......	3.65	3.83	4.36	3.90	3.24	2.45	2.02	......	......
Bolivar	18-21	5.38	3.78	5.40	5.09	3.58	4.01	3.74	2.39	3.13	2.24	3.76	4.31
Brownsville	21-23	......	.98	6.68	4.33	3.46	4.49	3.52	2.83	2.66	2.21	4.39	......
Covington	17-23	5.08	4.35	5.83	4.34	3.93	4.26	3.37	3.10	2.63	1.87	4.13	4.91
Dyersburg	8-23	......	3.90	4.87	5.24	3.66	4.08	3.60	2.95	3.09	2.28	4.55	3.89
Jackson	13	4.52	3.01	4.80	4.91	3.78	4.36	4.60	2.53	2.26	2.15	3.93	5.12
Kenton	4	4.72	2.53	5.06	4.03	2.32	2.74	3.10	2.15	2.92	.94	.70	7.43
McKenzie	16	......	......	......	......	......	......	......	......	......	......	4.06	......
Memphis	35	5.46	5.20	5.86	5.47	4.53	4.66	3.54	3.57	3.05	2.72	4.58	4.35
Milan	18-23	......	......	......	4.51	4.09	4.58	3.74	3.93	3.16	2.21	......	......
Savannah	19-22	4.85	4.98	5.78	4.44	4.10	4.94	4.17	3.60	3.83	2.22	3.77	4.93
Springville	....	3.99	1.92	6.30	3.22	2.55	2.67	1.66	1.60	4.08	......	1.33	7.19
Trenton	21	5.79	4.60	5.50	4.41	3.68	4.41	3.45	3.26	3.09	2.70	4.51	4.34
Wildersville	9	6.26	3.69	5.30	4.21	4.31	5.62	3.45	5.18	......	2.68	3.75	5.22
Average	....	4.76	3.48	5.48	4.15	3.67	4.34	3.86	2.97	3.05	2.12	3.24	4.77

Monthly average, 3.82 inches; yearly average, 45.89 inches.

The average annual rainfall varies from a minimum of about 43 inches yearly, as at Center Point, Tenn., and Cairo, Ill., to a maximum of about 52 or 53 inches, as at Savannah and Memphis, Tenn. The general average for the entire region is between 47 and 48 inches.

The monthly distribution is not uniform throughout the year. While the monthly average for the year is 3.92 inches, from July to October it is only 2.17 inches, and from November to March it is 5.90 inches. The driest part of the year is the late summer and fall; the wettest is the winter, especially the latter part of it. Streams and ponds are in consequence lowest in the late fall and in some cases become entirely dry. They are highest in late winter and very early spring. In many cases shallow wells are also affected almost as directly as the ponds and streams. During the long, dry fall the water may get low or fail altogether, while during winter and spring the supply is most abundant, and in some wells the water rises to the surface.

Deep wells receiving their supply from surface sources which may be many miles distant are not measurably affected by the seasonal variations in rainfall, and furnish an almost unvarying supply. Springs may, like deep wells, be unaffected by variations in the rainfall, or the ground-water level from which they derive their supply may be so near the surface that when it is lowered during prolonged dry weather the flow of the springs naturally diminishes or even entirely ceases.

ABSENCE OF LOWER ESCAPE.

Eutaw and Ripley formations.—For water to rise and flow from a deep well there must be no means of escape at a lower level. The Eutaw and Ripley formations are not known to outcrop except along their elevated edges on or near the margin of the embayment deposits. To the south, toward the Gulf of Mexico, along the deepest portion of the erosion trough in which they are deposited, the dip carries them farther from the surface; but it is highly probable that they either pass into finer grained impervious beds or are overlapped and sealed up by other fine-grained strata, so that there is no free escape south ward of the waters that enter their exposed edges along the belt of outcrop. The waters thus imprisoned fill the pore space in the beds up to the level of the ground water in the area of their outcrop, and so exert a pressure on all lower parts of the beds that forces the water in deep wells up nearly to the outcrop level. The amount by which the water in a well falls short of this level depends on the friction or resistance to the flow through the water-bearing bed, which is determined by the distance the water flows from its point of entrance into the bed and by the coarseness or fineness of the materials of which the bed is composed.

Lagrange formation.—The Lagrange either outcrops over much of the region or is covered by only a few feet of Lafayatte or Columbia deposits. Its contained waters consequently escape wherever the ordinary ground-water level intersects the surface, and they rise in deep bore holes to about the level of the ground water. The formation contains beds of close-grained sands and impermeable clays that may extend over considerable areas and confine the waters beneath under such pressure that they may rise, when these beds are pierced by the drill, to a level somewhat lower or higher than that of the local ground water, owing to the local lack of free vertical communication and circulation and to the more intimate connection of the lower coarser beds with some distant part of the formation whose elevation determines the pressure at the boring. Hence a partial escape only is found for the contained waters of the Lagrange. Under certain conditions wells sunk to porous strata in this formation may flow with slight heads. No great surface pressure is obtainable anywhere in it, or indeed in any of the other water-bearing formations in the area under consideration, since the difference in level between the distant source and the surface exit at the well mouth can not anywhere be great, because there are no great differences in surface elevation in the general region. The relation of these various beds to artesian conditions is shown in fig. 7.

PHYSICAL FEATURES OF REGION.

EMBAYMENT AREA IN TENNESSEE AND KENTUCKY.

TOPOGRAPHIC TYPES.

General character.—The surface of the part of Tennessee and Kentucky under discussion varies from a very flat flood plain along the main rivers and their principal tributaries to a gently rolling or hilly surface along the sides of the valleys and in the interstream areas. Occasionally the interstream areas are level and plateau-like and are fringed with hills that have been carved by the tributaries of the adjacent streams. Generally the surface is rolling or moderately hilly and is cut into bolder hills near the valleys of the larger streams. These valleys vary from a fraction of a mile to several miles in width, and a large part of each is the present-day flood plain. In most of the valleys there are also considerable portions of an older, higher flood plain which is from 2 to 20 feet or more above the present flood plain, and which, especially along the larger tributaries of Mississippi River in Tennessee, is several miles in width. This old flood plain is commonly known as the "second bottoms," and is generally separated from the present flood plain by a steep, well-marked scarp.

The types of surface described below have in their respective areas an influence on the local problems relating to water resources, the nature of which is set forth in some detail on later pages of this report.

Hills of erosion.—An unusually hilly belt in the eastern part of the Lagrange area extends across Tennessee and Kentucky, though it is most prominently developed in Hardeman and Henry counties, Tenn. The materials are soft sands with lenses of clay that are easily eroded. Gullies and ravines form rapidly in abandoned fields. These ravines average not over 20 or 30 feet in depth, but under especially favorable conditions they may become 100 feet deep or over.

Residual ridge.—A ridge half a mile wide and between 100 and 150 feet high extends northward from Mississippi into the southwestern part of McNairy County, Tenn., but gradually dies out to the north in this county. It is composed of Ripley sands and clays and owes its existence to the large amount of concretionary ironstone into which its sands have been cemented in many places and which has protected it from erosion while the areas on either side have worn away. This ridge is crossed by the Southern Railway in what is known as the "big cut" just west of Cypress station.

East of the ridge the Eutaw sands and clays that outcrop along the eastern edge of the embayment in the southern half of Tennessee are in many places cut into steep hills, both because of the nature of their materials and because of their situation on the short, steep drainage slope of Tennessee River.

Flatwoods.—The surface of parts of the belt underlain by the Porters Creek clays, in both Tennessee and Kentucky near the line between the two States, is of more than average flatness. In Mississippi this formation has so marked a tendency to produce flat topography that it is there known as the Flatwoods clay and the surface underlain by it as the flatwoods. Aside from the area mentioned above, its surface in Tennessee and Kentucky is not notably flat. In Illinois it is not known to form any portion of the actual surface, being there overlain and concealed, except along the Ohio River bluff at Caledonia, by Lafayette gravels and the loess.

Tennessee-Mississippi divide.—The most elevated part of western Tennessee is found in eastern McNairy County in a narrow belt extending north and south and forming the divide between the Mississippi and the Tennessee drainage. This divide has been called by Safford the Tennessee Ridge. It averages from 450 to 500 feet in height, though in places it reaches an altitude of about 600 feet above sea level. It extends northward parallel to Tennessee River and from 10 to 25 miles west of it. As this ridge is near Tennessee River it divides western Tennessee and western Kentucky into two drainage slopes of very unequal size. The one to the east, tributary to Tennessee River, is steep and narrow, and streams that flow directly into the Tennessee are short. In the northern half of the belt, however, the main tributaries, such as the Big Sandy in Tennessee and Blood and Clarks rivers in Kentucky, instead of entering the Tennessee direct, flow parallel to it, and hence are much longer than would be expected from the width of the slope. West of Tennessee Ridge the general surface slope to the Mississippi is much longer and gentler. The main streams, such as Wolf, Loosahatchie, Hatchee, and Obion rivers in Tennessee and Bayou de Chien, Obion Creek, and Mayfield Creek in Kentucky, flow more directly into the Mississippi, though Mayfield Creek makes a notable bend so that its upper part parallels the Mississippi, but flows in the opposite direction. The fall per mile in all these streams tributary to the Mississippi is small, and they do not as a rule furnish opportunities for developing water power. In places, indeed, their flood plains are undrained cypress swamps.

From Tennessee Ridge eastward the surface slopes gently, but along the edge of the Tennessee Valley there is a rather abrupt drop of 150 to 250 feet to the river flood plain. Westward from the divide the general surface slope is toward the Mississippi; but this statement is true in only a very broad sense. Everywhere the appreciable slope is toward the main drainage ways. As stated in the preceding paragraph, a high narrow ridge extends northward from Mississippi some distance into Tennessee along the outcrop of the Ripley sands and interrupts locally the general westward slope. Another higher belt that extends northward from the region of Grand Junction, past Jackson toward Milan, reaches elevations of over 500 feet on the divides between the streams that flow westward across it. This interruption in the general westward slope is not a single ridge, but rather a belt a number of miles in width. It coincides with the eastern part of the outcrop of the soft Lagrange sands with their interbedded clay lenses that give in detail the hilly topography already described.

Alluvial region.—West of the line of bluffs which terminates the uplands of western Tennessee and Kentucky, along Mississippi and Ohio rivers, there is a variable width of alluvial bottom lands, which belong to the flood plains of these streams, though under present conditions portions of them rise as low ridges or swells high enough not to be submerged during floods. The surface of these bottoms is either flat, broken by low ridges a few feet high, or intersected by narrow sloughs and partly filled channels in which water is found. It is somewhat higher near the river bank and this part is largely cleared and cultivated. Back from the river, near the bluffs, the surface is lower and much of it is swampy and uncleared. The slope of the surface is about the same as that of the high-water level of the Mississippi. This has an elevation at Cairo of about 320 feet and at the Mississippi State line of about 215 feet. Above Cairo the Ohio flood plain is well developed and wider on the Kentucky side of the river and has much the same characteristics as the Mississippi flood plain just described. Its elevation at Paducah is about 340 feet and at Cairo about 320 feet.

ORIGIN OF THE TOPOGRAPHY.

Except in the area adjacent to Reelfoot Lake, in the northwest corner of Tennessee, where there were surface disturbances during the New Madrid earthquake of 1812, all surface inequalities found in the region are due to erosion. The surface was originally a plain of marine deposition formed beneath the waters of the Gulf when it extended into southern Illinois. If several minor episodes of uplift and depression—probably with tilting or warping—are disregarded it may be said that this Gulf bottom was subsequently uplifted and has since been thoroughly but not deeply dissected by the streams that have established themselves on every part of it.

Stream activities.—Because the elevation was not great, erosion has not been profound. The streams soon cut as deeply into the surface as they could and then began widening their valleys. Since the materials are mostly soft sands and clays, valley widening and flood-plain formation have been relatively rapid. Flood plains on streams like the Wolf, the Forked Deer, and the Obion had grown in places from 3 to 5 miles or more wide when a further slight uplift caused the streams to incise themselves from a few feet to 20 feet beneath this level and begin the cutting away of the old flood plain, now called the second botoms, and the building of a new one which has attained a width of from a few hundred yards to a mile or more. Between the formation of the broad ancient flood plain and the uplift, which permitted the cutting of the present flood plain, there was a brief and slight depression during which the old plain was sheeted with a deposit of loess.

As a rule the hills carved from the old surface by stream erosion are higher, but of gentler slope near the main drainage ways, because they have been weathering away there longest; they are lower but of steeper slope along the upper waters of the tributaries, because there they have been most recently cut.

Nature of erosion in sandy and clayey strata.—While strata of soft sands are easily eroded into steep-sided hills separated by narrow gullies or ravines, the tops of these hills do not waste away with equal ease but remain at almost their original altitude. In a climate such as that of the region under discussion, two parallel outcrops of sands and clays, at the same original elevation, will erode very differently. The clays are apt to retain a reasonably flat surface which is slowly lowered by erosion, as, for instance, in the belt of Porter's Creek or "Flatwoods" clays immediately east of the Lagrange sands. Nearly all of the rain falling on the clay area must run off in surface streams.

Down any steep slopes that tend to develop by stream cutting the rain wash would be great and such quantities of material would be furnished to the streams as would not only prevent their cutting deep channels but tend to make them build flat flood plains. Time would witness only a gradual lowering of the general surface, whose gentle slopes would maintain the equilibrium between rain wash and stream transportation.

The sand area will be cut into hills, but the general level of the hilltops will remain almost unchanged. All of the rain falling on the surface would be directly absorbed as if by a blotter and streams would not be formed until the ground-water level rose to the surface in some low place. The stream thus originating would at once begin eroding the soft sands along its way. Since even during rains such a stream would be fed by percolation through the sands rather than by run-off from the surface, it would be left free to deepen its channel and carve the surface into hills, whose tops and sides would be almost free from surface rivulets during rains, and hence would not be subject to rapid wasting and lowering. Soft sands dredged from the proposed Nicaragua Canal and left in steep piles with surfaces in many cases at the angle of rest have remained for several years almost untouched by surface erosion, although the annual rainfall is over 250 inches, simply because the rain does not run off on the surface but soaks in.

Relation of geology to surface topography.—In some areas the character of the topography is determined largely by the geologic formation outcropping. Along the Mississippi bluffs, for instance, the surface rises abruptly from 100 to 180 feet above the alluvial flood plain. These bluffs are cut by narrow ravines, or "gulfs," as they are locally called, into steep-sided hills whose upper portions are largely prevented from weathering back into gentler slopes by a capping of 20 to 80 feet of loess, which may stand under favorable circumstances, as in the bluffs overlooking the river, in vertical cliffs.

Surface warping.—West of the outcrop of the Lagrange sands the general surface slopes gently toward Mississippi River, having an average elevation of about 400 feet along a north-south belt midway between Tennessee and Mississippi rivers in Tennessee and Kentucky. West of this belt, but some distance east of the Mississippi bluffs, in an area about halfway between the northern and southern boundaries of Tennessee, the average elevation is only about 350 feet. From this area northward the surface rises until along the Kentucky line and for some distance northward into Kentucky it has an average elevation of from 400 to 450 feet. South of the same area the general surface elevation declines until near Memphis it is about 300 feet. The uniformity of the general westward slope of the embayment deposits in Tennessee and Kentucky is thus interrupted toward Mississippi River by a warping that has depressed the southern part of the belt and raised the northern part.

Seismic disturbance.—The fact that this more elevated portion is near the area of maximum disturbance in the New Madrid earthquake of 1811 and 1812 suggests a causal relation between the two, especially since it is known that changes of level in the alluvial flood plain of the Mississippi at that time raised a considerable area of it into a broad, low dome. If 350 feet be somewhat arbitrarily assumed as the normal elevation in this higher area the objection might reasonably be made that from all of the facts known in regard to the detailed topography of the valleys and flood plains of the streams of this region tributary to the Mississippi, it is improbable that scarcely a hundred years ago the region underwent an elevation of 50 or 100 feet, else terracing and ponding would reveal it. It seems more probable to the writer that the region may have been elevated some few feet during the New Madrid earthquake and that during perhaps many previous earthquakes similar changes of level occurred whose aggregate effect has been to raise the general surface to the present level. As stated in detail on page 31, there is evidence that this Gulf embayment region was subject to earthquakes perhaps as early as late Eocene time and probably they have continued at intervals down to the present day. In the same way, although there are no records of sudden depressions or other changes of level since the advent of the white man, the general low level of the region near Memphis may be due to depressions during the same series of earthquake disturbances.

The differences in the elevation of the Tertiary and more recent strata as exposed in the Mississippi bluffs at Memphis and at points farther north to beyond Hickman, Ky., indicate that the region near Mississippi River has undergone differential elevation—in other words, has been warped—and if earthquake movements be thought inadequate to produce the effects seen, more quiet and slowly acting but more general and powerful crustal movement must be assumed as the cause, for the difference in elevation of the strata of these bluffs does not seem due to differences in surface erosion.

Elevation along the bluffs.—In the middle and northern part of Tennessee and into Kentucky the general surface rises somewhat as the bluffs of the Mississippi are approached. At Hickman, Ky., for instance, at the top of the bluff the elevation is 461 feet; while to the east it is from 50 to 100 feet less.

This does not seem to be the case at either Memphis on the south or Wickliffe on the north. The general surface at both these places seems either to be flat toward the east or to rise gently in that direction. The westward rise of the surface in northwestern Tennessee as the Mississippi bluffs are approached may possibly be due to doming caused by the earthquake activity in this region, as already alluded to or to some more general crustal movements.

EMBAYMENT AREA IN ILLINOIS.

In Illinois the Gulf embayment area includes the southeastern part of Alexander County, all of Pulaski County south of the swamps of Cache River above Ullin, all of Massac County south of the chain of swamps in its northern portion, and a very narrow strip in Pope County along its southern boundary.

This area in Illinois may be divided into two portions that differ from each other in their surface topography and elevation. One portion comprises the low, flat alluvial plains of Mississippi and Ohio rivers. The other portion is a rolling to hilly upland.

Flood plain.—The alluvial plains extend as a broad belt from Santa Fe down the Mississippi to Cairo and thence as a narrow belt up the Ohio to a point a few miles above Mound City, where the upland bluffs on the Illinois side close in on the river and continue with but slight interruption to a point a short distance north of Metropolis. There the flood plain again begins and widens as it extends up the river until it attains a width of several miles in the bend above Paducah. This flood plain extends up the Ohio beyond the limits of the Gulf embayment region.

The elevation of this low plain is about 320 feet at Cairo and about 340 or 350 feet along the edge bordering the upland. In places the alluvial plain and the upland meet along a sharply defined line, the upland surface rising abruptly as a steep-sided bluff. In other places the two types of surface meet and merge with gentler slopes.

Cache River Valley.—The flood plain of Cache River below Ullin is a part of this alluvial plain and is covered by backwater during floods. Above Ullin the valley of the Cache is a continuation of the same plain, though it is bordered on the south by a rolling upland that rises a hundred feet or more above it.

The Cache River valley is an abandoned valley of Ohio River and to this fact it owes its width, flat surface, and low grade. The Ohio formerly turned westward 3 or 4 miles below Golconda and followed the valley of Big Bay Creek for some distance, then continued westward to the present Cache River through the depression now occupied by the chain of swamps in northern Massac County. The Cumberland and Tennessee rivers then united at Paducah and followed the present course of the Ohio from there to Cairo.

Uplands.—The upland region includes all of Pulaski County lying southeast of the Cache River valley and north of the Mississippi and Ohio flood plain, which extends, as has been stated, a short distance north of Mound City. It also includes all of Massac County south of the chain of swamps which crosses its northern part, except the strip of Ohio flood plain in its southwestern part, and a small area of Pope County adjacent to the Massac County line. The upland has a rolling to hilly surface whose average elevation is 375 to 450 feet above sea level.

GEOLOGY.

GENERAL STATEMENT.

The rocks of the region under consideration consist of sands, clays, and gravels that range in age from Cretaceous to Recent, though the record is not one of continuous sedimentation. These deposits are for the most part unconsolidated. Here and there the sands may be locally cemented in part into an ironstone or ferruginous sandstone and in drilling a well one or more layers of such indurated sandstone are usually found somewhere in the section. These layers are as a rule from a few inches to a foot thick, rarely as much as 2 feet, and are usually found at the bottom of a stratum of sand resting immediately on a bed of clay. Their origin is simple. They are merely the lower portion of the bed of sand, once loose, but now cemented into a firm rock by iron oxide carried there in solution in water and prevented from descending farther by the underlying impervious clay. These thin layers are not thick enough or hard enough to offer any serious obstacle to the driller using tools primarily fitted for work in soft sand and clay. Usually a few blows from a heavy iron rod breaks them to pieces or a chisel point soon cuts through them.

In numerous places, especially on the eastern side of the region, gravels lying on or near the surface have been cemented by iron into a firm ironstone conglomerate. Ledges of this may be several feet thick, but as it lies at or near the surface in the higher parts of the region much of it has been undermined by erosion and either broken into loose blocks or removed entirely, so that it does not form a continuous stratum and rarely offers serious interference to well drilling.

DESCRIPTIONS OF THE ROCKS.

The geologic formations represented in the embayment deposits of this region, given in order from the oldest to the youngest, are the Eutaw sand, the Selma clay, and the Lagrange formation, of the Cretaceous; the Porters Creek clay and the Lafayette formation, of the Eocene; the Lafayette formation of the Pliocene; the Columbia sand, loess, and loam, of the Pleistocene, and the river alluvium, of Recent age. These rest on a floor of Paleozoic rocks.

PALEOZOIC FLOOR.

The rocks that underlie the unconsolidated deposits along their eastern edge near the southern line of Tennessee belong to the Mississippian series of the Carboniferous; in the deep well at Corinth, Miss., chert that apparently belonged to this series was struck at a depth of 450 feet. Northward in Tennesssee the Mississippian series soon disappears and Silurian limestones become the floor of the embayment. These were entered in the well at Lexington at a depth of 500 feet. No other deep wells in Tennessee, however, reach the limestones beneath the embayment sands and clays and their exact depth at other points in Tennessee is not known. To the north, in Benton County, the floor belongs to the Mississippian series, while still farther north, in Henry County, it is again Silurian, but the Mississippian rocks reappear near the Kentucky line and underlie the edge of the embayment through its entire extent in Kentucky and through southern Illinois at least as far west as Ullin. From Ullin westward to Mississippi River part of the marginal floor is Mississippian, part probably Devonian, and part Silurian.

In Kentucky three deep wells have passed through the embayment deposits and entered the Paleozoic rocks beneath. The deep well at Paducah reached the Mississippian at a depth of 324 feet. The one at Wickliffe is reported to have entered the same series at a depth of 1,000 feet. At La Center Mississippian chert was encountered at a depth of 387 feet. In southern Illinois deep wells at Cairo entered the underlying Mississippian chert, or Elco gravel, as it is locally known, at a depth of 525 feet. At Mound City the depth to the chert is reported to be 605 feet. The depth to the Paleozoic floor over the rest of the area under consideration is of much interest in connection with water-supply problems. No direct measurements can be had at present because no other deep wells have gone through the embayment deposits. The well that has penetrated these deposits farthest is the deep well at Memphis, a record of which is given on page 114. The bottom of the well, at a depth of 1,147 feet, is down 121 feet in the Porters Creek clay. If it is assumed that this formation has there its maximum thickness of 175 feet, as observed elsewhere, and that the Ripley formation, Selma clay, and Eutaw sand have their maximum observed thickness, the Paleozoic floor would be reached at Memphis at a depth of about 1,160 feet below the bottom of the deep well, or about 2,300 feet from the surface. At no one place, however, have these formations been found to have each its maximum thickness, but where one is thicker than the average another may be thinner or even entirely absent, so that if there is not an aggregate thickening of these beds as compared with their development in other places, the depth to the Paleozoic floor at Memphis will be considerably less than 2,300 feet—perhaps several hundred feet less.

It should, however, be as clearly borne in mind that one or more of these lower beds may thicken materially or that other formations not appearing as surface outcrops in this area may be present in the section and make the distance to the hard-rock floor greater than that given above. While deep drilling in loose sands and clays is attended with difficulties, yet if it were thought desirable to explore to further depth the water-bearing deposits underlying Memphis, the boring might easily be carried to a depth of 2,500 feet or more. At Galveston, Tex., a few years ago, a well was successfully sunk through loose sands and clays to a depth of 3,070 feet.

CRETACEOUS SYSTEM.

EUTAW SAND.[a]

Extent.—The Eutaw sand is the oldest of the embayment formations and rests upon the hard rocks of the Paleozoic floor. It outcrops along the eastern edge of the embayment deposits in Hardin and Decatur counties and the extreme southern part of Benton County, Tenn., in a belt whose width varies from 2 to 8 miles and averages somewhat less than 4 miles. In the deeper part of the embayment it very probably extends somewhat farther north than its extreme northern outcrop, but that it does not underlie the entire embayment is shown by its absence in deep borings in the northern part of the area, at Paducah, La Center, Hickman, and Cairo. It is impossible to determine its northern limits beneath the later deposits in the absence of wells deep enough to reach the Paleozoic floor, but it may be fairly assumed that it probably underlies all of the embayment area in Tennessee west of its outcrop. Under most of this area, however, it is at such a depth that there is not much likelihood of wells reaching it, because water will probably be obtained at less depths from overlying beds.

Lithologic character.—The Eutaw beds are composed predominantly of sand, which is, however, interbedded with a subordinate amount of clay. The deposit was formed in shallow water characterized by weak but constantly and rapidly changing currents so that the sand and clay are ever varying in their interbedding. The conditions were not marine, but probably those of brackish water. In a continuous exposure of several hundred yards beds of sand or clay may be seen to grade wholly or partly from one to the other several times, or in a bed of one material a lens of the other may appear and rapidly thicken or may remain a thin layer and disappear in a short distance. In places the sand and clay are interlaminated in very thin layers and in many such cases the laminæ are cross-bedded. The cross-

[a] This formation is here identical with the Coffee sand of Safford, and, while direct tracing to Eutaw localities in Alabama has not been done, it is most probably the close equivalent of the Eutaw of that State. In the Tennessee area it is not thought to include any beds equivalent either to the Tombigbee sand above or the Tuscaloosa below. If the Tombigbee has an equivalent in this area it is most probably included in the basal part of the Selma clay. The Tuscaloosa is not believed to be represented here.

bedding is weak, being usually at a gentle angle only and dying out in a few feet. At no place seen by the writer does it involve a large mass of material in any one spot.

As a result of this abrupt variation in lithologic character no two sections of the Eutaw sand taken a few rods apart will agree in detailed thickness of beds. Just east of Parsons, Tenn., in the railroad cut, there are at the base about 4 feet of conglomerate with angular and rounded chert cobbles up to 8 or 10 inches in diameter, overlain by very dark blue lignitic sandy shales in thin papery layers. These shales are locally interbedded with several layers 4 to 8 inches thick of coarse material, which contains rounded chert masses 4 to 6 inches in diameter and numerous similar-sized angular pieces of Devonian black shale that must have been derived from some Devonian exposure very near by, along the shore at that time. Some rods to the west the lignitic shale passes beneath cross-bedded sands that contain a sprinkling of rounded gravel up to an inch in diameter. These sands are variable in texture and contain occasional thin layers of leaden-gray clay that are persistent for only short distances. Farther west this layer of sand and gravel seems almost to wedge out as it passes beneath track level, and over it lies a fine leaden-gray to dark-blue or purplish clay about 20 feet thick, overlain by about 10 feet of lighter colored sandy clay. Owing to variations in their thickness and the lowness of the banks of the cut, the average thickness of several of the lower beds described above can not be determined, but is perhaps 10 to 20 feet each.

Section.—The best exposure of the Eutaw sand is found at Coffee Bluff, on the west bank of Tennessee River in Hardin Country, Tenn. The river washes the foot of the bluff for nearly 2 miles, but at no point is the base of the formation shown, so the exact thickness there can not be ascertained. At the point where the highway reaches the top of the bluff the following section was obtained:

Section at Coffee Bluff, Tennessee.

	Feet.
1. Back half a mile west of the edge of the bluff, red and yellow chert gravels of Lafayette age with overlying reddish sandy clay	15
2. Along descending slope of road from above point to the edge of the bluff are poorly exposed light-colored sands and leaden-colored clays interbedded in thin layers which are usually minutely laminated	120
3. At top of bluff, light-colored sands similar in color, texture, and structure to those below	12
4. Dark slate-colored clay in thin laminæ, usually a very pure and fine-grained clay, but in places with thin, sandy layers. It contains small fragments of indistinct plants and shows at its base local unconformity with the underlying beds	25
5. Fine gray sand interbedded with slaty or leaden-colored clay in fissile papery laminæ. The sand and clay are often interlaminated and more or less cross-bedded; in places a relatively pure bed of sand or clay several feet thick grades over along the bedding plane into the other within a few yards. On the surface of the thin fissile shales are indistinct leaf impressions.	

	Feet.
The sand and clay alike carry more or less lignitized wood, which is in small pieces except in the lower part of this division, where logs of it are found. Decomposing pyrite is associated with the lignite. Two logs of petrified wood projected from this sand and clay when Safford made the measurements recorded on page 412 of his Geology of Tennessee. These have since disappeared by the recession of the bluffs from undercutting by the river. Some of the sand is flecked with fine mica particles. In places a tendency to induration is noticeable in the sands, though generally they are rather soft. The cross-bedding is always on a small scale and frequent reversals of direction are to be seen	40
6. Sand varying in color from light gray to canary yellow, micaceous	3
7. Sand, gray and lignitic, with much decomposing pyrite, to water's edge	15

The more lignitic sand and clay showed in many places white and yellowish-brown incrustations, due to efflorescence by the sulphates and other salts resulting from the decomposition of the pyrite. The water trickling from these beds along the face of the bluff was charged with iron salts and was precipitating hydrated iron oxide, which covered the ground as a red or yellow slimy scum.

At Crump and Pittsburg Landing, 4 and 8½ miles, respectively, south of Coffee Bluff, are imperfectly exposed sections of the Eutaw sand. These sections show interbedded sands and clays very similar in appearance to those in the lower part of Coffee Bluff. Some of the sand at Pittsburg Landing is locally cemented into a loose ferruginous sandstone.

Dip and thickness.—The Eutaw sand dips westward at a low angle and passes beneath the Selma clay. No exact measurement of its thickness has been made. The best partial section is that at Coffee Bluff given above. Over 215 feet are exposed there, but the exact thickness is not known, as the strata dip slightly westward in the half mile that the upper part of the section stretches back from the bluff. The base is not exposed at low water, but the underlying Paleozoic limestones outcrop some distance downstream and also above, at Savannah, on the opposite bank, almost in line with Coffee Bluff. It is probable that at the bluff not more than 25 to 50 feet of the sand are beneath low-water level, and if a slight allowance be made for the low westward dip in the upper part of the section the formation is not far from 250 to 275 feet thick. The deep well at Lexington passes entirely through it, but unfortunately the position of its top could not be determined from the record given—from memory, as usual—by the driller. A well at Corinth, Miss., seems to have entered it at 90 feet according to one record and at 150 feet according to another record. This would make the Eutaw sand either 360 feet or 300 feet thick, as the underlying rock was reached at 450 feet. Other records at Corinth make it more likely that the formation was entered at a depth of 90 feet and that it is consequently 360 feet thick there.

SELMA CLAY.

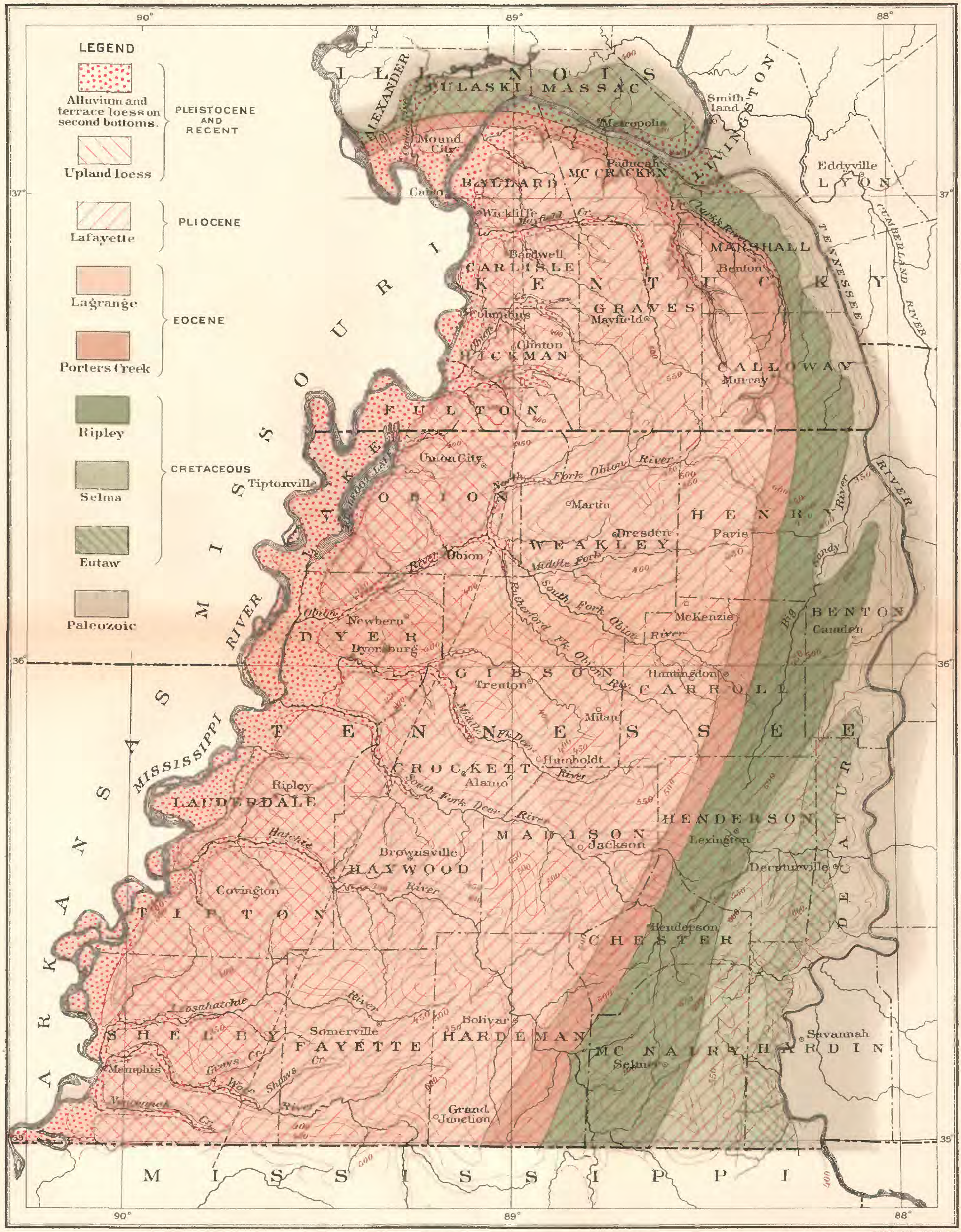
Extent.—The Selma clay rests upon the Eutaw sand and outcrops in a belt 6 or 8 miles wide that enters Tennessee from Mississippi and extends northward about halfway across the State. (See Pl. I.) Like the Eutaw sand, it then disappears, and while it may extend some distance farther north beneath the later Gulf embayment deposits there are no means of proving such to be the case. The problem of its northward extension corresponds to the similar problem discussed under the Eutaw sand (p. 23). The wells at Paducah, La Center, Hickman, and Cairo show the absence of both the Eutaw and the Selma.

Lithologic character.—The term Selma chalk, applied aptly enough in Mississippi and Alabama, is scarcely appropriate in Tennessee, where the formation is a clay that is light leaden gray or greenish when dry and somewhat darker colored when wet. Certain parts are a darker green from the presence of grains of glauconite. Fossil shells are common and in some places are so large and abundant that they have often been gathered and burned for lime. Throughout the formation, which is very uniform in character, the clay contains a considerable amount of lime, derived from the decay of the fossil shells, and very near or just at the base are usually found one or more thin layers of clay or greensand, indurated by the presence of the lime. Some layers are nearly free from the glauconite or greensand; in others it is fairly abundant. The formation was deposited under marine conditions.

When this clay is wet and unaffected by surface weathering it is often blue and is described by the well drillers as "blue dirt." Near the surface in natural exposures it weathers to a yellowish-green clay, that is exceedingly sticky when wet and that on drying shrinks and cracks open, so that it is known as "joint clay."

The clay is somewhat sandy, but no beds even approaching a pure sand were found in it. Water percolates through it slowly. Very much of the rainfall runs off on the surface and this is believed to explain the absence in so much of its outcrop area of beds of surficial gravel and sand, such as rest on the adjacent formations both to the east and to the west. The removal of these surficial gravel deposits is discussed more fully under the heading "Origin of the topography" (p. 17).

Thickness.—Near the Mississippi line the formation is between 350 and 375 feet thick. At Selmer, Tenn., it is 375 feet thick. To the north it thins to 100 feet or less before it disappears. In the deep well at Lexington, Tenn., the Selma clay and the underlying Eutaw sand are together 300 feet thick. The driller did not note any change in passing from one to the other, but this is not greatly to be wondered at, since east of Lexington along the railroad to Parsons the Eutaw sand contains much dark-gray clay.



GEOLOGIC MAP OF THE GULF EMBAYMENT IN TENNESSEE, KENTUCKY, AND ILLINOIS

Scale
10 0 10 20 30 miles

Contour interval 50 feet

1906

Compiled by L. C. Glenn after J. M. Safford, R. H. Loughridge, and A. H. Worthen, with personal observations

RIPLEY FORMATION.

Extent.—The Ripley formation extends across both Tennessee and Kentucky into southern Illinois and there curves westward. Its exact western extent in Illinois was not determined, partly from lack of time, but mainly because of the scarcity of outcrops due to the thickness of the overlying Lafayette and loess deposits on the uplands and of the alluvium on the Mississippi River flood plain. It is probable that the Ripley formation extends across to the Mississippi at Thebes, Ill., and is the sand described as overlying the Silurian limestone just above that place, though this sand may be a part of the Lagrange formation.

The belt occupied by the Ripley outcrop is about 12 miles wide at the southern boundary of Tennessee. To the north it narrows to about 8 or 9 miles in the center of the State and to 6 miles along the northern boundary. This width is maintained in Kentucky and is exceeded in southern Illinois.

Lithologic character.—Lithologically this formation bears considerable resemblance to the Eutaw sand. It is, however, composed more largely of sand and, at least in surface exposures, is predominantly lighter in color. The stratified sands of the Ripley show in some sections a considerable variety of colors, usually red, pink, light yellowish brown, and gray. With the sands are found beds of gray, leaden, or slate-colored clay 10 to 20 feet or more thick. In places the sand and clay are interbedded in thin layers. The sands are usually medium to fine-grained, and soft and incoherent. Induration by iron is, however, a prominent feature in certain places.

Many of the clay beds contain lignite, either in separate pieces or in thin beds of local development. Partly rotted and unidentifiable leaf remains are common. In a few places well-preserved leaf impressions were found, as, for instance, on the "sandhill" road east of Benton, Ky., about halfway up the ascent from the bottoms of East Fork of Clarks River to the uplands.

The sands contain a larger proportion of iron than any other formation in the region except the Lafayette. Part of this iron near the surface is peroxidized and colors the sands a deep red, which is very much like the color so often found in the sands of the Lafayette formation (see p. 42). This makes it difficult to determine the contact between the Ripley and the Lafayette, which generally overlies all the older formations. For instance, the contact is very obscure in the "big cut" (Pl. II, *A*) on the Southern Railway and has been a source of uncertainty and error in the interpretation of the section found there.[a]

The larger part of the iron occurs as a cement for the sands at cer-

[a] See Hilgard, E. W., Geology and Agriculture of Mississippi, 1860, p. 16; Safford, J. M., Geology of Tennessee, 1869, p. 418.

tain horizons and has converted them into sand ironstone that assumes a variety of shapes, some of which are unusual. A common form is the firm sandstone made by the cementing of several feet of sand by iron. Thin platy layers of ironstone also occur. Some of these are flat; others are curved into odd and fantastic shapes. At certain horizons concretionary ironstone tubes or pipes are found. These may be long, straight, separate pipes of uniform size and thickness or somewhat irregular and more or less flattened and united into a honeycombed mass, in which the tubes are parallel. Several horizons of such honeycombed ironstone concretions are to be seen in the "big cut," of which a section is given (see Pl. II, *B*.) Here these concretions form ledges that hold up the sides of the cut from caving.

In general, the sandstone layers or the plates or tubular masses become exposed by erosion and then act as a protection against further erosion. It is partly for this reason that the outcrop of the Ripley sand forms an elevated ridge that is very conspicuous in northern Mississippi and extends for a number of miles into Tennessee before it dies down into an elevated belt that usually forms the divide between the Tennessee and Mississippi River drainages. Another reason for the greater elevation of this and other sandy belts as compared with adjacent clay areas is the fact that a much larger proportion of the rainfall soaks into the sand than into the clay and so does not erode the surface. (See p. 17.)

In deep wells the sands are not usually so oxidized as in surface outcrops and so show grays or dark colors instead of the light ones mentioned above.

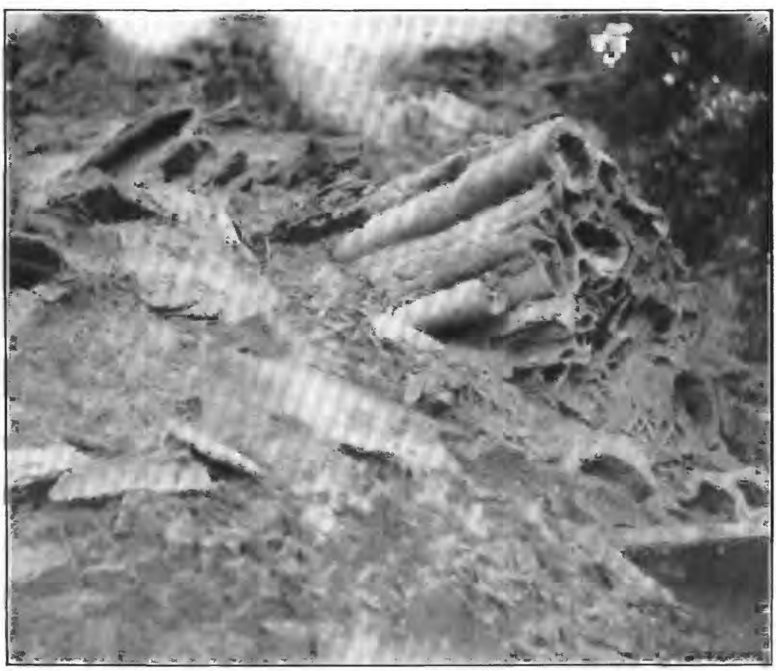
In some places, especially in Kentucky and in Massac County, Ill., the Ripley contains beds of clay suitable for pottery purposes.

Fossils.—No fossils other than plant remains are found in this formation in the area under consideration.

From this fact and from its lithologic character it is believed to be of nonmarine origin. It was deposited in fresh or brackish water here, but farther south in Mississippi marine conditions prevailed. The beds of impure limestone just east of Middleton, Tenn., containing remains of marine fossils and tentatively assigned by Safford to the top of the Ripley, are now known to belong to the Eocene. The plant remains found in the Ripley are usually fragmentary and unrecognizable. Its stratigraphic relations, however, and its continuity with strata in Mississippi that contain marine fossils make its Cretaceous age evident. It is the youngest Cretaceous formation of the region.

Section.—The best section of the Ripley formation is to be seen in the deep cut through the "big hill," 1½ miles west of Cypress station,

A. RIPLEY SAND IN THE BIG CUT, TENNESSEE.



B. TUBULAR SAND-IRONSTONE MASS IN RIPLEY SAND IN THE BIG CUT, TENNESSEE.

Tenn., on the Southern Railway. This section from the top downward is as follows:

Section of Ripley formation near Cypress, Tenn.

	Feet.
1. Red case-hardened Lafayette sand and clay, with a few broken pieces of ferruginous sandstone and scattering quartz pebbles marking the contact with the underlying Ripley	8
2. Fine red sand and clay, with rolled clay pellets and thin streaks of white clay	20–25
3. Concretionary tubular sand ironstone in single pipes or in masses of parallel ones, with soft sand cores	2–8
4. Fine variegated sand, having, as a whole, a light grayish color, but showing in detail red, white, brown, yellow, and purple streaks or mottling. Case-hardened, so that it breaks off in large masses	20
5. Ferruginous sandstone pipes and fluted masses as above	0–5
6. Fine sand and clay interbedded in thin laminæ; yellow, brown, cream, or gray; sands micaceous; leaf and other plant markings common but indistinct and unidentifiable, exposed down to 15 feet below track level	35

Dip and thickness.—The dip of the Ripley in Tennessee and southern Kentucky is, like that of the older formations, at a low angle to the west. In northern Kentucky it is southwest and in Illinois it is south. Its exact thickness in southern Tennessee is not known, but it is probably 500 feet. At Paducah, Ky., 204 feet of it were found in the deep well, and to get its entire thickness there probably 100 feet should be added to this for its eroded upper part. At Cairo, Ill., it is only 25 to 54 feet thick. At Wickliffe, Ky., it is reported to be 400 feet thick.

TERTIARY SYSTEM.

EOCENE SERIES.

PORTERS CREEK FORMATION.

Extent.—The Porters Creek formation, the oldest of the Eocene rocks of the region, rests unconformably on the Ripley sands of the Cretaceous and outcrops immediately west of the Ripley in a belt that is about 8 miles wide, in southern Tennessee, but averages only about 4 miles in width across the State. In Kentucky it widens out again, reaching 10 or 12 miles in northern Calloway County. The outcrop narrows much as it curves westward beyond Paducah and is concealed by the alluvial deposits of Ohio River before crossing into Illinois. In Illinois it is known to outcrop only along the bank of the Ohio, at Caledonia Landing, and for some distance to the north toward the Grand Chain. The exposures are for the most part poor, however, and its identification is made partly by a few indistinct fossil casts but mainly by the presence of greensand, which is absent from the Ripley below and the Lagrange above, but which is found in the lower part of the Porters Creek. Farther west across southern Illinois its outcrop is obscured by either the Lafayette gravels and the loess or by the alluvial deposits of the Cache and Mississippi River bottoms.

Lithologic character.—The formation is composed mainly of a fine-grained clay that is very dark gray or in places almost black when wet, but which becomes a light gray on drying. It is familiarly known in the region as soapstone. Interbedded with this clay are sometimes found, especially in the lower part of the formation, beds of fine, micaceous, silty sands, which are usually indurated into soft sandstones. The lower part of the formation also contains, interbedded with the gray clay and micaceous sand, beds of greensand that may contain enough calcareous matter to cement certain layers into impure limestone. The calcareous matter has doubtless been derived from marine shells, the hollow impressions of which are abundant in some of the more calcareous beds. Such beds have been found near the base of the Porters Creek formation at intervals from a point just east of Middleton, Tenn., nearly to Paducah, Ky.

At several places the leaden-gray clays and the greensands of the Porters Creek formation are intersected with sandstone dikes. These dikes vary in width from a fraction of an inch to as much as 2 feet, though the average width is only a few inches. In places they seem to occur singly and the few thus seen were wider than the average and ran in straight lines. More commonly a large number of small dikes occur together. These may run in any direction and are apparently without any system in their orientation. Some members of a group are persistent in direction and fairly constant in width, while others vary in direction and width and throw off branches that may end blindly or may curve and unite again with the main dike. The various dikes of a group intersect at almost any angle.

Some of the dikes show slickensided surfaces with vertical striations, and a few of the slickensided dikes show cracks produced by shearing that resulted from the differential movement of the rocks on either side of the dike. The faulting thus indicated is believed to have been of very small amount. In only two cases was it possible to ascertain by any discontinuity of beds that faulting had occurred. In these the amount of movement was between 1 foot and 2 feet only.

The sandstone filling these dikes is a soft, fine-grained, micaceous, silty rock similar to that interbedded with the clays of the formation. The dikes contain casts of marine invertebrate fossils similar to those found in the sandstone beds. In both cases all trace of shell substance has disappeared, but distinct impressions are left.

From the lithologic similarity and from the identity of the fossil casts it is believed that the material of the dikes was derived from the micaceous sandy beds of the formation, and that it was injected into the openings where it is now found while still an unconsolidated sand, whose mica particles would in the presence of water convert it into a very mobile quicksand and enable it to flow into the fissures without crushing to pieces the delicate shells it contained. This injection very probably occurred shortly after these beds were deposited, as it was evidently before the sand had become consolidated into a sandstone and before the calcareous matter of the shells contained in it had been removed by leaching.

The size, number, and relations of the fissures to each other lead to the belief that they are not the result of shrinkage of the sediments during consolidation, but that they were produced by earthquake disturbances in Eocene time not long after these beds were deposited, and that the micaceous sand was forced upward along with water into these cracks during the disturbances, just as in this same region the embayment deposits were much fissured during the New Madrid earthquake of 1811 and 1812 and sand and water, often in large quantities, were forced up through these fissures to the surface.

The sands in the Porters Creek tore off pieces of the clay from the walls of the fissures as they were forced up, and these pieces of clay, some rounded slightly but most of them still sharply angular, are found to-day as inclusions in the sandstone dikes. The sand thus injected became indurated, and it is probable that the slight faulting that produced the slickensiding and the shearing seen in some of the dikes was the result of another and later period of earthquake disturbance.

In Mississippi McGee [a] has recognized and described similar dikes. In Kentucky Loughridge [b] saw in a number of places dikes of sandstone in the Porters Creek, though he failed to recognize their true nature. Safford [c] apparently did not recognize them, nor did Harris,[d] though both evidently saw them—Safford near Wade Creek, where the writer first saw them, on the road from Bolivar to Purdy, and Harris at Crainesville, a few miles away. Harris describes them as sandstone concretions.

Thickness and dip.—The thickness of the Porters Creek, according to the best measurement available—that in the well at Jackson, Tenn.—is about 175 feet. At Wickliffe, Ky., it is 158 feet thick, and farther north, near the northern edge of the area, where it has probably suffered from erosion, its thickness is 124 feet at Cairo and 100 feet at Mound City, Ill. At Huntington, Tenn., the wells show 65 to 70 feet of it, but this may not be the full thickness there, as the wells probably start below the top. Just south of Paducah, Ky., a well has gone 140 feet into it without getting through it, and the deep well at Memphis, after penetrating 121 feet of it, stopped without getting through. It is very probable that the underlying Ripley

[a] McGee, W J, Bull. Geol. Soc. America, vol. 1, 1890, p. 440.
[b] Loughridge, R. H., Jackson Purchase Region, 1888, pp. 44, 252, 287.
[c] Safford, J. M., Geology of Tennessee, 1869, p. 423.
[d] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, p. 18.

sands would be reached in this well in less than 100 feet more. The dip is at a low angle to the west in Tennessee and averages for the section east of Memphis 22 feet per mile. It changes in Kentucky and southern Illinois to the southwest and the south, respectively, and increases in amount a few feet per mile.

Age and nomenclature.—Marine invertebrate fossils from the band of impure limestone and the calcareous greensand near the base show the fauna to be of lower Eocene age. A few casts from the Huddleston farm, near the mouth of Wade Creek, 8½ miles east of Bolivar and 2½ miles west of Crainesville, Tenn., were sent to Dr. W. H. Dall for identification. He reported *Crassatellites productus* Con., *Protocardia lenis* Con., *Venericardia alticostata* var. Con., and *Cucullæa macrodonta* Con. as recognizable and referred it to the upper portion of the formation, called by Harris and older authors the Lignitic, probably about E. A. Smith's Bashi series.

From the locality just mentioned Harris made a larger collection than the writer and has also collected extensively from the same beds at several other localities in the immediate neighborhood. The description of these localities and lists of the forms found are given in his monograph on the Midway stage.[a]

In 1860 Safford sent Gabb collections from these same beds made at three points in the vicinity of Middleton, Tenn. They were described by Gabb,[b] the impression then being that they were of Cretaceous age.

Occasional plant remains have been reported from the clays of this formation. In a cut on the Southern Railway at milepost 480.5, about a mile east of Middleton, Tenn., the writer found, in a bluish sandy clay containing some greensand, both casts of marine invertebrates and scattering leaf impressions, the latter somewhat fragmentary, but well enough preserved for identification. From want of time and from the fact that the geologic horizon was definitely known from the invertebrate remains, no collection of these leaves was made, though the locality would be a favorable one for correlating this Eocene fauna and flora, which were evidently contemporaneous.

Safford later recognized the Eocene age of the thin limestone east of Middleton at or near the base of this formation and proposed for it the name Middleton formation.[c] No definite upper limit, however, was set for the formation, though it apparently was meant to include only the calcareous beds. Since these calcareous beds are not sharply separable from the more purely argillaceous beds above, and since both together form a unit so far as all water-supply problems are concerned, it is thought best to regard as one formation the impure limestones, greensands, silty sandstones, and light leaden-colored clays

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[a] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, pp. 18–22.

[b] Jour. Acad. Nat. Sci. Phila., new ser., vol. 4, pp. 375–406.

[c] Safford, J. M., Notes on the Middleton formation of Tennessee, Mississippi, and Alabama: Bull. Geol. Soc. America, vol. 3, 1892, pp. 121–123.

that extend from the Ripley sands below to the Lagrange sands above and for these rocks to retain the geographic name Porters Creek, early proposed and used by Safford. It is the equivalent of the Flatwoods of the Mississippi geologists.

LAGRANGE FORMATION.

Of all the deposits in the area discussed the Lagrange is the thickest, covers the largest area, shows proportionally the least actual surface exposure, and is the most variable in composition and the most doubtful as to its exact age. It has in the past been the most puzzling to geologists and has led to the most errors on their part. Aside from the interest these facts give it, it is and always will be the most important of these formations as a source of water supplies because of the wide area underlain by it, the unusually good quality and quantity of the water it contains, and the moderate depth at which the water may usually be obtained.

Extent.—The eastern edge of the Lagrange formation extends from the southwestern part of Hardeman County, Tenn., north-northeastward through Chester, Madison, Henderson, Carroll, and Henry counties, Tenn., and southwestern Calloway, northeastern Graves, middle McCracken, and northern Ballard counties, Ky. It then passes westward into Pulaski County, Ill., not far south of Caledonia Landing. It is not possible to follow it westward across Pulaski and Alexander counties, because it is concealed beneath later deposits.

All of the area under consideration in this paper lying west and south of the line thus traced is underlain at no great depth by the Lagrange formation. The territory thus embraced is somewhat over two-thirds of the total area discussed. Although underlying so large a territory it forms the actual surface of but a small part, since on the uplands it is concealed by the Lafayette and the loess and loam, and in the Mississippi bottoms its upper part has been cut away to some extent by the river and then covered with alluvial deposits. At many places on the uplands the thin overlying deposits are cut through by streams and railways, so that abundant opportunities are presented for studying it and determining its extent.

Lithologic character.—The formation consists of interbedded sands, clays, and lignitic material. Much the larger part is sand, which is mostly fine grained, though here and there throughout the formation beds of medium or coarse sand or even gravel may be found. Such coarser beds do not seem to be continuous over any large area. While it is probable that if a coarse bed is struck in one well at any given depth it will also be found in other wells in the immediate vicinity, yet at Memphis beds reached by one well have not been found in other wells only a block or two distant.

The sands exposed to view are usually strongly cross-bedded and were deposited under brackish-water conditions in a sea characterized by strong and ever varying currents, so it is not strange that coarse sand or gravel found in one spot should be wanting a short distance away. The sand is usually sharp grained and much of it is so fine that it can not be kept out of deep wells even with the finest strainers. The color of the sand is usually a cream or light orange, though in many places streaks of it show rusty browns, light pinks, or light purples. In exposed sections these colors may wash out during rains and color all of the surface beneath them so as to give erroneous impressions as to the real color of much of the section unless it is examined by digging into it. In places the sand is darkened by lignitic material and may appear gray or grayish black.

The clays of the Lagrange vary from pure, fine-grained plastic material to sandy, silty clays that are often dark from organic matter or black from lignite. The clays of the lower part of the formation are characteristically fine grained, pure, plastic, and either very light colored or white. Chemically they are highly siliceous. Without doubt they have resulted from the thorough disintegration of the cherts of the surrounding Paleozoic land surface, which furnished the waste to the sea of that day.

The plastic, siliceous clays occur as lenses embedded in the sands and are found outcropping in a belt along the eastern part of the Lagrange area in both Tennessee and Kentucky. At numerous places they are mined and either used in local potteries or shipped in the raw condition to other States. Many of the beds contain great numbers of beautifully preserved leaf impressions and numerous collections have been made of these remains. The writer made collections at Grand Junction, Tenn., and at Hickman and Wickliffe, Ky. These were submitted to F. H. Knowlton for identification, and his detailed report is given on page 38, in the discussion of the age of the beds here included in the Lagrange. The clays mined in Pulaski and Massac counties, Ill., appear to belong not to this but to the Ripley formation, since they are found north of the outcrop of the Porters Creek formation along the Caledonia bluff.

The Lagrange is here made to include all of the beds between the Porters Creek clay beneath and the Lafayette gravel above. In contrast to the white plastic clays which characterize the lower part of it and outcrop near its eastern margin, dark-colored lignitic clays are often very prominent in its upper part and are exposed along the Mississippi bluffs or are penetrated in wells in the western portion of the area. At Memphis, for instance, there is a bed of blue clay about 150 to 200 feet thick at the top of the formation. At Randolph, Tenn., the lower part of the bluff is composed of dark lignitic clays with beds of lignite. At Hickman, Ky., the upper part of the formation is composed of fine-grained leaden-gray siliceous clays underlain by darker lignitic sandy clays. Wells at several other places near the Mississippi bluffs report dark clays or silts in the upper part of their sections. The dark-colored clays found at these various places are not, however, lithologically similar, and wells here and there in the area just east of the Mississippi bluffs fail to report it, but give sands instead in the upper part of the section. This indicates that there is not a uniform bed of clay overlying the light-colored cross-bedded sands familiar in Lagrange outcrops farther east, but that there are several clay or sandy-clay lenses, the one at Memphis being unusually thick and uniform in character, overlying the more purely sandy part of the formation and making up its upper portion.

The writer attempted to separate this upper clay portion from the lower part of the Lagrange and treat it as a distinct formation. It could not be traced by means of well records, and as the Lafayette gravel almost everywhere conceals all underlying beds in a belt 10 to 30 miles wide east of the Mississippi bluffs, it was impossible to trace it by surface exposures, except perhaps by such an amount of detailed work as was clearly out of the question in the time available. The effort to establish the clay as a separate formation, therefore, had to be abandoned. It is entirely possible or even probable that the upper part should be separated from the middle and lower parts and after very detailed work criteria may be forthcoming for this discrimination. At present it is impracticable and all the beds are lumped together, though certain facts brought out under the discussion of the age of the Lafayette (p. 40) render it probable that the upper clay is considerably younger than the plant-bearing clays in the lower part of the formation at Grand Junction, Tenn., and elsewhere.

Lignitic material is found throughout the formation, but is more abundant in the upper part, in the dark clays just described. In the clay pits in the lower port of the formation macerated and unidentifiable leaf remains occur in certain layers in such quantities as to make them look like rotten strawboard, as, for instance, in the pits just east of Grand Junction, Tenn. In places thin beds of lignite are reported in the lower part of the formation. Beds of lignite several feet thick near the top of the formation have been reached in numerous deep wells in the western parts of Haywood and Weakley counties, Tenn., and a number of natural exposures are known along the Mississippi bluffs. Years ago attempts were made at several places to mine the lignite, but were unsuccessful.

Section.—Admirable exposures of this formation are to be found at and near the town of Lagrange, Tenn., from which it takes its name. Lagrange is situated on a high divide running east and west, with a steep southward slope that forms the northern valley wall of Wolf River and overlooks both the river, flowing a mile away and 200 feet below it, and the gently rising surface on the south side of the river which stretches back for miles befor attaining the elevation of the north side.

Erosion is rapidly attacking this steep southern slope and ravines 100 to 150 feet deep are eating northward into the divide and undermining houses in the town of Lagrange. These ravines branch and rebranch a number of times, and in their ramifications present admirable opportunities for study not only of the Lagrange but also of the overlying Lafayette and Columbia formations. A view taken here is shown in Pl. III, *A*. The section exposed in these ravines in the southern edge of the town, on either side of the road leading south of Wolf River, is as follows:

Section at Lagrange, Tenn.

	Feet.
Columbia:	
1. Soft, loose, light-yellow to light-gray sands, cross-bedded	15–18
2. Soil layer, dark with organic matter	1
Lafayette:	
3. Massive bed of brick-red sand, case-hardened, showing very even top but very irregular lower surface and resting unconformably on the underlying sand.	4–15
Lagrange:	
4. Soft cross-bedded sands, mostly fine but in places coarse, of various light colors such as nearly white, light yellow, faint pink, and faint purplish with a few thin crusts and small rounded or short tubular concretions of sand ironstone in places. Near the top there is a clay lens of irregular shape ranging up to 8 or 10 feet thick	100

The lower part of the section is included by McGee[a] in the Lafayette, which throughout northern Mississippi and western Tennessee he considers as usually tripartite, the upper division being massive, case-hardened, loamy, brick-red sand, and the middle and lower divisions being softer, brighter-colored sand, often with clay lenses or beds containing leaf impressions. He would place the lower 100 feet of the above section in the middle and lower divisions of the Lafayette and regard the entire Lafayette at Lagrange as 200 feet or more in thickness. Elsewhere in the same paper, however, he expresses some doubt as to the correctness of this conclusion.

In the writer's studies of the Lafayette from Maryland southward across the intervening States into Georgia, thence westward at intervals into Tennessee, and thence northward in more detail into Illinois, he has never found it to contain clay lenses with plant impressions, nor indeed any fossils, except those of other ages mechanically introduced into it. The Lafayette proper should doubtless be limited, as Hilgard and others limit it in northern Mississippi, to the uppermost of McGee's three divisions, and his lower divisions recognized as belonging to some older formation, which in the section given above is the Lagrange. Further remarks concerning the lim-

[a] McGee, W J, The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 462.

A. RAPID EROSION IN LAGRANGE FORMATION AT LAGRANGE, TENN.

B. LAGRANGE AND LAFAYETTE FORMATIONS AND LOESS IN CUT AT RIPLEY, TENN.

itations of the Lafayette are given under the head of that formation (p. 42), and under the Columbia (p. 46) reference is made to the soil layer and overlying sands seen in the Lagrange section.

Good exposures of these Lagrange sands and clays may be seen at many other points. The clay pits and ravines near Grand Junction, Pinson, and Paris, Tenn., and Boaz and Mayfield, Ky., afford good opportunities for examining them. Exposures of a few feet are found at numerous places near Wickliffe, Ky., and an excellent section of 80 to 90 feet is presented in the bluff at Columbus, Ky., showing all of the characters of the typical Lagrange.

At Hickman, Ky., the bluff is composed almost entirely of fine-grained, jointed, blue to leaden-gray siliceous clay that extends from 30 feet above ordinary water level in the Mississippi upward 75 feet and is overlain by 10 feet of Lafayette gravel, and that by 65 feet of loess. This leaden-gray clay contains numerous small calcareous concretions, but no fossils of any kind were found in it. Beneath it and extending down to and below water level are 30 feet of soft sandy clay, containing much disseminated vegetable matter and identifiable leaf impressions. A collection of these leaves was made and sent to F. H. Knowlton, whose determinations are given on page 38.

The 75 feet of leaden-gray clay in the Hickman bluff differ lithologically very markedly from the usual type of Lagrange sediments. The underlying 30 feet are more nearly like the material commonly seen in the Lagrange in this vicinity, as, for instance, in the lower part of the Illinois Central Railroad cut at Curve, Tenn., a section of which is given under the Columbia (pp. 44, 93), and in the lower part of the section at Randolph, Tenn.

Age.—Nowhere in the region under discussion have marine fossils been found in the Lagrange. At various places, however, the abundant plant remains found often so beautifully preserved in the clays of the formation have been collected and studied by paleobotanists, and paleontologic evidence as to the age of the formation is limited to the results obtained from such study. The writer made collections from four localities while in the field. One of these was from a clay lens in the lower part of the bluff at Columbus, Ky. The second was from the 30 feet of sandy clay just above water level in the bluff at Hickman, Ky. The third was from a light-colored indurated clay found in the south bank of the small stream in the southern edge of Wickliffe, Ky. This spot is the one from which a collection was made for the Kentucky Geological Survey and pronounced by Lesquereux to belong to the Lignitic.[a] The fourth locality is a southward sloping hillside on the road about halfway between Lagrange and Grand Junction, Tenn., where leaf-bearing clays are well

[a] Loughridge, R. H., Jackson Purchase Region, 1888, p. 198.

exposed in numerous recently cut gullies. These collections were sent to F. H. Knowlton, whose report on them is as follows:

The present collection consists of a large number of leaves very beautifully preserved, for the most part in fine-grained plastic clay, occasionally in a more sandy clay. The collection has been very carefully made, and the collector is to be congratulated on the highly satisfactory manner in which it comes to hand for study.

Fossil plants from this general region have long been known, the first collection to which scientific attention was directed being apparently that described by Lesquereux from near Somerville, Fayette County, Tenn., obtained by J. M. Safford, and from the banks of Mississippi River near Columbus, Ky., collected by Owen and Lesquereux.[a] The species, of which several were described as new, were not figured in Lesquereux's paper, but ten years later (1869) were incorporated by Safford into his Geology of Tennessee [b] and a single plate devoted to them. Not all the new species were figured even at this time, but in working up a collection of plants from the Tertiary of Mississippi Lesquereux took occasion to describe and figure several species from Lagrange, Tenn., which were regarded as of the same age as those from Mississippi.[c] Nearly twenty years later two small collections made in the interest of the Kentucky Geological Survey were described by Lesquereux.[d] One of these was from Boaz station, Graves County, Ky., and the other from Wickliffe, Ballard County, Ky. Remarks on the age of the beds at these localities will be made later.

The present collection embraces fossils from four localities, as follows:

1. Columbus, Ky. This material, a white sandy clay, contains two species of *Quercus* and apparently a single species of *Salix*, none of them, so far as I can make out, being identical with the forms mentioned by Lesquereux from this locality. Probably a more extended search among living species would show affinities with these, but this I have not been able to give at this time.

2. Hickman, Ky. This is also a sandy clay, and embraces three forms—a single leaf each of a *Salix?* and *Menispermum canadense* L. and the balance a compound leaf of what appears to be *Tecoma radicans* L., or something near it.

3. Wickliffe, Ky. The largest and best lot, affording the following forms:

Salix angusta Al. Br.
Salix sp.
Quercus saffordi Lesq.
Quercus neriifolia Al. Br.
Quercus moorii Lesq.
Quercus n. sp.?
Myrica copeana Lesq.
Eucalyptus n. sp.
Sapindus angustifolius Lesq.
Sapindus dubius ? Unger.

4. Near Grand Junction, Tenn. The same kind of material as the last, containing the following:

Monocotyledonous plant (fragments).
Salix angusta Al. Br.
Quercus (2 species).
Juglans saffordiana? Lesq.
Sapindus angustifolius? Lesq.
Sapindus sp.
Cinnamomum? sp.?
Ceanothus meigsii Lesq.
Acacia sp. (nov.?).

In Lesquereux's original publication the beds at Somerville and Columbus were referred to the Pliocene, as was that at Boaz station, but later he regarded the deposits at Somerville as "most intimately related to the Miocene of Europe." Safford in his Geology of Tennessee inclined to the opinion that the Orange sand, which included the Somerville bed, should probably be regarded as Eocene, and apparently Lesquereux accepted this determination, for in his report on the Mississippi plants he referred them to the so-called Eo-Lignitic. The Wickliffe deposit was referred by Lesquereux directly to the lower Eocene.

Coming to the present collections, I see no reason to question the correctness of referring the Columbus fossils to the Pliocene, although I have not been able to identify any of the

[a] Am. Jour. Sci., 2d ser., vol. 27, 1859, pp. 363-366.
[b] Op. cit., pp. 425-428, Pl. K.
[c] Trans. Am. Philos. Soc., vol. 18, 1869, pp. 411-530, Pls. XIV-XXII.
[d] Proc. U. S. Nat. Mus., vol. 11, 1888, pp. 11-13, Pl. IV.

forms present with those mentioned by Lesquereux. The apparent preponderance of living species would make it unlikely that the age should be older than Pliocene. The plants from Hickman, Ky., although not identical with those from Columbus, are so modern in appearance that I regard them as Pliocene in age.

The plants from Wickliffe and near Grand Junction are similar in appearance and I regard them as of the same age, but their exact position is at present a little uncertain in my mind. That they are of the same age as those from Mississippi is hardly to be questioned, and I suppose they are to be regarded as "Eo-Lignitic" or Eocene, but they are so well preserved and in general so modern in appearance that I can not rid myself of the notion that they should be placed in the Miocene. However, I have not seen any of the field relations and so can not well define this impression. They are the same forms as those from Mississippi and belong to what has been called Orange sand or Eo-Lignitic, but they seem quite unlike other Eocene floras with which I am familiar.

There would seem to be no question that the bed near Grand Junction, the more eastern locality from which collections were made in Tennessee, and that at Wickliffe, the more northern one in Kentucky, each representing deposits that are typical of the Lagrange, are of the same age as those carrying the fossils described from Mississippi. These are generally regarded as belonging to the "Lignitic" and are consequently of Eocene age.

The beds at Columbus and Hickman are undoubtedly in the upper part of the Lagrange formation as defined here. Whether they are both of the same age, and also whether they may be correlated with the clays just beneath the Lafayette at Memphis or are older or younger, can not be determined from the data at hand. Lithologically the Columbus beds are not distinguishable from other exposures of typical Lagrange deposits, but they differ in appearance from the beds at Hickman, and if the two are of different age the Columbus beds are probably slightly older.

Loughridge[a] thought the Hickman beds to be the oldest Eocene deposits in Kentucky and placed them provisionally as a distinct group—the Hickman—beneath the Porters Creek, though he recognized and stated that their exact position with reference to the other divisions of the Eocene had not been positively ascertained. From a study of their field relations and of well sections made since Loughridge's work was done there can be no doubt that the Hickman beds are younger than the main body of the Lagrange, and are among the youngest of the pre-Lafayette deposits of the region.

The question then arises whether they are of the same age as the rest of the Lagrange beneath, or whether there is an unconformity in the Lagrange as here defined and the upper part should be separated and regarded as of distinctly later age. There is not at present sufficient stratigraphic evidence for such a separation, but the character of the plants would seem to favor it and it may be established by more detailed stratigraphic work and additional confirmatory paleobotanical evidence, so that the Hickman deposits

[a] Loughridge, R. H., Jackson Purchase Region, 1888, p. 37.

and other beds similarly situated along the Mississippi bluff, including perhaps the 200 feet of clay at Memphis, would be assigned to the Miocene or Pliocene.

Following the example of Safford in recording his belief as to the age of the leaf beds near Lagrange,[a] and that of Knowlton in the report given on pages 38–39, in speaking of the age of the Wickliffe and Grand Junction beds, the writer can not refrain from also recording his impression that these upper Lagrange beds are not of Pliocene age but belong to the Lignitic, and so are Eocene, though he recognizes that this is but an impression gained during field studies and that the evidence of the plants would seem to be against it. Until conclusive evidence is obtained for one view or the other it seems best to include the deposits in question in the Lagrange.

Nomenclature.—The terms Orange sand and Lagrange have both been applied by Safford to these deposits. So much confusion has arisen from the different usages of the term Orange sand by different geologists that by common consent it has been discarded.[b]

Thickness.—In the deep well at Memphis the Lagrange is 963 feet thick. The well at Dyersburg penetrated 678 feet of it and one at Hickman 750 feet without in either case reaching its base. In the Jackson well, near the eastern edge of the formation, its base was reached at a depth of 160 feet. At Wickliffe it is 430 feet thick and at Cairo 325 feet. The base of the formation dips from the margin of the deposit toward the center of the basin at from 22 to 27 feet per mile.

PLIOCENE SERIES.

LAFAYETTE FORMATION.

Extent.—Over all the above-described formations of the embayment region, and extending for miles farther eastward over the adjoining Paleozoic rocks, there is a thin blanket of sand and gravel that averages not over 20 feet in thickness, but may in places thicken to 40 feet or more.

This blanket is unbroken over much of the area, especially in the more level region away from the streams. The main streams have generally cut through and removed it, but in ascending the sides of their valleys one usually crosses the outcrop of the Lafayette before reaching the general upland surface.

In certain areas, however, it has been largely removed by erosion. Such areas are generally those containing the outcrop of one of the relatively impervious clay formations already described, such as the Selma clay or the Porters Creek, while the more pervious sandy formations on either side retain their Lafayette capping, only

[a] Safford, J. M., Geology of Tennessee, 1869, p. 426.

[b] See Hilgard, E. W., and Safford, J. M., Orange sand, Lagrange, and Appomattox: Am. Geologist, vol. 8, 1891, pp. 129–131.

slightly affected by erosion. An explanation of this selective removal has already been given (p. 17).

In Illinois the Lafayette is revealed beneath the loess in the deeper ravines and road and railway cuts and in the upland portions of Massac and Pulaski counties. Round Knob, 5½ miles north of Metropolis, in secs. 11 and 12, T. 15 S., R. 4 E., is capped by Lafayette ironstone conglomerate, 4 or 5 feet being visible. The deeper cuts on the Big Four Railroad near New Grand Chain station show Lafayette gravel under the loess, and the highways at intervals cut into it. The cut on the Illinois Central Railroad in the southern edge of Villa Ridge shows, beneath 15 to 20 feet of loess, 15 feet of Lafayette gravel resting on sands that may be of Cretaceous age. No effort was made to trace the Lafayette to the north beyond the edge of the embayment deposit, so that its northward extent in Illinois, just as its eastward extent in Tennessee, was not determined.

It has not been possible in the time devoted to this work to attempt to discriminate in detail the areas in which the formation is mainly absent from those in which it is present. Even in areas where it is predominantly absent small scattered remnants of it are often found. On the geologic map (Pl. I, p. 26) it is represented as a surficial deposit covering the entire area.

Character.—The sand which makes the larger part of the formation is usually orange or brick red in color and is often case-hardened and massive. Locally it is cemented by ferruginous matter into a firm red or rusty-brown sandstone and, instead of being massive and structureless, is distinctly stratified or cross-bedded.

The sands are often accompanied by gravels, which usually form the basal part of the formation, though locally they may occur in any part of the sand as narrow bands or be scattered irregularly through it. These gravels are especially prominent near Tennessee, Ohio, and Mississippi rivers. At many places along or near these streams the formation consists solely of a thick gravel bed. Away from these streams, as a rule, the amount of gravel is much less and the average size is smaller, showing very plainly that the streams have had an important influence in determining the distribution of the gravel.

The gravel phase is somewhat prominent in the region just west of Tennessee River, though there is apparently a decrease in the average size of the gravel as one goes downstream. The gravel in the Lafayette of Hardin County, Tenn., for instance, is coarser than that in Calloway County, Ky. The gravel pit on the Shiloh National Park road just south of Snake Creek shows 15 feet of well-rounded gravel that averages from 1 inch to 2 inches in diameter, though much of it is 3 inches and an occasional piece reaches 12 inches. Most of this deposit is chert stained yellow by iron, but there are some pieces of sandstone, quartzite, and vein quartz, and a piece of dark-purplish porphyry containing red jasper was seen.

At Memphis the gravel is well rounded and almost entirely of chert. The thickness of the bed varies from a feather edge up to 45 or 50 feet. At Columbus, Ky., the Lafayette is 45 feet thick, the lower 20 feet consisting of yellow chert gravel with average maximum diameters of 1 inch to $1\frac{1}{2}$ inches, but with a 4-inch layer of 3 to 4 inch pebbles. The upper 15 feet consist of a clayey sand at the base, grading into a gravel bed in the upper part. A few of the smaller and best rounded pebbles are of vein quartz, but a very careful search here and at other places along the Mississippi failed to reveal any pebbles of granitic or other crystalline rocks that might have had a northern origin.

Where the Lafayette contains an abundance of gravel the line of unconformity at its base is easily recognized, but where gravel is absent and the formation consists of materials very similar to those of the underlying beds and probably formed from them by a slight reworking it becomes a matter often of much difficulty to determine the contact.

While variations of material occur in the Lafayette, not only in different sections but even in the same section, the formation can not be divided, at least in the area under consideration, into two or more members, but must be regarded as a unit one of whose prominent characteristics is its variability. Its composition at any one place is at once a result and an index of the underlying materials from which it has principally been derived, the greatest exception to this rule being in those areas where the larger streams have added to it their tribute of foreign gravel.

Thickness.—It has already been stated in the discussion of the Lagrange section (p. 36) that of McGee's three divisions of the Lafayette only the uppermost is really Lafayette, while the lower two are Lagrange. Nowhere in the region is there evidence that the Lafayette reaches any notable thickness. If it is anywhere 50 feet thick it is exceptional, while half this amount, or even less, would be nearer the average.

The Lafayette usually contains an abundance of ferruginous matter, which gives it the deep-red color so characteristic of the formation and which in many places has cemented the gravels into an ironstone conglomerate that, where erosion has been especially vigorous, may be seen in remnants capping the hills, while blocks from the undermined portions strew their sides. In some places the sands are similarly cemented into a red sandstone. Where the gravel is loose, as is more commonly the case, the ferruginous matter is usually present in large quantities and makes the Lafayette gravel a most excellent road-building material by binding it together, so that it soon packs into a firm, hard road. Often a thin shell or plate of ironstone makes the very base of the Lafayette, and in some cases is thick enough to prevent the downward passage of percolating waters and thus form a local impervious stratum above which the sands may be saturated with water, while the underlying sands may be practically dry.

Ironstone conglomerate.—From inequalities of elevation of the basal impervious layer the water above it may be in small basins separated by areas where wells would fail to find water and two neighboring basins might not have water at the same level. If the impervious bottom of one of these be dug through, the water in it at once drains downward into the dry sand below. These relationships are shown graphically in fig. 5.

Section at Ripley, Tenn.—In the center of the deep railway cut at Ripley, Tenn. (Pl. III, *B*), Lagrange sands and clays extend up 25 feet, but disappear beneath track level toward each end of the cut. On the crest of the hill of Lagrange material thus revealed there are 4 or 5 feet of red case-hardened Lafayette sand that thickens on the flanks of the hill to 8 or 10 feet near the end of the cut. Over this sand in the center of the cut are 4 feet of gravel in soft, loose, light-colored sand which grades up into a dark-colored, damp, clayey loess 10 feet thick, overlain by a light-colored, dryer, more pulverulent loess 18 feet thick. At many points in the cut it is impossible to be sure of the existence of a line of unconformity between the Lafayette and the underlying Lagrange sands. The soft light-colored sand and gravel between the Lafayette and the loess belong to the Columbia (as does the loess) and are referred to again in the discussion of that formation (pp. 44, 46).

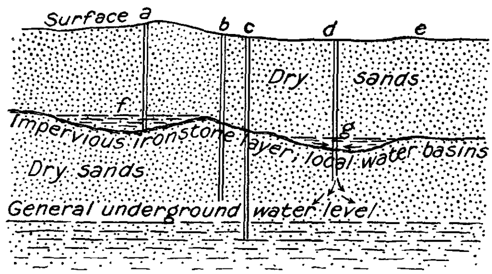


FIG. 5.—Diagram showing local water-bearing basins at various levels above dry sand. Well *a* obtains water from a local water-bearing basin at *f*. Well *d* struck a similar but slightly deeper local basin, but pierced the underlying impervious layer and allowed the basin to be drained downward. The well was abandoned before permanent water was reached. Wells *b* and *c* failed to find water at either the *f* or the *g* level; *b* was abandoned as a dry hole; *c* was continued slightly farther to permanent water level. Basins like *g* are sometimes drained by fissures caused by earthquakes in this region.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

COLUMBIA FORMATION.

Three kinds of deposits in this region will be grouped together under the Columbia formation. The first and oldest is a loose sand which overlies the Lafayette and underlies the loess, which is the second of the deposits here included. The third is a loam that overlies the loess in the area where the latter is found and extends east of that area for miles as a thin mantle spread over the Lafayette.

Sands.—At some places along the Mississippi bluffs and in a belt 10 to 20 miles wide east of the bluffs the loess seems to rest unconformably directly on the Lafayette sands or gravels. At other places, however, there is a distinctly differentiated bed of soft, loose, light-colored sand between the two. This sand often contains rounded pebbles similar to those of the Lafayette beneath, from which they have evidently been derived. Like the sand, which may also have originated from the Lafayette, the pebbles are usually bleached to a light gray. This difference in color and the softness of the sand serve to differentiate the deposit at once from the red, case-hardened Lafayette beneath. This sand may range in thickness up usually to 4 or 5 and exceptionally to 10 or 12 feet, and may attain its maximum and disappear again in 100 or 200 yards.

It commonly though not everywhere shows distinct unconformity on the Lafayette beneath and as a rule seems to grade upward into the lower, darker part of the loess without any perceptible break. Where the sand seems to be absent, the lowest part of the loess is usually somewhat sandy and may contain a small pebble here and there for several feet upward from its base. It is likely that in such cases the sandy basal part of the loess is the representative of the sand found elsewhere.

In the railway cut at Ripley, Tenn., a section of which is given on page 43, the soft sand and gravel over the Lafayette is usually sharply limited below, but in a few places seems to grade into the Lafayette. Near the ends of the cut the gravel in it practically disappears. Another excellent exposure of this sand is found some miles north of Ripley in the deep railway cut at Curve, Tenn., where the Lafayette is overlain by a soft, light-colored, loose sand with gravel that varies from a knife-edge to 3 feet in thickness and grades up into a dark silty loess. A view of this cut is given in Pl. IV, *A*.

It seems very probable that this bed of soft sand and gravel is not confined to the narrow belt in which the loess occurs, but extends eastward over much of the region in which later deposits overlie the Lafayette, as the section at Mayfield (p. 135) shows the presence of such a layer between the Lafayette gravel and the surface loam, and similar conditions were seen at other places. In many exposures, however, such differentiation of the material over the Lafayette in the middle and eastern parts of the area can not be satisfactorily made. Either this basal sand and gravel phase of the Columbia disappears in places, or, as is thought more probable, it merges by change of material into the loamy phase, so that where the two are found together because of the absence of the loess which separates them along the Mississippi bluffs they are blended into a unit.

Loess.—This member extends eastward 20 to 30 miles from the edge of the bluffs overlooking the Mississippi bottoms. In the bluffs

A. CUT AT CURVE, TENN.

Showing at "a" local ironstone hardpan at base of Lafayette, resting on Lagrange.

B. LOESS BLUFF AT MEMPHIS, TENN.

it is usually between 50 and 75 feet thick, but locally exceeds or falls short of those figures. It is reported to reach a thickness of 200 feet in places in western Tennessee, but the writer has never seen it quite as much as 100 feet thick. From its maximum thickness along the Mississippi bluffs, as given above, the loess thins eastward to a feather-edge before it disappears. This thinning renders it difficult to fix any but a somewhat arbitrary line to mark its eastern edge, and the difficulty is enhanced by the fact that in some sections, instead of thinning out, it appears to grade over into the loamy phase of the Columbia.

As seen in a number of excellent sections, the loess is composed of a lower dark part and an upper lighter one. The lower part seems to be denser or less porous than the upper. It contains more clay and will remain damp longer. The clay is so abundant in many sections that the material is easily plastic when damp, and on drying it shows in places a tendency to shrink and crack open. More usually, however, this lower part presents when dry the same general appearance as the upper part, except that it preserves the darker color. In weathering the lower part disintegrates and wears back less rapidly than the upper part, so that in places a shoulder or change of slope is developed where the two divisions meet. This was well shown in the deep railway cut at Ripley, Tenn., before the recent widening was done in double tracking the line. The darker, more silty portion of the loess, which seems to grade down into the sand and clay member, as already mentioned, is quite distinct from the upper part. The same distinction is to be seen in the cut at Curve, Tenn. At Memphis (Pl. IV, *B*), Randolph, and elsewhere the same bipartite character is shown by the loess. The upper part is the typical porous, open-textured, light, ashen-colored loess. In it and the lower, darker portion alike are found the usual calcareous concretions, small, irregular in their distribution, and many of them curiously shaped.

In each case observed the lower portion is thinner than the upper and the line between the two is horizontal and distinct. It may be questioned, however, whether this line represents a rapid transition without interruption in the deposition of the loess or, as is claimed by some, is indicative of an actual break in the process and represents a time interval between two periods of loess formation. Without wishing to express a decided opinion on the subject until he has had opportunity for further and more detailed study, the writer is inclined to the former view and would provisionally regard the loess in the area here considered as the product of one period of deposition rather than two.

Over much of the first tier of counties east of Mississippi River in Tennessee and Kentucky the loess averages 30 feet in thickness. It accordingly conceals the Lafayette except in an occasional stream cutting. In southern Illinois practically all of the upland area in which embayment deposits occur is overspread with a sheet of loess, usually a score or more feet in thickness.

The exact mode of formation of loess deposits has been a matter of much discussion and difference of opinion, but all are agreed that the material of the loess is the finely ground rock flour resulting from glacial erosion. The loess of the Mississippi Valley owes its origin to the great ice sheet that covered all of the northern part of the valley and extended in southern Illinois to within 20 miles of the head of the embayment deposits. There are differences of opinion, however, in regard to the manner of deposition of the material. Some insist that it has been transported and deposited by the wind. Others believe it has been transported by streams and deposited in water either on a flood plain or in the bottom of a lake—that it is fluviatile or lacustrine instead of eolian.

Without entering into a detailed discussion of the evidence for the conclusion here stated, the writer may state his belief that the loess of the region under consideration is of fluviatile and not of eolian origin. The grading upward of the sands and gravels into the loess, the local occurrence in the loess of sandy streaks that must have been water-laid, the bipartite division of the loess seen widely over the region, the regularity or evenness of the contact plane between the two parts, and the absence of wind-deposit structure all give basis for the opinion here expressed as to the mode of deposition.

Loam.—The third phase of the Columbia formation in this region is a yellowish or brownish loam in most of the area of its occurrence, though in some places it becomes a soft sand with very little argillaceous material. This phase is found mainly to the east of the area of the loess and is to be regarded as largely the equivalent of that member, though in some places in the loess area a few feet of loam overlie the loess.

The loose sand at the base of the Columbia blends with the overlying loam east of the loess area just as it grades up into the loess where the latter overlies it. In some places the blended sand and loam may be rather sandy, while in others they may grade into a clay. The best example of the sandy phase is found at Lagrange, Tenn., where the Lafayette is overlain by a layer of black soil a foot thick, and that by 15 feet or more of soft, light-colored, cross-bedded sand. This was the only locality in the entire region where a soil layer was found between the Lafayette and the Columbia. A similar soil layer was found by McGee at Holly Springs, Miss.[a] The appearance of the soil layer and the overlying sand at Lagrange, considered in connection with its peculiar topographic relationships,

[a] McGee, W J, The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 460.

suggests very strongly that the cross-bedded sand over the soil may be a local wind-made deposit of recent origin rather than a part of the Co umbia. It caps the southward-facing scarp that overlooks Wolf River. The steep slope down to the river is cut by many deep ravines whose bare sides are of soft, loose Lagrange sand. It is conceivable that the strong winds from the south blowing up the ravines might catch up the loose sand and carry it to the top of the scarp in such quantities as to account for the cross-bedded sands found there over the soil layer. The ascending sand-bearing air current would, on reaching the top of the scarp, produce an eddy in which the sand would be dropped, as is illustrated in fig. 6.

Although the writer has not seen the Holly Springs occurrence referred to above, yet McGee's statement that the topographic relationships are exactly similar to those at Lagrange is highly suggestive of a similar eolian origin for the sand there found over the soil layer.

The Columbia loam, east of the loess, is a thin veneer derived from the Lafayette and resting upon and partly concealing it. It is rarely over 10 or 12 feet thick and is often not more than half that thickness. It thins out to the east, and in Tennessee and Kentucky disappears before the eastern edge of the embayment deposits have been reached. In Illinois the loess makes the surface of the uplands of the embayment region, and the loam seems to be absent. It has not been found practicable to represent on the geologic map the area covered by the Columbia loam. In a general way its eastern edge crosses eastern Hardeman, eastern Madison, western Carroll, and western Henry counties in Tennessee, and western Calloway and western Marshall counties in Kentucky.

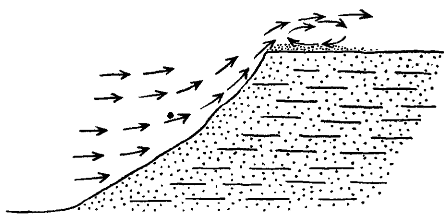


FIG. 6.—Section showing sand deposited in eddy of wind current on top of bluff.

RECENT DEPOSITS.

Alluvium.—Between Mississippi River and the bluffs that bound its valley on the east there is a varying width of flood plain composed of alluvial deposits. At a few points in Tennessee and Kentucky the river swings against the bluffs on its eastern side, but usually the alluvial plain is from 2 or 3 to 8 or 10 miles wide. In Illinois the Mississippi alluvial plain is a number of miles wide and the flood plain of the Ohio is of similar character, though it is mostly confined to the Kentucky side of the river. The main tributaries of the Mississippi, such as the Hatchie, the Forked Deer, and the Obion, have similar valleys composed of alluvial deposits and varying from 1 mile to several miles in width.

The materials composing these plains are sands and silts brought down by the rivers and deposited in time of flood, thus building up flood plains in the valleys which the rivers had previously carved out of the older formations of the region.

No extensive study of the alluvium was made, for want of time, but where examined in a number of places the silts seemed all to be of modern origin and the writer would assign the deposits seen at Memphis, those along the banks of the river from Memphis to Fulton, Tenn., those at Hickman, at Columbus, at Wickliffe, at Cairo, and at Paducah to the recent period. When it is considered how constantly and, as a rule, how rapidly Mississippi River is shifting the position of its channel because of meandering, and when it is further considered not only how each meander grows until the meander belt is a number of miles wide, but also how each meander is slowly working downstream, cutting away the materials before it while other materials are being deposited behind it, it may be concluded that nowhere near the river can any deposit in the flood plain remain long unmoved if it rises above the level to which the river can cut—a level which may be taken as about 100 feet beneath the flood-plain surface. Instances are innumerable of the cutting away of flood-plain deposits on one side and rebuilding on the other by the lateral swing of the river. It is, in fact, going on all the time, as the surveys of the Mississippi River Commission show. The entire channel may move a mile or more by such cutting in a few years, and the changes that have occurred within the memory of men yet living are so great that it is not improbable that the river may have swung entirely across its valley from Crowleys Ridge in Missouri and Arkansas to the Chickasaw and Columbus bluffs in Tennessee and Kentucky in 2,000 to 4,000 years.

That these alluvial deposits are geologically young is apparent from another line of reasoning. They have been deposited in a valley that is 30 miles wide at Memphis and 45 miles wide farther north. This valley has been cut at least 200 to 300 feet beneath the plain in which it is carved. The dissevered portions of this plain are seen to-day in the flat upland surface of the bluffs on the east and of Crowleys Ridge on the west. This surface, however, is capped with the loess and the excavation of the broad valley has mainly taken place since the loess was deposited. There was some cutting away of the Lafayette along the main Mississippi River before the loess was deposited, corresponding to the cutting on the tributaries of the Mississippi to form the second bottoms, where the Lafayette has been removed but the loess is present; but this cutting was not sufficient to account for the excavation of the valley as we now find it. Since the excavation was finished some alluvial filling has occurred, leaving the level of the flood plain as at present.

From borings made by the Mississippi River Commission it is concluded that in the portion of its valley from Cairo to Memphis the river has not cut into the embayment deposits more than between 100 and 150 feet beneath its present flood-plain surface, or in other words, has never cut very much deeper than its channel may now reach under favorable conditions for deep scouring.

These alluvial deposits are accordingly believed to be between 100 and 200 feet thick and of later age than the loess; parts of them, of course, are still forming. Near the river the deposits are sands and silts; farther away from the river they become gradually finer and pass into clays which are usually blue or dark colored from the organic matter present.

The same uplift which permitted the Mississippi to cut out so broad a valley in the loess-sheeted plain likewise permitted its tributaries to incise their courses beneath the uplands and to broaden their valleys until they were locally 5 to 10 miles wide. The alluvial deposits in the valleys of these tributaries are like those of the Mississippi and consist of silts and sands that usually contain much decaying vegetable matter. It is generally the rule that since the formation of these alluvial deposits by the tributaries of the Mississippi they have been cut into and another flood plain has been formed 10 to 15 or occasionally as much as 30 feet lower than the older alluvial surface. This older surface is known as the "second bottoms," while the lower plain is the present-day flood plain, large portions of which are swampy. It is surprising to note how characteristic a feature of the region these first and second bottoms are. They are found even along the smaller headwater streams in many places. The present flood plain, or first bottom, is usually much narrower than the second bottom.

The writer has been thus explicit in giving his conception of the very recent age of the alluvial deposits of the Mississippi in this region because various authors[a] have correlated parts, at least, of these deposits, from Memphis up as far, in one case, as Paducah, Ky., with the Port Hudson deposits of Mississippi. The stratigraphic position of the Port Hudson clay is between the Lafayette gravels beneath and the loess above. Since the valley in the region here considered was not excavated until after the loess had been deposited the clays found in this valley, at least from Memphis up, can not be older than the loess and so can not be of Port Hudson age.

The lithologic similarity of the Port Hudson clay and certain blue clays found in this region, notably about New Madrid, Mo., is only what might be expected. Both were formed by the same agency. Similar materials under these circumstances should form similar deposits whether they be of Port Hudson or of younger age.

[a] See McGee, W J, The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 400; Loughridge, R. H., Jackson Purchase Region, 1888, p. 74; Shepard, E. M., The New Madrid earthquake: Jour. Geol., 1905, p. 48.

GEOLOGIC STRUCTURE.

In discussing artesian conditions in the region and in describing the area of outcrop and dip of the various formations, much has already been said concerning the structure of the embayment deposits. Only a brief recapitulation is necessary here. It has already been stated that these deposits lie in the eastern half of a broad basin projecting northward from the Gulf region and ending in southern Illinois. On the floor of this basin the formations described in previous pages were laid down in succession in broad sheets one above another. The eastern edge of each formation in Tennessee and Kentucky usually does not overlap the edge of the formation beneath, but permits its exposure in an outcrop of varying width which extends northward across these two States. At the north end of the trough in southern Illinois the formations rise to the surface like the tip of a spoon. The western half of the basin lies in southwestern Missouri and eastern Arkansas.

It does not seem probable that the floor of this basin slopes at all uniformly from its outcropping edges to a deepest central line, but rather that the slope is relatively rapid near the sides of the trough and decreases farther out in it, or that a cross section of the trough is broadly U-shaped rather than broadly V-shaped. If so, as each of the formations that fill the trough is probably nearly uniform in its thickness, the dips are steeper near the margins of the trough than well out within it. Ascertained dips for short distances near the margins are about 30 feet per mile, while some of the data reported for southern Illinois would, if correct, indicate southward dips there of about 50 feet per mile. Well within the basin westward dips of 22 feet per mile are found.

There are no indications of any folding of the rocks of the embayment, but in the Porters Creek formation there has been in many places a slight faulting accompanying the earthquake disturbances that have caused the formation of the sandstone dikes described on page 30. In the Reelfoot Lake region the Lagrange sands were fissured and in places slightly faulted by the New Madrid earthquake of 1811–12. The vertical displacement seems, however, in no case to have exceeded a few feet. This faulting in the Porters Creek and the Lagrange has not materially affected the water-supply problems of the region here discussed. There seems to be no evidence, in this region, at least, that the artesian pressure has been decreased because the earthquake fissures provided channels for the water to escape. The approximate elevation to which artesian waters rise in various parts of the region is given for a number of places on page 160 and graphically represented in fig. 13. From this it is readily seen that

Dyersburg and Union City, Tenn., and Hickman, Ky., the nearest localities given to the earthquake center, do not show any abnormal depression of hydrostatic level when compared with other places near by.

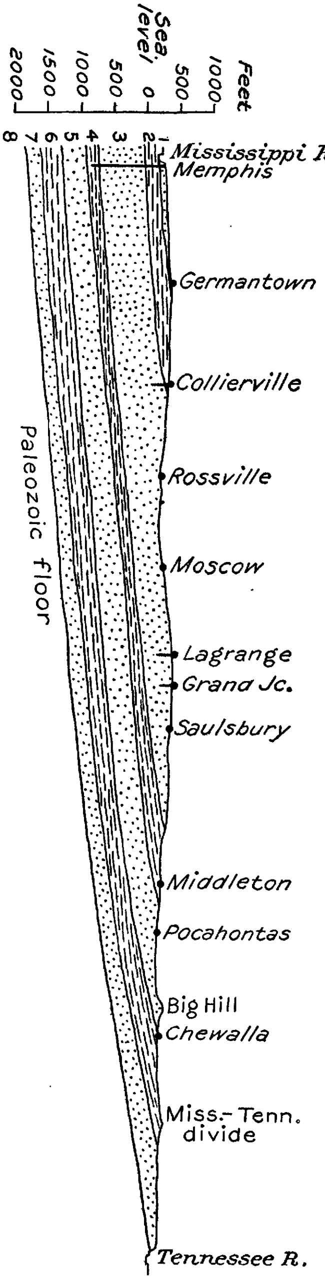


FIG. 7.—Section from Tennessee River westward to Memphis, Tenn. 1, Loess; 2, clay member of Lagrange; 3, sandy memberof Lagrange; 4, Porters Creek clay; 5, Ripley sand; 6, Selma clay; 7, Eutaw sand; 8, Paleozoic floor.

UNDERGROUND-WATER RESOURCES.

RESOURCES OF TENNESSEE, BY COUNTIES.

BENTON COUNTY.

Topography.—Benton is a long, narrow, county, lying just west of Tennessee River and extending north and south along the river for a distance of 40 miles. Its north end, which almost reaches the Kentucky line, is formed by the junction of Big Sandy and Tennessee rivers. The Big Sandy, which flows northward almost parallel to the Tennessee, forms its northern and about half of its western boundary. The area of the county, as given by the Twelfth Census (1900), is 430 square miles. The surface is best described as being rolling to hilly. Very little of it is level, owing to the proximity of Tennessee and Big Sandy rivers, whose numerous small tributaries have cut the originally level surface into hills near the rivers and made it rolling farther away from them. The streams are usually bordered by a flood plain and a second bottom which varies from a few hundred yards to half a mile in width.

The maximum elevation in the county is found along the ridge separating the Big Sandy and Tennessee river watersheds. This ridge attains heights of 500 to 600 feet above tide. The lowest point in the county is at the Big Sandy, where the elevation at low water is about 310 feet. Low water at Johnsonville is 322 feet. The elevation at Big Sandy station is 347 feet, at Camden 444 feet, and of the summit just west of Camden, on the Nashville, Chattanooga and St. Louis Railway, 486 feet. The average elevation of the county is between 400 and 450 feet. As it is on the eastern border of the embayment region, where the outcrop of the porous Ripley strata receives its water, very little artesian pressure could be expected anywhere in the county. Some wells on the flood plain of the Big Sandy, however, flow with a slight head.

Geology.—The contact between the Paleozoic limestones, shales, and cherts and the embayment deposits runs north and south through about the middle of the county. The eastern half of the county lies accordingly in the Paleozoic area, and will not be discussed here. The rocks of the western half are of Cretaceous and Pliocene age.

The Eutaw sand extends fôr a few miles northward into the south end of the county, but its area is small and its thickness can not be very great, owing to its relation to the Tennessee River drainage and to the fact that it feathers out here and disappears, not being found farther north. Water issues from the base of the Eutaw in springs along the hillsides in numerous places and is reached at from 20 to 40 feet in wells. It is chalybeate in places where there is much lignitic material in the formation.

It is probable that just west of the Eutaw area, in the extreme southwestern part of the county, there is along Birdsong Creek a small area of the Selma clay, though, owing to the topography, exposures are poor and the delimitation of the north end of the Selma outcrop has not been definitely made. The water in this formation is small in amount and of very poor quality. The Selma area in this county is so small as to be practically negligible.

The Ripley sand covers the western part of the county. Its eastern edge extends from the southwest corner of the county northward past Camden, and the formation embraces part of the divide between the Big Sandy and the Tennessee, extending probably as far north as the Louisville and Nashville Railroad before thinning out and disappearing. For some distance in its lower course the Big Sandy has cut through the Ripley sand into the underlying Paleozoic rocks. The Ripley furnishes abundant supplies of good water, but owing to its open, porous texture the depth of wells in this formation is greater than elsewhere, ranging from 60 to 100 feet or more. Springs are not so abundant in it as in other formations.

Overlying these Cretaceous formations and the Paleozoic rocks is a blanket of Lafayette sand, loam, and gravel that is tattered by erosion along the larger streams, but mantles the inter-stream areas in an unbroken sheet from 10 to 30 feet or more thick. In many places the formation contains limonitic iron ore in considerable quantities. In places springs issue from the base of the Lafayette, though they are usually weak and their flow may decrease or fail during long droughts.

Water resources.—Benton County is naturally well watered by streams that flow the year round and furnish abundant water for stock. Along the base of the hills numerous springs are found. In the embayment area these come mostly from the Lafayette or the Ripley, the latter furnishing the larger number and the stronger flows. Springs and wells usually yield soft, freestone water, but in a few cases it contains sulphur and iron. Domestic supplies are derived from springs and open wells, the latter being somewhat the more important source. These wells may be as shallow as 10 feet in low ground along streams or as deep as 100 feet on high ground in the Ripley sands. Very few cisterns are in use.

At Big Sandy station, elevation 372 feet, the principal water supply is derived from wells which range from 6 to 50 feet in depth and yield an abundance of soft water from gravel which underlies a clay bed 4 to 6 feet thick. Springs also are much used, and there are a few cisterns.

At Bristow open wells of moderate depth are exclusively used.

At Faxon springs and open wells 25 to 30 feet deep furnish the supply.

Gismonda is very near the edge of the Paleozoic area, and a number of sulphur and chalybeate springs flow from sands.

At Nobles the supply is derived from the Ripley sands by small bored wells that range from 60 to 125 feet in depth.

At Wyly there is a flowing well located 6 feet above high water on the Big Sandy. It is 1½ inches in diameter, 50 feet deep, and yields 5,000 gallons a day. The flow varies somewhat at times. Other wells are mostly open, are on higher ground, and furnish soft water at a depth of 25 to 30 feet.

At Zach the country is flat, and wells are from 10 to 20 feet deep. There are a few springs, but in summer their water is not cold.

CARROLL COUNTY.

Topography.—Carroll County is situated in the northeastern part of western Tennessee. For 2 miles on the northwest South Fork of Obion River separates it from Weakley County. Its area is 624 square miles.

The watershed between Mississippi and Tennessee rivers crosses the county in a direction somewhat east of north and separates it into an eastern slope which embraces about a third of the county and drains into Big Sandy and Tennessee rivers, and a western slope which embraces the rest of the county and drains into the Mississippi. The highest part of the county is along this divide, which has an elevation of from 450 to nearly or quite 500 feet. The lowest elevation is about 350 feet, at the points where the Big Sandy and South Fork of the Obion leave the county. The average elevation of the county is not far from 425 feet. The surface along the Tennessee-Mississippi divide is hilly and broken, for headwater erosion is active. The northern and western parts of the county are more level and the main streams here, as a rule, have broad, level flood plains and second bottoms.

Geology.—The Selma clay occurs in the extreme southeast corner of the county, but covers a very small area. West of it there is a belt of Ripley sand 6 to 8 miles in width that occupies the eastern part of the county, its western edge running about parallel with and 2 miles west of Big Sandy River. Along the broad valley of the Big Sandy water is found in the Ripley sand at slight depths, but on the uplands wells average from 50 to 125 feet in depth and furnish soft water.

West of the Ripley sands there is a belt of Porters Creek clay about 2 miles wide, its western edge passing through Huntington. This clay is popularly known as soapstone. It is variable in thickness, being in some wells only 10 feet thick, while in others it is 80 feet or more. In many places it is almost black and imparts a disagreeable odor to the water. Physicians report that people habitually using such water become pale, anæmic, and sickly. If the Porters Creek is everywhere less than 100 feet thick in this county, as it seems to be wherever records of its thickness have been obtained, it should always be possible to go through it and get good water from the underlying Ripley sands. To the west the Porters Creek dips under the Lagrange sand at a low angle and may be reached, in low places especially, in wells dug within half a mile or a mile west of its surface outcrop. Such wells should either be dug on through it to the Ripley sand or be stopped just above it, so as to draw water from the basal sands of the overlying Lagrange.

West of the Porters Creek clay belt the county is underlain by Lagrange sands and clays. The sands are soft and variable in texture so that coarse beds are not widely continuous, but occur at various horizons and extend each usually over a small area only. With the sands are thin beds of plastic clays, and locally these beds serve to confine the waters in the underlying sand. When such clay strata are dug or bored through the water often rises at once a number of feet, dependent on the local elevation. In low places, as along the bottoms of the streams in the western part of the county, artesian flows may be obtained. There are a number of such artesian wells less than 100 feet deep in the bottoms just west of Huntington. On the rolling uplands of the western part of the county the Lagrange yields water at depths of 35 to 100 feet. The water is always soft, but may in places contain iron and sulphur. Bold springs may rise from the Lagrange sands in the bottom lands along the streams, while out on the edges of the valleys, along the foot or on the slopes of the bordering hills, weaker springs issue from the base of the Lafayette.

Over the formations already named there is a covering of 10 to 20 feet of Lafayette sand and sandy clay. Occasionally there is a little gravel in the lower part, but as a rule gravel is inconspicuous or absent. In the western part of the county a few feet of Columbia loam overlie the Lafayette.

Water resources.—The streams of Carroll County are numerous enough to furnish a supply of running water for stock almost everywhere. These streams flow the year round. For household supplies open dug wells are much in use where water may be obtained at such moderate depths as 25 to 50 feet. Even for these depths, however, bored wells have been in recent years largely used instead of the olden-time dug wells, because they are easier to make and cheaper. Bored wells are also in use where it is necessary to go 50 to 100 feet or more, though for depths of 100 to 150 feet small pipe wells sunk by a hydraulic jet are common. The bored wells run from 4 to 12 inches in diameter and are curbed with wood. Water is usually drawn by a cylindrical bucket with a valve in the bottom. Some bored wells are curbed with terra-cotta pipe, and some of these, in in low places, where the ground-water level is nearly at the surface, overflow in spite of the loose joints of the terra-cotta—that is, they are artesian. The small-pipe wells are usually fitted with a force pump run by hand, wind, or steam power, the latter being used only where the well furnishes the boiler supply for a cotton gin, sawmill, or other manufacturing establishment. In the belt underlain by the Porters Creek clay, where well water is almost unfit to use, and in the more elevated parts of the Ripley and Lagrange areas, where the depth to water is often 100 feet or more, many cisterns are in use. Deep waters may be obtained in the central and western parts of the county from either the Lagrange or the Ripley sands. In the Lagrange it will probably nowhere be necessary to go deeper than 200 feet, and the water will rise to about 375 to 400 feet above the sea, the height decreasing westward. The water in the Ripley may be reached at depths of 250 to 300 feet from Huntington eastward; west of Huntington the Ripley sands lie deeper, and soon the Lagrange sands above become thick enough to furnish a deep-water supply. The few mineral springs in the county are sulphur or chalybeate and are of local note only.

At Atwood, elevation 439 feet, good pure water is found in abundance in the Lagrange sands at depths of 65 to 90 feet on the higher ground. One record showed surface sands and clay 20 feet, sand 18 or 20 feet, potter's clay 8 feet, yellow sand 76 feet (with water at 90 feet), gravel 6 feet.

At Carnsville, near the eastern edge of the Porters Creek clay, there are some wells in this formation that yield water unfit for use on account of its astringent taste and bad odor. Others, 30 to 75 feet deep in the Ripley sands, furnish an abundance of good water.

At Cedar Grove, where the Lagrange sands outcrop, the water supply is derived from shallow wells and numerous springs. Three miles to the south there is a sulphur and iron spring of some local note. There are deep wells.

At Clarksburg good water is obtained from the Ripley sand at depths ranging from 20 feet on low ground to 135 feet on higher ground. At the shallower depths wells were formerly dug, but now nearly all are bored, the usual size being 12 inches. There are few pipe wells and very few springs.

At Dollar, also, water is obtained from the Ripley sand by means of bored wells, the average depth being from 50 to 135 feet, though some are only 20 feet. A few springs are in use.

At Garrettsburg, where the Ripley sand outcrops, shallow open wells and springs are used, the wells for domestic supply and the springs for stock.

At Hico, elevation 389 feet, an abundant of good soft water is obtained from the Lagrange sand at depths of 30 to 50 feet.

At Hollow Rock, elevation 425 feet, water is struck in open wells in the low, flat part of town at depths of 15 to 25 feet, and on higher ground at depths of 40 to 80 feet. A mile or two west of town, on the Mississippi-Tennessee divide, wells average 100 feet deep. All are in Ripley sand. There are numerous springs in low places along the streams, but the water is not considered healthful. In Hollow Rock a well, formerly 60 feet deep, but now filled up, is reported to have had an abundance of good water in the summer, but to have gone dry in the winter.

At Hollow Rock Junction, elevation 416 feet, the Nashville, Chattanooga and St. Louis Railway uses a small stream for supplying its engines.

Huntington, elevation 414 feet, is situated on the western edge of the Porters Creek clay. In some places the dark unctuous clay, or so-called "soapstone," is at or within a few feet of the surface and varies from 10 to 75 or 80 feet thick. At other places there are from 20 to 50 feet of Lagrange and Lafayette sands over the Porters Creek clay. Some shallow wells are in the Lagrange sand and have good water; others are in the "soapstone" and have poor water; while still others go through the "soapstone" and get good water from the

Ripley sand beneath. These open wells vary in depth from 10 feet in the bottoms just west of town to 90 feet on the town level. Wells sunk 50 to 70 feet in the bottoms usually flow at the surface with a head of 2 or 3 feet. Their water is soft, but usually contains some iron and sulphur; it is derived from the base of the Lagrange sand. There are two deep wells within 5 feet of each other at the Huntington corporation light and water works. They are 6-inch wells, drilled in 1898, one being 213 and the other 265 feet deep. The water rises a few inches above the surface. A log given from memory is as follows:

Log of well at Huntington, Tenn.

	Feet.
Sand and clay (Lafayette and Lagrange)	40
"Soapstone" (Porters Creek clay)	65–70
Gray sand, partly somewhat indurated (Ripley)	155–160

These two wells are said to be capable of yielding 800,000 gallons per day. An average amount of about 25,000 gallons per day is pumped into the mains under a direct pressure of 60 pounds for ordinary service, which is increased to 120 pounds for fire service. A chemical analysis shows the water to contain small quantities of iron and calcium carbonates; sulphates of potash, lime, soda, magnesia, and alumina; sodium and potassium chlorides, and sulphureted hydrogen. It is somewhat hard for washing, and the iron makes clothes and vessels yellow. It deposits in boilers only a rusty sediment that is easily blown off. The cold water eats out the valves and joints of pipes, but the hot water does not injure either fittings or boilers. This water is considered very healthy. It is reported that in five years no case of typhoid fever has developed in town where the deep-well water is used.

At Lankford there is a flowing well 6 inches in diameter and 100 feet deep. The water is used for household purposes, and is said to have medicinal qualities.

At Lavinia water is obtained at 160 feet depth, the entire section being sand.

At Leach water is obtained from springs and ordinary shallow open wells in the Lagrange sand.

At McKenzie, elevation 481 feet, some cisterns are used, and there are numerous wells ranging from 23 to 95 feet deep, the shallower ones being dug, the deeper ones bored. The shallow wells show some tendency to fail during dry seasons. There are also a number of deeper driven wells in the town and immediate vicinity that range from 175 to 335 feet deep. Water is abundant and soft in all of them. In some it contains iron, but not in objectionable quantity. These wells are generally used for boiler supply and stock watering on large farms. The Louisville and Nashville Railroad has a 6-inch well, reported by one person to be 335 and by another to be 362 feet deep.

The material encountered was chiefly sand. Water rises to within 90 feet of the surface.

At McLemoresville there are some springs, but water is obtained from dug and bored wells 40 to 50 feet deep that get water in the Lagrange sand. The water is reported hard in one, soft in others.

At Mixie there are small bored wells and good, strong springs.

At Muse a supply of fair to good water is obtained from the Ripley sand. Wells are about 50 feet deep; the flow is rather weak.

At Post there is a bored well 24 feet deep that flows. The water is from the Porters Creek clay, and contains iron and sulphur.

At Townes a supply of good water is obtained from springs and shallow, open wells in the Ripley sand.

At Yuma, elevation 480 feet, a water supply is derived from the Ripley sand by ordinary open wells that range in depth from 20 feet in low places to 100 feet on higher ground.

CHESTER COUNTY.

Topography.—Chester County is situated in the southeastern part of the area discussed in this paper. It is of irregular shape. The area of the county is 300 square miles, nine-tenths of which belongs to the Mississippi drainage basin, the remainder draining into Tennessee River. The Mississippi-Tennessee divide crosses the eastern part of the county. Along the water parting the surface is high and the country much broken and in places hilly and rough. The elevation along this summit ridge reaches nearly or quite 600 feet above tide. The eastward slope is steep and much cut up by the headwaters of the tributaries of the Tennessee. The slope to the west is at first steep and rough also, the surface being much dissected by the headwaters of Forked Deer River, but the middle and western parts of the county are more nearly level. Between the streams the general surface is flat, being broken only in a narrow fringe along either side of the main stream valleys, which lie 20 to 40 feet lower than the general country level. The average elevation is between 450 and 500 feet, the highest point being about 600 feet on the dividing ridge, as already stated, and the lowest about 370 feet on the level of Forked Deer River at the point where it leaves the county. The streams east of the divide are all small and are the headwater tributaries of White Oak River and of Piney Creek or Beech Creek. West of the divide Forked Deer River attains considerable size before it leaves the county. A small area in the southwestern part of the county is drained by the headwaters of Piney Creek, a tributary of Hatchee River.

Geology.—The rocks of Chester County consist of the Selma clay and Ripley formation of the Cretaceous, the Porters Creek and Lagrange of the Eocene, and the Lafayette of the Pliocene.

The upper half of the Selma clay underlies about 20 square miles of the east end of the county. It lies entirely in the drainage basin of White Oak River and its western boundary extends almost north and south. The fine clays of this formation are exposed in gullies and along the ravines draining into the headwaters of White Oak River. They are overlain by Lafayette gravels and clays in places on the uplands where erosion has not been especially vigorous. The formation dips westward under the Ripley sands, which cross the county in a belt about 10 miles wide, their eastern part forming the dividing ridge between the Tennessee and Mississippi drainages and their western edge extending through Henderson. The Lafayette covering conceals a larger proportion of the Ripley than of the Selma.

The Porters Creek formation crosses the county in a belt 4 or 5 miles wide, which extends from the southern projection of the county on the Hardeman-McNairy county line in a direction somewhat east of north to the extreme northern part of the county on the Madison-Henderson county line. Much of the Lafayette has been removed from the Porters Creek area, so that its leaden-gray clays are exposed in numerous places. The Lagrange sands are found in the western part of the county, covering an area 3 or 4 miles wide.

The Lafayette is 10 to 20 feet thick and overlies all the older formations. Near the eastern edge of the county it contains a considerable amount of rounded gravel. To the west the gravel becomes less abundant.

Water resources.—The streams of the county are numerous and furnish in most cases a sufficient supply of water for stock. In a few cases ponds are used. In the rough and broken country in the eastern part of the county good springs flowing from the base of the Lafayette or from the Ripley sands are numerous and much used. The surface of the county is gently rolling or almost level to the west, and the springs are less abundant and valuable, though even in the more level portions springs may be found in the depressions along the streams. The main dependence for water in this part of the county, however, is on wells. The water level in the Ripley sands is generally deep. Good, unfailing wells run from 75 to 150 feet in depth. The worst water in the county is found in the Porters Creek area. As found in some wells, certain parts of this clay are reported to be as black as tar and to emit a strong, offensive odor. Water from these clays is usually small in quantity, hard, and of a disagreeable odor, which renders it unfit for use. In the lower half of the Porters Creek occur some fine-grained, silty sandstones, and water obtained from these beds, though still hard, is in larger quantity and usually without bad odor. In the Porters Creek area wells should either be stopped in the lower part of the overlying Lafayette, if this is locally thick enough to furnish a supply, or should be carried down entirely through the Porters Creek to the underlying Ripley sands, in which water of good quality, rising to a level somewhere near the surface, should be obtained.

At Brinley, where the Ripley sand is the surface formation, there are some wells 30 to 50 feet deep and others 90 to 130 feet deep. The deeper wells are bored, 10 to 12 inches in diameter; they furnish soft water. Some springs are in use.

At Cabo, also in the Ripley area, there are numerous springs and some weak, shallow wells. The best wells are bored, 100 to 125 feet deep; they strike good, soft water at 90 to 100 feet, usually though not always in large quantity, the variation depending on the texture of the sand.

At Deanburg, which is situated on a flat ridge between two creeks, an abundant water supply is obtained from the Lagrange sands at a depth of 50 feet. Along the creeks are numerous never-failing springs, fed from the Lafayette and Lagrange sands. All the water here is soft.

At Enville the supply is derived from wells 15 to 30 feet deep and rather weak in flow. Better and larger supplies could be obtained by drilling 200 to 300 feet through the Selma clay into the Eutaw sand.

At Henderson, elevation 421 feet, a supply of soft water is obtained from the upper part of the Ripley sand at a depth of 50 to 60 feet. Bored wells 5 to 10 inches in diameter are in common use. A "blowing well" is reported, from which air is said to escape, especially in damp weather and in winter. This is of the usual type of blowing wells, in which air is absorbed by the porous sands during high-barometer conditions, to be given out with more or less noise when the pressure is decreased, with a falling barometer.

At Jasper some springs are used. Wells are generally very shallow because the "soapstone" (Porters Creek clay) is soon struck and yields water unfit for use. A few bored wells obtain a potable but hard water from a firm sand or sandstone in the Porters Creek at 70 or 80 feet.

At Mifflin water of fair quality is obtained from the Porters Creek clay at depths ranging from 30 to 60 or 70 feet.

Montezuma lies just about at the eastern edge of the Porters Creek area, and outside of this area good water is obtained at depths of 20 to 70 feet. In the "soapstone" belt wells may go 100 to 150 feet and then be abandoned from failure to get water or from its foul odor. The water so obtained often contains iron and sulphur and is astringent and hard. There are numerous springs along the streams, and some of them contain iron or other mineral matter.

At Sweetlips, where the Ripley sand is the surface formation, good, soft water is obtained from wells 70 to 100, or, in some cases, 200 feet deep. Along the foot of the hills good springs are found. In some cases water is raised from the deeper wells by windmills.

CROCKETT COUNTY.

Topography.—Crockett County is elongated in a northwest-southeast direction and lies between Middle Fork of Forked Deer River on the northeast and South Fork of the same river on the southwest. It has an area of 267 square miles. The surface of the county is divided along a northwest-southeast line through its center into two slopes, one draining to the northeast into Middle Fork and the other to the southwest into South Fork of Forked Deer River. The central portion is a level and gently rolling upland, with an average general elevation of about 400 to 425 feet above sea level. Near the main rivers on either side, especially in the western, northwestern, and eastern portions, the surface is hilly, being cut up by the tributary streams. The highest portion is along the central dividing ridge near the southeast end of the county, with an elevation of about 425 feet. The lowest portion is along the two forks of Forked Deer River where they leave the northwest end of the county, and has an elevation of about 300 feet.

Geology.—The Lagrange formation underlies the entire county beneath a thin blanket of Lafayette sand and gravel, which forms the surface of much of the county, but is itself covered, especially in the northwest end, by a few feet of loess and loam. The Lagrange, while predominantly of light-colored sand, contains in the southeastern part of the county beds of light-colored clays and in the northwestern part clays dark with lignitic material that is pure enough in places to burn when dried. The sands which make the bulk of the Lagrange deposits are mostly fine grained, but local beds of coarser sand occur at irregular intervals and furnish the most abundant supply of water as well as the most favorable location for setting strainers.

Water resources.—The surface is one of gentle relief, and as water sinks rapidly through the loose, porous sand of the Lagrange there is in many cases no opportunity for springs to form, so that they are not abundant and the few which occur as a rule have a weak flow. Aside from the rivers that border the county on two sides there are no streams of great importance. Pond Creek, the largest stream in the county, flows northwestward from Alamo, and Cypress Creek flows northwestward through the eastern part of the county. The other streams are very small and usually go dry during the summer, so that for watering stock the inhabitants depend largely on artificial ponds. For domestic supply wells and cisterns are in use. The wells include almost all classes. The old wells are largely dug and 20 to 30 feet deep. More recently, bored wells 6 to 12 inches in diameter and pipe wells about 2 inches in diameter have come into use. The water table in the Lagrange sand is often at some distance below the surface, so that if water is not obtained at 20 or 30 feet in the base of the Lafayette, it is necessary to go from 100 to 200 feet to get an adequate supply in sand coarse enough to be checked by a strainer. None of the wells in the county flow and the water in some stands so low that it is raised by windmill, gasoline, or steam power. The water is generally soft. In places, that derived from the Lagrange contains iron.

Alamo is situated near the center of the county on a plain with a surface of Lafayette sand. Some cisterns are used. Shallow, open, or dug wells get water from the base of the Lafayette. Of recent years small bored wells from 80 to 200 feet deep have come into use and furnish a good and abundant supply. Windmills are used to pump some of the deeper wells.

At Bells, elevation 331 feet, a good supply of water is obtained by driven or tubular wells from the Lagrange sand at a depth of 85 to 100 feet, though some wells are 140 feet deep. The water rises within 30 or 40 feet of the surface.

At Cairo soft water is obtained from shallow wells about 30 feet deep and water which is reported as hard, but which more probably is chalybeate, from driven wells 150 feet deep. Water in the deep wells is struck at 140 feet and rises 90 feet in the pipe.

At Chestnut Bluff, on Forked Deer River, there are numerous springs at the foot of the hills. The wells, open and bored, range from 30 to 80 feet in depth. Blue clay is reached at about 30 feet, and in places, especially toward the west, it contains lignite. Wells stopped at this depth get good water from the overlying Lafayette sand, but in dry seasons they are apt to fail entirely. The deeper wells get a supply of hard water from beneath the clay. Wells for boiler supply are driven to 100 feet or more.

At Crockett Mills there is an abundance of water in quicksand at 30 to 50 feet, but this is so fine that strainers can not keep it out of the wells and they are sunk until coarser sand is reached or the depth becomes so great that the attempt is abandoned. The abrupt variation in the texture of the sand and the very small extent of any one coarse bed are shown by three driven wells here that are 132, 240, and 420 feet deep, respectively. They furnish large quantities of soft water that contains some iron. No record of the 420-foot well was obtainable, but the section is described as being alternating sand and clay, the sand being the more abundant. Water is pumped by steam or by windmill.

At Foster there are very few springs. Open, shallow wells are in general use.

At Friendship springs are but little used. Bored wells of 18-inch diameter range from 32 to 75 feet in depth, according to elevation chiefly. Driven wells 2 or 3 inches in diameter range from 85 to 100 feet in depth. The supply is abundant and is used for all purposes. Some wells contain iron.

At Maury City wells varying from 53 to 135 feet in depth furnish a good supply of water. They are pumped by hand or by gasoline engines.

DECATUR COUNTY.

Topography.—Decatur County lies just west of Tennessee River. The surface slopes eastward and the drainage is into the Tennessee. The western portion of the county has the greatest elevation. It is almost flat in places remote from the small streams that drain it, but along the streams the surface has been cut by erosion into hills. The elevation in this western part of the county ranges from 380 feet along the streams to about 550 or 600 feet on the highest ridges.

Geology.—Only the western two-fifths of the county is within the embayment, the remainder lying within the area of Paleozoic limestones. The line between these two geologic divisions runs with some sinuosities in a general north-south direction, passing through Decaturville and Parsons. It is not difficult for even the layman to recognize this line, for west of it the rocks are all soft sands and clays, while east of it they are hard limestones and cherts. The eastern part of the county, within the Paleozoic area, is not discussed in this report.

The oldest surface formation in the western part of the county is the Eutaw sand, which lies immediately on the hard Paleozoic rocks. One of the best sections, at Parsons, is described at some length on page 24. The exposure there and in railway cuts just to the west may be regarded as typical of the formation. The Eutaw sand extends westward into the adjoining county. In the extreme northwest corner of Decatur County it is overlain by the clays and marl of the Selma clay in a very small area covering not over 2 or 3 square miles.

Spread thinly over the Eutaw sand and extending eastward over the Paleozoic rocks as well is the Lafayette. In many places it has been cut through by erosion. Its proximity to Tennessee River is reflected in the large amount of rounded chert gravel it contains. This gravel is exactly similar to that now being carried down by the river. In many places the Lafayette gravel is cemented by limonite into a conglomerate, while here and there the iron is rich enough to be mined as an ore.

Water resources.—No attempts have been made within the embayment area of Decatur County to sink wells deeper than about 80 or 100 feet. The underlying formation is the Eutaw, which yields water of good quality in the sandy layers at depths varying according to the topography from 30 to 80 feet. The supply is usually abundant. There are also in this formation numerous beds of clay that contain lignitic material and decomposing iron pyrite. Water from wells or springs supplied by these strata sometimes contains sulphur and is usually more or less astringent from the iron sulphate present. In some cases the water on standing deposits a yellowish scum of hydrated iron oxide formed by the decomposition of iron carbonate.

At Beacon the supply is derived chiefly from wells of ordinary depth, those stopping in sand giving water free from mineral matter, while those in clay contain iron salts.

Parsons, elevation 488 feet, is situated on the eastern edge of the embayment deposits. Springs from the base of the Eutaw formation often contain iron and sulphur. Wells are generally used, and average 25 to 35 feet deep. Those dug to the sand and gravel at the base of the Eutaw obtain a good supply of pure, soft water; those stopping in an overlying clayey stratum obtain a less abundant supply of hard water, which may fail entirely in a dry season. Wells are either open, bored, or driven. There is no waterworks system in the town.

At Point Pleasant a supply is obtained from ordinary open or driven wells and from numerous springs along the bottom or lower slopes of the hills.

At Sugar Tree there are only shallow wells; the water in some of them is said to contain alum, while in others it is free from mineral ingredients. There are a few springs.

At Thurman the chief supply is from open wells that range from 30 to 80 feet in depth. Some springs are used.

DYER COUNTY.

Topography.—Dyer County is in the northwestern part of the embayment area of western Tennessee. It is bounded on the west by Mississippi River and on the south by Forked Deer River and its South Fork. The area is 500 square miles. The drainage is to the Mississippi directly or through Ohio River, Forked Deer River, or Reelfoot Lake.

The county may be divided into two parts that are topographically quite distinct. One is the rolling or hilly upland region, lying chiefly in the eastern half of the county. The other is the flat, alluvial bottom land of the Mississippi, the Obion, and other main streams. The upland is gently rolling except along the streams, where it becomes hilly, and along the line of bluffs separating it from the Mississippi bottom, where erosion has cut it into bold, steep hills that form the bluffs and overlook the broad expanse of bottom lands. The average elevation of the upland surface is about 375 feet; while that of the bottoms is from 100 to 150 feet less.

Geology.—The formations of importance for water-supply purposes in Dyer County are the Lagrange, the Lafayette, the loess, and the alluvium.

The Lagrange underlies the entire county. Although it is occasionally laid bare in ravines by the erosion of the overlying formations, it is generally concealed by one or more of these formations and is reached in wells at depths of 50 to 100 feet. It is the important water bearer of the area.

The Lafayette underlies the upland area of the county, resting on the Lagrange. It averages not over a score of feet in thickness. The Lafayette is not found beneath the bottom areas, because since its deposition it has been removed by the erosion which formed the stream valleys. It does not appear as a surface formation, except where the loess has been removed by erosion. It lies just beneath the loess and is reached in many wells.

The loess, like the Lafayette, occurs only in the upland part of the county and the second bottoms, and for the same reason it has elsewhere been removed by subsequent erosion. It rests on the Lafayette and often contains a stratum of gravel and sand at its base. It has a maximum thickness of 40 to 80 feet along the bluffs of the Mississippi, but thins out and gradually disappears to the east, so that a definite eastern limit for it can not be fixed. However the eastern edge of the county may be roughly taken as that limit.

The alluvium is found in the bottoms of the Mississippi and other streams. It rests directly on the Lagrange and varies in thickness up to 100 feet or more along the Mississippi. Along Obion and Forked Deer rivers the valley is divided topographically into a first and a second bottom. The first bottom is low and usually swampy and composed of alluvium. The second bottom is 10 to 20 feet higher as a rule and covered with loess.

Water resources.—In the more broken parts of the county, near the streams, springs issue from the Lafayette along the lower slopes of the hills. In the more level parts the open shallow wells in the loess usually yield hard water and early led to the use of cisterns. These are very easily and cheaply constructed in the loess and are extensively used. Of recent years driven wells 2 or 3 inches in diameter have come into use. These obtain a supply of fair to good water in the Lagrange at a depth of 150 to 250 feet, as a rule. The water is usually soft enough to use in washing, but may leave a soft or gummy scale in boilers. Water may be obtained from the Lagrange in all parts of the county, at reasonable depths, and should generally be of acceptable quality. The Lagrange here contains beds of clay, and much of the sand is fine, so that careful watch should be kept for any pocket of sand coarse enough to permit the use of a strainer. In the alluvial region the water obtained in shallow open or driven wells is generally unsatisfactory. Since the surface is everywhere either below or only slightly above high-water level in the rivers, wells in this region are shallow and draw their supplies of water practically from the surface. The water in the wells on the elevated strip of flood plain near the banks of the Mississippi rises and falls in harmony with the varying stages of the river surface. The water from the alluvium is usually hard and flat or "sweet" in taste and must contain considerable organic matter, resulting from the decomposition of the abundant plant remains that are embedded everywhere in the flood-plain deposits. Better water may be obtained on any of the flood plains by sinking deep wells into the underlying Lagrange formation.

At Bandmill, in the Mississippi bottom, poor water is obtained from the alluvium by shallow driven wells.

At Bogota, on a tributary of the Obion, there are no springs or open wells, but water is obtained from driven wells 18 to 20 feet deep. The quality is said to be good.

At Dyersburg, elevation 295 feet, on Forked Deer River, shallow open and driven wells and cisterns are used. The shallow wells run from 30 to 60 feet in depth. The 30-foot wells in the loess get poor surface water. The 60-foot wells go through the loess and get a better water from the Lafayette sand or the top of the Lagrange. The supply from this sand is large. Five wells in it yield about 250,000 gallons a day, but the water is hard and that from some of them scales badly in boilers. The old water company had an artesian well 6 inches in diameter and 650 feet deep, with a natural flow of about 150,000 gallons a day rising about 10 feet above the well mouth. When pumped the well was capable of yielding 1,000,000 gallons a day with proper air lift. The log, given from memory, is as follows:

Log of well at Dyersburg, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay	10	10
Blue clay	40	50
Sand, very fine on top, grading into a layer of pebbles 1 inch in diameter at bottom	40	90
Soft light-colored clay	25	115
Quicksand	30	145
Thin layers of fine sand and dark tough clay with lignite	275(?)	420 (?)
Sand, fine and coarse to bottom	230(?)	650

The water has not been analyzed, but it is not good for boiler or general industrial use, so that the municipal corporation which has bought out the old private water company now takes the town supply from Forked Deer River and forces it by two 1,000,000-gallon Worthington pumps into a standpipe 27 by 50 feet in size and 125 feet above the pumps. The supply is filtered by Jackson mechanical filters.

The Phœnix Cotton Oil Company has a well, drilled in 1899, at about the same elevation as the town well, and 591 feet deep. For the upper 200 feet the diameter is 8 inches; below that, 6 inches, with a 30-foot strainer. The log, given from memory by one of the proprietors of the mill, is as follows:

Log of well of Phœnix Cotton Oil Company, Dyersburg, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	200	200
"Soapstone" or hard pipe clay	+350	+550
White sand, mostly coarse	41	591

At 200 feet a weak flow of water containing considerable mineral matter was encountered. The natural flow is at first 100 gallons a minute under a head of 11 feet. This flow decreases slowly until the strainer is washed out by back pressure and then resumes its original volume. The water contains 138 parts per million of mineral matter, 114 parts of which are iron salts. The water flows naturally into a pool, which was at first shallow and aerated it sufficiently to cause most of the iron to be precipitated. The pool has lately been deepened and now aeration and precipitation are imperfect and a yellowish rust-colored soft scale is deposited in the boilers.

Another log of these two wells was given—also from memory—by Johnson and Fleming, of Memphis, who drilled both wells. It is as follows:

Log of well of Phœnix Cotton Oil Company, Dyersburg, Tenn.

	Feet.
Loess	5
Fine sand and gravel, gray-black in color	40 or 50
Silt, gray to black, full of leaves and lignite to 220 feet from surface	165 or 175
Blue clay, with leaves and logs	360
White pipeclay	20
White sand with fine particles of lignite and iron pyrite	28

They report the town well as 584 feet deep and the oil company's as 628. The oil company's purchase of pipe and strainer shows only 591 feet.

West of Dyersburg in the bottoms driven wells 2 inches in diameter and 10 to 40 feet deep are used. The water is poor and flat or "sweet." East of town, on the upland, wells average about 40 feet deep.

At Finley cisterns are used very largely.

At Lane there are a few springs, several open wells, some cisterns, and a number of driven wells 75 to 125 feet in depth. An approximate log of one of these is as follows:

Log of well at Lane, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay, becoming lighter downward	35	35
Blue clay	25	60
Sand, fine-grained, water-bearing	5	65
Blue clay	15	80
Sand, coarser, water-bearing	10	90
Blue clay, somewhat chalky	25	115
Sand, course, with gravel, water-bearing	5	120

The supply is abundant but the water is hard.

At Laplata water is obtained from shallow wells that average 30 feet in depth.

At Newbern, elevation 380 feet, cisterns were formerly much used. There is a town system of waterworks deriving an abundant supply from two wells, each 165 feet deep; one of 5-inch diameter, put down in 1892, the other of 8-inch diameter, put down in 1897. The water rises within about 70 feet of the surface. The supply is ample for the two pumps, which have a combined capacity of 8,000 gallons per hour. The water is soft and very good for washing. It forms a little soft scale in boilers which is easily removed by a boiler compound. It does not injure the iron, but corrodes brass connections rapidly. The health of the town is said to have been materially improved by the use of this water. Typhoid and malarial fevers especially have decreased in frequency. There are other wells of about the same depth at the Illinois Central Railroad water tank, the ice plant, a planing mill, and a flouring mill.

A generalized section given by Mr. J. L. Holt, a Newbern well driller, is as follows:

Generalized section at Newbern, Tenn.

	Feet.
Yellow clay (loess)	30±
Sand, fine, only a little water in it (Lafayette)	4±
Joint clay, or soapstone, bluish gray	30–60
Quicksand, fine, silty, down to a total depth of 130–150 feet	35–85
Coarse yellow sand, penetrated	10–15

At the planing mill, on about the same level as the town well, no joint clay was encountered. Thirty feet of loess were followed by a quicksand that became coarser downward until the strainer was set at 110 feet depth.

Two miles west of Newbern the following record was obtained in a well made for Mr. Kit Haskins:

Log of Haskins well near Newbern, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellowish on top	50	50
Clay, reddish	50	100
Clay, blue	50	150
Clay, white	45	195
Sandstones	2	197
Sand, coarse, yellow, penetrated	13	210

Eight miles west of Newbern water was obtained on the upland for Mr. Guy Fairbanks at a depth of 156 feet. The section was as follows:

Log of Fairbanks well near Newbern, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow (loess)	50	50
Clay, blue (loess ?)	40	90
Sand and gravel with 2-foot indurated layer at base (Lafayette ?)	12	112
Quicksand with some gravel, penetrated (Lagrange)	54	166

Five miles south of Newbern, on the uplands north of Forked Deer River, a hard water not fit for boiler use is obtained at a depth of about 325 feet. The water rises to within 75 feet of the surface. The strata passed through were as follows:

Log of well on Forked Deer River near Newbern, Tenn. [a]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow (loess)	40	40
Sand, very fine, doughy	100	140
Clay, blue, tough	85	225
Sand, fine, blue, penetrated	100	325

[a] Figures are approximate.

Along Obion River wells on the first bottom average 50 feet in depth. They usually pass through blue mud from 20 to 50 feet thick and enter a bluish muddy sand, in which the well is made. Occasionally a pocket of gravel is encountered beneath the blue mud. On the second bottoms, which rise 15 to 25 feet above the first bottoms, and are from 4 to 12 miles wide, the average depth of wells is about 110 feet, and the average record is, from the top down, yellow to gray clay (loess), 20 to 40 feet thick; blue mud, often very soft, 20 to 30 feet thick; muddy quicksand as in first bottoms. There is no Lafayette gravel between the yellow clay, or loess, and the underlying blue mud of the Lagrange. In the cutting of the broad valley represented by the second bottom the Lafayette was removed; the loess was then laid down alike over upland and valley floor; then uplift came and the loess was removed from the area now occupied by the streams and the first or present bottom.

On the uplands east of Newbern, toward Trenton, water is usually soft and is reached at about 50 to 55 feet. In some spots, which are not necessarily high places, one must go 90 or 100 feet to obtain an unfailing supply. In this region the loess soon thins out and disappears, and hence the water is apt to be soft.

At Templeton driven wells range in depth from 30 to 150 feet. The deeper ones yield an unfailing supply of water that is usually soft, but in some cases contains iron and other minerals. The water here, as elsewhere in the county at any notable depth, is obtained from sands of the Lagrange formation.

At Tennemo, on the Mississippi, poor water is obtained from shallow driven wells; river water is also used.

At Tigertail small driven wells average about 30 feet in depth.

At Trimble there are a few cisterns, but water is obtained mainly from driven wells that range from 40 to 110 feet in depth and furnish a good supply. The water in the shallow wells is hard; in the deeper ones it is somewhat soft and is used for boilers without much difficulty. The loess is about 30 or 40 feet thick and is underlain by a blue clay, often so soft as to run, 4 to 10 feet thick, followed by a fine quicksand, which usually becomes coarse enough at a depth of 80 to 110 feet to make the well there.

FAYETTE COUNTY.

Fayette County is in the southwestern part of the area discussed, and is bordered on the south by the State of Mississippi. Its area is 618 square miles. The entire county drains into Wolf, Loosahatchie, and Hatchee rivers, which are all tributary to the Mississippi. The larger part of the area is elevated and rolling. In the southeasten part of the county there are hills adjacent to the Wolf River valley. In the northwestern part the county on either side of the Loosahatchie is broken and hilly. The southeastern part of the county is the highest. Lagrange has an elevation of 531 feet, and elsewhere in the vicinity elevations of 550 to 575 feet are found. The general slope is westward, and the lowest elevation, about 260 feet, is on the western edge of the county, where Loosahatchie River leaves it.

Geology.—The underlying formation is everywhere the Lagrange. It is exposed in many places in the ravines and deep gullies, and contains clay beds that are mined in a number of places. The section at Lagrange, from which place the formation takes its name, is given on page 36. It is overlain by 10 to 20 feet of orange-colored sand belonging to the Lafayette, and this in turn by a few feet of Columbia sand or loam, or, in the northwestern part of the county, by the thin eastern edge of the loess.

Water resources.—As a rule, springs are not numerous in this county. The Lagrange consists here very largely of sands which absorb water freely, and contains comparatively few beds of clay extensive enough to intercept the water in its downward passage and guide it to the surface along their outcrops to form springs. The water table or ground-water level lies here farther from the surface than is the case either to the east or the west of this outcrop belt of the Lagrange. Springs are generally freestone. The depth to water, which is in many places 75 to 150 feet, makes open wells expensive and inconvenient, and so cisterns are largely used. Driven wells 2 or 3 inches in diameter have in recent years come into use in many sections. The deeper ones are usually pumped by windmills or by gasoline or steam engines. The quality of the water from the Lagrange sand is generally good. Occasionally a well strikes a bed of lignitic material and the water then contains iron and sulphur. In places weak flows may be obtained at the base of the Lafayette. As a rule, such water can not be depended on during dry seasons. It seems to gather in little local depressions on the upper surface of the Lagrange, being held up by an impervious crust of ironstone, which in places is found at the contact between these two formations, but which may be wanting within a hundred yards. If this impervious layer is penetrated, the Lagrange sand beneath is generally found dry, and one may dig 50 or 100 feet deeper, or more, before getting water in this formation. Water should be obtainable anywhere in the Lagrange at depths of not more than 200 or 250 feet, and in many places it is found at a depth considerably less. The streams of the county are numerous and except in dry seasons have an abundant flow. Some of them have considerable fall and furnish sites for small mills.

At Canadaville there are no springs, but most of the inhabitants use cisterns. Some small bored wells, ranging from 90 to 140 feet in depth, yield an abundant supply of good soft water, but in the deeper wells it rises only within 125 feet of the surface.

At Claxton only ordinary and driven wells are used. The latter may go 75 to 100 feet deep, and the water rises within about 40 feet of the surface. The water is soft and the quantity ample.

At Elba there are a few springs. The main water supply comes from bored wells of shallow depth.

At Gallaway, elevation 277 feet, a few cisterns are in use, but most of the people have shallow wells that derive their supply from the Lafayette sand beneath a loess covering. The water is consequently hard.

Ina is on an elevated plateau 500 feet above sea level. There are a few springs, but they are usually weak. The principal water supply is from ordinary pipe wells of small diameter that average 75 to 125 feet deep and furnish good soft water.

Lagrange is on an elevated ridge 532 feet above the sea. A detailed discussion of the geology is given on page 36. Wells are the main dependence for water. They vary greatly in depth. Some find water at 18 to 20 feet depth at the base of the Lafayette; others a few hundred yards away go 175 to 213 feet before getting a supply in the Lagrange sand. The water is soft and pure, but does not rise in the wells. Windmills are used for pumping.

At Lambert there are some springs along the streams; on the upland surface water is obtained from ordinary open wells.

At Macon most of the water is obtained from bored wells at depths of from 35 to 100 feet. There are a few springs, but they are along the streams and not convenient for use.

At Moorman small driven wells are largely used. One 103 feet deep struck water of good quality at 53 feet. It is pumped by a windmill. Others go as deep as 200 feet.

At Moscow, elevation 354 feet, the wells average 30 to 40 feet in depth. At that depth the flow is weak, but below the blue mud struck there water is found in abundance at depths of 60 to 80 feet. In the hills east of town water is reached at 90 to 100 feet.

At New Kent there are some wet-weather springs, but water is generally obtained from bored and dug wells. The supply from these is not always satisfactory, and many are reported to have gone dry after a few years.

At Oakland, elevation 388 feet, the wells are from 60 to 125 feet in depth. They are pumped by hand, or by steam where used for industrial purposes.

At Rossville, elevation 311 feet, water is obtained from white sand beneath a layer of pipe clay at 28 to 35 feet. It is soft, but contains some iron.

At Somerville, elevation 356 feet, the supply is furnished by open wells and driven wells from 100 to 150 feet deep. The water rises in some of these within 50 feet of the surface. It is in several cases reported hard. The supply is abundant.

At Taylors Chapel water is obtained from some good strong springs and wells that range from 25 to 125 feet in depth. In many places at depths of 30 to 40 feet a stratum of black mud is struck, averaging about 40 feet thick and furnishing foul-smelling water. It is underlain by a thin ironstone layer and when this is pierced good water, that rises 30 or 40 feet, is found in abundance. It is usually pure, but occasionally contains some iron or sulphur.

Yumyum has very few springs. Bored wells ranging from 30 to 40 feet in depth furnish a scant supply, but an abundance is reached by driven wells at depths of 125 to 200 feet.

GIBSON COUNTY.

Topography.—Gibson County is situated almost in the center of the embayment area of western Tennessee. Its shape is roughly a rectangle from which the northeast and southwest corners have been removed. It is bounded on the northeast by South Fork of Obion River and on the southwest chiefly by Middle Fork of Forked Deer River. The area is 625 square miles.

The entire county is in the Mississippi drainage area. The surface slopes gently to the northwest, and is mostly level or slightly rolling, for, as a rule, the streams have not cut deeply below the general level; only in the southern and eastern parts of the county is the surface broken or hilly. The stream valleys or flood plains are usually wide and the valley sides have moderate slopes. The streams do not have much fall, but flow gently, and are rather building up their flood plains than cutting them out. The greatest elevation is in the southeast corner, where it reaches slightly above 500 feet. The least elevation is about 280 feet, at the point where Forked Deer River leaves the western edge of the county. The average elevation of the upland is about 400 to 425 feet.

Geology.—The rocks that outcrop in Gibson County are the Lagrange, the Lafayette, and the Columbia loam and loess.

The Lagrange underlies the entire county and is the source of all deep waters. Because of the gentle character of the stream cutting it is not usually exposed. It consists here as elsewhere of sands and clays, the sands predominating.

The Lafayette rests upon the Lagrange on the uplands and the upper part of the valley slopes. It is here chiefly a red loamy or case-hardened sand and contains very little gravel. It averages perhaps 20 or 30 feet in thickness.

A few feet of light-colored Columbia loam usually overlie the Lafayette, and it is often hard to distinguish one formation from the other. In the northwestern part of the county this loam apparently passes into the loess.

Water resources.—The various tributaries of Obion and Forked Deer rivers provide most of the county with water for stock. Some portions of the county, however, are remote from streams and there ponds are dug in low places to catch water. For domestic use wells are the most common source of supply. To a limited extent cisterns are used, especially in the middle and western parts of the county, on the more elevated uplands, where wells would be in some places inconveniently deep. Along the sides of the valleys springs occur, but most of them come from the base of the Lafayette and have a weak flow. The wells range in depth from 25 to 35 feet in the low grounds near the streams and from 100 to 125 feet on the uplands. Exceptionally they may reach 200 feet, as in some places in the elevated southeastern part of the county. The water is generally soft where it does not come from the loess, which occurs in the northwestern part of the county. It is generally free from mineral matter, though in places where lignitic beds are present in the Lagrange it may contain iron and sulphur. Water in the deeper wells may rise on the uplands a good part of the way to the surface, while on the second bottoms and along the streams it rises just to or slightly above the surface. Many wells in low places that flow gently when first drilled stop flowing after a time, because of the partial choking up of the pores in the sand around the strainer by fine particles carried there by the flow of water to the well. In such cases back pressure by a pump washes the sand clean and restores the original flow for a time.

At Bradford, elevation 366 feet, water is obtained from dug and bored wells that vary in depth from 10 feet in low places to 160 feet on high ground. Usually an abundance of water may be had at 40 feet or less. Springs are few, small, and weak.

At Cades, elevation 374 feet, a black lignitic clay 90 feet thick is struck at a depth of about 30 feet. Beneath this is a water-bearing sand. In a well 140 feet deep the water stands 30 feet below the surface.

About 2 miles north of Cades the lignitic clay is absent. A well on the Fletcher Neal farm went 175 feet through sand only and obtained good water at 160 feet, but the water did not rise above that level.

At Clareville water is obtained chiefly from open and bored wells of 50 feet depth or less. There is a sulphur spring of local note only.

At Dyer, elevation 358 feet, both wells and cisterns are used. The wells average from 20 to 60 feet in depth. Some of the water is hard and the supply is usually not large. One well is reported 200 feet deep, but no further data concerning it could be had. A mile west of town there is a strong spring of pure soft water that has determined the location near it of a Methodist camp-meeting ground.

At Eaton there are few springs except along the edge of the Forked Deer bottom. Wells range from 20 to 40 feet in depth.

At Edmonds a plentiful supply of good water is obtained, mostly from small bored wells. There are a few open or dug wells. The depths of all are moderate.

At Gibson, elevation 389 feet, the bored wells range from 20 to 100 feet in depth, though the average is about 60 feet. In the deeper wells water rises 20 or 30 feet.

At Hooten there are a few springs. Most people have bored or dug wells that reach an abundant supply of water at from 20 to 40 feet.

At Laneview open and small bored wells range in depth from 50 to 130 feet. In a 128-foot well, the water stands 110 feet from the surface.

At Lonoke ordinary wells range from 15 to 100 feet in depth, according to location, and small pipe wells from 100 to 300 feet. The water is soft, but in some of the deeper wells contains iron or sulphur.

At Medina, elevation 502 feet, it is necessary to go to a depth of from 100 to 200 feet for water, and sometimes even at the latter depth the Lagrange sands fail to furnish a supply. The water is soft and pure where obtained.

Milan, elevation 421 feet, is underlain by about 20 or 22 feet of red Lafayette sand, below which in a part of the town is found a pipe clay 43 feet thick, while elsewhere, especially in the eastern part of town, instead of pipe clay a very dark or black lignitic clay is struck. This black clay occurs 3 or 4 miles north of town and for the same distance south. It reaches a thickness in places of 70 to 90 feet. Under it are 2 to 7 feet of yellow clay, then a 3 or 4 inch ironstone crust, easily broken by an iron bar. Below either the pipe clay or the ironstone is found a soft sand which varies in texture but often contains in its upper part some fine gravel. This sand is water-bearing and has been explored to a depth of 200 feet from the surface. The town corporation has two 6-inch wells, each 113 feet deep, with 20-foot No. 6 Cook strainers. The water rises within 20 feet of the surface. It is pumped into a large cistern or reservoir and is forced thence into the mains under a service pressure of 40 to 45 pounds and a fire pressure of 100 to 125 pounds. The water is very clear and is said to be good for all purposes. It forms in boilers a very small amount of soft scale. The pumps have a capacity of 500,000 gallons per day. The actual daily consumption averages 60,000 gallons. Open wells get surface water at the base of the Lafayette at depths of 20 to 25 feet. This water is usually unsatisfactory and the best open or pipe wells are from 65 to 90 feet deep. They tend to fill up, however, with the fine soft sand in which they stop. On the higher hills in the vicinity the wells go 100 or 125 feet deep, and in such localities an occasional cistern is found. Elsewhere in this vicinity cisterns are not used.

At Neboville there are along the water courses some small springs that are used for stock. Wells average from 40 to 80 feet in depth. The water is generally soft.

At Rutherford water is obtained from dug wells 50 to 70 feet deep; it is reported hard in some cases. Driven or pipe wells averaging about 160 feet in depth are also used.

At Skullbone there are no springs; water is obtained from open or bored wells, some of which are 90 feet deep, with the water standing 70 feet from the surface.

At Trenton, elevation 315 feet, a town supply is obtained from four 4-inch wells 119, 147, 152, and 165 feet deep, and two 6-inch wells 130 and 165 feet deep. In the 130-foot well the strainer is 24 feet long; in the others 16 feet. Five are in a row only 22 feet apart; the sixth is 40 feet distant from this row. As a consequence they interfere with each other. They have a combined natural flow under a head of about 2 feet of 90 gallons per minute. Except in case of fire and during July, August, and September, when daily consumption is at a maximum, the natural flow is adequate for all purposes. The two pumps have each a capacity of 250,000 gallons per day and force the water into the mains under a service pressure of 45 pounds per square inch. The water is very clear and pure and since 1897, when the system was installed, the health of the town has notably improved, fevers especially showing a marked decrease. In sinking the wells 15 feet of a second-bottom deposit of sandy clay was first passed through and then a water-filled sand which extends down 155 feet and is followed by 1 foot of sand ironstone and that by a light-colored pipe clay which was not explored further. The sand in which the strainers were set is very fine and some gets through even a No. 6 Cook strainer, so that as little pumping as possible is done. Common open wells in town run from 20 to 40 feet deep, and some cisterns are still in use. These are now generally filled from the city mains and during the hot months keep the water cooler than it is in the mains. A stave mill, a fourth of a mile north of the town wells has a 4-inch well 147 feet deep, with a record similar to the town wells. In the surrounding country the open wells vary from 20 or 25 feet in depth in the stream valleys to 100 feet on the uplands. Some cisterns are in use.

At Yorkville there is a mineral spring of some local repute.

HARDEMAN COUNTY.

Topography.—Hardeman County adjoins the State line on the south and is almost halfway between Tennessee and Mississippi rivers. It is quadrangular in shape, with a small irregularity in the northeast corner. Its area is 655 square miles. The central and western parts of the county are gently rolling and the northern, eastern, and southern parts are broken and hilly. The county is drained almost entirely by Hatchee River and its tributaries. The course of the Hatchee is from southeast to northwest through the center of the county, and its tributaries on either side have their general courses almost at right angles to the main stream. The most elevated part of the county is the southwestern, where the higher ridges or remnants of the former plateau surface reach altitudes of slightly over 600 feet, and the general elevation is between 500 and 600 feet. The rest of the county averages between 400 and 500 feet. The lowest point is about 300 feet, where the Hatchee leaves the county. The general surface slope is northward or northwestward.

Geology.—The geologic formations of Hardeman County are the Ripley, Porters Creek, Lagrange, Lafayette, and Columbia.

The Ripley is found only in a narrow belt along the extreme eastern edge of the county, east of Muddy Creek near Middleton and east of Crainesville. It has its usual character, consisting of soft light-colored or variegated sands with occasional thin clay lenses.

The Porters Creek overlies the Ripley and succeeds it to the west as a surface formation. It runs through the eastern part of the county in a direction slightly east of north in a belt that averages from 6 to 9 miles wide. Its eastern edge along the Southern Railway is just east of Muddy Creek near Middleton and passes through Crainesville. Its western edge may be seen on the road from Bolivar to Crainesville just east of the bridge over the Hatchie. Much of it is a fine clay, ashen gray when dry but darker when wet, and is popularly known as soapstone. A more sandy phase is sometimes known as alum earth.

The Lagrange lies west of the Porters Creek belt and underlies all of the central and western parts of the county. While predominantly of sand, it contains lenses of plastic clay and occasional beds of lignitic material.

The Lafayette has its usual character, being a surface veneer of orange-red sand found on the higher levels, 10 to perhaps 40 feet thick. Over it in places may be discriminated 5 to 10 feet of lighter-colored, softer sand representing the Columbia.

Water resources.—The county is naturally well watered. Streams are found everywhere within short distances and furnish ample supplies for stock. Their flow is fairly constant, since most of the water comes from sandy formations that furnish an almost unfailing supply. Many bold springs of good freestone water flow from the sands of the Lafayette, the Lagrange, or the Ripley. The springs from the Porters Creek "soapstone" clay are weak and the water is usually astringent from alum and iron. Wells in the sands obtain good water. Where the Lafayette is locally thick wells often reach water in its lower part above an iron crust or hardpan separating it from the underlying formation. The quantity of this Lafayette water is limited and during dry seasons it may fail altogether. Furthermore, it is surface water and so is liable to contamination. The Lagrange furnishes good pure water except where lignitic beds locally occur. There it contains iron, sulphur, or alum to some extent. The depth at which water may be obtained in it varies largely with the topography. On the uplands it is generally necessary to go from 75 to 150 feet. In a belt of very porous dry sands in this formation that extends 2 or 3 miles on either side of Grand Junction and runs northeastward to Hickory Valley and beyond it is often necessary to go 200 feet or more. In such places and also in the area underlain by the Porters Creek clay cisterns are often used. The Porters Creek furnishes unsatisfactory water. It is hard and contains iron and alum. The odor in some cases is so disagreeable that even stock will not touch it, and the supply, even where the water is of tolerable quality, is usually small. In many cases open wells, which are usually dug less than 100 feet, fail to obtain water.

Open wells should be stopped in the base of the Lafayette just above the clay if that formation will yield any water. If not, the small tubular or driven well should be used and should be put down through the Porters Creek clay to the upper layers of the Ripley sand, where a supply of good water should be struck that will rise a considerable distance toward the surface. Difficulty should not be experienced in sinking through the Porters Creek clay if struck anywhere near the surface, as it is nowhere known to be as much as 200 feet thick and is probably not greatly over 100 to 125 feet in this county.

At Bolivar, elevation 449 feet, water is obtained from wells that average 70 to 80 feet in depth. The upper 20 to 30 feet are in Lafayette sand and the rest of the section is in Lagrange sand. An unsuccessful attempt to sink a deep well was made some years ago, but the cause of the failure could not be learned. There should be no difficulty in obtaining water from the lower layers of the Lagrange, which is probably 200 feet or less in thickness here. After this is passed no water could be hoped for until the Porters Creek clay—perhaps 150 or 175 feet thick—had been gone through; then water should be struck in the upper part of the Ripley under sufficient pressure to rise within about 100 feet of the surface.

Crainesville is situated on the eastern edge of the Porters Creek clay. Wells average 40 to 50 feet in depth. Those in the clay furnish poor water, while those in the Ripley sand furnish good water. If the clay is struck, digging should be continued until it is passed through, for it can nowhere in the village be over a few score feet thick. Wells in the Ripley sand to the east are from 30 to 50 feet deep and furnish good water. Those in the alluvium of the Wade Creek bottom west of town furnish poor water at depths of 14 to 25 feet. Farther west in the "soapstone" belt good water is sometimes obtained in the basal part of the Lafayette sand just above the leaden-colored clay. If the latter is entered the water is generally poor.

At Essary Springs Hatchie River is used for stock, and springs and wells furnish the domestic supply. The wells vary from 20 to 60 feet in depth. The water in some is free from all mineral matter; in others it contains iron. The spring water commonly contains iron and is largely used.

At Grand Junction, elevation 573 feet, shallow wells in the basal part of the Lafayette at depths of 15 to 25 feet furnish a scant supply of surface water and go dry during late summer and autumn. Cisterns are largely used for domestic supply. Two driven wells of 2-inch diameter, one 145 and the other 195 feet deep, find water in the Lagrange sand. The deeper one passes through the following strata:

Log of well at Grand Junction, Tenn.

	Feet.
Clay, sandy, red (Lafayette)	12
Clay, fine, white, plastic	22
Sand, white, clean, sharp	20
Clay, white, as above	2
Sand, light red, coarse at top and bottom (penetrated)	139

Water was struck at 152 feet, but did not rise. At 195 feet the sand was coarse enough to set the strainer. This well is pumped by steam. The 145-foot well belonging to the town is pumped with difficulty by hand and is not much used.

At Hickory Valley, elevation 566 feet, shallow wells have an average depth of about 60 feet. They are not always reliable and may go dry; many of them have been abandoned for cisterns or for deep tubular wells that range from 150 to 210 feet in depth according to the topography. In some the water is very good and pure; in others it contains some iron. Similar conditions as to depth and quality prevail for 3 miles east and 3 miles west of town. Five miles to the east springs are numerous and wells average only 30 or 35 feet deep.

At Middleburg, elevation 537 feet, wells range in depth from 25 feet in the base of the Lafayette to 180 feet in the underlying Lagrange. Water is abundant and soft.

At Middleton, elevation 407 feet, water is rarely found above the dark Porters Creek clay, which is reached at a depth of 15 or 20 feet. Wells average 20 or 25 feet in depth and furnish poor to fair water. One well 102 feet deep was abandoned in the Porters Creek clay without finding water, when perhaps 50 feet more would have carried it into the underlying Ripley sand, where a good supply of soft water that would rise much of the way to the surface could have been expected. Cisterns are used to some extent, though in the main the people endure the poor water from the Porters Creek clay. It is surprising that no one has drilled through this into the Ripley, which at the farthest should be found at less than 200 feet from the surface.

At Newcastle the wells average 100 feet in depth.

At Pocahontas, elevation 394 feet, a water supply is obtained from wells that average 25 or 30 feet in depth. In the hills near by wells reach 100 feet or more in depth. The water is soft and comes from the Ripley sand.

At Rogers Springs the "soapstone" occurs near the surface. A little water of poor quality is obtained in its upper part about 35 to 40 feet from the surface. An exploratory hole 80 feet deep failed to find other water.

Saulsbury, elevation 534 feet, is situated on the thin eastern part of the Lagrange, which is capped on the higher levels by about 20 feet of Lafayette sand. Water is usually obtained in Lagrange sand at depths of 85 to 90 feet. Two miles south of town the Porters Creek clay is struck at 110 feet, and a mile west of town at 130 feet. Water was obtained in moderate quantities just above the clay.

At Toone, elevation 392 feet, water is obtained from wells and springs. Wells range from 20 to 100 feet in depth.

At Whiteville, elevation 500 feet, bored wells range in depth from 50 to 140 feet, most of them from 100 to 125 feet. The quality and quantity of the water are both good.

HARDIN COUNTY.

Topography.—Hardin County lies at the southeast corner of the area discussed in this paper, and is bounded on the south by Mississippi and Alabama. Its area is 587 square miles. Only a part of the county is within the embayment area, about two-thirds being east of Tennessee River. West of the Tennessee there are small areas of Paleozoic rocks where the river enters and leaves the county. The western part of the county slopes eastward and is drained by numerous small streams into the Tennessee. Along these streams the surface has been cut by erosion into hills. Away from the streams much of the surface is gently rolling. The highest portions are along the western boundary and average about 500 or 525 feet in elevation. The lowest point, about 350 feet, is at low water on the Tennessee where it leaves the county.

Geology.—The formations outcropping in this county are the Eutaw sand, Selma clay, and Lafayette.

The Eutaw sand lies immediately west of Tennessee River in the middle part of its course across the county and is well exposed at Coffee, Crump, and Pittsburg Landing. A section at Coffee Bluff is given on page 24. The Eutaw is found just beneath the Lafayette over all of the area except a narrow strip in the western and northwestern parts, which is underlain by the leaden-colored clays and shell marl of the Selma. Over both of these formations is spread a thin veneer of Lafayette, which is still intact on much of the upland surface, but has been removed on the stream slopes. It contains much chert gravel and is usually highly ferruginous.

Water resources.—Springs are numerous along the lower slopes of the hills. Those from the Selma clay are more or less impregnated with lime, while those from the Eutaw sand may be free from mineral matter or may contain iron and sulphur. Springs in the slight depressions occurring in the more elevated rolling portions of the county are from the base of the Lafayette and are apt to be weak. Streams are numerous but as a rule small. In the Eutaw area wells are usually open or bored, and vary from 30 to 70 feet in depth, the deeper ones being on the bluffs near the river. In the Selma area it is necessary either to bore through the clay 200 feet or more in order to reach good water in the underlying Eutaw sand or to stop in the Lafayette before the Selma is reached, provided the Lafayette is thick enough to reach below permanent ground-water level and furnish a supply. Cisterns are but little used.

At Crump water is obtained from some good strong springs and from numerous wells, averaging 50 to 70 feet in depth. The water at this depth comes from the upper part of the Eutaw formation and is abundant and good.

At Hamburg, in the Tennessee River Valley, water is obtained from shallow wells sunk in the alluvial deposits. The quality is fair to good.

At Hurley there are several springs that furnish chalybeate water and open wells 60 to 70 feet deep that furnish good water from the Eutaw sand.

At Morris Chapel soft water is obtained from the Eutaw formation by wells from 15 to 50 feet deep. The average depth is 40 to 45 feet.

At Pittsburg Landing, in the Shiloh National Park, wells pass through 10 feet of Lafayette surface clay, 15 to 20 feet of Lafayette gravel, partly cemented by iron, and into the Eutaw sand to a total depth of from 40 to 70 feet, where good pure water is obtained. From Pittsburg Landing westward for some miles open wells averaging 40 to 50 feet in depth and drawing from the Eutaw sand are the chief water supply.

HAYWOOD COUNTY.

Topography.—Haywood County is situated somewhat southwest of the center of the embayment area of western Tennessee. It is roughly quadrangular in shape, its northern boundary, however, being quite sinuous, partly because a portion of it is formed by South Fork of Forked Deer River. Its area is 520 square miles. The surface is a gently undulating plain with an average elevation of about 325 feet. Although the county is drained into the Mississippi by two northwestward-flowing streams—South Fork of Forked Deer River on the northern border and the Hatchee across the southern half—the general surface does not slope to the northwest, but instead falls gently north or south toward one or the other of these two streams. The divide between them is low and undulating and runs east and west, passing through Brownsville. Stream cutting is nowhere deep, for the stream slopes, and consequently stream velocities, are uniformly slight. Another consequence of the absence of abrupt ravines is that springs are rare and usually weak and worthless.

Geology.—The entire county is underlain by the Lagrange formation, which is reached in wells at depths rarely greater than 25 to 50 feet, but which seldom are exposed in natural cuttings, the stream valleys being so shallow. Over the Lagrange are 10 to 20 feet of Lafayette red sand or sandy clay, covered by 5 to 12 feet of light-colored loam that westward from Brownsville rapidly assumes a loess-like character, so that in a few miles it might very properly be called loess.

Water resources.—Springs are few and weak, and as a source of water supply are practically negligible. During dry weather they fail entirely. The numerous small streams that flow freely during the winter also go dry during the summer and autumn. Artificial ponds or deep wells are used for watering stock. The domestic supply is obtained from cisterns, ordinary wells, and deep wells, and the latter are rapidly coming into use also for industrial purposes. Most of the deep wells are of about 2-inch diameter, but vary considerably in depth. Perhaps a majority are between 80 and 150 feet deep, but some go 225 or 250 feet. The difference in depth is partly attributable to differences in surface elevation, those on hills going deeper than those on lower ground, and partly to differences in texture of the sands, which may make it necessary to go to considerable depths after water is reached before sand coarse enough to be checked by a strainer is found. All the wells are in Lagrange sand and, except where lignitic beds are encountered, furnish, as a rule, good, soft water.

At Belle Eagle water is obtained from springs and ordinary open wells, some of which reach 70 feet in depth.

Brownsville, on the divide between the two main drainage systems of the county, has an elevation of 344 feet. Previous to the introduction of a system of waterworks private wells and cisterns furnished the water supply. In the western part of town wells averaging 30 or 40 feet in depth gave good water and were exclusively used. In the eastern part of town wells are 80 feet deep, though water is not always obtained at that depth even, and the water is of only fair quality owing to mineral matter contained in it. In this part of town cisterns are largely used. Since the introduction of waterworks many have abandoned their wells and cisterns and use the town water. This is obtained from two wells 6 and 8 inches in diameter, respectively, each 230 feet deep. They were originally only 116 feet deep, but the sand at that depth was so fine that it entered through even the finest strainer slots and rapidly cut out the pump valves. By deepening to 230 feet coarser sand was found. The water is raised by air lift into a reservoir, whence it is forced either into a tank that gives a service pressure of 45 pounds, or directly into the mains under about three times this pressure for fire purposes. By the air lift 500,000 gallons per day can be pumped. The average daily consumption is 150,000 gallons. There are two pumps for forcing into the tank or mains of 500,000-gallon capacity each. The water is very good for general purposes and for boiler use, though it forms a small amount of hard scale. No log or analysis could be obtained. According to one statement it rises to within 30 feet of the surface; to another, 47½ feet. The latter is probably the more accurate.

The electric light and ice company has a well 130 feet deep, but the water foams in boilers and is used only for the ammonia condensers. Town water is used for the boilers.

Blackwell's lumber mill has a 2-inch well 138 feet deep that is used for supplying the boilers. The water rises to within 45 or 50 feet of the surface. The log, from memory, is as follows:

Log of well at Blackwell's lumber mill, Brownsville, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay (Lafayette and Columbia)	50	50
Sand	4	54
Clay, blue, tough	76	130
Sand, coarse, gray	8	138

Chester's Hardwood Lumber Company has a 3-inch well 109 feet deep, with the surface of the water at the same level as in the Blackwell well. Its log is as follows:

Log of well of Chester's Hardwood Lumber Company, Brownsville, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	15	15
Clay, blue	70	85
Sand, with some clay	15	100
Sand, coarse	9	109

The ground-water level is about 45 feet below the surface in these wells, and the largest element of uncertainty and the one on which the depth of the well in any given case here or elsewhere in town chiefly depends is the depth to sand coarse enough to be kept out of the strainers.

At Dancyville there are no springs of consequence. Wells are from 40 to 100 feet deep. Blue mud is often struck, and the water from it is poor, but when it can be obtained in the sand above the blue mud it is of better quality. Cisterns are largely used. Two miles west of town a 2-inch well was sunk through sand and clay 60 feet into a water-bearing sand that grew coarser to the bottom at 130 feet. The water is soft and is raised by a windmill.

At Eurekaton there are no springs or shallow wells except along the creek or river bottoms. Upland wells range from 75 to 125 feet in depth.

At Forked Deer there are only a few springs, and wells 40 or 50 feet deep yield very hard water. Good, soft water is obtained at depths of 100 or 150 feet in sand beneath blue clay. The log of Mr. J. W. Pearson's well is as follows:

Log of Pearson well, Forked Deer, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay (loess?)	40	40
Sand, water bearing (Lafayette)	5	45
Clay, blue	95	140
Sand, coarse, water bearing, entered	10	150

At Ged open wells are chiefly used and run 25 to 40 feet deep, getting water from about the base of the Lafayette, or close beneath it. The water is generally soft, though in some wells it is hard owing to the loess-like surface loam. A number of 2-inch wells have been sunk to 80 feet in sand that becomes coarser until at that depth a strainer can keep it out. Half a mile away Mr. Columbus Hinkle has on high ground a 2-inch well 247 feet deep. The water is soft, rises to within 60 feet of the surface, and is used for boiler purposes. The blue clay shown by the log is found over much of the county, and has in many places just above it a bed of lignite several feet thick. The log is as follows:

Log of Hinkle well, Ged, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand, variegated, mixed	60	60
Sand, fine, with water	18±	78±
Lignite	4	82
Clay, blue (to 240 feet from surface)	158±	240±
Sand, coarse, gray, water bearing (penetrated)	7	247±

Two miles east of Ged a well being driven for Mr. Jim Livingston had the following log:

Log of Livingston well near Ged, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay	20	20
Sand	30	50
Sand, quick	20	70
Lignite	4	74
Clay, blue	186	260
Sand, water bearing, thin, just entering	....	....

At Hanley there are no springs. Water is obtained from ordinary open and small pipe wells. It is generally good.

At Harvey there are a few small springs of no consequence. The water supply is from ordinary wells averaging 65 to 70 feet and deep or bored wells 100 to 125 feet deep. Water is good and soft.

At Jones, elevation 325 feet, an abundance of water rises nearly to the surface from a depth of about 75 feet.

At Keeling there are no springs. Wells, either open or small pipe, furnish soft water and range from 30 to 60 feet in depth. In one well 96 feet deep the water rises within 46 feet of the surface.

At Koho there are numerous springs and wells averaging in low places 20 feet deep.

At Rein, elevation 364 feet, water is obtained from dug or bored wells that range from 25 to 100 feet in depth.

Near Rudolph, in the edge of the Forked Deer bottom, a 2-inch well for the Hatchie Lumber Company passes through tough alluvial clay 32 feet, fine sand 5 feet, lignite 4 feet, blue clay 24 feet, coarse sand with soft water 5 feet.

At Stanton Depot, elevation 290 feet, water is obtained from small pipe wells that average about 140 feet in depth. The town well has the following log:

Log of town well at Stanton Depot, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay	40	40
Sand	4	44
Clay, blue	96	140
Sand rock, soft	$\frac{2}{3}$	$140\frac{2}{3}$

When the 8-inch indurated layer had been penetrated the water rose within 40 feet of the surface. No lignite was obtained in this well, but in the others less than a mile away it was found. A well less than 100 yards from the town well found no blue clay, but only sand with a small amount of clay. A dozen or more of these small deep wells have been made in the immediate neighborhood and they all present about the same features.

At Tibbs there are no springs. Wells average 35 feet in depth and perhaps a third of them furnish a scant supply of water.

At Wellwood there are both dug and bored wells that vary in depth from 12 to 96 feet. The water from the shallow wells is inclined to be hard, that from the deeper ones soft.

HENDERSON COUNTY.

Topography.—Henderson County is situated near the eastern margin of the area discussed and its northern boundary is about midway between Kentucky and Mississippi. The area is 515 square miles. The divide between Tennessee and Mississippi rivers crosses the county from north to south. The drainage of the western third goes to the Mississippi and that of the rest to Tennessee. The surface along this divide reaches an elevation of about 600 feet in a number of places, but along the streams it is considerably lower. The average elevation is about 500 feet. The lowest point in the county is probably where Beech River crosses the eastern boundary at an elevation close to 360 feet. South Fork of Forked Deer River, however, crosses the western boundary at only a few feet higher, and the Big Sandy crosses the northern boundary at slightly less than 400 feet. Big Sandy and Beech rivers and important branches of Forked Deer and Obion rivers all rise in the county and flow out radially. With their tributaries they have cut much of the surface into hills. Along the main divide and in much of the eastern slope the surface is very hilly. The streams have considerable fall and so have rapid currents and are actively eroding the surface.

Geology.—The formations found in this county include the Eutaw, Selma, Ripley, Porters Creek, Lagrange, and Lafayette.

The western edge of the Eutaw formation extends just slightly into the eastern part of the county. It dips to the west and passes beneath the other formations so that it underlies the entire county.

The Selma clay forms a belt 4 to 9 miles wide, extending north and south immediately west of the Eutaw outcrop. Its western edge is a few miles east of Lexington. The leaden and darker colored clays and marls characteristic of this formation are exposed in numerous railway cuts between Warrens Bluff and Darden.

The Ripley sands cross the center of the county from north to south in a belt 6 to 10 miles wide. They are distinguishable from the overlying Lafayette sands chiefly by their lighter color and their softer nature. Exposures occur in the deeper stream and railway cuttings.

A belt of typical leaden-gray Porters Creek clay, 3 to 5 miles wide, lies next west of the Ripley, and is succeeded in turn by the Lagrange, while over all the Lafayette is spread, as usual, in a thin veneer.

The exact thickness of no one of these formations in this county is known exactly. From the log of the Lexington well (p. 88) the Eutaw, the Selma clay, and perhaps half of the Ripley have an aggregate thickness of 500 feet, of which the upper 200 feet are probably Ripley. The Porters Creek must be not far from 100 feet thick. The Lafayette probably never reaches more than 20 or 30 feet.

Water resources.—There are many good springs among the hills that flow with undiminished volume the year round and feed the numerous streams, so that during summer they do not fail. Water for stock is obtainable almost everywhere, and some of the streams have fall and volume enough to furnish power for small mills. Where springs are not convenient for domestic purposes, water may be obtained at depths of 50 feet or less in many places, and only in rare cases is it necessary to go deeper than 100 or 125 feet. Water obtained from the Eutaw, Ripley, or Lagrange sands is, as a rule, good and soft, though it may have, especially if from the Eutaw, some iron or iron and sulphur. Water from either the Selma or the Porters Creek is almost certain to be hard and of deficient quantity. It may in addition be flat and insipid, and in some cases is foul smelling and entirely unfit for use. Neither of these formations is very thick in this county, and if one is struck before a supply of water is obtained it should be bored through—probably less than 100 feet additional—and the underlying sand tested. Water will almost certainly be obtained and will probably be of good quality and quantity. Cisterns are used to some extent in the area of the Selma clay and the Porters Creek clay and in other areas, where, because of the local elevation the depth to underground water is inconveniently great, say 75 or 100 feet or more.

At Atkins water is obtained from ordinary wells and an occasional spring.

At Crucifer, in the Lagrange area, there are only ordinary wells that range from 20 to 85 feet deep according to elevation. There are a few springs.

At Darden, elevation 392 feet, near the western edge of the Eutaw sand, some bold springs in low places flow from the Eutaw, but the chief supply of water is obtained from wells that range from 15 to 75 feet in depth. The water in the deeper wells is good and soft and rises somewhat in the well.

At Dolen weak flows are obtained from pipe wells in the Selma clay—there called simply "black dirt"—at ordinary depths. The water is hard and in some wells it also contains alkali or alum. Small pipe wells or even 6 to 12 inch bored wells should be sunk easily through the Selma clay and get good water from the underlying Eutaw sand.

At Farmville there are a few springs and numerous ordinary dug and bored wells, some of which are 80 feet deep. The water is soft, but the quantity is not always large.

At Hinson Springs, elevation 440 feet, there are several chalybeate springs flowing from the Ripley sands, that are discussed on page —.

At Huron, elevation 416 feet, there are a few springs and cisterns and wells from 30 to 60 feet deep that furnish soft water.

At Law, in the Lagrange sand area, wells furnish soft water from sand under pipe clay at an average depth of 50 or 60 feet, the range being from 20 to 85 feet.

Lexington, in the Ripley sand area, elevation 484 feet, has no system of waterworks, but depends on individual wells for its water supply. These wells average 50 or 60 feet in depth. Some on high ground are 80 feet deep. The quality of the water is good. No cisterns are used.

The Nashville, Chattanooga and St. Louis Railway finished in February, 1903, a well 700 feet deep that has not been a success. The driller gave the following log from memory:

Log of well of Nashville, Chattanooga and St. Louis Railway, Lexington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand, with shells of soft sand ironstone 6 or 8 inches thick scattered through it, and a little clay, water in all below first 50 or 60 feet (Lafayette and Ripley)	200	200
Clay, blue, with a little water-bearing sand and gravel at the bottom (Selma and Eutaw)	300	500
Limestone pure, no chert (penetrated)	200	700

At 700 feet the well was abandoned. At 675 feet water was struck that rose within about 80 feet of the surface, but the quantity was considered insufficient. The writer believes that with proper management this well would have been a success and yielded all the water needed by the railway. Either of two parts of the section gone through would have yielded a supply of water that would have risen within 75 or 100 feet of the surface. The elevation of Lexington and the nearness and elevation of outcrops of these two water-bearing beds to the east are such that there was no chance to get a flowing well. The driller was not familiar with drilling in soft strata, did not know how coarse sand had to be in order to be kept out by a strainer, and so passed through the Ripley sand without testing it. When the basal sand and conglomerate bed of the Eutaw beneath the blue clay was reached, it was found to be quicksand, and although the water rose probably within about 100 feet of the surface, sand also ran in rapidly, and the water was not tested, but the casing was driven down to the limestone below in order to shut it off. When this had been done practically all hope of getting a successful well had vanished. Had the conditions of drilling in sand and clay been more perfectly understood the well very probably would have been finished successfully, either in the Ripley sand, at a depth of 200 feet or less, or, at the farthest, in the coarse water-bearing sand and cobbles at the base of the Eutaw at 500 feet. The Ripley water would have certainly been a good boiler water, and very probably the Eutaw water would have been good also.

At Life, elevation 520 feet, there are some springs near the streams. Wells average 75 feet in depth, but some go to 100 or 120 feet.

At Long there are a number of ordinary wells 60 to 70 feet deep that yield a soft water of small quantity.

At McHaney water is obtained from springs and ordinary wells, all being freestone.

Middlefork is on the ridge dividing the Mississippi and the Tennessee drainages. It is in the Ripley sand area, in which good soft water is obtained, but the wells are mostly bored and have an average depth of 120 to 140 feet. In low places a few shallow dug wells are in use and good springs occur along the streams.

At Pipkin there are several wells from 10 to 40 feet in depth and a great many springs.

At Reagan poor water is obtained from the Selma clay by shallow open or deeper bored wells. Cisterns are largely used.

At Safford water is obtained from shallow wells.

At Spellings there are numerous springs and shallow wells.

At Whitefern there are numerous springs, some of which are chalybeate. Wells are generally used, however, for domestic supply. Water of good quality is abundant at depths of 18 to 30 feet.

At Wildersville, elevation 476 feet, in the Ripley sand area, freestone water is obtained from wells that average about 50 feet deep.

HENRY COUNTY.

Topography.—Henry County lies on the eastern edge of the area discussed. It is bounded by Kentucky on the north and by Big Sandy and Tennessee rivers on the east. The area is 625 square miles. The Tennessee-Mississippi divide crosses the middle of the county in a direction somewhat east of north. The surface along this divide is rough and broken. On the east it has a relatively steep slope toward Tennessee and Big Sandy rivers, but becomes somewhat less hilly, though stream activity on the Tennessee side is more marked than on the other side. West of the divide the general surface at first has a considerable slope, but soon flattens out into a nearly level plain that stretches westward to the Mississippi bluffs. The greatest elevation is slightly more than 600 feet, along the divide in the northwestern part of the county. The least elevation is about 300 or 305 feet, at the point where Tennessee River leaves the State. The average elevation of the county is about 500 feet, though some portions depart materially from this average. The drainage of the eastern slope is largely to the Big Sandy; that of the western into the headwaters of the various branches of the Obion.

Geology.—A strip a few miles wide along Big Sandy and Tennessee rivers on the eastern edge of the county belongs to the Paleozoic area, and is not considered here. West of this strip the county is underlain by the Ripley, Porters Creek, Lagrange, and Lafayette formations.

The Ripley sands overlie the Paleozoic limestones in a belt averaging 5 miles in width, which crosses the eastern part of the county from north to south and dips westward beneath the Porters Creek clay. The latter formation lies next west of the Ripley in a belt about 3 or 4 miles wide, also running north and south. Its western edge is at Paris, where it may be seen dipping westward and passing under the Lagrange, which underlies the remaining half of the county and has its usual character. Over all there is a deposit of 10 to 20 feet of Lafayette, chiefly a red sand, but with some small gravel at its base in places. There are also here and there above the typical Lafayette sand a few feet of light-colored, softer, sandy loam that may represent the Columbia.

Water resources.—In the Ripley area springs are numerous and strong, and furnish pure water. In the Lagrange area they are of the same character, but somewhat less numerous, because surface erosion has not produced as great diversity of relief there as in the Ripley area. In the Porters Creek clay belt they are scarce, weak, and poor as a rule. The streams are numerous and usually have a permanent flow. Many of them have sufficient volume and fall to furnish power for mills. Underground water of good quality is available at moderate depths anywhere within the embayment part of the county. In the western half it may be obtained from the Lagrange sands at depths rarely exceeding 100 to 150 feet. In the Porters Creek clay belt or just west of it, on the thin eastern edge of the Lagrange, good water may be had from the underlying Ripley by going through the Porters Creek, as has been done in the town wells at Paris. In such wells the water will rise part way to the surface. In the Porters Creek area, where the surface water is poor, and in elevated parts of the Lagrange and Ripley areas, where the distance to underground water is several score feet, cisterns are much used.

At Buchanan soft water is obtained from the Ripley at depths of 75 to 80 feet.

At Como, in the Lagrange area, there are no springs. Dug and small bored wells are used.

At Cottage Grove, in the Lagrange area, soft water is struck at depths of 75 to 100 feet. About half the people use cisterns.

At Eastwood, near the contact between the Porters Creek clay and the Lagrange sands, there are some springs of good water, but wells drilled 80 or 90 feet deep get hard iron and sulphur water from the Porters Creek clay, or "soapstone." They should be drilled somewhat deeper, to the Ripley sand.

At Freeland the Ripley sand is the surface formation. Soft water is obtained from springs and from open and bored wells of an average depth of about 40 feet.

At Hastings, in the Lagrange area, there are springs and ordinary and bored wells 30 or 40 feet in depth. The water is soft.

At Mansfield, elevation 448 feet, in the Ripley area, soft water is obtained from shallow open and bored wells.

At Mountvista, in the Ripley area, soft water is struck at depths of 60 to 80 feet. Wells are open or bored.

At Nobles wells are from 40 to 70 feet deep. The water in the shallower wells seems to be hard and in the deeper ones soft. No records of strata encountered were obtained, but possibly the shallower are in the Porters Creek clay and the deeper in the Ripley sand.

At Osage soft water is obtained from the Lagrange sand at depths of 100 to 150 feet. Cisterns are used generally.

At Owens Hill, in the Ripley area, soft water is obtained at a depth of 16 feet in low places and of 75 or 80 feet on the upland level.

Paris, elevation at Nashville, Chattanooga and St. Louis depot 512 feet, at Louisville and Nashville depot 474 feet, is on the eastern edge of the Lagrange. The Porters Creek clay is exposed in the deeper cuttings. There are a few cisterns in use, and ordinary wells get water from near the base of the Lagrange at an average depth of 30 to 60 feet. A large spring near town is reported to flow 300,000 gallons per day. The city waterworks has two wells, one 8 and the other 6 inches in diameter, each 376 feet deep. The elevation of the well heads is 470 feet and water stands 70 feet below the top. Water is raised by air lift into a surface cistern, from which it is forced into a steel tank of 70,000 gallons capacity, that gives a service pressure of 35 pounds. For fire purposes a direct pressure of 100 pounds, or more if necessary, is used. The capacity of the pumps is 500,000 gallons per day; the average daily consumption, 150,000 gallons. The water is perfectly clear, and is good for all purposes. After standing, a slight red ferruginous deposit forms and discolors vessels. The following analysis was reported by the St. Louis Sampling and Testing Works May 14, 1902:

Analysis of water from well at city waterworks, Paris, Tenn.

	Parts per million.
Silica (SiO_2)	3.6
Oxides of aluminum and iron ($Al_2O_3+Fe_2O_3$)	9.2
Calcium (Ca)	5.7
Magnesium (Mg)	3.4
Sodium (Na)	1.5
Carbonate radicle (CO_3)	9.6
Sulphate radicle (SO_4)	8.9
Chlorine (Cl)	4.4
	46.3
Volatile solids	14.4
Fixed solids	44.0
Total solids	58.4

At Peryear, elevation 612 feet, in the Lagrange sand area, soft water is obtained at depths of 100 or 115 feet.

Routon, elevation 575 feet, is in the Lagrange area. Small bored wells are commonly used, ranging from 60 to 90 feet in depth, and furnishing a moderate amount of soft water of fine quality.

At Vandyck, elevation 416 feet, on the eastern edge of the Porters Creek clay, wells average about 40 feet in depth. One, 87 feet deep, is a blowing well whenever the weather is changing. The springs are described as being weak and impregnated with sulphur, iron, and alum. They very probably flow from the Porters Creek formation.

LAKE COUNTY.

Topography.—Lake County is situated in the northwest corner of Tennessee. It lies between Reelfoot Lake on the east and Mississippi River on the west. Its length, north and south, is about 35 miles. Its width, east and west, varies from 3 to 12 miles. It is one of the smallest counties in the State, the area being 128 square miles. The entire county is situated in the alluvial region of the Mississippi and the surface is very level, with neither hills nor ravines. The county is so low that about two-fifths of the surface is overflowed at high water. The average elevation is about 300 feet. The general surface slope is southward, in conformity with the river slope, the elevation being about 315 feet on the northern line and 290 on the southern.

Geology.—The surface formation is everywhere the alluvium of the Mississippi flood plain. The geologic relation and age of this alluvium have been discussed somewhat fully on page 48, and need not be treated here. From the records of the few borings that have penetrated the alluvium, it would seem to be from 100 to 150 feet deep. Beneath it lies the Lagrange, but so far as known it has not been explored by deep borings in this county.

Water resources.—There are no streams in the county except the sloughs from the river or Reelfoot Lake. Ponds are easily made for watering stock, and cisterns and shallow wells are used for domestic supply. The well water is of the usual unsatisfactory alluvial-region type, and is obtained at depths of 20 to 35 feet.

At Hathaway water is obtained from Mississippi River and from wells that average 35 feet in depth. The water in the wells rises and falls with the river.

At Keefe shallow pumped wells are used.

At Madie hard water is obtained from open and pumped wells that average 25 or 30 feet in depth.

At Ridgeley water is obtained by pumping from driven wells about 25 feet in depth. The water is hard, and contains iron sulphate or copperas.

LAUDERDALE COUNTY.

Topography.—Lauderdale County is bounded by Mississippi River on the west and lies midway between the northern and southern boundaries of Tennessee. Its area is 460 square miles. The western half of the county and a narrow area along Hatchee River on the southern boundary belong to the alluvial plain of the Mississippi and its tributaries, and so are low and level, in part swampy. The remainder of the county rises from the flood-plain level, usually by abrupt bluffs, to a general elevation of about 350 feet. The edges of the upland or plateau surface adjacent to the alluvial region are deeply cut by streams, and the resulting hills are steep and bold. Elsewhere the plateau surface is level or gently rolling. Along the principal streams a second bottom or terrace is usually developed, rising 10 to 20 feet above the present flood plain, and reaching in places a width of several miles. The drainage all passes through the Forked Deer and the Hatchee to the Mississippi.

Geology.—The formations represented in the county are the Lagrange, Lafayette, loess, and alluvium.

The Lagrange is rarely exposed except along the lower parts of the steep bluffs and in occasional deep railway cuts, as at Ripley (see p. 43) and Curve. The section in the long, deep cut just south of the station at Curve shows at the base 15 to 18 feet of a dark-blue lignitic clay bedded in very thin layers and somewhat sandy. Over it lie 6 to 9 feet of a yellow to rusty-yellow purer clay, also lignitic, covered by 25 feet of Lafayette sand and gravel. The gravel is well rounded chert and vein quartz, averaging 1 inch or less in diameter, but with occasional pebbles reaching 2 or 3 inches. The gravel is in irregular streaks throughout the formation and composes about 20 per cent of it. The sand is coarse and red and is case-hardened, so that it stands with vertical faces. Over it is a variable layer of soft, light-colored sand and gravel up to 3 feet thick. This grades up into 25 feet of loess, which seems hardly separable into a lower and an upper division, though the lower 5 or 6 feet are darker than the remainder. Beneath the dark Lagrange clay in the bottom of the cut is a quicksand, on which the track rests, and which is a perpetual source of trouble and expense to the railway. A view of the section in the cut is given in Pl. IV, *A*, p. 44.

The Lafayette in Lauderdale County is a coarse sand, with a considerable proportion of pebbles as a result of the nearness of Mississippi River. It overlies the Lagrange everywhere except in the alluvial region, where it has been removed by stream erosion. It is exposed in only a few places, being, as a rule, overlain and concealed by the loess, which varies from 1 foot to several score feet in thickness. The loess mantles the uplands and seems to extend down over the second bottoms along the main streams, though the observations of the writer were not full enough to settle this last point definitely.

Water resources.—There are many streams in the county, so that it is generally well watered. For domestic purposes cisterns have long been widely used, because of the hardness of the water from shallow wells, which almost invariably stop in the lower part of the loess. Such wells are, however, used in many places despite the hardness of the water. Water that is generally, though not invariably, soft and good may be had usually at depths of 100 to 300 feet, the depth varying chiefly with the texture of the sand, though in some cases it is determined by the occurrence of sandy clay beds, which in this region are generally lignitic and furnish a poor quality and small quantity of water. The wells may go down several hundred feet in exceptional instances, as at Ripley, for example. At the foot of the steeper bluffs springs occur, but the water is usually hard and has an unpalatable taste, commonly described as "sweet."

The shallow water in the alluvial region is always poor, and brick cisterns are difficult to keep from cracking because of the soft, yielding nature of the alluvial deposits. It would seem that in this region cisterns should be built of cypress, but so far as known this wood has never been used for that purpose.

At Arp water is obtained from springs at the foot of the hills and from dug and bored wells 20 to 30 feet deep. The hills rise perhaps 75 feet high and on the top of one a well was bored 208 feet and abandoned without getting water. Some water was found in the base of the Lafayette, but the quantity was thought insufficient. The following is the log:

Log of well at Arp, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay (loess)	50	50
Sand and gravel (Lafayette)	34	84
Blue sandy loam and streaks of lignite	66	150
Blue sandy clay (penetrated)	58	208

At Ashport, on the Mississippi, a number of small tubular wells about 50 feet deep yield hard water. They go through about 8 feet of surface loam into sand mixed with some gravel, which soon becomes water bearing. At 30 feet from the surface this gives place to a coarse blue sand that runs to 52 feet and is underlain by gravel, which was not explored.

At Bexar a well drilled 135 feet deep got a good supply of water that rose about 15 feet in the pipe. The log was as follows:

Log of well at Bexar, Tenn.

	Thickness.	Depth.
	Feet	*Feet.*
Yellow clay (loess)	35	35
Sand and gravel (Lafayette)	4	39
Sand, white, coarse, with a little gravel	12	51
Gravel	8	59
Sand, white, with a number of 3 or 4 foot layers of gravel in it	42	101
Sand, water bearing, but without pressure	19	120
Gravel	10	130
Clay, blue	$\frac{1}{3}$	$130\frac{1}{3}$
Sand, white, with water, which rises about 15 feet	4	$134\frac{1}{3}$
Clay	Streak.	....
Gravel (not explored).		

At Double Bridges both wells and cisterns are used. Wells vary from 20 to 100 feet deep and many of them are bored. Quicksand occasionally interferes with borings. The quality of the water is usually fair to good.

At Dry Hill cisterns are generally used. Wells on the hills obtain soft water at depths of 100 feet or more.

At Edith, on the edge of the bluff overlooking the Mississippi flood plain, cisterns are used almost exclusively. Water from shallow wells is hard and sweet. It is also found at about 150 feet, and there are three deep wells 2 or 3 inches in diameter and 165 feet deep. Two are at mills, and are pumped by steam. The other is pumped by hand. They furnish an abundant supply of water, said to be alkaline and to have a diuretic effect. The log is as follows:

Log of deep wells at Edith, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay (loess)	80	80
Sand and gravel, red, in alternate layers each 3 to 4 feet thick (Lafayette)	20	100
Sand in yellow and white streaks, dry	50	150
Sand, same, water bearing	15	165

At Fulton cisterns are used almost entirely. There are one or two wells about 75 feet deep, but the water is hard.

At Gates, elevation 321 feet, water is obtained from both cisterns and shallow wells that average 30 to 45 feet in depth and furnish hard water. A well drilled 114 feet gave the following log:

Log of deep well at Gates, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	8	8
Blue mud	15	23
Clay, blue, stiff	15	38
Sand and gravel	10	48
Blue mud	52	100
Sand, with water rising within 30 feet of the surface	14	114

At Glimp water is obtained from cisterns and common wells 25 to 50 feet deep.

At Halespoint, on the Mississippi flood plain, there are only shallow wells that yield the usual poor flood-plain water.

At Halls, elevation 312 feet, water is obtained from cisterns and from a few wells drilled to about 160 feet, where a water-bearing sand is found. There is pressure enough to raise the water within 30 feet of the surface.

At Henning, elevation 292 feet, hard water is obtained from dug wells that average about 40 feet deep.

At Mack water is struck at depths of about 20 feet and 80 or 90 feet. Water from the latter depth rises about 25 feet. All of the water is hard, and that from the deeper wells contains some iron.

At Ripley, elevation 390 feet, there were formerly many wells that averaged about 85 feet deep, some of which gave soft water, while others gave hard. Cisterns have since been almost entirely substituted for them. Around the foot of the bluffs near town are numerous springs, most of which yield hard water. The town system of waterworks is supplied by three wells about 10 feet apart, two being 6-inch, the other 4-inch, and each being 100 feet deep. The water is hard and produces a hard scale when used in boilers. It stands at 65 feet from the surface, and the wells yield 150,000 gallons a day.

At Tams Landing, on Mississippi River, a mile below Halespoint, there are alternating beds of sand and gravel that have been explored to a depth of 84 feet. Hard water is struck at 21 feet.

MADISON COUNTY.

Topography.—Madison County lies just south of the center of the embayment area of Tennessee and has an area of 545 square miles. The county belongs to the Mississippi drainage basin and so slopes slightly to the west or northwest. The surface in the eastern, southeastern, and southern parts of the county is considerably broken. The central part of the county is rolling, and the western, northwestern, and northern parts are more nearly level. On the ridges between the main streams the surface rises to an elevation of about 500 feet and, while there is considerable difference in relief between various parts of the county, the average elevation is about 450 feet. The highest points are in the southeastern part of the county and are between 500 and 550 feet. The lowest point is about 315 feet, where South Fork of Forked Deer River leaves the county.

Geology.—The formations of the county are the Porters Creek, the Lagrange, and the Lafayette.

The Porters Creek clay occurs along the southeastern edge of the county, south of the point where the Nashville, Chattanooga and St. Louis Railway enters it. This clay outcrops in a belt from 4 to 6

ARTESIAN WELL AT JACKSON, TENN.

miles wide, of which only the western half lies within the county. The Lagrange succeeds it to the west and underlies all the rest of the county, but is largely concealed by the red or orange sands of the Lafayette, which averages about 20 feet in thickness and forms the surface except where removed by stream erosion.

Water resources.—The streams of the county are numerous and the longer ones flow perennially. Many of the smaller streams become very low and sluggish or go dry altogether during late summer and fall. In localities where streams fail ponds are provided for watering stock. Springs occur along the foot of the hills and are used to some extent, but the principal water supply comes from wells in the base of the Lafayette or the top of the Lagrange sands. This water is freestone, but in the small Porters Creek area in the southeastern part of the county the water is poor and hard when the well is made in the dark clay of this formation. Water of good quality and quantity should be obtained in deep wells anywhere in the county. In the western part it would come from the Lagrange sands. In the eastern part, within the Lagrange area, it might still in many places be obtained from the base of the Lagrange at depths of 100 to 150 feet, or from the Ripley sands beneath the Porters Creek clay at depths of 150 to 200 feet additional. It seems most probable that the deep well at Jackson (see p. 98; also Pl. V) ends in the Ripley sand. Such an interpretation would make the Ripley include in the Jackson section a clay bed containing shark's teeth, but this formation is nowhere in surface exposure in Tennessee known to contain such a bed. Marine fossils occur in it in Mississippi, however, only a short distance south of the Tennessee line. One alternative supposition, that the 72 feet of fossiliferous dark lead-colored clay is Porters Creek, gives that formation an abnormal thickness of 288 feet. The other alternative supposition, that this bed represents the Selma clay, makes that formation only 72 feet thick and the Ripley sand above it only 41 feet thick—both of which would be abnormally thin, the Ripley especially so.[a]

At Andrews Chapel water is obtained from wells that run usually from 50 to 60 feet deep, but are exceptionally 100 feet deep.

At Beechbluff, elevation 396 feet, water is obtained from springs and from wells of 20 or 30 feet depth. Much of the water contains iron and sulphur.

At Carroll, elevation 369 feet, wells average 18 to 40 feet deep; in

[a] Since the above was put in type the writer has had an opportunity to examine a partial set of borings from the Jackson deep well and also some notes made while drilling was in progress. From these it seems that the base of the Lagrange is at 157 feet depth; the Porters Creek extends from 157 to 335 feet; the Ripley sand from 335, probably to 405, feet; the Selma clay probably from 405 to 499½ feet, and the Eutaw from there down. There is some uncertainty as to the upper and lower limits of the Selma clay, but the section from 405 to 438 feet seems without doubt to belong to it. This will modify and explain somewhat the section of this well given on page 98. The well shows an electric current of about half a volt.

the surrounding country they are from 40 to 150 feet deep. The water is soft. In some cases the quantity is reported as insufficient.

At Catalpa there are some springs and good water is obtained from wells that range from 20 to 60 feet in depth.

At Claybrook soft water is procured from wells that average 60 feet in depth.

At Hatchie, elevation 328 feet, soft water is obtained from pumps and open wells ranging from 15 to 40 feet in depth.

At Jackson the elevation of the ground at the crossing of the Illinois Central and the Mobile and Ohio railroads is reported to be 425 feet, of the mark at the Federal building 394 feet, and of the Nashville, Chattanooga and St. Louis depot 340 feet, though this last figure would seem to be too low. Water is obtained in shallow wells at a depth of 30 to 50 feet, depending on the surface elevation. A battery of 22 wells of the city water company drew 1,000,000 gallons daily at a depth of 40 feet, while another group of 18 of these wells now yields about 2,500,000 gallons daily from a second water-bearing sand at a depth of about 100 feet. The pores of the sand become clogged after a time and are flushed out by forcing a current backward into it. The shallower wells yield water that forms a coating of oxide of iron in the pipes. The water from the deep well already mentioned dissolves and loosens up this deposit so that it comes out in small particles and makes the water for the moment a blood-red color. The deep-well water on standing some hours gives off CO_2 and becomes opalescent while a flocculent precipitate of iron is forming. This iron soon settles and leaves the water once more clear. The wells in the water-bearing stratum at 90 to 100 feet below the surface have a galvanic current of one-fourth to one-half volt, due probably to the corrosion of the copper in the strainer by the sulphuric acid resulting from the decomposition of the iron pyrite. Lead pipes, if grounded by a copper wire, are eaten up by electrolysis in about eighteen months. The log of the deep well is as follows:

Log of deep well at Jackson, Tenn. [a]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, sandy, red (Lafayette)	12	12
Clay, tough, blue	16	28
Sand, coarse white	12	40
Clay, snow white, very tough	6	46
Sand, nearly pure white, some small gravel and thin ironstone crusts, water bearing at base	60	106
Clay, at top light colored, lower part variegated red, yellow, etc	43	149
Sandstone, dark brick-red, soft (base of Lagrange)	11	160
Clay, fine, leaden-colored (Porters Creek)	170	330
Rock, dark, hard (limestone?) (base of Porters Creek)	5	335
Sand, white, with water	13	348
Quicksand, white, very micaceous	28	376
Shales, dark leaden-colored, with hard streaks of micaceous sandy material, lignite fragments, and iron pyrite. At about 418 feet shark's teeth	72	448
Sand, white, water bearing	77	525
Hard material (not entered).		

[a] See, however, footnote on page 97.

At Leighton water is obtained from ordinary wells and from a 2-inch driven well that penetrated coarse sand to a depth of 75 feet, where the underground-water level was reached. The sand grew coarser to 120 feet, at which depth the well was finished.

At Malesus, elevation 453 feet, water is obtained from wells that average about 60 feet in depth, but range from 40 to 100 feet.

At Mercer, elevation 344 feet, water is obtained from a creek, from springs, and from wells ranging from 25 to 100 feet in depth, with an average of 40 feet.

At Neelys, elevation 504 feet, water is obtained at depths that range from 60 to 150 feet, the deeper wells being much more reliable. Pools are used for stock water.

At Norwood, elevation 448 feet, water is obtained at depths of about 80 to 100 feet. Pools are used for watering stock.

At Rollins bored wells about 100 feet deep are generally used.

At Springcreek there are small tubular and bored wells that range from 70 to 100 feet in depth.

M'NAIRY COUNTY.

Topography.—McNairy County is situated in the southeastern part of the embayment area in Tennessee. Its eastern edge almost reaches the Paleozoic rocks. Its southern boundary forms part of the Tennessee-Mississippi line. The area is 570 square miles. The eastern half of the county is crossed from north to south by the divide between Tennessee and Mississippi rivers, so that two-thirds of the county slopes westward and one-third eastward. The lowest point in this dividing ridge is at the head of Lick Creek, on the southern edge of the county, where the elevation is 520 feet. Just northeast of Purdy the ridge is about 600 feet high. The lowest point in the county is at about 345 or 350 feet elevation, where Rose Creek crosses its western boundary. The plateau surface of the county averages between 450 and 500 feet in height. The main divide north of Purdy is hilly. The eastern and southeastern parts are more nearly level. The southwestern and western parts, near the Hatchee and its tributaries, are broken and hilly.

Geology.—The formations of the county are the Eutaw, the Selma, the Ripley, the Porters Creek, and the Lafayette.

The Eutaw sand is found at the surface only in a small area in the southeast corner of the county, but as it dips westward it underlies all the other formations.

The Selma clay has a greater development, both in area and in thickness, in this county than elsewhere in Tennessee. The thickness varies from 350 feet in the southern part of the county to about 300 feet in the northern part. The width of the belt decreases from about 10 miles in the southern part to 5 miles in the northern part. Over much of this belt the Lafayette, which once covered it entirely, has been removed by erosion, leaving the bare leaden-colored clay, greensand, and fossil shells exposed at the surface in areas many of which are of considerable extent.

The next formation to the west is the Ripley. It occupies all of the county west of the Selma clay belt except a few square miles of Porters Creek clay in the extreme northwest corner. The Ripley forms a prominent ridge that enters the State from Mississippi and extends a number of miles northward before it dies down and merges with the general plateau surface. A discussion of the origin of this ridge, as well as the section at the point where it is cut through by the Southern Railway in the "big cut" just west of Cypress, are given on page 29.

Water resources.—Numerous springs from the sands of the Eutaw and the Ripley flow the year round and feed streams that water every part of the county. From the high divide northeast of Purdy streams flow radially in almost all directions. Water from the Eutaw and Ripley, whether obtained by springs or by wells, is soft and generally free or almost free from iron and sulphur. Water from the dark clays of the Selma and Porters Creek is generally poor. For years it has been the custom in the Selma area to bore 6 or 8 inch wells 200 to 300 feet through the clay into the underlying Eutaw sand, the water in which rises in many cases nearly to the surface. In some places in these areas of poor water cisterns have been used, though not to so great an extent as in the tier of loess counties adjoining the Mississippi. Occasionally a pond for stock watering is found. Wells range from 20 to 70 feet in depth except in the Selma clay, where they may be from 200 to 300 feet deep.

Adamsville is on a plain or table-land between two creek valleys. The joint clay of the Selma reaches practically to the surface in some places; in others it is covered by 20 to 25 feet of Lafayette. Wells average 16 to 20 feet in depth and give soft or hard water according as they are in the Lafayette or the Selma.

At Acton water is obtained from ordinary open wells 30 or 40 feet deep. A number of springs yield iron and sulphur water that is used locally for medicinal purposes.

At Bethel Springs, elevation 459 feet, there are springs and numerous wells that average 30 feet deep but range from 20 to 40 feet. The water is impregnated with iron and sulphur.

At Caffey there are no springs; water is obtained from ordinary wells that have an average depth of only about 15 feet.

At Gravehill water is obtained chiefly from bored wells that go through the Selma clay and are between 200 and 300 feet deep.

At Leapwood, near the junction of the Ripley and the Selma, there are several large springs, some shallow wells, and a small well 360 feet deep.

At McNairy, elevation 449 feet, there are some springs and numerous wells that average about 35 feet deep. The water is soft and in many wells contains sulphur.

At Michie there are shallow open wells and good springs.

At Purdy, on the Mississippi-Tennessee divide, which is here a narrow plateau, many springs flow from the base of hills on either side. In the town, wells in the base of the Lafayette average about 30 feet deep, while those that enter the Selma clay go 200 féet or more before reaching the Eutaw sand.

At Selmer, elevation 460 feet, the supply is obtained chiefly from wells 20 to 80 feet deep. There are a few cisterns, and one well, 416 feet deep, gets water from the Eutaw sand. The casing goes down only about 50 or 60 feet. The water rises to within 30 feet of the surface and is slightly hard. The log is as follows:

Log of well at Selmer, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay (Lafayette)	25	25
Clay, blue (Selma)	375	400
Sand, water-bearing (Eutaw) (entered)	16	416

At Stantonville the Lafayette is 35 to 40 feet thick, and has at the base several feet of rounded chert gravel in which water is abundant. Beneath it is the Eutaw sand, but this is somewhat quick and tends to fill up a well. A mile or less to the west the Selma clay is struck, and wells are bored 80 to 250 feet through it into the Eutaw sand below. The water rises in some places nearly to the top.

OBION COUNTY.

Topography.—Obion County is in the northwestern part of Tennessee. Its northern boundary is the State line, and its western boundary is the western shore of Reelfoot Lake. A part of the eastern boundary is formed by branches of Obion River. The area is 505 square miles. A narrow belt along the eastern shore of Reelfoot Lake and a belt for the most part several miles wide along Obion River are low and level and subject to overflow. On either side of this swamp belt of the Obion there is a level bench or second bottom 15 to 25 feet higher than the first bottom and, as a rule, several miles wide. The remainder of the county is more elevated and forms a part of the general upland or so-called plateau slope of western Tennessee. Its surface varies from rolling to abruptly hilly, especially along the western border, where the region is known as the lake hills. The lowest part of the county is the surface of Reelfoot Lake and the swamps bordering it. These have an elevation of about 260 or 270 feet. The highest point is probably in the northern part of the county near the Mobile and Ohio Railroad, where the elevation is slightly over 400 feet. The average elevation of the upland is about 350 or 375 feet.

Geology.—The geologic formations of the county are the Lagrange, Lafayette, loess, and alluvium.

The Lagrange underlies the entire county, but is concealed, except here and there along the base and lower slopes of the lake hills, by one or more of the other formations, all of which are merely surficial. Drill records and an examination of the near-by exposures at Hickman, Ky., indicate that the Lagrange contains rather more clayey material in this region than in its type region in Fayette County. Water-bearing sands are, however, found in it, and wells are generally successful.

The Lafayette is found on the uplands only, and is 20 to 30 feet thick. The upper part is, as a rule, orange or yellow sand, while the lower part consists of well-rounded chert gravel. In some places the gravel and sand are interbedded. The gravel is more abundant near the river.

The loess mantles the Lafayette on the uplands and laps down over the second bottoms, where it lies directly upon the Lagrange. It has its usual character and is 20 to 80 feet thick in the central and western parts of the county, but thins out in the eastern part and practically disappears by merging into a surface loam a few feet thick, which is everywhere revealed in railway and other cuttings overlying the Lafayette.

The alluvium is confined to the Obion and Reelfoot swamps.

Water resources.—Along the sides of the stream valleys and among the hills springs are frequently found. Those in the swamps are sweet and many others are hard or contain iron and sulphur, so that, as a rule, they are not a valuable source of water supply. The springs feed numerous streams that during winter furnish water for stock in nearly all parts of the county, but during the summer all except the main branches of Obion River shrink away to a series of pools or go entirely dry. Ponds must then be relied on for stock watering. Wells generally reach water at comparatively shallow depths, usually in the Lafayette sand and gravel, but in the loess region this water is commonly hard. Deeper wells have been drilled in a number of places and get water from the Lagrange. In the loess region cisterns are largely used on the uplands, but on the second bottoms the loess or clay is so soft that it is often hard to keep the cistern from settling and cracking so as to let the surface water seep in, and in such places wells are used.

At Crockett, elevation 290 feet, there are small shallow wells and a number of springs.

At Elbridge there are only ordinary shallow wells and a few springs.

At Glass wells are usually 20 to 40 feet deep, and soft. One on the river bottom is 96 feet deep, striking water at 90 feet that rose within 20 feet of the surface.

At Gratis and Guelph water is obtained from ordinary shallow wells and springs.

At Kenton, elevation 309 feet, wells on the hills generally yield fine water. Those on the bottoms are not so good and may fill almost full during wet weather. Along the bottoms are springs, most of which are impregnated with iron or iron and sulphur. The water in some of the wells is hard because of the loess; in others below this formation it is soft.

At Masonhall the wells range from 30 to 65 feet in depth. The shallower wells are in loess, and the water rises and falls with the seasons. The deeper ones are in the Lafayette sand. There are numerous springs.

At McConnell, elevation 354 feet, good water is struck at a depth of 30 to 40 feet.

Minnick is in the loess area, and has but few wells or springs. Cisterns are almost universally used. A 3-inch well started in a ravine on Lafayette sand and gravel, which it passed through at 50 feet and entered blue clay; this continued to a depth of 280 feet, and contained, at intervals of 10 or 15 feet, hardpans or indurated beds, slightly gritty, that averaged about a foot each in thickness. At 280 feet the blue clay changed to a gray clay, in which the indurated layers occurred at about 5-foot intervals. In this material, at a depth of 300 feet, the well was abandoned.

At Moriah water is obtained from springs and wells, some of the latter being 40 to 50 feet deep.

At Obion, elevation 289 feet, there are some shallow surface wells. Good water is obtained from sand at a depth of about 80 feet. It is generally soft and abundant.

At Polk, elevation 330 feet, there are no springs, wells and cisterns being used. The wells are generally hard and average about 30 feet deep. A few are 40 or 50 feet deep.

At Rives, elevation 295 feet, there are a few cisterns, but the black clay loam in which they are dug is not firm enough to keep them from cracking. Shallow wells with water of only fair quality are the chief source of supply. These average about 32 to 35 feet in depth. In wet weather they fill up with water. A deep well drilled for the Illinois Central Railroad had the following log:

Log of Illinois Central Railroad well at Rives, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay, dark, loamy	40	40
Sand, water bearing	20	60
Clay, blue "gumbo"	82	142
Sand coarse white, water bearing	18	160
Silty or bastard sand, very fine grained, with sticky blue clay in places (entered)	540	700

No water supply having been found below 160 feet, the pipe was pulled back and the well made at that depth. The water rises within 10 feet of the surface. The diameter of the well is 10 inches and 150,000 gallons a day are pumped for locomotive use.

In the hills west of Rives, which is on the broad second bottom or terrace, wells average 70 to 80 feet in depth. Cisterns are largely used.

At Samburg, at the foot of the lake bluff, water is obtained from numerous springs that flow from the bluff. Wells are very shallow and the water poor.

At Spout Spring there are some springs and ordinary wells, but cisterns are more commonly used than anything else.

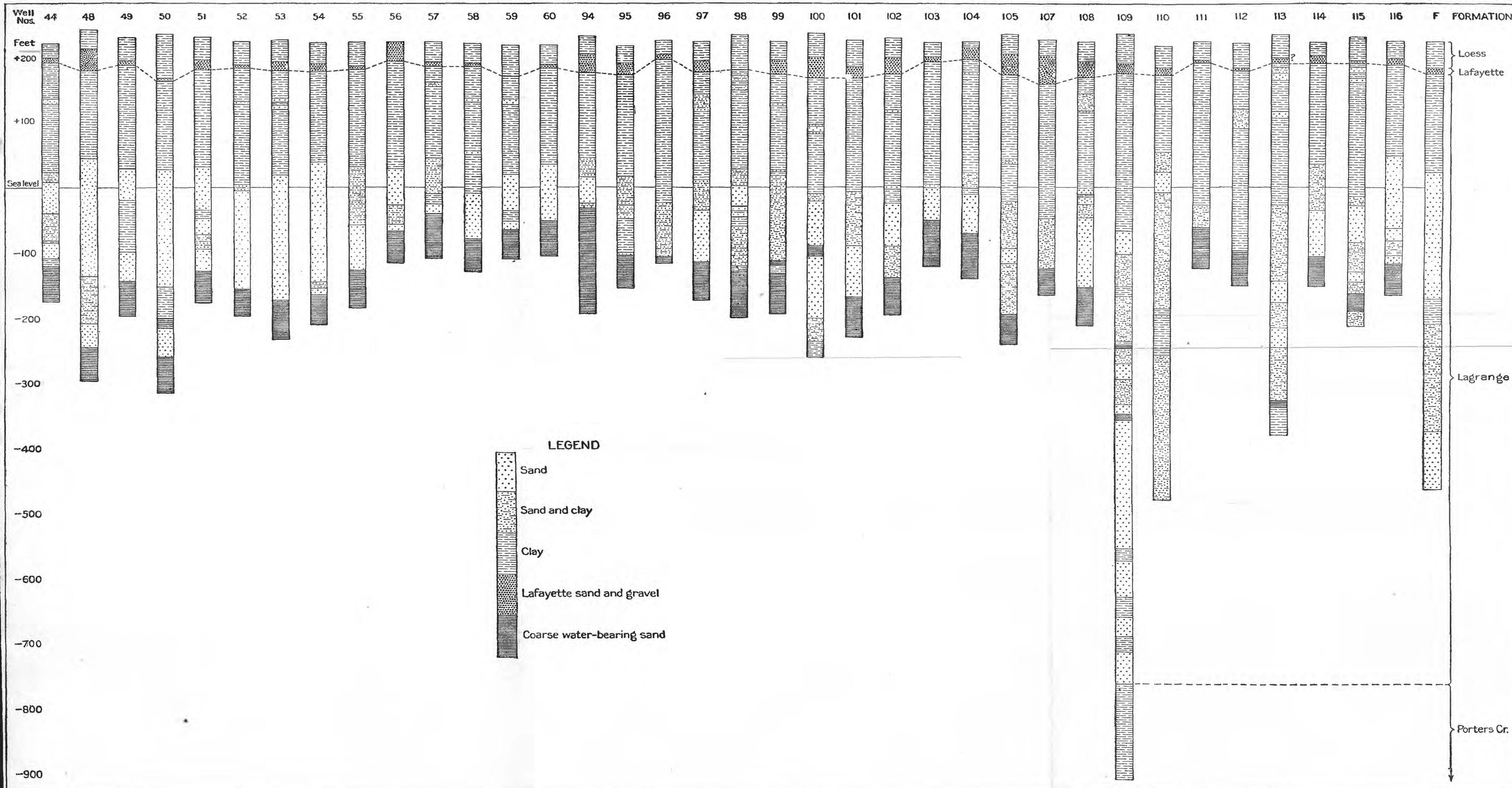
At Troy wells average about 25 feet in depth and furnish hard water.

At Union City, elevation 328 feet, water is obtained from open wells that average about 25 feet deep. Small tube wells are from 150 to 200 feet deep. The town waterworks has two 8-inch wells, each 150 feet deep, that pump 240,000 gallons per day. Each has 40-foot Cook strainers. The water rises within 35 feet of the surface. It is slightly hard, but does not form a scale. The ice company has an 8-inch well 125 feet deep, with a 30-foot Cook strainer. The water rises within 28 feet of the surface. It forms a little soft scale that is easily blown out of the boilers. The waterworks has since finished a 535-foot well, but no record could be obtained either of it or of the shallower wells. The health of the town is said to be greatly improved since deep water began to be used. Fevers, both malarial and typhoid, have decreased 50 per cent or more.

At Woodland Mills the domestic supply is obtained from dug wells of from 20 to 45 feet depth.

SHELBY COUNTY.

Topography.—Shelby County is in the southwest corner of Tennessee. It is bounded on the west by Mississippi River and on the south by the State line. The area is 769 square miles. The lowest portion of the county is the flat flood plain of the Mississippi and its tributaries, the largest of which are Loosahatchie and Wolf rivers. Along these latter streams there is usually a terrace or second bottom, but this is not so well developed nor so wide as the corresponding topographic feature in Obion County. The greater part of the county consists of the gently rolling upland that slopes slightly northwestward and ends abruptly on the western side in a line of bluffs that cross the county north and south and overlook the Mississippi swamp to the west. The average elevation of the county is about 300 feet. The highest point is about 400 feet above the sea and is on the southeastern edge of the county. The lowest point is where the Missis-



COMPARATIVE SECTIONS OF WELLS AT MEMPHIS, TENN.

sippi leaves the State, low water there being about 200 feet above sea level.

Geology.—The Lagrange, Lafayette, loess, and alluvium are all represented in the county. The Lagrange is the underlying formation of the entire county. As shown in the deep well at Memphis (see p. 114), it is 950 feet thick, the upper 200 feet being clay and the remainder sand and clay interbedded in rapidly varying manner. Pl. VI shows the abrupt variation in the character of the individual strata of such deposits as the Lagrange.

The Lafayette overlies the Lagrange. In some places it has been entirely removed, but in others it reaches a maximum thickness of 30 to 40 feet. It consists of coarse sand with a large but varying proportion of gravel. Above it is the loess, which may attain a thickness of 60 to 80 feet, but is usually somewhat less. In the eastern part of the county it mingles with and passes into a surface loam which overlies the Lafayette. The river flood plains have a deposit of Recent alluvium that attains a thickness along the Mississippi of over 100 feet.

Water resources.—Springs and shallow wells in the loess furnish hard water. Wells in the alluvium also give poor water, which seems here, as elsewhere, to become more highly impregnated with iron, magnesia, and other mineral ingredients the deeper the well is sunk, so that, if shallow wells are to be used, the shallower the better, so far as the mineral contents of the water are concerned. In the loess area many use cisterns. Deep water of good quality may generally be obtained in the Lagrange at a depth of from 200 to 500 feet, though locally the sands are too fine for even the finest strainers, as has been the case in a number of borings in Memphis. A number of features concerning the Memphis supply that are discussed in the local data (p. 108) are more or less applicable to water-supply problems all over the county.

At Arlington cisterns are used and numerous shallow wells in gravel strike water at a depth of from 15 to 35 feet. Some of the water is soft, some hard, and some contains iron and sulphur. The Louisville and Nashville Railroad well, 228 feet deep, gets water in sand at 195 feet which rises within 12 feet of the surface. The water is pure and soft and excellent for locomotive use. The log, given from memory, is as follows:

Log of well of Louisville and Nashville Railroad at Arlington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	50	50
Orange sand and gravel	12	62
Clay, brown, with some lignite	133	195
Sand, white, water-bearing (entered)	33	228

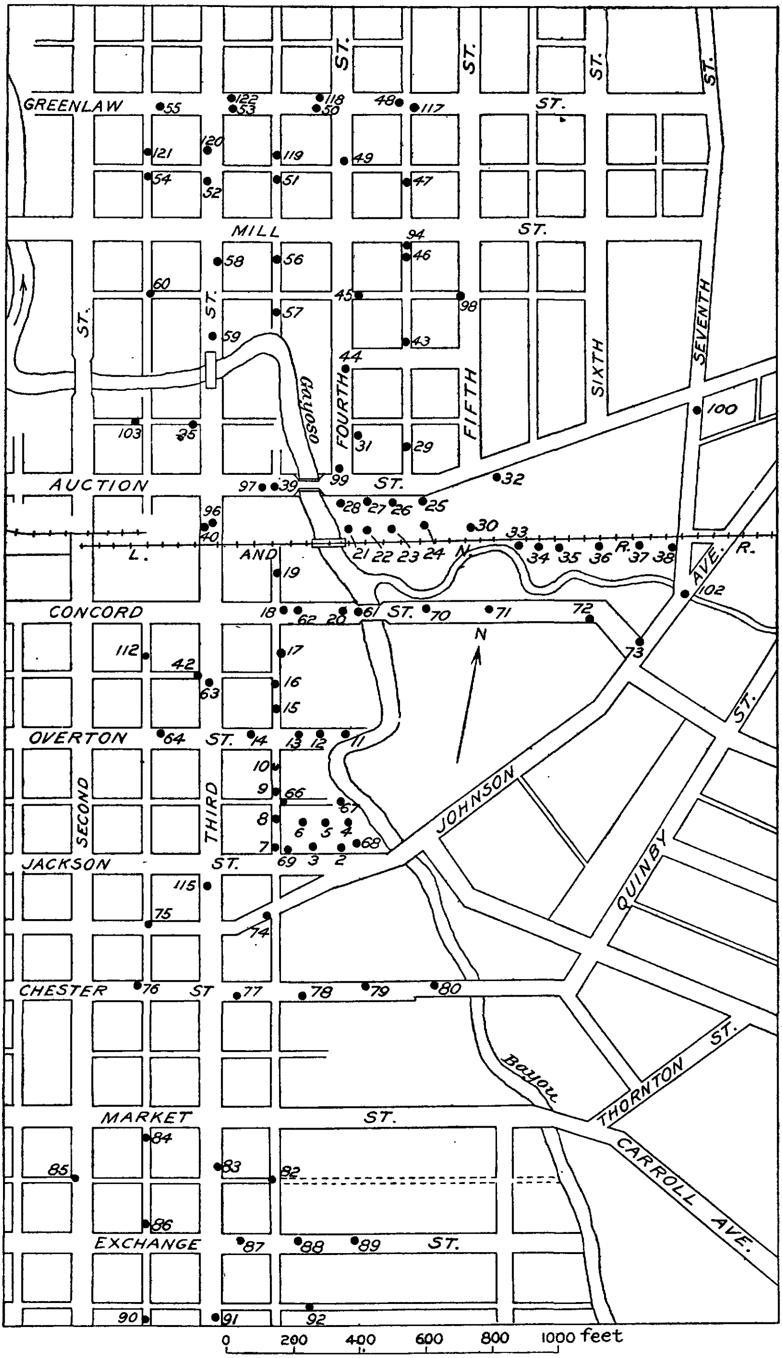


FIG. 8.—Diagram showing location of wells at Memphis, Tenn.

The strainer is 32 feet long and the well yields all that can be pumped by a suction pump set on the surface, of 24,000 gallons per hour capacity.

At Bartlett there are only common wells.

At Bleak there are ordinary shallow wells, some very strong springs, and a driven well 2½ inches in diameter and 176 feet deep, in which the water rises within 47 feet of the surface and is hard.

At Brunswick wells vary in depth from 20 feet in the lowlands to 70 feet on the hills. The lowland water is of poor quality. That in the hills is good and soft.

At Buntyn, elevation 290 feet, on the flat upland between Wolf River and Nonconnah Creek, water is found in the Lafayette or upper part of the Lagrange at depths that vary from 40 to 85 feet. Most wells are bored.

At Capleville, elevation 317 feet, cistern water is largely used. Wells range from 40 to 125 feet in depth. The deeper wells furnish soft water.

At Collierville, elevation 377 feet, cisterns were formerly used very largely. Water is found at a depth of 95 to 100 feet in sand so fine that it rapidly fills the wells and so but few are used. A town system of waterworks has been established with two wells 6 feet apart, driven 239 and 248 feet, with 16-foot Cook strainers. The water stands 95 feet below the surface and is raised by pumps that have a capacity of 7,500 gallons per hour. The water is reported to be very pure and fevers are said by physicians to have decreased 50 per cent since its use began. The log of the 248-foot well is as follows:

Log of well at Collierville, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay soil	6	6
Red sand and gravel	14	20
White sand with water at 95 feet; grows coarser downward	150	170
Pipe clay	8	178
Sand and gravel, water bearing	82	260

The gravel at 248 feet was better than that at 260 feet and the pipe was pulled back to it. Good pure springs are found at the foot of the ridge on either side of the town and wells in the lowlands of either the Wolf or the Coldwater average about 20 feet deep. There are several tubular wells 2½ inches in diameter and 130 to 140 feet deep in the vicinity. Most of them are pumped by gasoline or steam engines.

At Cordova, elevation 372 feet, water-bearing strata are struck at depths of 50, 80, and 100 feet. There are several small tubular wells that draw from the lowest stratum at a depth of 125 or 130 feet. The water is soft and is used for both boiler and domestic purposes.

At Eads, elevation 348 feet, there are very few wells or springs, cisterns being used almost exclusively.

At Foresthill open and bored wells are used, the latter being about 100 feet deep. The water is abundant and soft.

Germantown, elevation 377 feet, is supplied partly by cisterns and partly by wells that have a range in depth of 38 to 70 feet and an average of 60 feet.

Granberry obtains a supply chiefly from ordinary wells. One 2-inch well 118 feet deep furnishes an abundant supply of soft water for a gin and mill.

Irene gets its water supply from shallow wells and cisterns. One tubular well 2½ inches in diameter and 175 feet deep furnishes a boiler supply for a mill.

Kerrville, elevation 335 feet, gets its water supply almost entirely from ordinary dug wells 30 to 50 feet deep.

At Madge wells are from 20 to 75 feet in depth. The water is soft, but not always abundant.

At Massey, elevation 323 feet, there is one 200-foot well yielding water reported to be hard.

At Mayville, near Nonconnah Creek, there are only shallow bored wells.

Memphis has an elevation of 250 to 280 feet in the business part of the city, but in the eastern part the general elevation is 300 feet or more. Extreme low water in the Mississippi is 182 feet and extreme high water 218 feet. Prior to 1870 the entire water supply was obtained from cisterns and individual shallow wells. A public supply from Wolf River was then introduced, but it was never perfectly satisfactory, chiefly because of its turbidity. In 1886 an ice company sunk a well 354 feet deep and obtained a flow of water which rose several feet above the surface. Efforts to obtain a city supply from the same sources were so successful that a temporary pumping plant for the wells then sunk was erected in 1889 and the Wolf River plant abandoned. In 1890 the present pumping station was put into operation, and since then there has been a constant extension in the wells and the distributing mains. In August, 1903, 124 wells had been put down, of which 16 failed to find a stratum of coarse sand thick enough to justify completing them, and 4 had not then been connected. The first 42 wells sunk were abandoned in 1899, having had a life of about ten years each. The wells made now are of better material and are better cared for and will probably last fifteen years. For depreciation and city growth about eight or ten new wells are required each year. The cost of each new well is about $5,000.

The texture of the sand varies very rapidly, so that while the entire mass is water-logged, sand coarse enough to be kept out of a strainer with slots one one hundred and fiftieth of an inch wide may not be found at the same level in two adjacent wells, but they may "get water"—that is, get coarse sand—at very different depths or one well may not get it at all (see fig. 9). If fine sand only is encountered, the well is not finished, as this sand cuts out the strainer slots in a year or two and also fills up the tunnels and pump well. At best the life of the strainers is only about three and one-half or four years. They are overhauled at the end of two years.

The yield per well varies considerably because of differences in the coarseness of the sand in which the strainers are placed. Wells 100 feet apart may show wide variation from this cause. Well No. 94 when new had a capacity of 988,000 gallons per month, while No. 98, one block distant, gave only 401,000 gallons per month. New wells should have a monthly capacity of 500,000 to 700,000 gallons. Within two or three months they usually run down to about 400,000. Occasionally one holds up for six months or a year. Five months after starting, well No. 94 had decreased to 591,000 and No. 98 to 363,000 gallons. This decreased flow is caused by the stopping up of the pores in the coarse sand around the strainer or of the slots in the strainer itself by fine sand carried in by the draft of water entering the well. To remedy it water is forced back by the pumps from the well into the sand around it. In this flushing a device is used that permits the water to be forced out through the slots of only a small portion of the strainer at a time, thus insuring a much more thorough cleansing than would otherwise be possible. Wells are flushed foot by foot about twice a year, and at times between they are flushed the entire length of the strainer at once. After flushing, the wells often show a larger flow than when new. Four wells that had fallen off 32 per cent in nine months increased their flow after flushing about 13 per cent above the original amount.

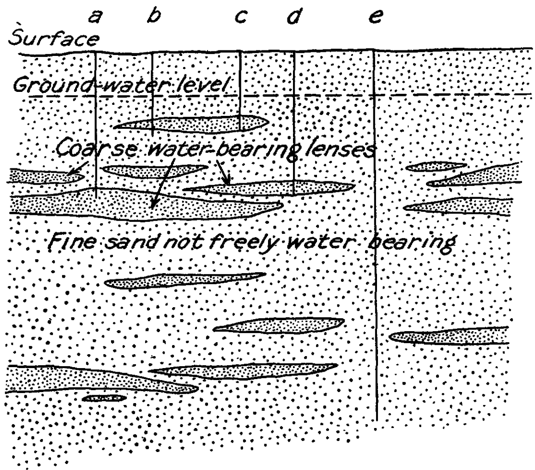


FIG. 9.—Diagram showing variation in texture of sand and its effect on depth and success of a well. Wells *b* and *c* obtain water from the same lens of coarse sand; wells *a* and *d* fail to strike this local lens, but go as deep again and obtain water at the same depth, but from different lenses; well *e* fails to strike coarse sand at all and is finally abandoned.

The level to which water from the Lagrange sand originally rose at Memphis was 225.1 feet above the sea. This elevation was sufficient to permit it to flow at the surface in the lower parts of the city. Where the city wells have been put down the water will not rise to the surface. Instead of placing a pump in each well, the wells are connected by underground drifts with a reservoir, or tunnel, at

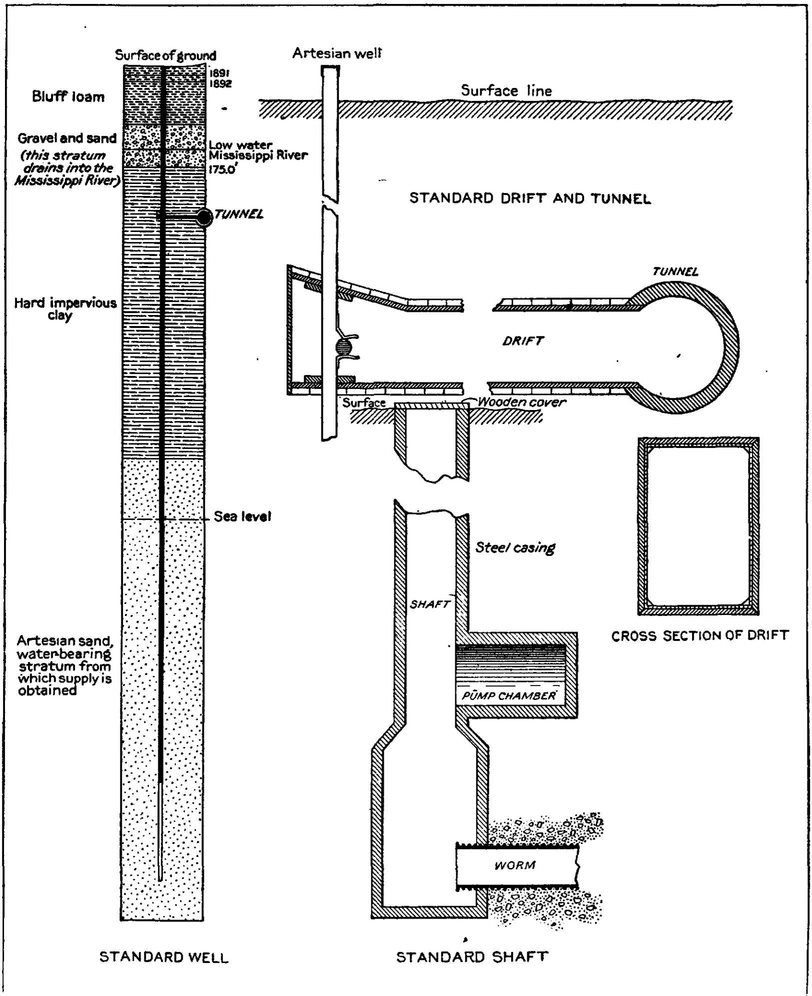


FIG. 10.—Section of well, drift, tunnel, and shaft at Memphis, Tenn. (After Hider, Omberg, and Bell.)

a level considerably lower than that to which the water would rise in them. The wells discharge into this tunnel, which is 5 feet in diameter and about three-fourths of a mile long. It is situated from 75 to 80 feet below the surface of the ground, in the upper part of the thick clay bed which underlies the city and forms the impervious upper member of the Lagrange formation at this point. In the tunnel the water flows by gravity to a suction chamber, from which it is lifted to the surface by pumps and forced into mains for distribution over the city. At intervals shafts are sunk to the drifts, and in them are placed gates which permit groups of wells to be cut off from the remainder and each individual well to be shut off from the tunnel, so that it may be pumped out for inspection or repairs. A section of well, drift, tunnel, and shaft is shown in fig. 10.

When the water in the suction chamber is lowered to about the bottom of the suction pipes of the pumps, the wells flow under their greatest head. When less water is pumped, the level of the water in the pump well rises, the head of flow for the wells is lowered, and their flow automatically diminishes until it equals the amount being pumped. The plant contains three Worthington direct-acting pumping engines, each of 10,000,000 gallons daily capacity. The water is forced by these pumps directly into the mains, which connect with a steel standpipe 20 feet in diameter and 160 feet high. This serves chiefly as a pressure regulator, though to a very limited extent it also acts as a reservoir.

The water is clear and sparkling when freshly drawn, but on exposure or heating gives off free carbonic acid gas and then precipitates iron oxide, the iron at first existing in the water as a carbonate. The nascent carbonic acid attacks the threads on wrought-iron pipe and corrodes them, but does not seriously damage brass or cast iron or the inside of wrought-iron pipes. In steam boilers a scum or soft scale is formed, but does little or no damage if the boilers are frequently cleaned. For drinking and many other purposes the water is very satisfactory, but there is enough calcium carbonate present to interfere somewhat with its use in laundry work, for which many use cistern water. When the artesian water is heated, however, it precipitates the calcium carbonate and may then be used for washing.

Analyses of Memphis artesian water.

	1.	2.	3.	4.	5.
Volatile solids	24.94	14.96	19.96	....	....
Fixed solids	64.86	69.86	74.84	....	....
Total solids	89.80	84.82	94.80	86.64	92.85
Chlorine	2.165	2.095	2.494	1.796	None.
Silica	Little.	Little.	....	Little.	Present.
Nitrates	None.	None.	None.	None.	....
Nitrites	.032	.023	.023	Faint trace	....
Free ammonia	.012	.000	.006	.014	.009
Albuminoid ammonia	.009	.006	.006	.031	.014
Oxygen consumed	.000	.000	.000	.420	....

1, 2. Charles Smart, analyst, June, 1887.
3. Charles Smart, analyst, July, 1888.
4. J. W. Mallet, analyst, June, 1887.
5. E. H. S. Bailey, analyst, June, 1887.
In addition Professor Mallet reports as present soda, potassia, lime, magnesia, iron, iron carbonate, sulphates, traces of phosphates, free nitrogen, almost no oxygen, organic carbon 0.86, organic nitrogen 0.28 part per million.

There has been a remarkable lowering of the death rate since the introduction of the artesian water and the extension of the sewerage system. While this has been partly due to better sanitary conditions resulting from the development of the sewer system, it has also been due largely to the healthfulness of the water itself. The increase of population, extension of sewers, and increased use of city water are graphically shown in their relationship to the decreasing death rate in fig. 11.

Most of the wells in use are located within an area of a quarter of a square mile, and it is calculated that the ultimate limit of economic supply from this area will be about 25,000,000 gallons per day. The present daily consumption is over 20,000,000 gallons and this rate shows each year an increase of about 1,000,000 gallons. In order not to interfere with the yield of the present cluster of

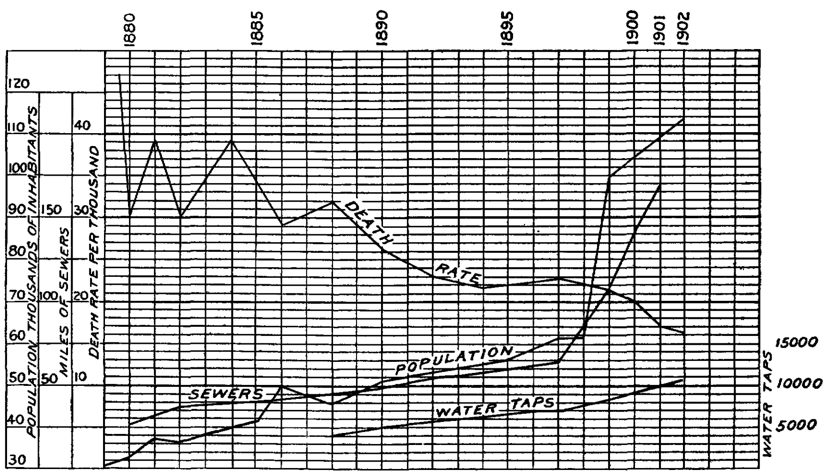


FIG. 11.—Diagram showing increase of population and decrease of death rate in Memphis, Tenn., after the extension of sewers and water mains. (After Hider, Omberg, and Bell.)

wells, new wells are now being located in South Memphis, at a distance of 4 or 5 miles from the old wells, where a new group may soon be developed, so as to give a similar yield of about 25,000,000 gallons a day from a quarter of a square mile. When the city has grown large enough to require a daily supply of 50,000,000 gallons additional units must be provided to meet both the normal increase in consumption and the deterioration in condition and consequently decreased yield of the units already fully developed. It is conceived by the writer that just as the sand in the small area around each well becomes more or less clogged by the indraft of water to the well, so the sand around any quarter square mile or other unit area will in time become similarly clogged and show a decreased yield. Such decrease will be permanent, for it will manifestly be impracticable to flush out an underground area of even comparatively small size when in order to flush a single well most efficiently it must be taken a foot at a time. The expansion of the present system involves an extension of mains and the erection of new substations at considerable cost. The writer believes that the present system is not capable of indefinite expansion, and hence that it can not be regarded as a permanent system for a rapidly growing city like Memphis. When it has been extended to its ultimate economic limit, the city must either turn to Mississippi River for a water supply or explore the deeper lying sands in the hope that they may yield a more abundant supply than is found in the Lagrange. When this limit will be reached it is impossible to say. It may be reached in twenty-five years from now, or it may possibly be fifty years. The present supply has numerous advantages from a sanitary point of view which render its retention and further enlargement advisable as long as it can be done with economy.

The problems arising from the use of Mississippi River water do not require extended discussion here. If the turbidity were removed by settling or filtration, or a combination of the two, the principal objection to the use of the river water would be removed. Other problems would be of purely an engineering character and would be as capable of easy solution.

The hydraulic level in the vicinity of the city pumping plant has been successively lowered by the increase of the amount pumped so that the actual hydraulic surface in the water-bearing sand around the city pumping station forms an inverted cone whose apex is a point in the pump shaft at an average elevation above the sea of 170 feet, the water in the shaft being kept down to this level by the pumps. The curves made by the hydraulic surface in 1898 and in 1902, when about 9,000,000 and 12,000,000 gallons, respectively, were pumped daily, are graphically shown in fig. 12. The probable surface resulting from the establishment of a second pumping plant is also shown.

In view of the steady increase in the consumption of water, the Ripley formation should be tested as a water bearer. It would not take much additional work to deepen the 1,147-foot well sufficiently for that purpose, since it can not be far above the top of the Ripley as it now stands. Details as to the probable thickness of the Porters Creek formation at Memphis are given on page 31. It is impossible to predict accurately the condition of the Ripley beds at Memphis or the character of the water they may contain. It is very probable that this formation would be found there, as elsewhere, to be coarse enough to be a water bearer and that the water contained in it would be of good quality. There is no special reason, indeed, for believing that it would yield water much different from that now obtained in the Lagrange sands, for the two formations are very similar in lithologic character. Should the deep well be sunk to the Ripley and the water there be found insufficient in quantity or inferior in quality the well need in no wise affect the present supply. If it were desired to shut off the water, the well could be plugged at any depth desired and the pipe above that depth either cut or allowed to remain.

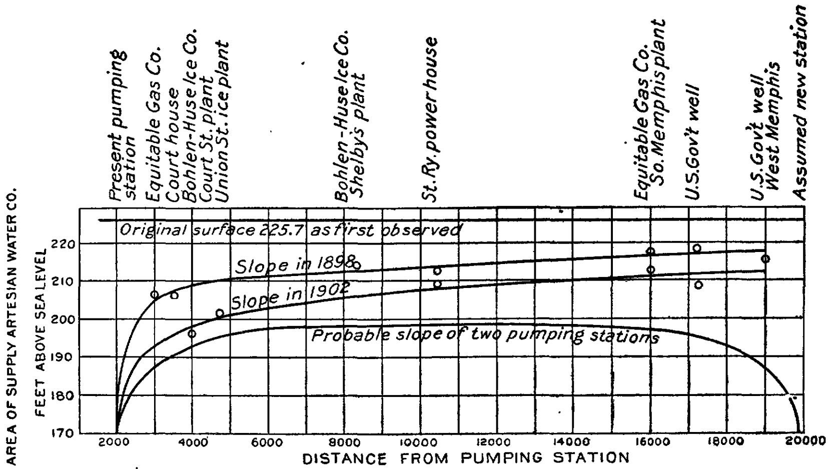


FIG. 12.—Diagram showing slope of artesian hydraulic surface and probable effect of a second pumping station at Memphis, Tenn. (After Hider, Omberg, and Bell.)

The Ripley is probably underlain by the Selma clay, and it in turn by the Eutaw sand, which is also water bearing. The depth, however, to the Eutaw at Memphis is probably so great as to prevent its economical use for city water supply unless the yield per well were much greater than that obtained from any of the wells now in use.

Log of Well No. 109, Memphis, Tenn.

[Elevation, 238 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	27	27
Hard brown clay	10	37
Slightly soft brown clay	8.4	45.4
Gravel and sand	4	49.4
Soft brown clay and sand	14	63.4
Slightly hard brown clay	12.5	75.9
Stiff blue clay	3	78.9
Soft blue clay	4.4	83.3
Stiff blue clay and sand	2.6	85.9
Soft brown clay and sand	1	86.9
Very hard brown clay	2	88.9
Hard reddish clay	1.5	90.4
Hard blue clay	15.5	105.9
Soft blue clay	15.1	121
Stiff blue clay	1	122
Soft brown clay	4	126
Slightly hard brown clay	1.3	127.3
Stiff brown clay	1	128.3

Log of Well No. 109, Memphis, Tenn.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Hard brown clay	1	129.3
Very hard brown clay	5.7	135
Hard brown clay	61	196
Slightly hard blue clay	18	214
Hard blue clay	9	223
Sandy blue clay	53	276
Fine sand and clay	27	303
Fine sand	35.4	338.4
Fine sand and lumps of blue clay	41.6	380
Coarse sand and lumps of blue clay	10	390
Soft blue clay	17	407
Sandy blue clay	10	417
Fine sand and clay	15	432
Sandy blue clay	13	445
Fine sand and clay	7	452
Sandy blue clay	22	474
Fine sand	26	476.6
Sandy blue clay	6.6	483.2
Fine sand	.8	484
Coarse sand and clay	6	490
Soft blue clay	2.3	492.3
Clay and sand	17.7	510
Very fine sand	25	535
Very fine sand and clay	38.2	573.2
Very fine sand	16.8	590
Very coarse sand with lignite	8	598
Lignite, pyrite, and clay	2	600
Very fine sand and lignite	195	795
Soft white clay	17	812
Very fine sand	53	865
Hard brown clay	31	896
Fine white sand	30	926
Hard brown clay	24	950
Fine sand	50	1,000
Stiff brown clay	25.6	1,025.6
Very hard, substantial rock	.5	1,026.1
Very stiff blue clay	27.9	1,054
Very hard clay	93.5	1,147.5

At Millington water is obtained at a depth of 20 to 40 feet and better water at 80 to 100 feet. Cisterns are largely used.

At Mullins, elevation 284 feet, water is obtained from springs, cisterns, and wells that average 30 or 40 feet in depth.

At Pearley the wells are from 16 to 60 feet deep.

At Ramsey cisterns only are used.

At Sloanville water is struck in Lafayette gravel at a depth of 34 feet. Water-bearing gravel is also reached at a depth of 83 feet. Some wells yield soft water, but in most it is hard.

At Whitehaven, elevation 303 feet, only dug or bored wells of about 50 feet average depth are in use.

TIPTON COUNTY.

Topography.—Tipton County is bounded by Mississippi River on the west. Its area is 430 square miles. The surface may be divided topographically into three parts, the lowest of which is the alluvial plain of Mississippi and Hatchee rivers. This low plain forms a narrow belt along the western and northern borders. Next, there is along the Hatchee a terrace belt of varying but not great width. The third part is the upland surface, which is gently rolling or level except near the bluffs that form its western margin, where it is cut into steep-sided hills. The average elevation is about 325 feet, but the elevations of only a few points in the county are known. The highest of these is 378 feet, on top of the bluff at Randolph. The lowest (about 200 feet) is at low water in the Mississippi where it leaves the county.

Geology.—The geology of the county is exactly similar to that of Shelby County, just south of it. The Lagrange everywhere underlies the alluvium in the bottoms, and the Lafayette on the uplands. The Lafayette in turn is overlain by the loess and the latter seems to extend down onto the terrace area.

Water resources.—The county is fairly well watered by flowing streams, which are the main dependence for stock water. For domestic use, wells, cisterns, and springs are used, wells being the most common. Wells in the loess, as well as springs that flow from it, give hard water. The use of small driven wells from 100 to several hundred feet deep is becoming more general. Good soft water from the Lagrange sand should be obtained almost anywhere at depths of from 100 to 250 feet. The entire drainage is to the Mississippi.

At Almira wells average 65 or 70 feet in depth; some are dug, others bored. The dug wells are the more satisfactory. The water is generally soft.

At Atoka, elevation 424 feet, water is obtained chiefly from ordinary wells. There are a few springs, but most of them go dry during the summer.

At Bride there is difficulty in drilling wells because of caving. The water is hard. Cisterns are used almost exclusively.

At Covington, elevation 316 feet, water is generally obtained from open wells of about 40 feet average depth. The town system is supplied by four wells 6 inches in diameter and 100 to 110 feet deep. Each flows 3 gallons a minute under a head of about 5 feet. The daily consumption is 50,000 gallons. Direct pressure is used. The water is soft and of excellent quality, and the health of the town has been greatly improved by its use. The section, reported from memory, is as follows:

Log of wells at Covington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	8	8
Blue clay	4	12
White and reddish sand	12	24
Coarse white sand	86	110

At the station the Illinois Central Railroad has an 8-inch well 533 feet deep, in which the water rises within 31 feet of the surface. It has a temperature of 66° F., is soft, and makes a good boiler water. Nine thousand gallons per minute may be obtained with the present pumping plant. The record given is as follows:

Log of well at Illinois Central station, Covington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Blue clay	100	100
Fine white sand	18	118
Blue clay	100	218
Quicksand	100	318
Fine tough gray clay	182	500
Sand	4	504
White pipeclay	4	508
Very coarse sand, water-bearing	25	533

At Dawsons the wells on the upland range from 40 to 80 feet in depth. An occasional well furnishes soft water. Wells in the bottoms are 10 to 20 feet deep, and the water rises to the top during the winter.

At Gift cisterns are used.

At Mason water is obtained at a depth of about 35 feet. One well is 200 feet deep.

At Phelan water is obtained from dug wells 45 to 60 feet deep. The water in most of them is good, but is easily lowered.

At Quito cisterns are most used. Wells average 35 feet in depth, and the water is generally hard. Two miles to the west, along the bluffs overlooking the Mississippi alluvial region, springs are abundant.

At Tabernacle there is a 4-inch bored well sunk to a depth of 225 feet. The water is abundant and soft and rises to within 106 feet of the surface. The section down to 184 feet, where the water rose 78 feet in the pipe, was chiefly alternating sand and clay. This was followed by a thin sand-ironstone layer, then 21 feet of blue clay, and beneath it another sand, which was entered to a depth of 225 feet from the surface. The water in this sand rose within 165 feet of the surface only, and so the casing was pulled back and the well made at 184 feet.

At Tipton, elevation 342 feet, dug wells from 30 to 50 feet in depth furnish hard water. Some springs are also used.

At Walts, on the Mississippi, the only wells are shallow driven wells in which the water rises and falls with the river surface. The quality of the water is not good; the shallower the wells are the less iron the water contains.

WEAKLEY COUNTY.

Topography.—Weakley County is bounded by the Kentucky line on the north and is almost midway between Tennessee and Mississippi rivers. Its area is 565 square miles. The surface is gently rolling, except around Dresden and in the northeastern part of the county, where it is hilly. The general slope is westward and the drainage is to the Mississippi. Elevations of about 500 feet are found on some of the hills near Dresden. South Fork of Obion River has an elevation of about 290 feet where it leaves the county, and North Fork is but slightly higher. The average elevation is between 400 and 450 feet.

Geology.—The formations of the county are the Lagrange, the Lafayette, and the Columbia loam. The Lagrange underlies the entire county, and while generally concealed by one or both of the other formations it is exposed in the deeper railway and stream cuttings. It consists, as usual, of soft sands interbedded with occasional strata of clay. The Lafayette is a red clayey sand and contains very little gravel. It is 10 to 20 feet thick and is exposed in most of the natural and artificial cuttings. Over it are generally found 5 to 10 feet of a softer, lighter-colored sandy loam that in places is very much like loess in its physical characteristics.

Water resources.—The county is watered by numerous streams, the larger of which flow westward. Many of the smaller streams become dry during the late summer and autumn and recourse is then had to ponds and wells for stock water. Springs are not numerous nor strong. The ground-water level, as is often the case in the middle and eastern parts of the Lagrange belt, lies at some distance below the surface, and wells which furnish the chief water supply average 50 or more feet in depth. In some cases, where the depth to water is greater than usual, cisterns are used.

At Dresden, elevation 416 feet, there is no system of waterworks; water is obtained chiefly from open wells that average 50 feet in depth. The water is good, soft, and abundant. A few persons use cisterns. In the surrounding country wells in low places near streams may be only 20 feet deep, while on hills they go to 80 feet or more.

At Gardner, elevation 337 feet, water is obtained from common open wells only.

At Gleeson Station, elevation 397 feet, good water is struck at depths of 50 to 100 feet.

At Greenfield, elevation 434 feet, ordinary wells are in general use. There is one well 200 feet deep and another 400 feet deep, detailed records of which could not be obtained. The water in the 200-foot well rises within 116 feet of the surface, and is pumped; the yield is 60 gallons per minute. The water contains some iron and is used for domestic and boiler purposes. The water in the 400-foot well rises to about the same elevation, but is dark colored and does not taste good.

At Kimery springs are weak and of little use. Wells 25 to 100 feet deep and small tubular wells 100 to 160 feet deep are used The water is soft, and, in the deeper wells, abundant.

At Logan water is obtained from springs along the hillsides and from wells that average 50 feet in depth.

At Martin, elevation 419 feet, water is obtained from cisterns and open wells. The wells range from 60 to 90 feet in depth and furnish good soft water from the Lagrange sand. Occasionally a well strikes water above a local hardpan, at the base of the Lafayette, at a depth of 20 or 25 feet. If this hardpan is dug through the water immediately drains down into the underlying dry Lagrange sand, and permanent water is not reached short of 60 to 80 feet below the surface.

The town put in a system of waterworks in 1898, getting the supply from two 8-inch wells, each 316 feet deep. The water rises within 90 feet of the surface, and is raised by air lifts, with a capacity of 12,000 gallons per hour for each well, into two surface reservoirs of 28,000 and 96,000 gallons capacity. From these it is forced into the mains by direct pressure. The town wells are on a level with the railway crossing. No complete log could be obtained. The water is so clear that it looks bluish; it is soft and excellent for domestic and industrial purposes. The ice company has a 4-inch well 130 feet deep, the top of which is about 2 feet lower than the town wells. The water rises within 69 feet of the surface, and is of good quality. From the record of this well and other sources the following may be given as the approximate section at Martin:

Generalized section at Martin, Tenn.

	Feet.
Surface sand and clay	20
Sand with occasional beds of clay, each 3 or 4 feet thick	50
Sand, water bearing	10– 15
Pipe clay (to a total depth of 100 feet)	15– 20
Sand, water bearing	30±
Clay, black lignite	60– 90
Sand, fine, with clay	80–100
Sand, coarse, water bearing	15+

The upper water-bearing sand seems to run very uniform in elevation in the vicinity of Martin, ranging in depth from 25 feet in the valleys to 150 or 160 feet beneath the hills. The layer of lignitic clay is also reported to underlie a large part of the country around Martin. Some parts are pure enough lignite to burn when dried. Occasionally a log of lignite is struck in the sand over the lignitic clay.

At Meda, elevation 424 feet, water is obtained from cisterns, from shallow dug wells 25 to 40 feet deep, and from small bored wells 50 to 100 feet deep. The water is soft, but is not very abundant.

At Ore Spring there are some ordinary springs and shallow open and deep bored wells, the latter ranging from 60 to 100 feet in depth. The water is abundant and soft.

At Ralstons Station, elevation 429 feet, water is obtained from cisterns, and shallow wells 25 to 40 feet deep. There is one tubular well 166 feet deep that furnishes an abundance of soft water, but no record of it could be obtained.

At Rinda water is obtained from bored wells 30 to 150 feet deep.

At Ruthville water is obtained from cisterns and from ordinary wells 50 to 75 feet deep.

At Sharon, elevation 416 feet, water is obtained from wells, cisterns, and ponds. The wells range in depth from 50 to 150 feet, but the water is especially good and abundant at 100 to 150 feet. At the foot of the hills on the north side of Obion River are numerous springs. Small streams go dry in the fall and ponds are used for stock water.

At Terrell there are wells from 30 to 60 feet deep.

At Unity water is obtained from common wells and springs.

MINERAL WATERS OF WESTERN TENNESSEE.

There are a number of mineral springs or wells in western Tennessee that are more or less widely known for their therapeutic properties. Some few have been developed into summer resorts, but most are undeveloped and are used only locally.

Austin Springs, at Unity, Weakley County, have something more than a local reputation for their medicinal properties. They are 15 miles east of Fulton, Ky. The water is a sulphureted chalybeate, in which iron is the chief ingredient, but small amounts of calcium, magnesium, potassium, sodium, and chlorine are also reported present. It is reputed to be valuable for rheumatism and general kidney and stomach troubles. The water is sold locally.

At Bethel Springs, McNairy County, elevation 458 feet, there is a chalybeate spring that has long been known and used for its curative properties. No analysis is known to have been made.

Brock Springs, in the western part of Weakley County, 10 miles west of Dresden, is a local resort, but has no permanent improvements. Visitors camp out and live in tents. The quality of the water could not be ascertained.

The Cotton artesian well, half a mile southwest of Huntington, Carroll County, was bored in 1879 to a depth of 67 feet and cased with terra-cotta piping. The water flows several gallons per minute. It is a very palatable chalybeate. A hotel has been erected near it.

Dunlap Chalybeate Springs are about 2½ miles south of Bolivar, Hardeman County.

At Dyersburg the water for the Phoenix Cotton Oil Company's deep well has considerable local repute for use in kidney troubles. No analysis has been made, but it is known to contain considerable iron and a little calcium, and probably magnesia also.

The water from Essery Springs, 3 miles south of Pocahontas, on the southern edge of Hardeman County, has been known for years and used for kidney and stomach disorders.

Gibson Wells, 12 miles northwest of Humboldt, Gibson County, is one of the best developed summer resorts of western Tennessee. Extensive hotel accommodations have been provided. The wells afford chalybeate and sulphur waters that are used for indigestion and nervous and malarial disorders.

Glenn Spring, 7 miles from Atoka, Tipton County, is at the base of the Mississippi River bluffs. The water has long been used for liver, kidney, and digestive disorders. The following analysis was made in 1880 by W. T. Lupton:[a]

Analysis of alkaline carbonate water from Glenn Spring, Tennessee.

	Parts per million.		Parts per million.
Silica (SiO_2)	24	Carbonate radicle (CO_3)	206
Iron (Fe)	4.5	Sulphate radicle (SO_4)	2.6
Calcium (Ca)	66	Chlorine (Cl)	1.7
Magnesium (Mg)	35		
Sodium (Na)	13		355.4
Potassium (K)	2.6		

The water from Hargrove Spring, 6 miles south of Ripley, Lauderdale County, is alkaline and useful, especially in kidney and bladder troubles and for gout and rheumatism.

Hawkins Spring, 1½ miles from Huntington, Carroll County, on the edge of the bottoms, is a bold chalybeate spring.

Hinson Springs is on the Nashville, Chattanooga and St. Louis Railway, 2 miles west of Lexington, Henderson County. There are two chalybeate springs, two sulphur springs, and a freestone spring, all near each other. The place has been a summer resort for fifty or seventy-five years. The waters have not been analyzed, but they are recommended for stomach, kidney, and bladder troubles.

At Jackson there is an artesian well, which forms part of the city water-supply system, and yields water that is regarded as having medicinal properties. A description of it has already been given (p. 97). The water is slightly chalybeate and alkaline, as the following analyses show:

[a] Crook, J. K., Mineral Waters of the United States, p. 439.

Analyses of water from well at Jackson, Tenn.

[Parts per million.]

	1.	2.	3.	4.
Silica (SiO_2)	16	14	15	1.2
Oxides of iron and alumina ($Fe_2O_3+Al_2O_3$)	45	....	.50	6.4
Calcium (Ca)	1.6	....	2.9	4.3
Magnesium (Mg)	.67	4.2	....	2.9
Sodium (Na)	12	5.1	....	12
Carbonate radicle (CO_3)	19	(a)	2.5	21
Sulphate radicle (SO_4)	....	26	3	....
Chlorine (Cl)	1.3	1.7	....	5.1
Potassium (K)	....	1.4	....	....
Free ammonia	....	None.	....	....
Albumin oil ammonia	....	Trace.	....	....
Residue on evaporation	....	....	55.7	....
Residue on ignition	....	....	44.7	....
Soluble organic matter	....	....	23.9	....
Insoluble organic matter	....	....	20.8	....
Nitrate radicle	....	....	....	7.6

a Not determined.

1. C. N. Miller, analyst.
2. W. E. Stone, analyst. "The water is to be regarded as exceptionally pure. The solid matter is present in quantities so small that it is difficult to make the determination; its form is mainly that of sulphate of soda and lime, with traces of potash and magnesia."
3. Henry Carmichael, analyst. "The water represented by above sample is exceptionally soft and is well adapted for boiler supply or bleaching purposes."
4. Pittsburg Testing Laboratory, analyst.

Mason's wells, in Madison County, 3 miles from Pinson and 11 miles from Jackson, have long had a reputation for their curative properties in stomach and kidney disorders. The water is chalybeate and mildly astringent. The principal well is 70 feet deep and has 30 feet of water in it.

Pryor Chalybeate Spring, 2½ miles east of Paris, Henry County, has a bold flow.

At Raleigh, Shelby County, is a group of six springs that were analyzed by Mr. Theo. Hernner and found to contain the following:[a]

Analysis of water from springs at Raleigh, Tenn.

	Parts per million.		Parts per million.
Silica (SiO_2)	26	Carbonate radicle (CO_3)	86
Iron (Fe)	31	Sulphate radicle (SO_4)	10.3
Calcium (Ca)	23	Chlorine (Cl)	6.2
Magnesium (Mg)	9		
Sodium (Na)	6.3		197.8

Sulphur Springs water, Decatur County, has a local reputation for dyspepsia and stomach troubles. No analysis has ever been made.

RESOURCES OF KENTUCKY, BY COUNTIES.

BALLARD COUNTY.

Topography.—Ballard County is in the extreme northwestern part both of the Jackson purchase region and of the portion of Kentucky

a Safford, J. M., An annotated catalogue of the mineral springs and wells of Tennessee, a contribution to a report on the water supply of the State: Suppl. to Bull. State Bd. Health, Tenn. for Oct., 1885, pp. 15, 16.

lying west of the Tennessee River. It is bounded on the west and north by Mississippi and Ohio rivers and on the south by Mayfield Creek. Its area is 237 square miles. The county is divisible topographically into three parts that differ in their general surface elevation as well as in other respects. The lowest of these is the flood plain or bottoms along Mississippi and Ohio rivers. This is absent at Wickliffe, where the Mississippi is swinging eastward against the bluffs, but its width reaches 6 miles in the middle western part of the county and decreases to a mile at the northeast corner of the county. The surface of this plain is broken by a number of low sand ridges whose general trend parallels the river. These ridges are separated by old lakes, ponds, and sloughs—the remains of abandoned and partly filled river channels. The average elevation of this part of the county is between 300 and 320 feet. The higher ridges and the margin along the river bank are cultivated in many places, but the greater part is a poorly drained wooded swamp. The second topographic division is an old terrace level with a surface about 30 or 35 feet higher than that of the flood plain. This forms a belt 4 to 6 miles wide that crosses the northern part of the county adjacent to the flood-plain belt. The remaining and largest part of the county is the general upland region, which has an elevation of between 400 and 425 feet. The surface is level or gently rolling except near the western margin and along the streams, especially Mayfield Creek, where it is hilly.

Geology.—The surface formations are the Lagrange, Lafayette, loess, and alluvium. The Lagrange underlies all of the county except the northern part, where both the Porters Creek and the Ripley are doubtless to be found beneath the thin covering of alluvial material. They are not exposed naturally and no wells have been sunk to them in the alluvial region; their exact position and boundaries are therefore largely conjectural. The Lagrange has its usual character, being a soft, light-colored sand with occasional strata of clay. It is exposed only in the sides of the deeper and more abrupt cuttings.

Over the Lagrange is a layer of 10 to 30 feet of Lafayette sand and gravel. This extends over the entire upland area of the county, except where it has been removed by stream erosion. It apparently covers the terrace area in the northern part of the county also, though the writer is not sure that this gravel is as old as the Lafayette gravel on the uplands to the south. It seems more probable that it is an Ohio River gravel of later age. This terrace belt extends up the Ohio to Paducah, McCracken County, which is situated on it, and beyond, and throughout presents the same characteristics and the same problem as to the age of its gravels.

The alluvium covers the flood plains of the two great rivers.

Water resources.—There are numerous streams that generally furnish water for stock. In some places, where the surface is flat, natural ponds hold water practically all the year, and artificial ponds may be readily made. The alluvium furnishes water everywhere at slight depths, but the quality of such water is generally poor to fair only. The gravel on the terrace and on the upland is often water-bearing. In the terrace gravels the water is usually hard, while on the uplands the water from the Lafayette is in some places hard and in others soft. In numerous places, however, there is no hardpan or clay at the base of the Lafayette to form an impervious basin, and then water is only reached at a considerably greater depth in the Lagrange. An abundance of water of good quality should be found practically everywhere at the base of the embayment deposits or in the immediately underlying chert that forms the upper part of the Paleozoic floor. The depth to this old floor is probably not over 400 or 500 feet, except on the southern edge of the county, where it seems to sink rapidly to 1,000 feet. Good water may be obtained in sufficient quantity for manufacturing or domestic purposes from the Lagrange sand, at depths of 150 to 300 feet, in almost any part of the county. Over the uplands ordinary wells are 60 to 100 feet deep.

At Bandana, on the terrace plains, water is obtained by ordinary wells at moderate depth.

At Barlow City water is struck at a depth of about 70 feet. Bored wells and cisterns are used.

At Blandville, elevation 445 feet, cisterns are used principally, but there are some open wells that reach 140 feet in depth.

At La Center, elevation 404 feet, there is a deep well drilled for the Illinois Central Railroad for engine use, the log of which is as follows:

Log of Illinois Central Railroad well at La Center, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay (loess, loam)	20	20
Sand and clay (Lafayette)	18	38
Cement gravel (Lafayette)	38	76
Sandy clay (Lagrange)	34	110
Marl and streaks of sand (Lagrange)	28	138
Gumbo (Porters Creek)	112	250
White sand (Ripley)	5	255
Brown sand and clay (Ripley)	132	387
Limestone (Mississippian)	10	397
Gumbo and "Elco" gravel, mixed (Mississippian)	48	445
Brown sand and clay (Mississippian)	113	558

At Lovelaceville, in a valley tributary to Mayfield Creek, the wells are from 30 to 40 feet deep. The water is hard in some and soft in others. In the neighboring hills wells run 50 to 100 feet in depth.

At Ogden there are few cisterns; most of the supply is obtained from bored wells. The region is so flat that there are no springs.

At Oscar there are only shallow wells.

At Slater there are some wells ranging from 40 to 75 feet in depth, but the water is generally considered poor and is very little used. Cisterns are almost exclusively used for domestic supply, while ponds are used for stock.

At Wickliffe, elevation 322 feet, there are only a few open wells that average 40 or 50 feet in depth. In the surrounding country the farmers use cisterns almost exclusively, the water from shallow wells being hard because of the loess.

The town built waterworks in 1901, getting the water from a 6-inch well 147 feet deep, from which 6,000 gallons per hour are pumped into a standpipe for distribution. The log is as follows:

Log of waterworks well at Wickliffe, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	6	6
Dark clay	30	36
Sand, with a little water	2	38
Blue clay, partly sandy	90	128
Coarse sand, water bearing	19	147
Potters' clay (penetrated)	5	152

The casing was pulled back to 147 feet and the well finished with a 19-foot strainer. The yield has shown no tendency to decrease. The water is soft and quite satisfactory for general town purposes and for boiler use.

Analysis of water from waterworks well at Wickliffe, Ky.

	Parts per million.
Silica (SiO_2)	21
Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$)	8.6
Calcium (Ca)	9.5
Magnesium (Mg)	5.1
Sodium (Na)	6.7
Carbonate radicle (CO_3)	27
Sulphate radicle (SO_4)	5.8
Chlorine (Cl)	6
Free CO_2	85
Alkalinity	70
Incrusting solids	71
Nonincrusting solids	19

A few years ago a local company drilled for oil in the southern edge of town and got artesian water instead. The elevation of the well head is about 20 feet below track level and the same distance below the level of the town well given above. The water flows about 5 or 6 gallons a minute. The following log was given from memory:

Log of well in southern part of Wickliffe, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay and gravel	12	12
Potter's clay } (Lagrange)	130	142
Coarse sand, clear, yellowish, or reddish } (Lagrange)	300	442
Blue marl or soapstone (Porters Creek)	158	600
Soft sand, water bearing } (Ripley)	10	610
Blue marl with some kaolin, down to 1,000 feet depth } (Ripley)	390	1,000
Flinty limestone (penetrated)	20	1,020

The present flow is from the 600-foot level. The water is largely used for drinking and has acquired the reputation of being very valuable for kidney diseases. An analysis by C. G. Heinrichs is as follows:

Analysis of water from well at Wickliffe, Ky.

[Analyst, C. G. Heinrichs.]

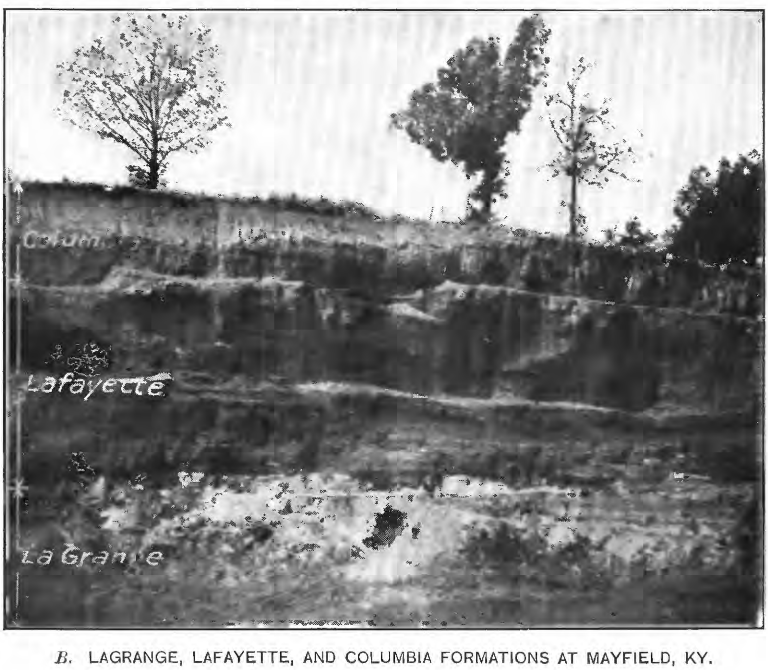
	Parts per million.
Silica (SiO_2)	7.3
Iron (Fe)	1.6
Calcium (Ca)	40
Magnesium (Mg)	11
Sodium (Na)	47
Carbonate radicle (CO_3)	87
Bicarbonate radicle (HCO_3)	48
Sulphate radicle (SO_4)	17
Chlorine (Cl)	24
	283
Free CO_2	41
Lithium	Strong trace.

A view of this well is given in Pl. VII, *A*.

CALLOWAY COUNTY.

Topography.—Calloway County is in the southeast corner of the Jackson Purchase region. Its southern border adjoins Tennessee, and its eastern boundary is Tennessee River. Its area is 402 square miles, of which about 350 are included in the area discussed here. The eastern portion along Blood River, adjoining the Tennessee Valley, is broken and hilly, and there are also hills on either side of the forks of Clarks River. Away from the neighborhood of the streams the surface is as a rule gently rolling. South of Murray there is a considerable area of "flatwoods" underlain and caused by the Porters Creek clay. The highest portion of the county is along the Tennessee line, where an elevation of about 600 feet is reached. The general slope is to the north. The average elevation of the county is from 500 to 525 feet. The lowest point is low water in the Tennessee at the northeast corner of the county, which is about 295 or 300 feet above the sea.

A. ARTESIAN WELL AT WICKLIFFE, KY.



B. LAGRANGE, LAFAYETTE, AND COLUMBIA FORMATIONS AT MAYFIELD, KY.

Geology.—The formations of the embayment portion of the county are the Ripley, Porters Creek, Lagrange, Lafayette, and Columbia loam. The Ripley consists of sands and clays and is exposed chiefly along Blood River and the upper part of Jonathans Creek, where the surficial formations are removed by stream erosion. It dips to the west beneath the Porters Creek. The leaden-colored clays and greensand of this formation are exposed along East and West forks of Clarks River and their tributaries. An excellent exposure showing numerous small interlacing sandstone dikes may be seen at low water on East Fork of Clarks River, between the highway and railroad bridges just south of town. West of the Porters Creek formation the sand and clays of the Lagrange are found in the western part of the county. All of the older formations are generally concealed, except along the streams, by the sand and gravel of the Lafayette. This gravel is in places, especially in the central and eastern parts of the county, 20 to 40 feet thick. An excellent exposure may be seen in the railway gravel pit just south of Murray. It is there a highly ferruginous, prevailingly orange-colored gravel, which is distinctly cross-bedded and has numerous sand pockets and some iron crusts in it. It shows 25 feet of gravel, overlain by 8 or 10 feet of sandy clay, with irregular gravel streaks through it in places. Above the Lafayette in many places are 5 or 10 feet of softer, leached-out or light-colored, sandy clay or loam that probably represents the Columbia and is the equivalent of the loess found along the Mississippi River bluffs to the west.

Water resources.—While there are numerous streams in the county, much of it is not well watered, and in dry seasons many of the small streams fail altogether. Ponds are widely used for stock. Underground water is reached in the stream valleys at depths of 20 to 30 feet, but on the uplands it is often 100 to 150 feet to permanent water, and in such places cisterns are usually used instead of wells. Water from the Porters Creek clay or "soapstone" is not good. This clay does not seem to be very thick in many places along its eastern margin, and it may there be dug or drilled through without difficulty. Under it good water should generally be obtained from the Ripley sand.

At Backusburg, in the valley of West Fork of Clarks River, there are numerous springs and shallow wells.

At Coldwater several large springs and wells that are 60 to 80 feet deep provide the water supply.

At Crossland cisterns are used almost exclusively on account of the depth to underground water.

At Dexter, elevation 424 feet, lying in a stream valley, water is obtained at a depth of 16 to 20 feet. On the neighboring uplands wells are 30 to 40 feet deep; many yield chalybeate water.

At Harris Grove water is struck usually at depths of 30 to 50 feet. One well 110 feet deep is a blowing well; during foul weather the wind rushes out strongly.

At Hazel a domestic supply is obtained from wells ranging from 30 to 60 feet in depth. The water is good and pure. Streams and ponds are used for stock.

At Lynngrove an abundant supply of soft water that contains some iron is obtained at a depth of 115 feet. Two wells—one 2-inch, the other 3-inch—were drilled there to a depth of 174 feet, and furnish excellent water from 115 feet depth. The log is as follows:

Log of well at Lynngrove, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	15	15
Red clay	25	40
Gravel and sand	40	80
Red sand	10	90
Pottery clay	12	102
Yellow sand, with water at 115 feet	72	174

At Murray, elevation 480 feet, both wells and cisterns are used in about equal numbers. The wells used average about 30 or 40 feet in depth and are situated on low grounds or slopes near by. On higher ground water is deeper, a few wells being 100 feet deep, and the one in the court-house square 140 feet deep. The latter well goes through the surface soil, the Lafayette gravel, and the Porters Creek clay and gets water from the Ripley sand. In many places water may be obtained at the base of the Lafayette. If found in the Porters Creek it is hard and unfit to use. Wells are then usually abandoned, though it would be easy to sink them through this formation, as it seems to be from 5 to 30 feet thick only, and get water from the Ripley sand. In the uplands to the east of Murray very few wells are used, and in the corresponding area west of town the number is even less, cisterns being used in both areas because of the depth to water.

The Nashville, Chattanooga and St. Louis Railway dug a large brick well near the station to a depth of 73.6 feet and then sunk a pipe in the bottom of it to a total depth of 215 feet. The water rises to about 50 feet below the surface and stands about 23 feet in the large well. It is used for locomotives. The following log has been furnished by Mr. E. F. Doudna, of Mayfield, Ky.:

Log of well of Nashville, Chattanooga and St. Louis Railway at Murray, Ky.

		Thickness.	Depth.
		Feet.	*Feet.*
Sand, gravel, and clay		46.3	46.3
Quicksand		7.0	53.3
Clay, hard, black (Porters Creek)		20.0	73.3
Sand, slightly mixed with yellow clay		33.4	106.7
Bastard sand		28.0	134.7
Fine sand		5.0	139.7
Coarse sand and water		8.0	147.7
Shell of sand rock		3.0	150.7
Tough blue and black clay		15.0	165.7
Soapstone, slightly mixed with sand	Ripley.	16.0	181.7
Pure sand, fine		11.0	192.7
Hard shells of sand rock		1.5	194.2
Fine sand		3.5	197.7
Blue soapstone		1.0	198.7
Coarse dark sand with water		3.0	201.7
Coarse white sand with water		13.0	214.7

At New Concord water is struck in fine sand at a depth of 50 to 70 feet.

At Stella cisterns are used exclusively.

At Wadesboro water is obtained from springs along the foot of the hills and from wells back on the uplands that range from 20 to 60 feet in depth and furnish good water.

At Wetzel wells average about 50 feet deep. All contain more or less iron; cisterns are largely used.

CARLISLE COUNTY.

Topography.—Carlisle County is situated on the western edge of the Jackson Purchase region, almost midway between its northern and southern extremes. Its western boundary is formed by Mississippi River and its northern boundary is Mayfield Creek. Its area is 188 square miles. Along its western border there is a fringe of Mississippi bottom of varying width. The eastern margin of this bottom is formed by a bluff that rises from 75 to 150 feet above it. Eastward from the bluff the general upland, which includes all of the remainder of the county, has a rolling surface. The upland slopes slightly to the northwest and has an average elevation of about 400 feet. Low water in the Mississippi is about 275 feet and high water about 315 feet.

Geology.—The formations are the Lagrange, the Lafayette, the loess, and the alluvium. The Lagrange consists of light-colored sands and clays, with occasional beds of lignite. It is exposed along the bluffs and in occasional stream cuttings. On the upland surface the Lafayette sand and gravel, 10 to 30 feet thick, rests on the Lagrange. The bluffs overlooking the alluvial region are capped by the loess, which rests on the Lafayette and may be 20 to 50 or 60 feet thick near the bluffs, but gradually thins out to the east and merges into a surface loam. The surface of the Mississippi bottoms is composed of Recent alluvium.

Water resources.—There are numerous streams in the county which flow into Mississippi River, Mayfield Creek, and Obion Creek. The smaller of these streams may go dry in the fall. The larger ones are permanent. For domestic purposes cisterns are largely used in the loess region, because of the hardness of the shallow water. They are also used in the middle and eastern parts of the county in places where the depth to underground water is inconveniently great. The average depth of wells on the uplands may be taken at from 60 to 100 feet. Water may be obtained at any point from the Lagrange. For a supply sufficient for domestic or boiler use it would not usually be necessary to go more than 150 or 200 feet, the depth in any one case depending on the coarseness of the sand. For town supply it might be advisable to explore the deeper beds, as there is usually no difficulty in pulling a pipe back in case a better supply is not found at the greater depth. Along Mayfield and Obion creeks bold springs of pure, cold water from the Lagrange sands occur. Back on the uplands weak springs, in which the water is not so pure nor so cold, are found in local depressions here and there. As a rule they are used for watering stock only, and some of them go dry in late summer.

At Arlington open wells from 30 to 50 feet deep afford a limited supply of water. If larger quantities are wanted, for manufacturing or other purposes, it is necessary to go considerably deeper. Several wells for boiler supply are reported to be 120 feet deep, but in the log given below lignitic clay occurs at this level. One well is reported to be 228 feet deep, with water rising within 12 feet of the surface. It furnishes all the water that can be raised by a suction pump with a capacity of 400 gallons a minute, located on the surface. The log, given from memory, is as follows:

Log of well at Arlington, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	50	50
Orange sand and gravel with clay	12	62
Brown clay, lignitic	133	195
White water-bearing sand	33	228

At Bardwell, elevation 357 feet, there are numerous ordinary wells. The town waterworks gets a supply from two wells reported to be about 250 feet deep. The Illinois Central Railroad has two wells that furnish an abundance of water for all railroad purposes. The following log of these two wells was given from memory:

Log of Illinois Central Railroad wells at Bardwell, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	100	100
Sand and blue clay in alternate strata, individual beds of sand being not over about 6 feet thick	523	623

The pipe was pulled back and a 20-foot strainer set at 120 feet from the surface. The water rises within about 30 feet of the surface and is soft and excellent for all purposes. The elevation of the well head is about 386 feet, 4 feet lower than the railroad level given above.

At Cunningham bored wells are used very largely.

At Laketon, elevation 314 feet, there is a well owned by the Mobile and Ohio Railroad which furnishes from the Lagrange an excellent water for locomotive use. Detailed data could not be procured.

At Milburn water is obtained from open and bored wells that range in depth from 20 to 60 feet. The quality of the water is good. There are very few springs.

FULTON COUNTY.

Topography.—Fulton County is in the extreme southwestern part of Kentucky. It is bounded on the south by Tennessee and on the west by Mississippi River. Its area is 178 square miles. Something more than a third of the county is in the alluvial region of Mississippi and Bayou de Chien rivers and Obion Creek. This portion is low and flat, its average elevation being about 290 feet. The remainder of the county, extending from Hickman southward and eastward, is a level to rolling upland whose western and northwestern borders are hilly or bluff-like. The bluff at Hickman rises to an elevation of 461 feet and may be the highest point in the county. Low water in the Mississippi at Hickman is 257 feet and high water 303 feet. The average elevation of the upland is about 400 feet.

Geology.—The formations of this county are the Lagrange, the Lafayette, the loess, and the alluvium. Their relationships are exactly the same as in Carlisle County (p. 129). The Lagrange has in this county, however, a greater amount of fine siliceous clay than usual. The best exposures are in the bluff at Hickman, a section of which is given on page 37. This section has been discussed so fully on pages 37–9 that repetition is not necessary here.

Water resources.—Springs along the bluffs are usually strong and yield either pure or chalybeate water. Elsewhere they are weak. Wells in the alluvium are shallow, as usual, and furnish poor water. On the uplands water may be reached in sufficient quantities for domestic use at depths of 40 to 100 feet. When obtained at slight depth it is apt to be hard. The Lagrange contains comparatively few beds of water-bearing sand coarse enough to set a strainer in and hence difficulty is experienced in some places in making a satisfactory deep well in it. A log of such a well is given under Hickman (p. 133). The streams on the uplands are all small and some go dry at times, so that in places ponds or wells must be used for stock water.

At Fulton, elevation 366 feet, water is obtained at depths ranging from 25 to 100 feet. There is a system of waterworks supplied by several wells, each 100 feet deep. The quality of the water is medium. It is used for general domestic purposes and also by the Illinois Central Railroad in locomotives. Between 600,000 and 700,000 gallons per day may be pumped. The log is as follows:

Log of Illinois Central Railroad well at Fulton, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	25	25
Shell of rock	$\frac{2}{3}$	$25\frac{2}{3}$
Sand	22 ±	$47\frac{2}{3}$ ±
Yellow clay	23	70 ±
Coarse, white water-bearing sand (entered)	30	100 ±

At Hickman, elevation of low water, 275 feet; high water, 303 feet; railway, 306 feet; top of bluff, 461 feet, water is obtained from ordinary wells and from cisterns to some extent. A waterworks plant has been built, and water is pumped to a standpipe on top of the bluffs, from which it flows into the mains.

Capt. H. A. Tyler has a deep well on the upland near town, 130 feet above high-water mark, or 433 feet above sea level. The water rises within 110 feet of the surface. It is soft and good for washing or boiler purposes. It contains some iron. Two logs were given. The first, by Captain Tyler, is as follows:

Log of Tyler well near Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay (loess)	80	80
Soft sandstone (Lafayette)	10	90
Blue clay	460	550
Very fine sand	6	556
Tough blue clay	144	700
White water-bearing sand (entered)	17	717

A 20-foot strainer point was set at 717 feet. The well is 6 inches in diameter, and 5,400 gallons per hour may be pumped. Another driller had previously gone to a depth of 830 feet within 10 feet of this well, but the pipe was telescoped. From 717 to 830 feet the section is reported to be mostly sand, with a little clay.

The second log is by Mr. W. B. Johnson, of Johnson & Flemming, the drillers. It is as follows:

Log of Tyler well, near Hickman, Ky., given by drillers.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	80	80
Orange sand and gravel	30	110
White sand and gravel, traces of clay	165	275
Blue clay	182	457
Hard rock	6	463
Blue clay	157	620
White pipe-clay	80	700
Coarse water-bearing sand	17	717

The well was successfully finished at this depth.

It is interesting in this connection to be able to compare these logs with that given by Mr. W. F. Crosby, of Crosby & Co., the drillers of the well 10 feet distant, in which the pipe was telescoped at 830 feet, in order to see how three records of the same section, all given from memory, compare. It is as follows:

Log of drill hole at Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay and sand	200	200
Quicksand	30	230
Blue and brown gumbo clay, lignitic	280	510
White chalky substance with a fine vein of water just under it, not tested	40	550
Blue gumbo clay, lignitic, as above	150	700
Sand	160	860

A comparison shows that while there is agreement in that the larger part of each section is lignitic clay, and water-bearing sand was reached at a depth of 700 feet, there is considerable difference in details, and this may often be true where records are given from memory. Men who make a business of drilling wells would undoubtedly find it to their own advantage to keep careful logs of all wells drilled, especially when drilling in sands and clays so variable in thickness that memory can not be depended on to preserve the details of the various sections.

In a valley 3½ miles somewhat north of east from Hickman, at an elevation estimated to be about 30 feet above high-water mark (about 333 feet above tide), a well was drilled on Mr. R. A. Tyler's stock farm. The water is hard, and rises within 30 feet of the surface. The log is as follows:

Log of well on R. A. Tyler farm, near Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay with small iron nodules (loess with buckshot)	57	57
Gray-black quicksand with lignite	53	110
Coarse white water-bearing sand, parted by very thin strata of white pipe clay.	82	192

Near Hickman is the Nick Combs mineral spring, which is discussed on page 145.

At Jordan, elevation 398 feet, water is obtained from wells and cisterns. Wells vary from 35 to 110 feet. Water is most abundant at 100 feet, and is reported to be hard.

GRAVES COUNTY.

Topography.—Graves County is quadrangular, its long dimension extending north and south. It is situated in the middle of the Jackson Purchase region from east to west and extends from the Tennessee line more than two-thirds of the way to Ohio River. It is the largest of the Kentucky counties here discussed, its area being 550 square miles. The surface slopes gently to the northwest. It may be described as level to rolling away from the main drainage lines and hilly along them. Especially on the eastern (right-hand) side of West Fork of Clarks River and Mayfield Creek, the two principal streams of the county, the valley wall rises steeply to the upland level. On the western side of each stream, however, the ascent to the general upland level is not abrupt, but gradual. The highest point in the county and also in the Jackson Purchase region, according to Loughridge, is in the southern portion, about halfway between Lynnville and Pilot Oak. Its elevation is given by Loughridge as 625 feet. The average elevation of the southern part of the county is about 550 feet. The slight northwestward slope makes the elevation of the northern part of the county about 425 or 450 feet. The lowest point is about 320 feet, where West Fork of Clarks River leaves the county.

Geology.—The geologic formations of the county are the Porters Creek, Lagrange, Lafayette, and Columbia loam. The Porters Creek is confined to the northeastern part of the county and is concealed by the Lafayette except where the latter has been removed by erosion along West Fork of Clarks River. It has its typical character, being a dark leaden-colored clay, usually called soapstone, with occasional silty or sandy beds. The clays in many places are cut by sandstone dikes, as has been described at some length on page 30. The thickness of this clay is probably not over 125 or 150 feet. It dips westward beneath the Lagrange.

The Lagrange underlies all of the county except the Porters Creek area just mentioned. It also is concealed by the Lafayette except in stream or other cuttings. It consists of light-colored sands and clays, some of which are dark with lignitic matter, while others are white and plastic and are mined for pottery making.

The Lafayette is well developed as an orange-colored sand, grading down into or underlain by a gravel bed which forms its basal portion. This gravel is highly ferruginous as a rule.

On the uplands the Columbia loam rests on the Lafayette. It is a light-colored sand beneath, usually soft and containing a few pebbles derived from the Lafayette, and grades up into a loam, the entire thickness being 5 to 10 feet. A most excellent exposure is seen in the town gravel pit just east of the railroad track in the southern part of Mayfield. Pl. VII, *B* (p. 126), is a view of this pit. It shows at the base 18 feet of soft variegated and cross-bedded Lagrange sand. Over it, with a sharp contact line between them, are 20 to 22 feet of Lafayette gravel. It has much sand intermixed and some thin iron crusts and stands well in vertical faces. The gravel is principally chert, though there are some pieces of vein quartz. It is used for road material and is being removed in two benches, which are well shown in the plate. Over this and separated by a sharp but irregular line are 10 feet of material that is lighter in color and softer, so that it does not stand up with vertical faces so readily. The lower 3 or 4 feet of it are chert and vein-quartz pebbles, similar in size and rounding to the Lafayette pebbles below, from which they were undoubtedly derived. The slight reworking to which they have been subjected has deprived them of their iron and of their bright color and given them a leached appearance. They grade upward into sand and the sand into surface loam, both of which have the same light-brown or leached color, which readily serves to differentiate this deposit from the Lafayette beneath. It is the representative of the Columbia. In the plate it is the upper bench extending to the top of the pit.

Water resources.—Except along the stream valleys, springs are few and generally weak. The small streams have in consequence weak flows, and the great majority of them go dry in late summer. West Fork of Clarks River runs all the year. Everyone has ponds for stock. Along the stream valleys water may generally be reached in wells 20 to 30 feet deep. On the uplands in the southern, central, and northeastern parts of the county wells are 60 to 125 feet deep, and in some places do not then reach water. In the northwestern part of the county the average depth to water is somewhat less. Cisterns are largely used.

It should be possible to get good water in the "soapstone" or Porters Creek area by going through it into the Ripley sand beneath. In the Lagrange area good water may be obtained almost anywhere at depths of 200 to 400 feet. Because of the great average elevation of the county, water will not rise to the surface, and, indeed, in most of the county there will probably be little if any rise at all. Shallower water is found at the base of the Lafayette in places where there is enough hardpan to make an impervious basin. Such wells are weak and are apt to fail in dry seasons, and are in addition fed by surface rain water, and so liable to contamination.

At Bloom there are a few springs, but water is generally obtained from cisterns.

At Cuba water is obtained from wells that are from 100 to 150 feet deep; cisterns are largely used.

There are some good springs in the neighborhood of Dublin, but no wells. Cisterns are used.

At Fancyfarm the supply has come from cisterns chiefly, but small tubular wells, some of which are 120 or 130 feet deep, are coming into use. They furnish good, pure water from the Lagrange sand. In low places wells are less than 50 feet in depth.

At Farmington cisterns are used almost exclusively because of the depth to underground water. There are a few small tubular wells 120 to 165 feet deep.

At Folsomdale there are a few wells, but cisterns are almost universally used.

At Freda there is only one well. It is 90 feet deep and is not used. There are a few springs. Cisterns are used by all.

At Golo cisterns are used almost exclusively. The few wells and springs are used for watering stock.

At Lowes water is obtained mostly from cisterns. There are only a few wells and they average 100 feet or more in depth.

At Lynnville cisterns are used almost exclusively. A blue clay is struck very near the surface and few of the attempts at boring wells are successful. It is probable that a well sunk 100 or 150 feet would go through this blue clay and find water-bearing sand in the Lagrange. Such clay beds in the Lagrange are not usually over 100 or 150 feet thick.

At Mayfield, elevation 480 feet, underground water is struck at a depth of 90 or 100 feet, and cisterns have been largely used there and in the surrounding country, where the same conditions as to depth to water prevail. A system of waterworks has been installed by a private corporation, which has one 10-inch well 304 feet deep, one 8-inch well 300 feet deep, and two 8-inch wells 160 feet deep. The water stands in them at about 80 or 90 feet from the surface. It is pure and clear and is raised by air lift to the surface and then forced into a standpipe. Only one well is pumped at a time. The average daily consumption is about 250,000 gallons. The following log was given by the driller, Mr. W. B. Johnson, of Johnson & Flemming:

Log of well at Mayfield, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay, like loess	12	12
Orange sand and gravel, dry	60	72
Orange sand and gravel, water bearing	218	290
Thin parting of pipe clay at		290
White water-bearing sand	50	340

At Pryorsburg, elevation 420 feet, water is obtained from wells 30 to 40 feet deep and from cisterns.

At Ragsdale cisterns are used principally. Wells are scarce.

At Sedalia six wells of small diameter from 120 to 170 feet deep furnish a very pure water. Cisterns are largely used.

At Symsonia there are no wells or springs of any note. Cisterns are used.

At Tice cisterns are used almost exclusively. There are a few wells 30 to 75 feet deep.

At Viola, in the valley of Mayfield Creek, wells are 18 to 75 feet deep; most of them are bored and the water has more or less iron in it.

At Vultoncreek water is obtained from cisterns for domestic use and from ponds for stock. The few springs go dry in summer. There are no wells in the vicinity.

At Water Valley, elevation 386 feet, wells are used principally. They range from 25 to 40 feet in depth. Cisterns are also used to a considerable extent. A mineral well is noted on page 146.

HICKMAN COUNTY.

Topography.—Hickman is one of the western tier of counties and reaches on its western side Mississippi River and on its southern side the Tennessee State line. Its area is 224 square miles. Along the Mississippi and the lower course of Obion Creek within the county there is a small area of low alluvial land. The remainder of the county is a level or rolling upland in the interstream areas, which becomes broken and hilly along the main streams and near the bluffs that overlook the Mississippi flood plain. The average elevation of the upland is about 375 feet and of the alluvial region about 310 feet. Low water in the Mississippi is 260 to 270 feet. The upland slopes gently westward and is drained by Bayou de Chien and Obion Creek into the Mississippi.

Geology.—The geology of the county is the same as that of Carlisle County on the north and Fulton County on the south. The underlying formation is everywhere the Lagrange sand. It is admirably exposed at Chalk Bluff below Columbus and at Columbus. At the latter place about 80 feet of it may be seen forming the base of the bluff, the upper part being a grayish, somewhat jointed clay resembling slightly the clay so prominent in the middle and upper parts of the bluff at Hickman.

Over the Lagrange are 35 feet of Lafayette in the Columbus bluff, the lower 20 feet being gravel and the upper 15 feet a sand at the base, which grades up into a gravel at the top. Eastward from the bluff the Lafayette is as a rule not so thick and is not so heavily charged with gravel.

Along the bluffs facing the Mississippi the loess overlies the Lafayette. The lower part is usually darker than the upper, as described on page 45. The thickness may reach 60 or 80 feet. To the east it thins down and merges into the surface loam.

The alluvium rests on the Lagrange in the river and creek bottoms. It is believed to be of Recent origin.

Water resources.—Streams are numerous and the larger ones flow perennially. Along their valley sides springs are found, but their situation generally precludes their use for domestic supply. Along with the streams and scattered artificial ponds they are used for stock watering. In the alluvial region water of medium quality is obtained at depths of a few to a score feet. Back on the uplands wells vary considerably in depth, but often go 75 or 100 feet. Cisterns are used in many places because of the hardness of the water in the loess area or the depth to it elsewhere. Good water may be gotten in the Lagrange at moderate depths, and small driven wells should be found practicable at any point where difficulty is encountered in obtaining a satisfactory supply.

At Clinton—elevation at Illinois Central Railroad 354 feet, at courthouse 389 feet—there are numerous bored wells 100 to 150 feet deep. The town supply is obtained from two wells that draw their water from white sand 135 or 140 feet deep. It is reported to be hard and to contain iron. The water stands within 30 feet of the surface.

At Columbus water is obtained from shallow wells and cisterns. Factories get their boiler supply from Mississippi River.

Moscow, elevation 313 feet, derives most of its water supply from ordinary wells 40 to 60 feet deep. There are a few pipe wells 80 to 130 feet deep. Both kinds furnish good pure water.

At Oakton, elevation 315 feet, there are a number of pipe wells 75 to 125 feet deep that furnish supplies for domestic and boiler use.

At Springhill hard water is struck at an average depth of 60 feet. Wells in the neighborhood range in depth from 25 to 200 feet. Cisterns are used almost exclusively.

At Stubbs hard water is obtained in wells 20 to 40 feet deep and water of better quality, though frequently containing some iron, in wells 80 to 130 feet deep.

M'CRACKEN COUNTY.

Topography.—McCracken is the eastern of the two northern counties of the Jackson Purchase region. Its northern and northeastern boundaries are Ohio and Tennessee rivers. Its area is 241 square miles. Topographically, there is a threefold division of the surface, just as in Ballard County (p. 122). Along Ohio and Tennessee rivers there is a narrow strip of alluvial flood plain whose elevation on the eastern edge of the county, along the Tennessee, is about 325 feet, and in the northwest corner, on the Ohio, about 315 feet. This flood-plain belt is in many places very narrow. Lying just south of the flood-plain belt is a second bottom or terrace 25 to 35 feet higher than the first bottom. It has an average width of 3 or 4 miles and extends up Clarks River and its east and west forks to a point beyond the county line. It embraces an area of about 85 square miles. At Paducah, which is built upon it, it is well developed and has an elevation of 340 feet. Its surface is level except near the streams which cross it and have trenched their channels 15 to 25 feet beneath its surface. The remainder of the county is an upland region with a rolling surface that is almost level in the interstream areas and considerably broken near the streams that drain it. The general upland slope is slightly northward and its average elevation is not far from 400 feet.

Geology.—The Ripley, Porters Creek, Lagrange, Lafayette, Columbia, and Recent alluvium all occur within the county. The Ripley underlies a strip along the eastern edge and is exposed here and there along Clarks River and on the Tennessee at low water as far north perhaps as Paducah, though at the latter place the writer failed to find any exposures. In the deep well at Paducah, a log of which is given on page 141, it was struck at a depth of 60 feet and is a soft sand with a number of clay lenses that are usually lignitic where seen in the surface exposures in the vicinity.

The Porters Creek overlies the Ripley and in the southeast corner of the county is exposed at intervals along both forks of Clarks River and for some distance down the main stream. It is well exposed on two hills 3 and 4 miles, respectively, south of Paducah, on the road to Mayfield, where it consists of joint clay and silty sand, the latter partly indurated and containing casts of Eocene fossils. Northwest of Paducah it probably underlies most, if not all, of the second bottom as well as the northern edge of the upland, though it is almost entirely concealed by later deposits. Its thickness is about 150 feet.

The Lagrange underlies the central and southwestern parts of the county, but is not exposed except along the deeper stream cuttings. It has its usual character, being a light-colored sand interbedded with occasional clays that are either white or more or less lignitic.

The red Lafayette sand and gravel overlies the Lagrange and the Porters Creek on the upland. It is somewhat uncertain whether it should be regarded as present on the old terrace level or not, but the writer is inclined to think that the gravel and overlying sand and clay on this terrace are not so old as the Lafayette and should more properly be classed as part of the Columbia. At Paducah this terrace has on the surface from a few feet to 30 or 40 feet of silty sand and clay, and beneath it a hard "cement gravel," as it is popularly known, 20 to 30 or more feet thick, with pebbles up to 4 or 5 inches in diameter.

The terrace is cut distinctly beneath the Lafayette-capped upland, and its pebbles are larger than those of the near-by Lafayette gravels, so that it seems younger than the Lafayette.

A few feet of Columbia sand and surface loam overlie the Lafayette and form the actual surface of the upland.

The alluvium is a very narrow strip along Tennessee and Ohio rivers, and is regarded by the writer as entirely Recent in origin. It has been correlated with the Port Hudson, but reasons have been given on page 49 for believing that the Port Hudson does not extend so far north.

Water resources.—There are a number of permanent streams in the county. Clarks River crosses the east end and Mayfield Creek the southwestern part, while a number of small streams rise in the county and flow northward into the Ohio or the Tennessee. Along these streams springs are numerous, but they are utilized to only a limited extent. Most of the water supply of the county is from wells and cisterns. In the terrace belt the water found in the underlying gravel is hard, and the silty material over it is not firm enough to keep cistern walls from cracking and letting water seep into them. In this area exploration for deeper waters should be made. In most places within it the dark Porters Creek clay will probably be found beneath the terrace gravel. This should be drilled through and careful watch kept for a bed of sand in the underlying Ripley coarse enough to be checked by a strainer. If this is not found, the bottom of the Ripley should be reached at a depth of 300 to 400 feet or less, and water would probably be found there or in the broken Paleozoic chert that underlies the embayment deposits in this region. On the uplands wells go from 20 to 150 feet before reaching underground water, and in many places cisterns are used instead.

At Grahamville water is obtained almost entirely from drilled wells. It is said to be very satisfactory as to quality and quantity. There are very few cisterns and practically no springs.

At Massac water is struck in sand at depths of 100 to 120 feet.

At Maxonmill there are a number of fine springs. Wells average from 20 to 40 feet deep and are either bored or dug. One dug in the flats of Massac Creek and described by Loughridge[a] reached the Porters Creek clay at 18 feet from the surface and passed through it and into Ripley sand at a depth of 116 feet, when the water rose 60 feet, but contained so much sulphureted hydrogen that it was unfit for use.

Paducah, elevation of low water 284 feet, high water 334 feet, average town elevation about 341 feet, is underlain by from a few feet to 30 or 40 feet of silty material and that by 20 or 30 feet of rounded gravel in which water is abundant but hard and chalybeate, besides

[a] Jackson Purchase Region, 1888, p. 253.

being probably contaminated by organic matter from the surface. Numerous cisterns have been built, but they almost invariably settle somewhat and crack enough to let in seepage water. The city water supply is pumped from Ohio River into a standpipe that gives a pressure of 40 pounds, which, in case of fire, is increased to 100 pounds by direct pressure. The daily consumption is about 2,200,000 gallons.

A well at the old vinegar works has the following log:[a]

Log of well at vinegar works, Paducah, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam or heavy yellowish clays	30	30
Gravel	10	40
Blackish-blue clay	8	48
Colored sand	6	54
Blackish-blue clay	8	62
Fine white sand to water	50	112

A well was bored about 1888 at Paducah for gas and abandoned at a depth of 1,250 feet. The log, as given by Loughridge,[b] is as follows:

Log of boring for gas at Paducah, Ky.

	Thickness.	Depth.
Post Lafayette:	*Feet.*	*Feet.*
Micaceous brownish surface loam	40	40
Rounded chert and quartz gravel	20	60
Ripley:		
Fine micaceous sand and clay, interlaminated	204	264
Mississippian:		
Débris of white and dark chert, hyaline sand, pyrites, and smoky-quartz crystals. The lower 18 feet is cemented by a bright-red iron ocher, and holds numerous crinoids, bryozoa, and plates and spines of the echinoid *Archæocidaris*	71	335
White, porous, and slightly calcareous rock; also containing many crinoids, bryozoa, and echinoids	90	425
Dark impure limestone, with some crinoids and bryozoa, fragments of cemented calcareous material, and a small flat mass of quartz crystals; the rock is cavernous	45	470
Limestone and siliceous rock, dark and light colored; some calc spar; crinoids, cyathophylloid corals, and pyrites in lower portion; rock is cavernous	48	518
Dark calcareous shale, blue marl, and sand, with small crinoids, spines, and plates of *Archæocidaris*, and cyathophylloid corals	32	550
White calcareous shale, with calc spar, pyrites, and a few crinoids	185	735
Blue limestone, with crinoids; a pentremite brought up from upper portion	400	1,135
Blue limestone, with crinoids; this bed, with the lower portion of that above, is permeated with cracks filled with sand, etc., to bottom of boring	115	1,250

At Ragland a water supply is derived from wells which range from 35 to 65 feet in depth.

Woodville, elevation 423 feet, depends mainly on cisterns. A few 2-inch wells go about 140 feet deep and get water from sand. It contains some iron. The log is as follows:

[a] Loughridge, R. H., op. cit., p. 250.

[b] Op. cit., pp. 321-326.

Log of well at Woodville, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	17	17
Cement gravel	23	40
Loose gravel	20	60
White chalk	2	62
Sand, bowlders, and streaks of pipe clay	25	87
Sand, red at top, then yellow, then white	57	144

MARSHALL COUNTY.

Topography.—The northern and eastern boundaries of Marshall County are formed by Tennessee River. Its area is 332 square miles. Along the Tennessee there is a very narrow flood plain. Rising 25 to 35 feet above it is an old flood plain or terrace from 1 to 2 miles in width, which is merely a continuation of the terrace noted along Ohio River in Ballard and McCracken counties and which has an elevation in the northwestern part of the county of about 340 feet and in the southeastern part of about 350 feet. This same old terrace level forms the valley of East Fork of Clarks River, which flows northwestward across the middle part of the county. This valley has an average width of a mile or more. The remainder of the county is an upland which is almost level in the parts remote from streams, but which, especially along the border adjacent to the Tennessee River Valley, is hilly and much broken by the numerous small streams flowing into the Tennessee. It is also somewhat broken along either side of the valley of East Fork of Clarks River. The upland slopes gently northward and nearly all of the drainage is northward. Its average elevation is between 425 and 450 feet.

Geology.—A strip of Paleozoic limestone lying along the eastern side of the county has a width of 4 to 6 miles west of Tennessee River. Only the portion of the county west of this strip belongs to the embayment region. The formations represented in it are the Ripley, Porters Creek, Lafayette, Columbia, and alluvium.

The Ripley extends from the valley of East Fork of Clarks River eastward to the Paleozoic area and forms a belt about 4 miles wide in the southern part of the county and 6 miles wide in the northern part. It consists of fine micaceous sands and interlaminated dark-gray clays that contain lignitic matter in places. Excellent exposures may be seen at Snow Hill, on the eastern side of Clarks River Valley, along the road from Benton to Briensburg. Away from the stream cuttings the Ripley is concealed by the overlying gravels and sandy clay belonging to the Lafayette and Columbia, but is reached on the upland east of Clarks River at depths of 40 to 50 feet in wells. The thickness of the formation here is not known, but is probably between 200 and 300 feet.

The Porters Creek clay overlies the Ripley on the east and extends from East Fork of Clarks River westward across the remainder of the county. It is, as usual, a joint clay and is almost black when wet, but light gray when dry. With it there are some greensand and some fine silty sand, which is usually indurated into a sandstone or mudstone. It is exposed only along the stream valleys. The writer had no opportunity to examine its outcrop west of West Fork of Clarks River, but accepts its presence there as far west as Pritchard, Graves County, on the authority of Loughridge. Along and east of West Fork it is typically developed. The Porters Creek belt is peculiar in this region in being much broader in surface exposure than it is elsewhere in Kentucky or Tennessee. The width reached is 12 or 14 miles.

The Lafayette has at its base a variable thickness of gravel, which grows heavier, as a rule, to the east and is in many places cemented into an ironstone conglomerate. Above the gravel there are usually 10 or 15 feet of red sand or sandy clay, which also belongs to the Lafayette. This is usually overlain by a few feet of leached surface clay or loam that probably represents the Columbia. In places this loam has some reworked gravel at its base. The Lafayette and Columbia together usually have an aggregate thickness of 30 to 40 feet, and on the uplands completely conceal the underlying formations.

Water resources.—While the larger streams flow the year round, many of the smaller ones go dry in the fall. Springs are numerous along the stream valleys, but elsewhere are scarce or entirely absent. Ponds are used in many places for watering stock. The domestic supply is derived from wells and cisterns, the latter being perhaps the more common. Water may generally be obtained along the valleys at depths of 20 to 40 feet and on the upland at 35 to 40 feet in many places at the base of the Lafayette. Wells often go dry in the summer, and there seems to be a general impression that since the 1886 earthquake they have been more liable to go dry than before. This same opinion has been met with elsewhere in the region, but nowhere was it found so strong as in this county. It is probable that this earthquake may have produced slight cracks in the hardpan ironstone crusts which locally form water-containing basins at the base of the Lafayette and that the downward seepage through these cracks is great enough to cause the basins to be more readily drained during dry seasons than formerly, and hence to cause the wells to go dry more readily. Where a well failed altogether after the earthquake, it would seem evident that the fissures produced were so large that the local basin could no longer hold water, but was drained down into the dry sands beneath.

In the region underlain by the Porters Creek if water is not struck at the base of the overlying Lafayette the well is generally abandoned and a cistern dug. In many places farms have both wells and cisterns. On the uplands east of East Fork of Clarks River the depth to water in the Ripley sand is in many places 60 to 100 feet or more, and in much of that region cisterns are used exclusively for domestic supply and ponds for stock.

At Benton, elevation 368 feet, water is obtained mostly from cisterns. Wells are often dug and in some places reach water at a depth of 35 or 40 feet above the black or dark-gray Porters Creek clay. Such wells prove satisfactory. If this clay, usually described as a black or blue mud, is encountered, the well is abandoned, as water from it is hard and astringent.

In the country west of Benton wells average 35 to 40 feet deep and get water at or just above the base of the Lafayette gravel. Such water is in some wells found to be hard and in others soft. The supply is usually limited, and the well may go dry in late summer. In other places no water is obtained above the Porters Creek clay, and resort is had to cisterns. These are perhaps scarcely as numerous as wells. Probably 40 or 45 per cent of the people use them, while many have both cisterns and wells.

Brewer is well supplied with ordinary wells of 30 to 50 feet depth and springs which bubble out along the foot of the hills bordering the valley of West Fork of Clarks River.

At Briensburg cisterns are used exclusively. In the country around cisterns are the common source of supply. Wells are rare because of the depth to the Ripley sand and the uncertainty of getting water in it.

At Coy water is supplied by wells 30 or 40 feet deep.

At Fairdealing there are a few springs, and some wells that average 35 to 50 feet deep, but furnish only a small amount of water. Most people have cisterns. The springs are at the foot of bluffs along streams, and are mostly chalybeate.

At Fristoe, elevation 352 feet, there are no wells or springs; cisterns are used. From its location in the valley of Clarks River, it should be an easy matter to bore or drive a well through the "soapstone" or Porters Creek clay. While much of the Ripley sand is too fine to be water bearing, yet some beds are usually found in it coarse enough to hold an abundance of water, and as a test with a driven well is not expensive, it would be well worth making.

At Harvey water is obtained from wells 25 to 50 feet deep. In some places the Porters Creek clay is struck before water is reached, and then the well is abandoned and a cistern substituted. In the country just north of Harvey cisterns are used exclusively. Wells do not go dry, but usually have weak flows. Some yield hard water and some soft, according to the nearness or remoteness of the underlying Porters Creek clay.

At Oaklevel water is obtained entirely from shallow wells.

At Palma cisterns are used almost exclusively.

At Paul there are a few springs, but the main water supply is obtained from wells 50 to 75 feet deep.

At Scale there are numerous springs, wells, and cisterns. Wells in low places run about 20 feet deep; on high ground they are 50 to 60 feet. Springs are considerably used for domestic supply.

At Tatumsville cisterns are used almost exclusively for domestic supply and ponds for watering stock.

MINERAL WATERS OF WESTERN KENTUCKY.

Britts Spring, at Stubblefield, Graves County, flows from the bottom of a bluff near a creek and forms along its course a reddish or yellowish deposit of iron hydrate, such as is so characteristic of chalybeate waters. The water is reported by the owner to contain 314 parts per million of solid matter, mainly carbonates of iron and calcium. It has some carbonate of magnesia, traces of the sulphates and chlorides of sodium, potassium, and magnesium, and a good deal of organic matter. It is said to be beneficial in malarial and stomach troubles.

Nick Combs Spring is at the foot of the Mississippi River bluffs, 4 miles southwest of Hickman, Fulton County. There are no hotel accommodations, but the spring has long been known, and people afflicted with kidney or stomach troubles go there in the summer and camp out. The water is chalybeate. Rheumatism, especially, is said to be benefited by its use. Dr. Robert Porter, chemist of the Kentucky Geological Survey, reports[a] it to contain free carbonic acid and 302 parts per million of salts. "These consist of iron, manganese, lime, and magnesia carbonates, with some lime and magnesia sulphates."

Kilgore Spring, 2 miles south of Blandville, Ballard County, is reported by Doctor Peter, as quoted by Loughridge, to yield a slightly chalybeate and alkaline saline water and to contain 64 parts per million of solids. These consist of carbonates, chlorides, and sulphates of iron, soda, lime, and magnesia, with a trace of lithia and some silica.

McGee Spring, on Hurricane Creek, southeast of Blandville, Ballard County, is reported by Doctor Peter to give a good alkaline saline chalybeate water containing 1,645 parts per million of solids and only a trace of organic matter. His analysis is as follows:[b]

[a] Loughridge, R. H., Jackson Purchase Region, 1888, p. 137.

[b] Loughridge, op. cit., p. 138.

Analysis of water from McGee Spring, Ballard County, Ky.

	Parts per million.
Silica (SiO_2)	240
Iron (Fe)	182
Calcium (Ca)	67
Magnesium (Mg)	47
Sodium (Na)	244
Potassium (K)	50
Carbonate radicle (CO_3)	590
Sulphate radicle (SO_4)	62
Chlorine (Cl)	163
	1,645

At Sedalia, Graves County, there is a mineral well 133 feet deep at which a hotel has been erected for the accommodation of guests. An analysis of the water by A. M. Peter shows it to contain 77.1 parts per million of solids, "nearly half of which is organic, the rest consisting of carbonate of iron and silica, with small quantities of carbonates, sulphates, and chlorides of calcium, magnesium, and sodium and traces of potassium and lithium compounds."

Water Valley well, at Water Valley, Graves County, yields a sulphate saline water containing, according to an analysis by A. M. Peter, 3,422 parts per million of solids, composed of sulphates of calcium, magnesium, and manganese, a little chloride of sodium, and traces of the sulphates of strontium, potassium, and lithium, and having a decidedly acid reaction. It is recommended especially in diseases of the stomach, liver, kidney, and bowels.

The water from Wickliffe artesian well, at Wickliffe, Ballard County, a description and analysis of which are given on page 125, has earned a reputation of being very valuable in kidney disorders, having made, as reported, remarkable cures in some serious cases.

RESOURCES OF SOUTHERN ILLINOIS.

Area included.—The Cretaceous and Eocene embayment deposits in Illinois are confined to Alexander, Massac, Pulaski, and Pope counties, in the extreme southern part of the State. Later surficial deposits of gravels, loess, and loam extend beyond these counties, but do not present hydrographic problems that would warrant their inclusion and discussion here. Since observations were not made in as much detail here as elsewhere, these counties will not be discussed separately, but all the data obtained will be given together.

Because of the presence of the loess, Lafayette, or alluvium over almost the entire embayment area of southern Illinois, it is difficult to give accurately the outlines of the area so included. The boundary may, however, be approximately traced as follows: Beginning on the east at New Liberty, on Ohio River in Pope County, the edge of the embayment deposits as they overlap the Mississippian rocks runs northwestward just north of the Pope-Massac County line for 12 miles or more and then continues almost coincident with this county line until within a mile or two of the chain of swamps in northern Massac County. It then curves southwestward and westward parallel and 1 to 2 miles south of this chain of swamps and the westward continuation of the same low valley, once occupied by the Ohio, but now by the Cache, until it crosses the Cache at Ullin. It continues its westward course 4 or 5 miles west of Ullin, and then curves southwestward until near the northern end of Horseshoe Lake. Thence it turns westward and reaches Mississippi River at Santa Fe. The area thus included is about 480 square miles.

Topography.—The region may be divided topographically into three parts. The first is the present low flood plain of Mississippi, Ohio, and Cache rivers. The second is a higher, older flood plain corresponding to the terrace level found south of the Ohio in Kentucky. In some places the edge of this old plain is well marked, while in others it seems to rise irregularly from the lower bottom. It is most prominently developed on the Ohio in Massac County above Metropolis. The third part is the rolling to hilly upland surface, the average elevation of which is probably near 400 feet.

Geology.—The formations found within the area are the Ripley, Porters Creek, Lagrange, Lafayette, loess, and alluvium. In addition, the underlying Paleozoic rock that forms the floor of the embayment region outcrops in a few places near the edge of the area and in Ohio River at Grand Chain, where it is evidently faulted. It is also reached in the few places where deep wells have been sunk.

The surficial covering so thoroughly conceals the embayment formations that it is impossible to give with any great accuracy their areal extent without much detailed work, and even then extensive boring would very probably be necessary to accurately delimit them. It may be said, however, that the Ripley underlies the loess and Lafayette probably over a small area in the south end of Pope County and over all of Massac County included within the embayment region. Along its northern edge it is rather thin, and ordinary wells occasionally go through it and enter the Paleozoic rock, here usually a limestone. The Ripley consists of interbedded clays and sands. The clays are either light colored and plastic, in which case they may be mined for pottery use, or dark blue or brown, from disseminated organic matter or lignite. Occasionally one of these dark-blue clays struck in ordinary wells is fetid, probably from hydrogen sulphide. The sands are in most cases fine grained. Here and there a coarse bed is struck, and at the base of the formation there is reported to be a gravel and cobble bed forming a basal conglomerate. This formation is exposed in various places between Grand Chain Landing and New Grand Chain and between Metropolis and

New Columbia, and is very similar lithologically to the Lagrange formation as typically developed in Tennessee. In the clay pits at Grand Chain Landing the clays contain leaf impressions. The Ripley probably forms most or all of the exposures of sand and clay to be seen along the Cache River bluffs below Ullin.

The Porters Creek is exposed at the surface only in the bluffs near North Caledonia, and even there the exposure contains so much sand and sandy clay that it could not be surely identified as Porters Creek were it not for the greensand present. As already stated greensand indicating marine conditions is found in Tennessee and Kentucky to be characteristic of the Porters Creek, but is entirely absent in the Ripley below and in the Lagrange above, both of which are of nonmarine origin. The Porters Creek is struck in the deep well at Mound City at a depth of 180 feet and is 100 feet thick. At Cairo it is reached at a depth of 375 feet and is 124 feet thick. In each case only 25 feet of sand representing the Ripley, if the writer's interpretation of the section is correct, were found under the Porters Creek. The areal extent of the formation west of the North Caledonia exposure is not known. It may have a narrow surface outcrop or may be entirely concealed by the overlap of the Lagrange.

The Lagrange also is poorly exposed in Illinois, but from exposures and well sections in Kentucky a short distance south of Cairo it seems practically certain that its base is reached in the Cairo wells at a depth of 375 feet and at Mound City at a depth of 180 feet. Since it is not much different lithologically from the Ripley, both being nonmarine, more or less lignitic sands and clays, it is possible that at least a portion of the sand and clay found north of Grand Chain and Metropolis may really belong to the Lagrange, having overlapped the Porters Creek outcrop. While field exposures might fail to settle the question thus raised, it should be capable of easy solution from the paleobotanical evidence in the shape of leaf impressions which the clays in that border region would furnish. Unfortunately no such study has yet been made of these deposits.

The Lafayette contains its customary quota of chert gravel, and a larger proportion of it than usual is cemented by limonite into an ironstone conglomerate. It is found on the uplands wherever stream cuttings or railway excavations have gone below the loess and is seen along the bluffs of the Ohio in a few places. At Metropolis and just above, at old Fort Massac, a well-cemented ironstone conglomerate is exposed at or near water level and extends below it. This material possesses apparently all the characters of the Lafayette and may be of that age, but the ease with which gravels of even very recent age may become cemented into a firm ironstone that looks very much like typical Lafayette gravel was forcibly impressed on the writer some time since during a trip down Tennessee

River, and so he prefers to regard the age of these conglomerates in the Ohio, while probably Lafayette, as not clearly proved.

On the uplands the loess mantles everything in Pulaski County, and it is also found in numerous places in the western part of Massac County from Metropolis northward, though much thinner than in Pulaski County.

The alluvium occurs in the low plain of Mississippi, Ohio, and Cache rivers.

Water resources.—Springs and small streams are not very abundant in the region, and ponds are commonly in use for stock. The domestic supply is derived from wells and cisterns. Water from wells on the uplands varies much in quality and in depth. It is hard or soft, according to the presence or absence of the loess. In some places it is inconveniently deep and in a few instances it is reported as foul smelling. In many cases, however, good water is obtained in open wells and a large number of such wells are in use. Some farmers have wells, cisterns, and ponds. In the alluvial region the shallow water is hard, and at Cairo and Mound City deep wells have been put down that furnish an abundance of water suitable for most purposes.

At America, Pulaski County, wells of moderate depth and cisterns are used. Two miles to the west, on what is probably an extension of the terrace plain, wells run 25 to 30 feet deep and give hard water. The section is entirely through clay, and it seems that deeper wells fail to find Lafayette gravel, showing that probably it had been cut out before the clay was deposited. The clay is very likely the equivalent of the loess on the hills farther north. These hills rise 40 to 60 feet, and in them wells strike hard water at depths of 30 to 40 feet in the Lafayette gravel beneath the loess. Some wells go through this gravel and get water at greater depth in what is probably Ripley, though it may be overlapping Lagrange. The quality of the water would be about the same in either case.

One and three-fourths miles south of Belknap, Johnson County, on the bayou, a driven well entered, at a depth of 12 feet, a sand that was somewhat quick and contained lignitic streaks and gravel layers at intervals. It was sunk to 116 feet, when the pipe proved too weak to drive farther and the well was abandoned. Water rises 112 feet in it. This shows a considerable depth of soft material, probably largely or entirely alluvial, in the abandoned channel of the Ohio at this locality.

At Cairo, Alexandria County, elevation of extreme low water 267 feet, of high water 321 feet, and of union depot 313 feet, water is struck in sand and gravel deposits underneath the surface clay at a depth of about 50 feet. It is hard and otherwise objectionable from a sanitary point of view. Cisterns were formerly used, but difficulty was experienced in preventing them from cracking and letting in seepage water. The city water supply is obtained from Ohio River. It is pumped at the rate of about 2,000,000 gallons per day into a standpipe 160 feet high. The water contains some lime and scales somewhat. One firm heats water for boiler use to between 186° and 206° F., and thus precipitates most of the calcium carbonate.

In and near Cairo several deep wells have been sunk. The location and logs of several of them are as follows:

The first deep boring is at the power station of the Cairo Electric Light and Power Company, on lot 29, city block 26, and was drilled in 1896–97 to a depth of 1,040 feet. The diameter is 10 inches at the top and decreases to 6½ inches at the bottom. The log is as follows:

Log of well of Cairo Electric Light and Power Company, Cairo, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4.5	4.5
Sandy blue clay	50.5	55
Sand and gravel, similar to river deposit	60	115
Sand with kaolin partings	15	130
Kaolin	4	134
Sand with a few thin layers of kaolin and traces of shale and lignite	240	374
Shale or marl, slate colored	124	498
Very soft sand	20	518
Partings of shale and lignite	5	523
Chert or "Elco" gravel	177	700
Chert pebbles	5	705
Hard, reddish calcareous sandstone; no water in it	335	1,040

From the sand at 498–518 feet water rose to the surface and flowed about a gallon a minute. The following sanitary analysis of this water was made at the University of Illinois by Prof. A. W. Palmer:

Analysis of water obtained between 498 and 518 feet from well of Cairo Electric Light and Power Company, Cairo, Ill.

	Parts per million.
Nitrogen as free ammonia	0.35
Nitrogen as albuminoid ammonia	.022
Nitrogen as nitrites	.009
Nitrogen as nitrates	.204
Chlorine as chlorides	83
Oxygen consumed	3.4
Total solids by evaporation	365
Fixed residue	348
Volatile matter (loss on ignition)	17.1

Comments of analyst: "Too much time—ten days—had elapsed between collection and analysis to be sure of sanitary condition, though it is probably satisfactory. The mineral matter consists mainly of carbonate of lime, with some sodium chloride and very little sulphate. Not excessively hard. Not likely to form a hard scale in boilers."

Professor Palmer also analyzed the water from the 705-foot level, with the following results:

Analysis of water from depth of 705 feet in well of Cairo Electric Light and Power Company, Cairo, Ill.

[Parts per million.]

	1.	2.
Nitrogen as free ammonia	0.36	0.36
Nitrogen as albuminoid ammonia	.016	.02
Nitrogen as nitrites	None.	None.
Nitrogen as nitrates	.06	.06
Chlorine as chlorides	110	110
Oxygen consumed	1.4	1.2
Total solids by evaporation	356	353
Fixed residue	346	339
Volatile matter (loss on ignition)	10	14
Hardness	115	....

Comments of analyst: "Of exceptional purity and perfectly safe and wholesome for drinking. Hardness is quite moderate." The two samples were taken at the same time.

The Halliday Hotel well, on lot 24, hotel addition to city of Cairo, has practically the same log as the one given above. The boring went to 824 feet, but there was no increase of water below the 700-foot level. It was drilled in 1897; diameter at the top 8 inches, at the bottom 4½ inches; temperature 62° F.; head 12 feet above the surface.

A well on the W. P. Halliday estate, near the mouth of Cache River, in about the center of the NE. ¼ sec. 2, T. 17 S., R. 1 W., in Alexander County, had the following log:

Log of Halliday well in the NE. ¼ sec. 2, T. 17 S., R. 1 W., Illinois.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and blue clay (buckshot)	40	40
Sand and gravel; drift with kaolin partings	104	144
Brown shale or marl	112	256
Gray sand	54	310
Chert, fractured—"flint rock"	72	382
Dark-brown sand	10	392
Chert, fractured—"flint rock"	34	426
White sand	42	468
Flint rock with slight fractures	62	730
Flint pebbles	7	737
Flint rock	69	806

From the last 7 feet water with a head of 12 feet flows at an estimated rate of half a million gallons a day. There was no increase in water below 735 feet. Drilled in 1898; temperature 62° F.

Another well at E. W. Halliday's residence on lot 16, block 70, between ninth and tenth and Walnut and Cedar streets, in Cairo, had the following log:

Log of well at residence of E. W. Halliday, lot 16, block 70, Cairo, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and friable blue clay (loess or terrace)	50	50
White sand with thin partings of kaolin (Lagrange)	325	375
Gray shale or marl (Porters Creek)	130	505
Fine, closely compacted white sand (Ripley)	24	529
Flint rock, but slight fractures (Paleozoic)	220	749
Flint pebbles	4	753
Hard calcareous sandstone	58	811

From the 753-foot level there is a flow of 60 gallons per minute, with a head of 12 feet above the surface. The temperature is 62° F. Four hundred gallons per minute may be pumped.

There are other similar wells at several manufacturing establishments in Cairo and the records run much the same. The temperature seems to be 62° F. in each case and the static head is the same. The material described as flint is a very light colored chert of Mississippian age that is exposed in a 150 or 200 foot face at a quarry between Tamms and Elco, from which it is extensively shipped for railroad ballast and road metal. In this locality it is highly fractured, so that it is virtually of macadam size without crushing. As struck in wells it is in some places massive and solid, while in others it is seamed and broken, and is then called gravel by the drillers, though in neither wells nor in the Elco gravel quarry is the material waterworn or rounded, being simply mechanically disintegrated chert still in place.

Grand Chain station, Pulaski County, is on the upland. The surface is covered with loess to a depth of 10 to 40 feet. In a few places it is cut through and the Lafayette gravel beneath is revealed. Many people use cisterns. Water is struck at depths ranging from 20 feet in low places to 85 feet on higher levels. Much of it is hard. Ponds are generally used for stock.

At Metropolis, Massac County, wells in town are from 30 to 50 feet, and end in what seems to be Lafayette gravel, as it is exposed near old Fort Massac at water level in ledges that dip gently under water and reappear a mile up the river. North of town wells average 50 to 60 feet in depth, and get water from the Ripley sand a short distance beneath the Lafayette gravel. In some places wells have been dug 150 feet without getting water. As a rule the water is soft, especially in the deeper wells. Cisterns are easily excavated in the soft loess that forms the surface and many are used.

Northeast and east of Metropolis water is found at depths of 60 to 125 feet in the Ripley sands, where they are not too close grained to furnish an adequate supply, as is often the case. Many cisterns are in use in this section of the county.

At Mound City, Pulaski County, there is an 8-inch well that flows with a 6-foot head. No analysis of the water could be obtained. It is fairly good for boilers and is used for ice making and general town supply. The log is as follows:

Log of well at Mound City, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	20	20
Gravel and sand (Lagrange)	160	180
Blue shale (Porters Creek)	100	280
Dark sand (Ripley)	25	305
"Elco" gravel (Paleozoic)	300	605
Limestone	45	650

Round Knob, Massac County, is just south of the swamps that mark the old course of the Ohio westward across the northern part of the county. Hard Paleozoic rock is struck at depths of 20 to 30 feet and so very few wells have been put down. Cisterns may be easily constructed in the loess, sand, and gravel that cover the old hard rocks and they are used almost exclusively. In the swamps to the north water is everywhere near the surface and is readily obtained by driving a few feet of pipe and attaching a small suction or pitcher pump, as it is usually called. Needless to say the quality of this surface swamp water is not the best.

At Tamms, Alexander County, on a part of the old river-terrace plain, water is obtained from driven wells of 18 to 25 feet depth in river gravel and alluvium. Some wells give hard water, others soft. Cisterns are largely used.

PROPERTIES OF THE WATER.

As might be expected the underground waters of the region discussed in this paper vary much in quality, but the variations are caused chiefly by differences in the amounts of a few substances that are ordinarily found present.

The most common type of water may be described as a pure water, or one practically free from mineral ingredients. Many of the springs and shallow wells and a number of the deep wells furnish water of this character. This is especially true of springs and wells located in the sandy formations such as the Eutaw, Ripley, Lagrange, and, in a restricted sense because of its thinness, the Lafayette. The purer sands of these formations contain very little that is soluble in the water that percolates through them and hence it contains little or no dissolved mineral matter.

When the sands are not pure but contain, as they do in certain places, vegetable matter, usually in the form of lignite, along with various chemical compounds that have resulted from its decomposition, the water is apt to dissolve more or less of these substances and acquires thereby a mineral character.

The above-mentioned formations, with the exception of the Lafayette, contain beds of clay here and there that are generally lignitic and as a result contain more or less iron pyrite. Water derived from these clay beds is always more or less mineralized, but in many cases is perfectly usable for most purposes. Such mineral waters are described along with others on page 120. These clays exist either as strata of considerable areal extent or as local lenses embedded in the sands, but though they may be silty and somewhat porous there seems to be as a rule very little circulation of water between them and the surrounding sand. A well ending in the silty clay may derive a scant or moderate supply of water from it, and another near by, ending just above or just below it, may furnish a pure water of very different character. This is especially true of local lenses of clay or silt that occur in the Lagrange. They probably represent either old stream channels abandoned and silted up or similarly filled old long-shore lagoons behind sand bars of the contemporary estuary in which the sands were then being deposited. Deep waters are more apt to contain mineral matter than shallow waters in the same kind of material, because of the many chances for deep waters, in their long underground course form their entrance into the beds to their exit in wells, to come into contact with soluble substances, and this tendency is further increased by the greater solvent powers they possess by being under pressure during their slow underground course. In view of this fact it is surprising that so many of the deep waters are so pure.

The mineral waters of the region come either from the clays contained in the Eutaw, Ripley, or Lagrange formations or from the Selma, Porters Creek, loess, or alluvium. Local clay beds may possibly be struck in the Eutaw, Ripley, and Lagrange at almost any place, so that no geographic bounds for such cases can be stated. Wherever struck, however, good water may usually be gotten by going somewhat deeper and entering an underlying sand.

The areas of Selma, Porters Creek, loess, and alluvium may be seen from the geologic map (Pl. I, p. 26). In the Selma clay area the water is usually hard because of the calcium carbonate it contains, while in the Porters Creek area it is hard usually from the same cause and may contain in addition sulphates of iron and alumina, which make it astringent or like alum to the taste. In some places the Porters Creek water contains so much sulphureted hydrogen that both man and beast refuse to touch it. In the loess area the water is hard because of calcium carbonate dissolved from the loess. In the alluvial region the water usually contains iron carbonate or sulphate and very often calcium and magnesium carbonate and sulphate in addition.

The mineral salts usually found in the waters of the region, then, are calcium and magnesium carbonate and sulphate, iron carbonate, and occasionally iron sulphate. Carbonic acid gas is present in the carbonate waters to hold the lime, magnesia, and iron oxide in solution, and sulphureted hydrogen is occasionally found. These and and other compounds appear in the chemical and sanitary analysis given in the preceding pages. They will each be discussed briefly here and the way they affect the quality of the water will be indicated.

The calcium and magnesium carbonate and sulphate render the water hard. This hardness may be removed by boiling or by heating almost to the boiling point when it is caused by the carbonates, and such water is known as temporarily hard. If, however, the hardness is caused by the sulphates it can not be so readily overcome and the water is then said to be permanently hard.

When soap is added to a hard water, chemical combination occurs between the soap and the carbonates and sulphates and no soap is available for making a lather to aid in washing until all of these salts have thus entered into combination. In this way much soap is wasted and the insoluble compounds formed make a sticky, gummy precipitate that is disagreeable and highly objectionable. Hard water is therefore undesirable for washing and laundry purposes.

If the hardness is temporary—that is, due to carbonates—it may be removed by a preliminary boiling of the water, when the free carbonic acid which holds the carbonate in solution is driven off and the carbonate is precipitated. If the hardness is permanent, or due to sulphates, it can be removed only with considerable more difficulty by processes which are described in the discussion of boiler waters (p. 157). Most of the hard waters of the region are "temporarily hard."

In cooking, hard water deposits incrustations on the inside of vessels in which it is boiled and also deposits lime salts on the vegetables or meats and tends to darken vegetables cooked in it. For drinking, however, it is probably not objectionable from a sanitary point of view, though it may impart a taste to the water not entirely pleasant, and is supposed by many to be harmful in rheumatic and gouty disorders. In certain diseases of the bowels, kidneys, and bladder the carbonate of calcium is probably beneficial and the carbonate of magnesium is even more valuable.

There is comparatively little definite information as to the effect of hard water when used for stock. In some places a good proportion of the diseases of horses is attributed to their drinking hard water.

Iron carbonate when held in solution in water by an excess of carbonic acid is precipitated when the water reaches the surface and is allowed to stand for some hours, thus permitting the escape of the carbonic acid. The precipitated iron carbonate decomposes and an iron oxide is formed, which may be seen as a red or yellow slimy incrustation in the vessel holding the water or along its course from a spring. Such water is at first clear and sparkling. On standing, it becomes more or less opalescent or milky while the precipitation is going on and when this is completed it is once more clear, but is no longer chalybeate.

Aside from the lime and magnesia salts already mentioned, iron carbonate is the most widely distributed of the minerals in the waters of the region. Nearly all the "mineral springs" of the region are chalybeate. For cooking purposes such water is objectionable because of the discoloration caused by the precipitated iron. It is even more objectionable for washing white clothes, as it stains them yellow or brown.

Iron is an essential ingredient of the red corpuscles of the blood and is also found in various other portions of the body. Chalybeate waters are valuable for drinking in cases of anemia and generally in impoverished conditions of the blood arising from any cause.

Sulphate of iron is found in some of the waters, especially in those of the Porters Creek area. Such water is astringent and tonic, but is not so palatable nor so generally valuable as a remedial agent as that containing carbonate of iron.

In the carbonated waters free carbonic-acid gas enables the water to hold in solution such carbonates as may be present. This gas imparts to the water an attractive sparkle and is an aid in cases of indigestion and stomach disorders. Sulphureted hydrogen is present in some springs and wells and may be instantly detected by the odor as of rotten eggs which characterizes it. Such water is considered of value in certain kidney and bowel troubles and in rheumatism, gout, and skin diseases.

In sanitary analyses judgment as to the healthfulness of any given water must be based very largely on a knowledge of the local conditions or surroundings, and the analytical findings should always be interpreted by such knowledge.

USES OF THE WATER.

The principal uses of water in this region are for household and laundry purposes, stock watering, and steam boilers, but it is also used to a greater or less extent for soap making, wool washing, dyeing, brewing, and distilling. In the section on properties of the water sufficient reference was made to the qualities necessary for household, laundry, and stock use. The qualities of water which affect its use for the remaining purposes mentioned above will be briefly described here.

The most important industrial use of water in the region is for steam boilers. Numerous steam sawmills, corn and flouring mills, and cotton gins are scattered over the region, while in the towns and cities steam is used for a great variety of power purposes. The railways use large quantities in their locomotives and at many places have sunk their own deep wells.

Where the boiler water is soft, no difficulty arises from its use, but where hard a deposit known as scale forms in the boiler. The scale formed by water containing calcium or magnesium carbonate is deposited in the bottom of the boiler, usually as a loose, soft slush, that is easily removed by blowing off the boilers. If the water is permanently hard, however, the scale formed by the calcium and magnesium sulphates is deposited on the tubes and bottom of the boiler as a hard coating that is difficult to remove, and because it is such a poor conductor of heat causes a much larger fuel consumption for the same steam production. It is calculated that scale one-fourth inch thick requires 50 per cent increase in fuel and scale one-half inch thick 150 per cent increase.

To obviate the difficulties arising from scale, hard water may be softened by treatment before or after being introduced into the boiler. If temporarily hard water is raised to the boiling point before being used for feed water, the carbonates are deposited. This practice is followed at a number of steam plants in the region. There is some loss of heat by radiation in the softening tanks, but the net cost is low, as the softened water enters the boiler at almost the boiling point. Permanently hard water does not deposit its sulphates at boiling temperature, but must be heated in a closed vessel to a temperature of 150° C. or over, and even then the precipitation is not complete. Such water may be softened more conveniently by adding sodium carbonate, when a chemical interchange takes place, and sodium sulphate and calcium carbonate form and are precipitated as a soft, incoherent deposit that may be easily removed.

Many steam plants in the region use boiler compounds, certain quantities of which are introduced into the boiler at stated intervals. Such compounds when intelligently and carefully prepared are efficient and satisfactory, though it is probable that in most cases they cost entirely too much. It may be said that 3 cents per thousand gallons is a fair cost for softening and that any excess above this sum is so much money wasted. Aside from the question of cost, however, an honestly prepared boiler compound has many advantages for the small plant, where often the boiler is cared for by a man without the technical knowledge necessary for applying an intelligent treatment to the water.

Many substances are recommended for the treatment of water in the boiler. Some act chemically, while others are mechanical and designed to entangle the scale or mix with it and prevent its getting hard or adhering firmly. Some of these are good, others may do neither harm nor good, while still others at the temperature and pressure of a working boiler are corrosive and injurious. They include such substances as powdered glass, tan bark, coal dust, molasses, sawdust, chips of wood, burnt sugar, ground coffee, logwood, soda ash, caustic soda, table salt, and many others. Any treatment should be applied only with a full knowledge of the composition of the water.

In soap making soft water is highly desirable, because calcium and magnesium salts cause a loss of lye by their union with it to form insoluble compounds that are useless for cleansing purposes.

In some cases farmers in the region wash their own wool clip, and there are one or two woolen factories that also wash wool. The water for such use should be soft. Hard water makes the fiber less pliable and in the finishing stages of the washing a deposit of lime salts is formed that clings to the wool and interferes with dyeing.

In dyeing as pure a water as possible should be used. If it contains organic matter, putrefaction of the dye extracts used may result. Lime is objectionable in mordanting and aniline dyes dissolve poorly in water containing it. Iron is also harmful in dyeing with certain colors and is prohibitive of bleaching.

The quality of the water used in brewing has a very important influence on the color, taste, and other qualities of the beer produced. The water so used should be a good drinking water and free from organic matter. Ammonia, nitrates, and nitrites are objectionable. Calcium sulphate improves the quality of the product, and if deficient is added. Sodium chloride in small quantities is not objectionable, but in larger quantities prevents the germination of the malt. While a little iron may be harmless, it makes the product darker and in larger quantities interferes with malting and may produce an objectionable odor. Calcium and magnesium carbonates should be present in moderate quantities, especially if calcium sulphate is deficient. They tend to give the product a lighter color and to improve its taste and keeping qualities. Organic matter is harmful since it causes putrefactive fermentation in the malt. Iron compounds retard germination. Calcium chloride checks the development of the yeast in the fermentation of beer, while calcium sulphate promotes it. Much the same is true of the qualities desirable in distilling.

STATIC LEVEL OF UNDERGROUND WATER.

The elevation to which underground water rises in a number of the more important places in the region has been ascertained with as much accuracy as possible. In a few cases where there was an uncertainty involving only a few feet one way or the other, this is indicated by the ± sign. Where data given are suspected of being entirely wrong, the figure is followed by an interrogation mark.

As shown on the sketch map (fig. 13), these elevations are fairly

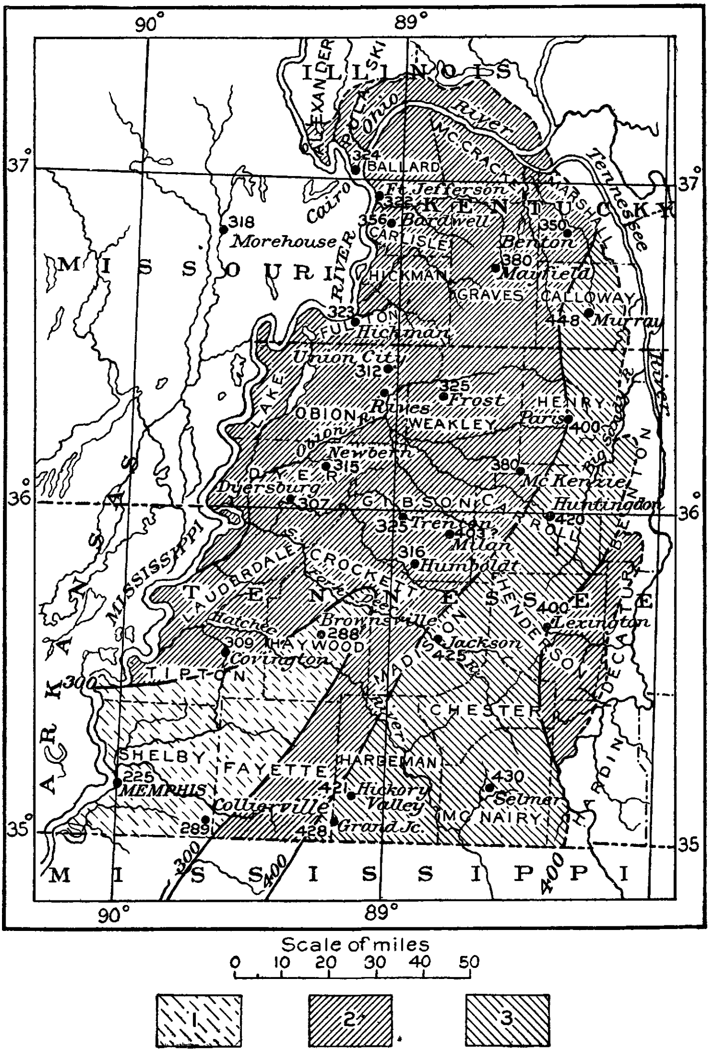


FIG. 13.—Sketch map showing hydrostatic levels. 1, Water rises between 200 and 300 feet above sea level; 2, between 300 and 400 feet; 3, between 400 and 500 feet.

well distributed over the area and vary in a rational way, in view of the facts that the outcrop of the porous beds in the embayment area across Tennessee and Kentucky is to the east and that water flowing through these beds encounters friction enough to cause it to rise to successively less and less height as it goes westward. Water also enters at the outcrop across the north end of the area in Illinois and flows southward with a similarly decreased gradient. By reference to the map an approximation may be had of the height to which underground water would rise at almost any place in the region. The following list gives the elevation above sea level to which deep underground water rises at the places indicated:

Elevation to which underground water rises in embayment area of Tennessee, Kentucky, and Illinois.

	Feet.		Feet.
Bardwell, Ky	356	McKenzie, Tenn	380
Benton, Ky	350	Martin, Tenn	325
Brownsville, Tenn	288	Mayfield, Ky	380±
Cairo, Ill	324	Memphis, Tenn	225
Collierville, Tenn	289	Milan, Tenn	403?
Covington, Tenn	309	Morehouse, Mo	318
Dyersburg, Tenn	307±	Murray, Ky	448
Grand Junction, Tenn	428	Newbern, Tenn	315
Hickman, Ky	323	Paris, Tenn	400
Hickory Valley, Tenn	421	Rives, Tenn	300
Humboldt, Tenn	316	Selmer, Tenn	430
Huntington, Tenn	420	Trenton, Tenn	325±
Jackson, Tenn	435±	Union City, Tenn	312
Lexington, Tenn	400	Wickliffe, Ky	322±

METHODS AND COST OF WELL DRILLING.

In olden times open dug wells were the only kind used, and in localities where underground waters are near the surface they are still common. In most cases they are 3 or 4 feet in diameter. Where the material is very firm they are either not cased or the casing is set in only the lower part. Where the material is soft a casing, usually of wood and square, is used for the whole depth. Occasionally such wells are walled with brick. Where 20 to 40 feet deep they cost on the average from 40 to 50 cents per foot to dig if in soft sand or loess. If the material is clay and harder the cost is somewhat more.

The bored well was next introduced in the region. The first one was put down toward the middle of the nineteenth century and they soon became common in the Selma clay and other areas where it was necessary to go to considerable depths, such as 200 feet or more. These wells were usually 10 or 12 inches in diameter and in firm clay were left uncurbed below the first 10 or 20 feet. In softer materials, where curbing was necessary, a square or octagonal curbing of 2-inch plank was pushed down after the auger, which was essentially like a wood auger. In case a consolidated layer was struck it was broken to pieces, usually by a crowbar or other heavy iron let drop drill fashion upon it. Long cylindrical buckets with valves in the bottom are used for drawing the water. In many places such wells are put down to-day and prove very satisfactory. They cost 15 to 30 cents per foot, according to kind of material and depth.

Driven wells have come into use within comparatively recent years. Where the depth to water is known to be slight a 2 or 3 inch piece of iron pipe, usually galvanized, is shod with a short strainer, or perforated section, pointed sharp at the end, and driven by force into the ground, and a small suction or pitcher pump attached to the upper end. Such a well has the advantage of having a tight joint between the earth around and the outside of the pipe, so that surface water and contamination can not directly enter the well by trickling down the sides of it. Such a well 20 to 40 feet deep will cost complete considerably less than a dollar per foot. Sometimes such wells are driven deeper, but a depth is soon reached beyond which it is not practicable to drive the pipe, as it telescopes.

Where greater depth is necessary than can readily be obtained by driving, the pipe is "pumped down," as it is called. An outer pipe is sunk into the ground and within it is sunk another which is shod on its lower end with a small chisel or cutting edge to loosen up the material and which has a current of water forced down through it to wash to the surface the earth loosened by the bit. Such wells are in many cases 2 inches in diameter and 100 to 200 feet or more in depth. A well of this size usually furnishes an adequate supply for all household purposes. At mills of any kind wells 3 to 4 inches in diameter are often used. For a town or other large supply the diameter is 6, 8, 10, or 12 inches and the inner pipe is kept turning; this mode of drilling is called the hydraulic rotary process. In work in quicksands the counter pressure of the column of water forced down from the surface is often the only thing that prevents the sand from rushing up inside the outer pipe and settling around the tools so that it would be impossible either to sink farther or pull back the pipe or the tools. Such work requires much experience and care, and if quicksands are encountered the tools are kept going day and night from the time the well is started until it is finished, to prevent the loss of the well and tools.

If hard beds are encountered, an ordinary hard-rock deep-well drill must be used, and the hole may have to be reamed out afterwards in order to drive the casing lower. In some cases where hard rock, such as the Paleozoic floor beneath the embayment deposits was struck, a diamond drill has been used to deepen the well. At Cairo, Ill., and elsewhere in that vicinity, however, such attempts were unsuccessful because of the hard, sharp-edged chert, or "Elco" gravel, encountered. This chert soon tore the diamonds from their setting or cut to pieces the soft iron cuff that held them and caused their loss. The ordinary chisel-shaped deep-well drill was substituted and worked without trouble.

Where such wells are drilled the outfit of the driller must be extensive and must include a standard-sized deep-well rig or derrick and equipment for hard rock, sand, clay, and quicksand. It is work, too, in which experience and good judgment are necessary in deciding where to place the strainer or finish the well in order to get a good supply of water, free from milkiness or clay, and from sand that will slip through the strainer slots to cut them out, clog up the well, or cut out valve packing and piston chambers. Drilling soft deposits, such as characterize this region, is an art in itself and requires experience that can be obtained only in such a region. No amount of drilling in hard rocks will prepare a driller for successful work in soft materials.

The cost of drilling wells of this type varies somewhat, but for wells 150 to 200 feet deep the cost per foot runs about as follows: Two-inch, $1; 3-inch, $1.50; 4-inch, $2; 6-inch, $3.50; including casing and a hand pump for the smaller wells. For large, deep wells, where a more elaborate outfit is necessary, the cost is considerably more, and for 10-inch wells 600 to 1,000 feet deep or over may run $7 to $9 per foot. The Memphis wells cost complete with the best of materials and double or triple casing and tunnel connections about $5,000 each, while private wells there ranging from 400 to 600 feet deep can be bored for about $8 per foot. There is one record of a well in another part of the region drilled partly 8-inch and partly 6-inch and about 600 feet deep for $1,800, but this is exceptionally low and probably the figures given were not meant to include the cost of the casing.

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N.

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