DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 233

WATER RESOURCES

OF THE

BLUE GRASS REGION, KENTUCKY

BY

GEORGE CHARLTON MATSON

WITH A CHAPTER ON THE

QUALITY OF THE WATERS

BY

CHASE PALMER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1909

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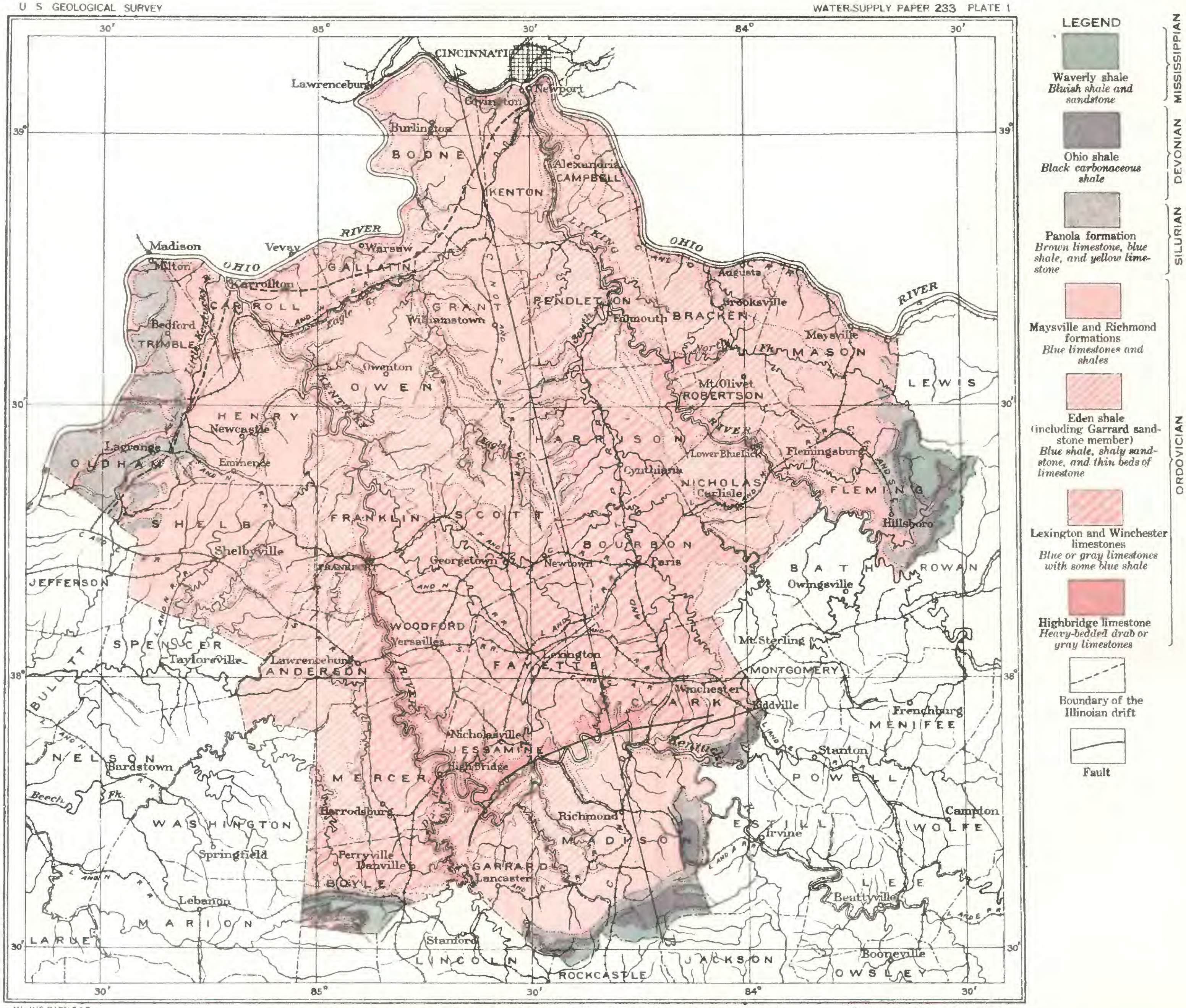

GEOLOGIC MAP OF THE BLUE GRASS REGION, KENTUCKY

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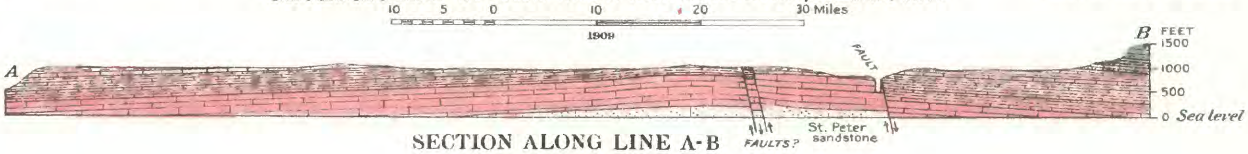

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WATER RESOURCES OF THE BLUE GRASS REGION, KENTUCKY.

By George Charlton Matson.

INTRODUCTION.

The area described in this report comprises about 7,225 square miles in northeastern Kentucky, lying between parallels 38° and 40° north latitude and meridians 83° and 86° west longitude. It includes the major portion of what is commonly known as the "Blue Grass region," together with small areas of the more mountainous portions of the State, and covers the following counties: Anderson, Boone, Bourbon, Boyle, Bracken, Campbell, Carroll, Clark, Fayette, Fleming, Franklin, Gallatin, Garrard, Grant, Harrison, Henry, Jessamine, Kenton, Madison, Mason, Mercer, Nicholas, Oldham, Owen, Pendleton, Robertson, Scott, Shelby, Trimble, and Woodford. It is bounded on the north and west by Ohio River; on the east and south by portions of the boundary lines of the marginal counties. (See Pl. I.)

Geographically the Blue Grass region forms part of the Appalachian Plateau, which extends from the eastern edge of the Allegheny Mountains and the Cumberland Plateau westward to the Mississippi lowlands. Because this part of the Appalachian Plateau is drained by Ohio River, Campbell[a] suggested that it be called the Ohio Basin. The northwestern boundary of the Ohio Basin was regarded as extending from Mississippi River near Cairo across Illinois, Indiana, and Ohio to the west end of Lake Erie.

No systematic study of the occurrence of underground water in Kentucky was made prior to the summer of 1906, when such work was assigned by the United States Geological Survey to the author of this paper, who completed field and office work within the following year; but it should not be inferred that no earlier observations were made. Numerous references to the occurrence of water are found in the early reports of the State Geological Survey, by Dr. David Dale Owen. Underground waters, especially the mineral springs of the region, are discussed in some detail in the reports issued while Prof. N. S. Shaler was state geologist. Many observations on the mineral springs of Kentucky were made by W. M. Linney while John R. Proctor was

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898, p. 1.

state geologist. Since the beginning of the present Kentucky Geological Survey, of which Prof. Charles J. Norwood is director, the underground waters have been studied by Prof. Arthur M. Miller and others, and a recent report by Prof. August F. Foerste discusses the waters of the Silurian and Devonian formations of the east-central part of the State. Chemical studies of Kentucky waters were begun about the middle of the last century by Dr. Robert Peter, chemist of a university at Lexington, Ky., and when the first Geological Survey of Kentucky was organized Doctor Peter was appointed its chemist. After his death he was succeeded by his son, Dr. Alfred M. Peter. Any adequate discussion of the work done by these men is impracticable; the magnitude and great value of the work will be evident to all who examine the various reports of the Kentucky Geological Survey and the Kentucky Agricultural Experiment Station.

In 1904 Dr. Chase Palmer began a chemical study of the waters of Kentucky, Salt, Dix, and Green rivers. This work was continued in 1905 and Doctor Palmer then extended his investigations to the underground waters of the State. The results of part of his work are presented in the chemical chapter which forms part of this report. Incidental references to the water resources are found in all the histories of the State, but the most important publications about the water resources of the Blue Grass region are the various reports of the Geological Survey of Kentucky and the annual reports of the Agricultural Experiment Station. The information in regard to the quality of the water is especially voluminous. This information consists largely of analyses made by Dr. Robert Peter, chemist of the first and second geological surveys of the State, and his son, Dr. A. M. Peter, chemist of the Kentucky Agricultural Experiment Station. A part of the information given in the state reports has been compiled for publication in this paper, but most of it is in such form that it can not readily be arranged for presentation. A list of the principal reports dealing with Kentucky waters is presented herewith, and to these publications the reader is referred for further information.

LIST OF PAPERS CONTAINING INFORMATION IN REGARD TO KENTUCKY WATERS.

Geological Survey of Kentucky.
- David Dale Owen, director.
  - Report for 1854–55. 1856.
  - Second Report, for 1856–57. 1857.
  - Third Report, for 1856–57. 1857.
  - Fourth Report, for 1858–59. 1861.
- N. S. Shaler, director.
  - Reports of Progress, 1874–75, vol. 1, new series, 1876.
  - Reports of Progress, 1877, vol. 2, new series, 1877.
  - Reports of progress, 1877, vol. 3, new series, 1877.
  - Report of Progress, 1878, vol. 4, new series, 1878.
  - Report of Progress, 1880, vol. 5, new series, 1880.

Geological Survey of Kentucky—Continued.
  John R. Proctor, director.
    Geology of Garrard County, by W. M. Linney. 1882.
    Geology of Mercer County, by W. M. Linney. 1882.
    Geology of Clark County, by W. M. Linney. 1884.
    Geology of Mason County, by W. M. Linney. 1885.
    Geology of Fleming County, by W. M. Linney. 1886.
    Geology of Henry County, by W. M. Linney. 1887.
    Geology of Shelby County, by W. M. Linney. 1887.
    Geology of Oldham County, by W. M. Linney. 1887.
    Chemical analyses, A, 1884, by Robert Peter, chemist, and John H. Talbot and A. M. Peter, chemical assistants.
      The first, second, and third chemical reports of the Geological Survey of Kentucky; reprinted from vols. 1, 4, and 5, new series.
    Chemical report, A, vol. 2, 1885, by Robert Peter, chemist, and A. M. Peter, assistant chemist.
      Contains the fourth chemical report of the Geological Survey of Kentucky; reprinted from vol. 5, new series (pp. 5–93).
    Chemical report, A, vol. 3, 1888.
  C. J. Norwood, director.
    The oil and gas sands of Kentucky, by J. B. Hoeing. Bull. No. 1, 1905.
    The lead and zinc bearing rocks of central Kentucky, by Arthur M. Miller. Bull. No. 2, 1905.
    Chemical report of the coals, clays, mineral waters, etc., of Kentucky, by Robert Peter. Bull. No. 3, 1905.
    The Silurian, Devonian, and Irvine formations of east-central Kentucky, with an account of their clays and limestones, by Aug. F. Foerste. Bull. No. 7, 1906.

Kentucky Agricultural Experiment Station.
  First Annual Report. 1888.
  Seventh Annual Report. 1894.
  Eighth Annual Report. 1895.
  Tenth Annual Report. 1897.
  Eleventh Annual Report. 1898.
  Twelfth Annual Report. 1899.
  Thirteenth Annual Report. 1900.
  Fourteenth Annual Report. 1901.
  Fifteenth Annual Report. 1902.
  Sixteenth Annual Report. 1903.
  Seventeenth Annual Report. 1904.
  Eighteenth Annual Report. 1905.

HISTORICAL SKETCH.

The pioneers of Kentucky entered the State through the mountain passes to the east, bringing with them, perforce, the barest necessities of life, and were compelled to rely on game for a large part of their food supplies. These early settlers found that certain saline springs were frequented by large game, and that these springs or the traces (trails) leading to them formed the best hunting grounds.

The sites of Boonesboro (founded by Daniel Boone) and Harrodsburg, the first settlements in the State, were chosen because of their proximity to good springs, and one of the springs near Boonesboro furnished salt water, which doubtless attracted deer and other wild animals. The same reason determined the location of scores of the early settlements and nearly all the important cities and towns of the State. Some of the Kentucky springs, such as Bryant Station Spring and Lower Blue Lick Spring, were later made famous in connection with the struggles of the settlers against the Indians, and still later large springs formed objective points for the armies of both Bragg and Buell.

Practically all the old mansions of the Blue Grass region were built where spring water was accessible, but when the inhabitants began to build houses upon the divides many wells and cisterns were dug. Doubtless the disastrous cholera epidemics of the first half of the eighteenth century stimulated the digging of cisterns, and during the last generation many have been constructed. In favorable localities the drilled wells have largely supplanted the dug wells, but they will probably never supplant the cisterns.

The early industrial enterprises of the Blue Grass region consisted of mills and distilleries, many of which relied upon springs for their water supplies; but with the development of the country, the establishment of new routes of travel and new centers of trade, and the enlargement of the industrial enterprises, the spring supplies became inadequate and many of them have been abandoned. At the present time much water for industrial use is drawn from streams or wells, although springs continue to hold a very important place, and in some localities drilled or driven wells are used.

As already indicated, the villages grew up about springs from which each family drew enough water for its individual needs; but when the villages came to install public supplies, they commonly sought either well or surface water, until at present only one city, Georgetown, takes its water supply from a spring. While it has usually proved impracticable to use either wells or springs for municipal supplies, many of the smaller towns have public wells or springs which furnish water for a number of families.

NEED OF THE INVESTIGATION.

The great need for definite information in regard to the water resources of the country has long been evident to both practical and scientific men, and in the Blue Grass region the subject has keen interest for sanitarians, householders, manufacturers, and civic communities.

In Kentucky, as elsewhere, the occasional outbreaks of water-borne diseases, such as typhoid fever, have emphasized the necessity of obtaining pure water supplies or preventing the pollution of present supplies. Hundreds or even thousands of dollars have been wasted in unsuccessful attempts to procure water by drilling deep wells, and the usefulness and the safety of many city supplies have been seriously impaired by improper location or faulty construction of wells. Two examples of useless drilling may be cited. At one place, where water was needed for the irrigation of flowers, an attempt was made to obtain a supply by drilling about 600 feet into a rock formation that furnishes large quantities of water in only a few places, and never furnishes water of the quality needed except within about 100 feet of the surface; and an attempt was made to supply water for a small city by sinking a well to a depth of nearly 2,000 feet in a locality where there was no possibility of procuring enough fresh water from a single well to supply more than two or three families, and where no water suitable for a city supply could be found more than 100 feet below the surface. Obviously a knowledge of these conditions would have effected great saving in time and money.

The problem of procuring water for industrial purposes is recognized as of great importance, particularly when a large amount of water of a certain quality or of a definite range of temperature is required. Many manufacturing plants have been located with an absolute disregard of the suitability of the available water supply, and the owners have subsequently found the cost of procuring the needed water one of their heaviest burdens. It is probable that some factories in the Blue Grass region will, in the course of a few years, be forced to pipe water from a considerable distance or move their entire plants.

In some parts of the area water for stock is obtained directly from springs and streams, and in other localities dams are built to impound surface water. Many stockmen, however, realize that stagnant water is inferior in quality, and some have already drilled wells to supply their stock; others would undoubtedly adopt the same means if they had any assurance that water of satisfactory quality could be obtained. A few have selected poor locations for the wells and have obtained inadequate supplies of water of unsatisfactory quality.

GEOLOGY.

GEOLOGIC HISTORY.

The rocks which underlie the Blue Grass region comprise formations belonging to the early periods of geologic history. The systems represented are known to geologists as Ordovician, Silurian, Devonian, Carboniferous, etc. The rocks belonging to each of these groups are further subdivided into the formations which are mentioned in the accompanying table and in the subsequent pages of the text. In the table the name of the oldest formation is placed at the bottom and the succeeding formations are arranged in regular order. This arrangement is a most satisfactory one, because when undisturbed the formations lie one upon another like the leaves of a book. However, in this case the leaves are great masses of stone in the form of clay, sand, shale, sandstone, and limestone, sometimes nearly homogeneous, but more often mixed together or arranged in successive beds from a fraction of an inch to several feet in thickness.

All the older formations of the Blue Grass region were deposited in water, and are therefore called sedimentary rocks. A careful study of these rocks will reveal many interesting facts concerning their history. Embedded in the limestones and shales are many shells, which represent the organic life which existed in the water while the rocks were being deposited. Some of these shells appear much like those which now live in the seas, while many others may be connected with forms now living by examining the rocks of successive geologic ages and noting the gradual modifications which have taken place. The relation between the shells of organisms now living in marine waters and those found embedded in the rocks of the Blue Grass region, together with many other facts, show that the formations were deposited beneath the sea. Although it is difficult to restore the outlines of the ancient ocean in which the geologic formations of the Blue Grass region were deposited, the composition of the rocks gives much information concerning the depth and character of the waters. As most of the shells must have belonged to organisms which lived in shallow water, the depth of the sea could not have been very great. This conclusion would also be reached by a consideration of the nature of the material comprising the rocks themselves. The worn character of some shells bears testimony of such wave action as would take place only in shallow water, and the presence of sand and mud, which have since been consolidated into sandstone and shale, is evidence of shallow water and the proximity of land to supply such sediments. The great thickness of some of the limestone shows the existence of long periods when the seas were comparatively free from sediment and animal life flourished and decayed, leaving their calcareous shells to be consolidated into rock. In the Blue Grass region the earlier formations appear to have been deposited in comparatively clear waters, for the older rocks are largely limestone. The younger formations were laid down in seas which were often muddy. and hence sandstones and shales predominate.

After the deposition of the limestones, sandstones, and shales of the Blue Grass region, the rocks were raised above sea level in the form of a low dome. Probably the arching of the strata had been begun at an earlier date, but it culminated about the close of the deposition of the Carboniferous rocks. The apex of this dome lies in Jessamine County, and hence it is known as the "Jessamine dome." From the apex the rocks dip gradually outward, sinking at the rate of a few feet per mile. In places the forces which produced the doming disrupted the rocks and caused the severed ends of the beds to slip past each other. Such breaks are known as faults, and the Kentucky River fault, which is shown in a solid line on the accompanying map, is an excellent example. Other smaller faults occur in various parts of the region. Following the doming came a long period of erosion, which reduced the surface to a low plain, known to geologists as a peneplain. Subsequent uplift permitted the dissection of the early peneplain and the formation of another at a lower level. The early peneplain is represented by the tops of the mountains which border the Blue Grass region, and the younger one by the uplands which surround Lexington. This upland, which is known as the Lexington peneplain, was formed during the portion of geologic time known as the Tertiary. The meandering streams of Tertiary time deposited broad belts of gravel, sand, and clay in their shallow valleys, and the remnants of these deposits constitute the Irvine formation. Since the deposition of the Irvine formation the Blue Grass region has been subjected to erosion, and the streams have cut deep channels, of which the Kentucky River gorge is an excellent example.

At the beginning of the Quaternary there was a great change in climatic conditions, which permitted the formation of a vast sheet of ice in northeastern North America. This ice sheet existed in the glacial period, and at the time of its maximum extent its southern border reached beyond Ohio River into Kentucky. After the ice had melted from the United States, there were other glacial invasions, which extended into northern Ohio, but did not reach as far south as Kentucky. During one of these glaciations, which is known as the Iowan, a deposit of buff-colored silt was spread over a narrow strip of land south of Ohio River from the vicinity of La Grange to Fort Thomas. This silt, which is called loess, is an important surface formation in the area mentioned.

A later glaciation, known as the Wisconsin, extended into Ohio. The waters derived from the melting of this ice sheet spread broad terraces of sand and gravel in the Ohio Valley. These terraces may be seen in the Ohio Valley, where they form broad flats above the level flood plains of the stream.

CLASSIFICATION OF ROCKS.

The name Blue Grass region has been restricted by some authors to the area in which rocks of Ordovician age occur at the surface, but the area described in this report includes also formations belonging to the Silurian, Devonian, and Carboniferous systems. The Ordovician formations, however, cover so large a part of the region that they are discussed more fully than those belonging to the other systems.

The following table shows the sequence, character, and thickness of the geologic formations found in the Blue Grass region and the amount and character of the water supply furnished by them.

TABLE 1.—*Geologic column in Blue Grass region.*

System.	Formation.	Character and thickness.	Water supply.	
			To shallow wells.	To deep drilled wells.
Quaternary.	Alluvium.	Sand and gravel along principal streams; coarse clayey gravel along small streams.	Small supplies.	Water in abundance.
	Gravels (Wisconsin).	Sand and gravel in the valleys of the streams. 80 to 120 feet thick.		Water abundant, but hard.
	Loess (Iowan).	Buff loesslike silt, but lacking characteristic texture of loess. Up to 6 feet thick.	Unimportant.	
	Till (Illinoian).	Red or yellow pebbly clay; locally of assorted sands and gravels. 5 to 300 feet thick.	Sands and gravels furnish soft water in abundance to a few wells.	
Tertiary.	Irvine.	Yellow or red clays, sands, and gravels. 3 to 12 feet thick.	Rarely water-bearing; soft water in a few localities.	
Carboniferous.	Newman limestone.	Occurs in small areas on Waverly shale. Not important in this region.		
	Waverly shale.	100 feet or more of blue shale, covered by interbedded shales and hard, even-bedded greenish sandstones. Contains concretionary iron oxide at one or more horizons. 300 feet thick.	The sandstone furnishes very pure soft water at its junction with the underlying shale. The shale furnishes no water.	Not penetrated by deep wells in the Blue Grass region.
Devonian.	Ohio shale.	Thin-bedded carbonaceous black shale. 150 feet thick.	Yields an abundance of highly mineralized water. The most common mineral waters are sulphur, chalybeate, and alum.	Not penetrated by deep wells in the Blue Grass region.

		Usually a cherty magnesian limestone with some shale beds. 30 feet thick.	Furnishes considerable water where the limestone rests on shale. The water is hard and contains magnesia.	Yields moderate quantities of magnesian water.
Silurian.	Panola.	Blue shales and yellow limestones, in places containing chert. Locally includes some sandstone. Varies greatly in thickness, with a maximum of 60 feet. Includes sediments of Niagaran and Onondaga age.	The limestones furnish good supplies of hard water containing magnesia. The shales supply some mineral water for springs and shallow wells.	The limestones furnish considerable water in some localities.
		Heavy-bedded arenaceous limestones, gray or blue, weathering to buff; about 10 feet of dense calcareous shale in the lower part. Locally an impure sandstone. 60 feet thick.	Furnishes an abundance of water in the limestone areas and where the sandstone is not too shaly. Water usually contains considerable magnesia.	Seldom penetrated by wells. The sandy phase may furnish some water.
	Richmond.	Blue or dove-colored nodular limestones and blue shale, the shale beds predominating. 125 feet thick.	Furnishes moderate quantities of hard water.	Seldom furnishes satisfactory supplies.
Ordovician.		Interbedded blue limestone and shale. Shale predominates in northern part of the region, but heavy beds of limestone occur farther south. 80 feet thick.	Where heavy beds of limestone are at the surface, good supplies of hard water are obtained from springs and shallow wells.	The limestone beds furnish considerable water where within 100 feet of the surface. Deep wells may encounter brackish water containing hydrogen sulphide. The best supplies are obtained where the limestone layers are near the surface.
	Maysville.	Interbedded blue limestones and shales, the alternate layers usually thin and nodular. In general the shales predominate, and the limestone layers are in places thin and shaly. Some moderately heavy beds of limestone occur at certain horizons, but the usual thickness of single beds is less than 1 foot. 230 feet thick.	This formation yields moderate quantities of hard water. Water conditions are most favorable where the formation contains most limestone at or near the surface. Contains many springs of moderate size, and shallow wells are commonly successful.	Seldom yields water at depths greater than 150 feet. The best supplies of hard water are commonly obtained within 50 feet of the surface, though in some localities good supplies are obtained at a depth of 100 feet or slightly more. Water encountered below the level of the surface streams is apt to be brackish and to contain hydrogen sulphide.

TABLE 1.—*Geologic column in Blue Grass region*—Continued.

System.	Formation.	Character and thickness.	Water supply.	
			To shallow wells.	To deep drilled wells.
	Eden shale.	In southern part of region upper beds are of shaly sandstones, in some places concretionary, called the Garrard sandstone member; lower part is same as the Eden farther north. In northern part of region the formation consists of blue shales, containing some sandy layers and local beds of limestone. Maximum thickness of the Garrard sandstone member is about 150 feet, and it gradually thins northward. 200+ feet thick.	The sandstone supplies moderate quantities of water in some localities. The shale supplies small quantities of water.	Seldom water-bearing. Deep wells are unsuccessful.
	Winchester limestone.	Blue and gray limestones with some blue shales. Limestone layers commonly rough and in some places having waved upper surface. 60+ feet thick.	Moderate quantities of hard water.	Usually furnishes no fresh water, but may supply strong brines, which often contain hydrogen sulphide.
	Lexington limestone.	Gray crystalline limestone, usually lighter colored and more cherty than the underlying limestone. (Flanagan chert member.) 75 feet thick.	Yields an abundance of hard water for springs and wells. Contains many large underground streams and supplies large springs.	Many good wells. When penetrated below the level of surface drainage the supplies are saline and saline-sulphur.
		Lower 10-35 feet consisting of light-drab argillaceous limestone with shale beds, overlain by 100 feet of gray or blue thin-bedded nodular limestone, separated by thin partings of shale; at the top 20-60 feet of subcrystalline, gray, siliceous sand and locally phosphatic limestone. 194 feet thick.	Supplies an abundance of hard water for springs and wells.	Below the levels of surface drainage supplies mineral waters—usually salt or salt-sulphur.
Ordovician.		Heavy-bedded coarse-grained crystalline cherty limestone; usually gray. 30 feet thick.	Yields considerable hard water.	Will supply no fresh water when found below level of surface streams. May yield salt-sulphur water.

		Dense fine-grained gray or light-drab limestone, 90 feet thick, near the base; covered by several feet of soft fine-grained limestone containing calcite crystals and some pyrite. The upper 20 to 40 feet dove-colored fine-grained limestones, containing many calcite crystals and separated by layers of shale a few inches to 4 feet thick. The top layer usually a light-gray crystalline limestone. Near the top a bed of soft unctuous green clay.	Considerable hard water for springs and shallow wells.	Yields considerable salt and salt-sulphur water.
	Highbridge limestone.	Dense fine-grained limestones, arranged in heavy even beds; light dove-colored to gray. Dolomitic at the top and bottom and containing many seams of dolomite through the entire series. 20 to 30 feet thick.	Some hard water for springs and shallow wells.	Not distinguished from the other Stones River formations. Will yield nothing but salt or salt-sulphur water.
		Dense fine-grained massive limestone, in places partly crystallized. Usually dark drab or dove-colored. Heavy bedded, but with some shaly partings. 285 feet thick.	Yields considerable hard water for springs and shallow wells in Kentucky River gorge. Contains some caverns.	Yields salt or salt-sulphur waters only.
		Known only from well records. Limestone resembling the overlying beds; rarely shale. 100+ feet thick.		Yields nothing but salt or salt-sulphur waters.
	St. Peter sandstone.	A siliceous limestone, not exposed and known only from well records. Occurs at horizon of St. Peter sandstone.		Yields strong salt-sulphur water under sufficient head to rise 580 to 600 feet above sea level. Furnishes flowing wells in the valleys of Ohio, Licking, and Kentucky rivers.

ORDOVICIAN SYSTEM.

ST. PETER SANDSTONE.

At a depth of 100 feet or more below the oldest rocks seen at the surface in Kentucky, the dark, fine-grained limestones of the surface formation are underlain by a greenish or white sandstone or sandy limestone, the transition, as indicated by the well records, being abrupt. This underlying formation has been called Calciferous by the Kentucky geologists, but it is correlated and usually identified with the St. Peter sandstone of the Mississippi Valley by most geologists working north of Ohio River. Well records indicate that beneath the Blue Grass region the St. Peter is composed largely of fine-grained siliceous limestone, whose thickness has not been determined in Kentucky, but wells that have been drilled to a depth of 500 to 700 feet below its top show no marked change in the character of the rock.

HIGHBRIDGE LIMESTONE.

The fine-grained limestone exposed in the Kentucky River gorge in the Richmond quadrangle was named by Campbell[a] the Highbridge, and Miller[b] subsequently included under this name all the rocks exposed in Kentucky lying below the top of Campbell's Highbridge limestone. As thus defined, the Highbridge comprises 400 feet of massive drab or dove-colored fine-grained limestone, in some places so even grained that it resembles lithographic stone. As a rule, however, it contains crystals of calcite, and near the top some of the layers are largely crystalline. About 100 feet beneath the top it is divided into two readily distinguishable parts by dolomitic layers. The lower limestone is nearly always heavy bedded, but the most of the layers of the upper limestone are thin and interbedded with shale beds ranging in thickness from 1 inch to 4 feet.

The great thickness of the Highbridge limestone appears to indicate deposition in comparatively clear water, but toward the close of this period of deposition land-derived sediments predominated at frequent intervals, during which the thin shale beds of the upper limestone were formed.

The Highbridge limestone is exposed in the Kentucky River gorge from below Frankfort to a short distance above Camp Nelson, and some isolated exposures are found in Madison, Clark, and Fayette counties, where the Kentucky River fault brings the upper division of the Highbridge to the surface. The formation is also exposed in the valleys of some of the tributaries of Kentucky River. Thus it extends along Dix River to a short distance south of the line between Boyle and Lincoln counties; along Clear Creek in Jessamine County,

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[b] Miller, Arthur M., The lead and zinc bearing rocks of central Kentucky: Bull. Kentucky Geol. Survey No. 2, 1905, pp. 10-16.

south of Troy; along Jessamine Creek to a point within 5 miles of Nicholasville; along Hickman Creek to a point just north of Union Mills; along Boone Creek to a point just east of Athens. On the smaller tributaries the Highbridge limestone seldom extends more than 5 miles from the river. It does not appear on the upland except in the southern part of Jessamine County.

LEXINGTON LIMESTONE.

As originally defined by Campbell,[a] the Lexington limestone included 140 to 160 feet of strata resting on the Highbridge limestone and covered by 50 feet of cherty limestone, which was mapped as the Flanagan chert. More extensive stratigraphic and paleontologic work led Miller[b] to include the Flanagan chert with the Lexington limestone. Under this definition the formation consists of 200 feet or more of coarse-grained blue or gray limestones, in some places containing shaly partings and thin beds of bluish shale. The limestones are in part thick bedded and in part thin bedded and nodular. At various localities nodules and lenses of chert occur in the upper 50 to 75 feet of the formation.

The Lexington limestone represents deposition in comparatively clear water, but with occasional sediments, which gave rise to the shale beds. Plate II, *B*, shows a section of the formation.

The formation is found over a large area in the region surrounding Lexington, and it is generally considered the basis of the finest bluegrass soils. The northern line of the Lexington limestone passes across Harrison, Bourbon, Scott, and Franklin counties; the western line lies a few miles west of Kentucky River from Franklin County to Boyle County; the southern line crosses northern Garrard and Madison counties; and the eastern line extends through Clark and Bourbon counties. In a part of this central area it is covered by the next younger formation, the Winchester limestone. Small exposures of Lexington limestone are also seen at various points along Ohio River from above Belmont to below Moscow, but in this region the formation does not lie high enough above the stream to reach the level of the upland. The upper beds of the Lexington limestone are important water-bearing strata.

WINCHESTER LIMESTONE.

The name Winchester is applied in this report to the series of interbedded blue limestones and shales resting on the Lexington limestone. As described by Campbell in the Richmond folio, the Winchester limestone included 200 to 230 feet of blue shales and limestones,

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[b] Miller, Arthur M., The lead and zinc bearing rocks of central Kentucky: Bull. Kentucky Geol. Survey No. 2, 1905, pp. 16-22.

extending from the top of the Flanagan chert to the base of his Garrard sandstone. The Winchester of Miller's report on the lead and zinc bearing rocks of central Kentucky represents the lower 40 feet of the rocks which Campbell called Winchester. Later work indicates that the use of the term Winchester to include the entire series of limestones and shales between the Lexington limestone and Campbell's Garrard sandstone is open to objection. At least the lower part and possibly the whole of Campbell's Garrard sandstone is to be correlated with the upper portion of the Eden shale at Cincinnati. Indeed, when traced northward the lower part of this sandstone gradually gives place to the Eden shale. Although the upper boundary of this sandstone, as developed on the eastern side of the Cincinnati arch, appears to fall within the beds usually classed with the lower division of the Maysville, it is thought advisable to adopt the classification which makes the Garrard sandstone a member of the Eden shale and restricts the name Winchester to the shaly limestone of late Trenton age which underlies the Eden shale.

The rocks of the Winchester limestone are much like those of the Lexington, except that the proportion of shale is larger. (See Pl. II, *A*.) At several localities the top of the formation is marked by the base of a current-formed bed of limestone, 18 inches or more in thickness, which shows marked cross lamination and contains fragments of the underlying rock. Many bits of crinoid stems in the layer have led to its being called the "crinoidal layer." In the valley of Licking River this layer appears to rest on the Winchester, but, according to Mr. Ulrich, opposite Cincinnati it rests on the lower part of the Lexington. Thus there appears to be a marked unconformity above the Winchester. The maximum thickness of the Winchester limestone is probably somewhat greater than the thickness given by Miller.

The Winchester appears to represent a period during which frequent alternations of clear and muddy water gave rise to a series of interbedded limestones and shales. The numerous shale beds make the Winchester a rather poor water-bearing formation, but where it is at the surface it usually yields enough water for domestic and farm uses.

The Winchester is exposed along Ohio River on the eastern and western sides of the Blue Grass region. A narrow band of it surrounds the central area of Lexington limestone, and large exposures of it are found within that area.

EDEN SHALE.

The rocks of this formation, where typically developed, comprise about 250 feet of blue shale containing thin scattered beds of blue limestone. In the valley of Ohio River at Cincinnati the Eden

A. WINCHESTER LIMESTONE, WINCHESTER, KY.

B. LEXINGTON LIMESTONE, PARIS, KY.

shale is locally separated from the underlying Lexington limestone by a few feet of gray shale containing characteristic Utica fossils. Near the southern border of the Blue Grass region the upper part of the formation is composed of the sandy shale and sandstone which, as already stated, were called by Campbell [a] the Garrard sandstone and are here called Garrard sandstone member, following the later definition which makes them a part of the Eden shale. The thickness of the Garrard sandstone member is variable, the maximum being about 150 feet. The thickness of the Eden shale where it includes the Garrard sandstone member also varies, but it is in no place more than 300 feet. Some of the limestone layers of the Eden have a wavy upper surface, which appears to be due to ripple marks formed during the deposition of the rock.

At the beginning of the deposition of the Eden shale a large amount of land-derived sediment appears to have been carried into the Ordovician sea. Evidence as to the source of the land-derived sediments forming the earlier beds is lacking, but the character of the Garrard sandstone member suggests that during the deposition of the upper part of the Eden shale considerable coarse sediment was being supplied from some land area to the south. The deposition of this coarse material continued throughout a large part of the period and into the earlier part of the Maysville.

The Eden shale is exposed along Ohio River and its principal tributaries and forms a rim from 15 to 30 miles wide around the central area of Lexington and Winchester limestones. The boundary between the Eden and the Maysville is difficult to map accurately because the Eden shale usually appears in the stream valleys within the areas of Maysville, and the Maysville at many places caps the hills of Eden shale some distance beyond the generalized boundary.

MAYSVILLE FORMATION.

The Maysville formation comprises a series of interbedded blue limestones and shales more than 200 feet thick. Few of the beds of limestone exceed 4 to 6 inches in thickness, and toward the top of the formation many of the beds are sandy. Evidence indicates that the Maysville formation is separable into several subdivisions, but the lithologic variations are as a rule so gradual that the writer found it impracticable to draw satisfactory lines in the time at his disposal. In general the proportion of shale beds is high in the lower and middle parts of the formation, but below the middle and near the top some heavy beds of limestone occur that are sufficiently thick to permit the formation of small caverns.

The transition from the conditions which existed during the deposition of the Eden shale appears to have been gradual, so that the

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

lower portion of the Maysville consists of shale in the northern part of the area and sandstone in the southern part. The limestone beds of the Maysville were deposited during short periods when the sea was comparatively clear.

The Maysville formation is exposed over a large area in the Blue Grass region. It forms a rim about the central area of the Lexington limestone, reaching Ohio River on the north and extending nearly to the mountains on the south.

RICHMOND FORMATION.

The Richmond formation is probably separable into at least three members, but in this report only two subdivisions are recognized. The lower part of the formation consists of blue or dove-colored even-bedded limestone, containing much interbedded shale. Commonly the shale is the predominating rock, and in some places, especially on the east side of the Jessamine dome, the rock appears to be almost entirely composed of sandy shale. The upper division of the Richmond consists of greenish to buff sandy limestones or calcareous sandstones, with some beds of shale. Near Ohio River the upper beds are largely limestone, but toward the south they give place to arenaceous limestones and sandstones which show a marked banding on exposure to the weather. Apparently some of the rocks classified as Medina by the early surveys of Kentucky belong to the upper division of the Richmond. Exposures of the limestone of the Richmond formation are to be seen in the vicinity of Milton, and they extend southward beyond the southern line of Oldham County.

The Richmond was observed at various points on the east and west sides of the Cincinnati arch. It forms a band of varying width about the south and west sides of the Maysville area, and it is well developed outside the Maysville areas on the east side of the Cincinnati arch.

SILURIAN-DEVONIAN ROCKS.

PANOLA FORMATION.

The rocks of Silurian and Devonian age in the area under discussion are sufficiently distinct to admit of separation into at least four formations, but with the exception of the Ohio shale, their thickness and areal extent are insufficient to permit their discrimination on a map of the scale here employed. For this reason the name Panola formation, which was proposed by Campbell, is used for the Silurian and Devonian rocks lying between the top of the Richmond formation and the base of the Ohio shale.

The Panola formation includes representatives of Niagaran and Onondaga age. The basal beds of Niagaran age consist of a heavy-bedded yellow limestone followed by interbedded limestone and blue shale. At some localities these beds contain low-grade iron ore. Niagaran time appears to be represented on the eastern side of the Cincinnati arch by 10 to 20 feet of blue shale containing more or less intercalated yellow limestone, but the corresponding formation on the west side consists mainly of several feet of heavy magnesian limestone which in places contains a little chert.

The strata of Onondaga age consist of 15 feet of buff magnesian limestone, with some thin beds of shale near the base. Some of the layers of this limestone contain numerous nodules of chert, and locally it is crowded with fossil corals.

The variations in the thickness and character of the members of the Panola formation—the many alternations from limestone to shale—suggest frequent changes in the conditions of deposition, especially those of the Niagaran strata. Some of the differences in thickness may be due to irregularities in the rate of deposition, but others are probably to be accounted for by supposing that an unconformity exists between the Silurian and Devonian. No detailed study was, however, made of outlying parts of the area, where these rocks are exposed.

DEVONIAN SYSTEM.

OHIO SHALE.

This formation consists of a thinly laminated, black, carbonaceous shale, which reaches a maximum thickness of about 150 feet in Fleming County and thins westward toward the west edge of Boyle County, where it passes outside the Blue Grass area. In the eastern part of the region few of the exposures exceed a few miles in width and in Boyle County the width is less than a mile. The formation is the equivalent of the Chattanooga shale farther south.

The relation of the Ohio shale to the underlying Devonian limestone was seen at several points. In some places the transition from the limestone to the shale is abrupt; in others it is by interbedding of the limestone and shale. The Ohio shale appears to have been deposited during a period when the sea was gradually encroaching upon the land. The fine sediments and the plant remains of this formation suggest that the sea was shallow and the adjacent land low.

CARBONIFEROUS SYSTEM.

WAVERLY SHALE.

The Waverly shale, which has a maximum thickness of 300 feet, includes about 100 feet of dense blue shale, which passes upward into interbedded shale and sandstone. Near the base of the shale are numerous concretions of iron carbonate which weather to a reddish brown. In most places the sandstones have a greenish or bluish tinge and they are commonly even bedded, but in some localities they are decidedly concretionary. Some beds of limestone occur on the tops of the mountains, but the areas are so small that they are not shown in the geologic map of the region

TERTIARY SYSTEM.

IRVINE FORMATION.

The valleys of the principal streams in the Blue Grass region present certain peculiarities which are worthy of note. All the large streams flow in steep-walled canyons, many of which have been cut 300 to 400 feet below the level of the uplands. Bordering the canyon valleys are broad rock shelves which are but little lower than the surrounding uplands and which were formed at a time when the streams flowing across the surface of the upland had so little fall that they meandered widely. These streams left along the rock shelves deposits of yellow and gray unconsolidated sand, gravel, and clay, which were called by Campbell [a] the Irvine formation and were referred tentatively to the Neocene. That the materials in these deposits were derived in part from the formations near the headwaters of the streams is shown by the occurrence of pebbles from those formations.

The Irvine formation occurs in isolated patches along Licking River in Fleming, Nicholas, Robertson, Harrison, Pendleton, Grant, and Campbell counties. Along Kentucky River the deposits were noted in Madison, Jessamine, Woodford, and Franklin counties, and they doubtless occur in the other counties bordering the river above Franklin County. They were not observed below the western boundary of Franklin County, although they probably occur there.

QUATERNARY SYSTEM.

GLACIAL DEPOSITS.

The deposits of glacial age in the Blue Grass region include the unassorted bowlder clay, the loess, and the assorted glaciofluvial gravels that form the terraces in the Ohio Valley.

Bowlder clay.—On the upland the bowlder clay is composed of 3 to 10 feet of red or yellow clay containing fragments of limestone, chert, and granitic rocks. The clay appears to be reworked residual material, and the limestone and chert are largely of local origin, but the granitic rocks are rare and must have been brought from beyond the northern boundary of the United States.

The eastern boundary of the bowlder-clay deposit extends northward from the southern line of Oldham County to the east bluff of Ohio River at Carrollton, passing a few miles east of La Grange and

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

Bedford. From Carrollton it extends northward, passing near Richwood, Boone County, and Buffington, Kenton County, and finally terminating at Ohio River near Fort Thomas. From Fort Thomas southward the boundary coincides very closely with the Ohio Valley to Augusta, at which point it swings eastward into Ohio. This boundary marks the farthest extent of the Illinoian ice sheet.

In the Ohio Valley, as shown by Leverett,[a] are deposits of partly assorted till which in some places rise to a considerable height above the river. The most conspicuous of these deposits are the glacial conglomerate at Split Rock, near Bellevue, Boone County, and a similar conglomerate at Augusta, in Bracken County. At Split Rock the conglomerate rises 250 to 300 feet above the Ohio, but at Augusta its height is only about 175 feet. Leverett mentions also that a morainic deposit on the east edge of the Ohio Valley at Carrollton occupies a sag in the hills between Kentucky and Ohio rivers and has a width of less than a mile, and a height of 200± feet above Ohio River.

The bowlder clay is correlated with the Illinoian drift farther west. Between the period of its deposition and the next glacial invasion there was a long interval known as the Sangamon interglacial epoch, during which the Illinoian drift deposits were probably more or less modified by erosion and weathering, but it is difficult to obtain evidence of these changes, because exposures are rare.

Loess.—The material classified as loess consists of 2 to 4 feet of buff loam, which rests on the till of the upland. As a rule, it contains more clay than typical loess and it lacks the loess texture. It closely resembles the residual clay of the region and can hardly be distinguished from the clay except where it rests on the till. The loess has usually been considered a deposit formed during the closing stage of the Iowan glaciation.

The deposition of the loess appears not to have been followed by any extensive topographic changes in the Blue Grass region. Some erosion has doubtless taken place, but the most noticeable change on the loess-covered area is seen in the numerous small sink holes where the glacial deposits are underlain by limestone beds.

Glacial gravel.—Glacial gravel forms terraces along Ohio River on the border of the Blue Grass region. It consists of 80 to 120± feet of coarse sand and gravel deposited from the waters supplied by the melting of the Wisconsin ice sheet. The materials composing this deposit are sand containing pebbles of limestone, sandstone, and the various granitic rocks which were carried by the glacier.

A deposit of sand and gravel, which ranges from 10 to 80 feet in thickness and which appears to be in part glacial and in part post-

[a] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 25-58.

glacial, is found along all the large streams of the region. Along Kentucky and Licking rivers fragments of terraces which rise to about the altitude of the glacial terraces are seen at many places. These deposits were probably made at the time when the terraces were being formed in the Ohio Valley.

Three well-defined terraces are recognizable at various points along Ohio River, but as in all of them the material is of fairly uniform character, the terraces have no effect upon the water capacity of the deposits. However, the depth to water in the glacial gravels is naturally greatest upon the highest terrace. A difference in the quality of the water has been reported in some localities, but on careful study it appeared that the variations in quality were due to the distance from the river and had no relation to the heights of the terraces.

ALLUVIUM.

On Ohio, Kentucky, and Licking rivers below the level of the glacial terraces are deposits of sand and gravel which are of recent origin. These deposits are nowhere extensive, and they exceed 50 feet in thickness at but few places.

Where the streams from the upland emerge in the valleys of the rivers they usually build alluvial fans, consisting of fragments of the country rock mixed with sand and clay. These alluvial fans are largest along Ohio River, but they also occur along the other large streams.

Many of the small streams of the region are bordered by narrow belts of coarse alluvium, which consist largely of partly rounded fragments of limestone mixed with more or less clay.

GEOLOGIC STRUCTURE.

JESSAMINE DOME.

The rocks of the Ohio Basin are not extensively folded and most of them dip slightly toward the northwest. The most important structural feature of the region is the broad arch, commonly known as the Cincinnati anticline. This arch extends from Nashville northeastward through Lexington nearly to Cincinnati, north of which it divides, one branch continuing northward, the other turning toward the northwest. South of Cincinnati the arch is separable into two broad domes; one of these culminates near Nashville, Tenn.; the apex of the other is in Jessamine County in central Kentucky. The Jessamine dome, as it has been called, has been so completely beveled by erosion that its dome structure has no apparent effect upon the surface, which is a broad plain deeply trenched by some of the larger streams. The erosion of this dome has exposed the Ordovician rocks which underlie the Blue Grass region. Outward from the apex of the dome the formations are successively younger, except where the regular order of the succession is broken by faults which have brought younger formations into abnormal contact with the older.

From the apex of the Jessamine dome the rocks dip gently outward in all directions, but the dip varies greatly in different directions, indicating that the dome is not symmetrical, and on the southern side the regularity of the dip is broken by faulting. From the apex of the dome along the crest of the uplift to Belmont, on Ohio River, the dip does not exceed 5 or 6 feet per mile; toward the north it is only 8 or 10 feet per mile; but the dips toward the east and west are much greater; the dips toward the northeast and northwest are about 25 to 30 feet, and toward the east and west nearly 50 feet per mile. The dips toward the south can not be satisfactorily determined because of the faulting, which has produced considerable displacement of the beds.

FAULTS.

The greater number of the faults of the Blue Grass region are strike faults; that is, the fault planes are parallel to the strike of the rocks. The most conspicuous fault is the Kentucky River fault, which extends from Clark County to Garrard County. It has a maximum throw of about 400 feet, which brings the Highbridge limestone into contact with the Garrard sandstone member of the Eden shale. Where this fault was observed, the movement appears to have been along a series of parallel planes, and at its eastern end near Ruckerville, as pointed out by Campbell,[a] the fault is represented by a slight fold. Another fault extends from Kentucky River northeastward near Ruckerville and into Bath County. The maximum movement along this fault plane is about 300 feet. Other faults are known to occur in Garrard and Madison counties, but in few of these is the displacement large.

Near Moberly there is a fault which runs parallel to the direction of dip—a dip fault.[a] The amount of displacement at this place is sufficient to bring the Ohio shale into contact with the Ordovician formations.

A strip of Eden shale extends from eastern Jessamine County northeastward across Fayette County. This strip of shale, which is from one-eighth to one-fourth mile wide, represents a place where two parallel faults have brought the Eden shale down into the area of Lexington limestone.[b] In northeastern Franklin County are two faults, which extend a considerable distance across the line into Scott County.[b] These two faults inclose a small fault block similar in origin to the one near Lexington. Other faults are known to occur in various parts of the region.

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[b] Miller, A. M., The lead and zinc bearing rocks of central Kentucky: Bull. Kentucky Geol. Survey No. 2, 1905, p. 7.

The geologic history of the Cincinnati arch has been long and complex, but a comprehensive discussion is beyond the scope of this paper. In general, it may be inferred that there were periods of partial emergence from beneath the sea, followed by more or less complete resubmergence. There is reason to believe that the faulting dates from the final emergence, which probably occurred during Carboniferous time. This question has been fully discussed by Miller in Bulletin 5 of the Kentucky Survey.

JOINTS AND BEDDING PLANES.

In the Blue Grass region there are two well-developed series of vertical joints at approximately right angles to each other. These joints have general north-south and east-west directions and are apparently very persistent. The spacing of the joints is somewhat irregular, and consequently it is difficult to state what interval there may be between joints at any given point.

Besides the joints, there are between the layers of rock numerous horizontal planes of separation known as "bedding planes." The spacing of the bedding planes varies from a fraction of an inch in the Eden shale to several feet in parts of the Highbridge limestone. The variation depends entirely on the thickness of the beds of rock, and consequently the number of bedding planes is greater in the shales than in the limestones.

In limestones and shales the joints and bedding planes have an important relation to the occurrence of underground water.

In rocks freshly exposed bedding planes and joints are usually but a small fraction of an inch in width; but near the surface the joints are wider, especially in the limestones, where they may be represented by caverns several feet wide. Within a few feet of the surface these openings are commonly filled with residual clay, and it is by the gradual removal of the limestone and the consequent enlargement of the cavern that the numerous sink holes of the region are formed. The enlargement, for obvious reasons, is most common along the lines where joints and bedding planes meet.

PHYSIOGRAPHY.

ALTITUDE OF THE SURFACE.

Altitudes within the Blue Grass region have an extreme range of about 1,100 feet, and the transition from one level to another is usually abrupt. The general altitude is between 800 and 1,000 feet above sea level. The higher points of the area, underlain by Ordovician rocks, rise to a nearly uniform altitude of 1,000 feet above sea level, while the lowest point, less than 400 feet above sea, is on Ohio

River at the southwest corner of Oldham County. On the southern margin of the area the hills of Mississippian rocks rise to an altitude of nearly 1,500 feet above sea level.

LEXINGTON PENEPLAIN.

The general attitude of the surface on the area of Ordovician rocks is that of a broad plain, above which the hills of the southern part of the area rise abruptly and into which the large streams have cut deep, narrow gorges. The smaller streams have not been able to lower their channels fast enough to keep pace with the main streams, and hence they enter the main streams with a very steep gradient, in places broken by falls and rapids.

There is locally an apparent parallelism of the plain surface and the bedding of the Ordovician rocks, which might suggest that the uniform height of the plain was due to a layer of hard rock; but when traced any considerable distance the surface is seen to cut across rocks of different ages and varying degrees of hardness.

To a nearly level surface produced by subaerial denudation the name "peneplain" is given, and the peneplain formed by the erosion of the Ordovician rocks was called by Campbell[a] the Lexington peneplain.

CRETACEOUS PENEPLAIN.

On the southern margin of the area the hills rise to a fairly uniform height of 500 feet above the Lexington peneplain, and this has led to the belief that they are remnants of an earlier peneplain. No part of the surface of this older peneplain is visible to-day, but its existence is inferred from the uniformity in the height of the hills, which are capped by rocks of different lithological character. This peneplain was referred by Campbell[b] to the Cretaceous.

CAVERNS.

In limestone rocks of uniform character and similar jointing, the rate of cavern formation depends largely upon the topography. Where the surface is rolling a smaller percentage of the rainfall enters the ground than where it is flat. Thus, the Lexington peneplain, with its nearly level surface, must have furnished exceptionally favorable conditions for the formation of caverns and the development of underground drainage systems.

The flat-topped remnants of the peneplain in Woodford, Franklin, and Fayette counties have the largest underground systems of drainage and supply the most copious springs of the region. Unfortunately,

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.
[b] Op. cit.

few of these caverns are accessible, and their size and the extent of their ramifications can be inferred only by the size of the springs and the number and size of the sink holes. On these flat-topped divides there is practically no surface drainage, and the topography is marked by a series of sink holes which receive a large part of the rainfall. It is probable that before the uplifting of the Lexington peneplain a large part of the surface was drained by underground streams, just as the divides are at the present time, and that the Neocene was the period when the formation of caverns was most rapid. Before the peneplain was uplifted the surface drainage was probably limited to the large streams and their principal tributaries. With the uplifting of the peneplain the surface drainage became more extensive and the areas of underground drainage were gradually restricted, but the formation of new caverns and the enlargement of the old has continued down to the present time.

SOILS.

CLASSIFICATION OF SOILS.

Since the time of the first settlement the Blue Grass region has been famous for its excellent soils, but considering the region as a whole the soils vary greatly in different localities, the finest types occurring in areas where the Lexington limestone forms the surface rock.

On the basis of origin the soil of the Blue Grass region may be said to include two types—residual and transported. The residual soils have resulted from the decomposition of the underlying rock and remain where they were formed. The transported soils are made up of disintegrated or decomposed rock particles and have been brought to their present position by the action of wind, water, or ice.

The sand dunes that occur in limited areas along the Ohio Valley and possibly the loess in the northern part of the region represent wind-transported soils. Some writers, however, would class the loess with water-transported soils.

The sands and gravels along the rivers form water-transported soils and are the result of mechanical disruption rather than chemical decomposition. In the valleys of Licking and Kentucky rivers these soils consist of assorted materials derived from the residual soils of the upland, but along Ohio River they were deposited by the flood waters which came from the melting of the continental ice sheet. As would be expected, the soils of the Ohio Valley are composed of the disintegrated fragments of various kinds of rock.

As the rocks of the region include limestones, sandstones, and shales, it might be expected that each kind of rock would yield a residual soil distinctive in type, but this is not always the case. Residual soils from limestones are largely due to solution, and this chemical action leaves behind it the insoluble sand and clay which was in the original rock. A soil derived from the calcareous shale may be much the same as one derived from a clayey limestone, and a calcareous sandstone may produce a soil which differs little from one derived from a siliceous limestone. The formation of the limestone soils requires the decomposition of a large amount of the original rock, for the sand and clay which make the soil usually form but a small percentage of the rock. The formation of soils from the shales or sandstones requires little besides the mechanical disintegration of the rock and very slight loss of volume results.

The statement made by many geologists that, as the residual soils are derived from the underlying rock, a geologic map is a good soil map, may or may not be true, depending entirely upon the units chosen as a basis for mapping If the formation mapped is in part siliceous limestone and in part argillaceous limestone, the soils from these two phases of the same formation may differ from each other more than they differ from the soils derived from sandstones and shales, respectively.

The classification of soils into types may also be based on texture, structure, color, content of organic matter, topography, and similarity of origin. The most important properties used in determining the soil type are the texture, which depends on the size of the soil particles, and the structure, which depends on the arrangement of these particles. Where a number of types are so closely related in source of material, method of formation, topographic position, and color that they grade one into another, they form a soil series. The soil series of the Ordovician limestones and interbedded shales has been called by the United States Bureau of Soils[a] the Hagerstown series.

In the Blue Grass region the types based on texture include stony clay, loam, and clay, and there are in addition phases of sandy loam and small areas of clay loam. The correlation of the Blue Grass soils derived from the Ordovician formations has not yet been completed, but they represent various textures which agree roughly with the textures of the different types in the Hagerstown series.

DISTRIBUTION OF SOILS.

The stony clay is found over considerable areas of the Eden shale and Maysville and Richmond formations. It consists of a clayey soil containing many fragments and occasional outcrops of limestone, and it occurs on the valley slopes in eroded areas of the formations mentioned. This soil produces good crops of corn, wheat, and tobacco, but its stony character and its marked tendency to erode adapts it better to grass and timber.

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[a] U. S. Dept. Agr., Bureau of Soils, Soil Survey Field Book, 1906, pp. 124–127.

The sandy loam found in the Ohio Valley is formed from the alluvium of the terraces. In some parts of the Ohio Valley the sand of the terraces has been reworked by the winds and formed into ridges and dunes. The sandy loam also occurs on the sandstones of the Waverly shale and in places on the Garrard sandstone member of the Eden shale, this phase being derived from the disintegration of the sandstones. In the Ohio Valley this soil occupies areas of slight relief and is subjected to little erosion, but the residual soils of the sandstones commonly occur in deeply dissected areas and are subject to rapid erosion. Soil of this type is well adapted to truck farming, but is rather too light and sandy for general farming. The sandy loam of the Garrard sandstone member of the Eden shale is said to produce good crops where the land is not too hilly for successful cultivation.

The loam soils of the Blue Grass region occur on the Lexington and Highbridge limestones, and in limited areas on the more calcareous phases of the Maysville and Richmond formations. Small areas of loam are also found in the Ohio Valley. The upland loam is derived from the decomposition of the Ordovician limestones, and is the finest blue-grass soil. It has gently rolling topography and is adapted to a large variety of crops, the principal ones being blue grass, corn, wheat, tobacco, and hemp. This soil, especially where derived from the Lexington limestone, produces fine blue-grass pastures, and on it are located the breeding farms which have made Kentucky famous for fine horses. The small areas of loam in the Ohio Valley are well adapted to general farming, but they do not equal the upland areas in value.

The clay soils occupy large areas on the Maysville and Richmond formations, the Eden shale, the Winchester limestone, and Siluro-Devonian rocks, and small areas also occur in the Ohio Valley. These soils vary greatly in value, the best types being formed from the decomposition of the rocks of the Maysville, Richmond, and Winchester formations. The topography of the areas of clay soil varies greatly. The best soils are usually situated in the gently rolling areas. On the soils derived from the Winchester limestone corn, tobacco, hemp, and grass are the principal crops. The Maysville and Richmond soils produce excellent crops of corn, wheat, and tobacco, some of the hilly areas being noted for their fine, white, burley leaf. The soils derived from the Siluro-Devonian limestones are excellent, being well adapted to general farming and producing good crops of corn, wheat, and grass. The shales of the Siluro-Devonian formations, however, yield a very poor soil, which is used for general farming. The Eden shale usually occupies hilly areas, and its soils are among the poorest in the region. They are subject to rapid erosion and are best adapted to the production of grass and timber. In many parts of the area the attempts to farm these soils are being abandoned, and they are being converted into pastures.

The loesslike silt-loam soils are intermediate in texture between the loam and clay loam. They consist largely of silt, with clay and sand and smaller quantities of materials of a coarse grade. These soils occupy a strip along the uplands bordering Ohio River and are locally of considerable value for agricultural purposes, especially in northern Boone County. In most places the area occupied by these soils does not exceed 4 or 5 miles in width, and it is nearly everywhere underlain by glacial materials, although it reaches a short distance beyond the glacial boundary and laps over the area of residual soils. The material is ordinarily not more than 3 feet thick, although in some places it may be 5 or 6 feet thick.

TEXTURE.

The great value of the soils of the Blue Grass region has been attributed to the composition of the rocks from which they are derived, but there are many other factors that affect their value. The most important of these are the texture and the drainage. The texture of the soil depends upon the size of its particles, and this is determined by means of a mechanical analysis. The following table shows the size of the soil particles in the Hagerstown soil types as determined by such analyses. Although the samples for these analyses were not all taken from the Blue Grass region, they are believed to be fairly representative of the principal soil types which occur on the Ordovician rocks of the area. The presence in the soil of a small amount of carbonate of lime causes the aggregation of some of the soil particles, and thus their character is slightly modified, but the aggregation is probably not sufficient to make any great change in the physical composition of the soil.

Even when a liberal allowance is made for the increased size of the soil grains due to aggregation of the smaller particles, it is clear that the openings in such fine-grained material must be very small. These small openings prevent the soil from absorbing water rapidly, but give it a great capacity for retaining moisture and bringing it within the reach of the plant roots by capillary action. The small size of the pores also brings the ground water in contact with a large amount of soluble material and thus favors the solution of the phosphorus and other elements of plant food contained in the rocks.

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TABLE 2.—*Textures of the Hagerstown soil types.*

[Compiled from the U. S. Department of Agriculture, Bureau of Soils Field Book, 1906, pp. 124-127.]

	Fine gravel, 2-1 mm.[a]	Coarse sand, 1-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.1 mm.	Very fine sand, 0.1-0.05 mm.	Silt, 0.05-0.005 mm.	Clay, 0.005 mm. or less.
Hagerstown stony loam:							
Soil	[b]2	4	3	6	11	52	22
Subsoil	2	3	2	4	7	38	44
Hagerstown stony clay:							
Soil	1	5	5	10	5	29	45
Subsoil	1	2	2	5	4	28	53
Hagerstown sandy loam:							
Soil	1	6	8	24	15	32	13
Subsoil	0	3	4	14	9	31	33
Hagerstown loam:							
Soil	5	3	3	7	10	46	23
Subsoil	2	3	2	6	8	38	39
Hagerstown clay loam:							
Soil	1	3	2	5	9	64	16
Subsoil	3	2	2	4	10	51	23
Hagerstown clay:							
Soil	1	2	2	9	8	41	33
Subsoil	0	1	1	6	5	29	56

[a] The figures at the top of the columns refer to the diameter of the soil particles.
[b] The figures in the various columns give the percentage of the grains of different diameters.

DRAINAGE.

Another factor which influences the value of the soils of the Blue Grass region is the excellent underdrainage provided by the crevices and channels in the rock. Indeed, if it were not for the removal of the excess of moisture through the underground drainage channels the fine-grained soils of the region would soon become so filled with water that plant growth would be greatly hindered.

CHEMICAL COMPOSITION.

The remarkable fertility of the Blue Grass region soils has generally been attributed to the compounds of phosphorus contained in considerable quantities in the Ordovician limestones. Although the value of the phosphates is unquestioned, other elements are recognized as important to soil fertility. Carbon, one of the principal elements which enter into the composition of plants, is supplied chiefly by carbonic acid from the air. Oxygen and hydrogen, the other elements which are abundant in plants, are supplied by water. In addition to the elements mentioned above, certain other substances, the most important including calcium, magnesium, sulphur, iron, nitrogen, phosphorus, and potassium, must be obtained from the earth. Some of these are needed by plants in such small quantities that most soils contain an ample supply, but the last three are of such essential value that it may become necessary to add them to poor soils in order to produce large crops.

The following table of analyses shows that the elements which enter into plant composition are so abundant in most Kentucky soils that it is unnecessary to add fertilizers. The amount of nitrogen in the soils was not determined, but as it is largely supplied by organic matter, it is safe to conclude that where the analysis of Blue Grass soils shows a large amount of organic matter, the supply of nitrogen will usually be ample. In many soils this organic matter represents the accumulation of long ages preceding the advent of civilized man and the beginning of cultivation in this region. As the nitrogen is required to produce plants, careful treatment is necessary to restore nitrogen or organic matter to the soil.

The phosphorus and potash in most of the soils were supplied by the decomposition of the calcareous rocks of the region, and the amount of each was determined by the composition of the original rock. Thus, the decomposition of the phosphatic limestones has produced soils rich in phosphorus. The amounts of potash and phosphorus (stated as phosphoric acid in the tables) should be compared with the amounts in Hilgard's averages of 466 soils from the humid region of the United States, which are also shown in the table. The States represented in making up Hilgard's averages and the number of analyses of soils from each are as follows: North Carolina, 20; South Carolina, 11; Georgia, 40; Florida, 7; Alabama, 50; Mississippi, 97; Arkansas, 38; Kentucky, 185; and Louisiana, 18. Although Kentucky soils averaged outnumber those from any other State, the best Kentucky soils were not included, because it was desired to use only those soils which were not derived from limestone.

A careful comparison of the analyses of Kentucky soils and the averages given by Hilgard shows that Kentucky soils as a whole are richer than the average in those mineral elements which support plants. While the siliceous Waverly and siliceous mudstone (probably Eden shale) soils are low in the elements of plant food, the soils of the Lexington (Trenton) and Panola ("Corniferous") formations are very much richer than the average, and practically all of the analyses appear to represent soils which are better than the average given by Hilgard. In comparing the analyses of the soils of the Blue Grass region with each other the superiority of the Lexington (Trenton) soils is very evident. From an examination of the list of analyses used in making the averages, it appears probable that some analyses of Winchester and Maysville limestone soils were included in the averages of Lexington (Trenton) soils. This, since the Winchester and Maysville limestone soils are, in general, poorer than those of the Lexington (Trenton), probably means that the averages are lower than if the analyses were entirely from the Lexington soils. Notwithstanding this fact, the analyses show that the soils are very rich in plant food, and experience has shown that their natural productivity is high.

TABLE 3.—*Chemical composition of Kentucky soils.*[a]

	Moisture.	Insoluble residue.	Organic and volatile matter.	Oxides of aluminum, iron, and manganese.	Calcium carbonate ($CaCO_3$).	Magnesium oxide (MgO).	Phosphoric anhydride (P_2O_5).	Potash (K_2O), extracted by acids.
Average of 3 Ohio Valley alluvial soils	2.51	84.31	3.47	9.84	0.10	0.19	0.12	0.45
Average of 21 Quaternary (loess) soils	2.27	88.10	2.94	6.94	.37	.29	.12	.26
Average of 10 Waverly soils	....	89.91	4.10	4.29	.14	.26	.10	.15
Average of 9 black slate soils	....	80.13	5.93	10.59	.48	.52	.23	.18
Average of 15 "Corniferous" limestone soils	....	83.52	5.07	9.06	.47	.63	.28	.34
Average of 16 Upper Silurian soils	....	82.40	6.23	10.49	.32	.42	.19	.24
Average of 11 siliceous mudstone (middle Hudson) soils	....	86.55	4.78	7.06	.10	.60	.16	.16
Average of 32 Trenton ("Blue") limestone soils	....	73.38	6.21	11.20	.75	.64	.33	.40
Average of 6 Birdseye limestone soils	....	85.80	4.45	6.51	.45	.38	.21	.18
Average of 234 Kentucky soils	....	84.63	4.47	8.00	.36	.34	.18	.26
Average for humid region[b]	4.65	84.03	3.64	7.56	[b].20	.22	.11	.22

[a] Peter, Robert, The composition of the soils, limestones, clays, and marls of Kentucky: Kentucky Geol. Survey, 2d ser., pt. 13, vol. 5, 1885, p. 113.

[b] Hilgard, E. W., A report on the relation of soil to climate: Weather Bureau Bull. No. 3, 1892, p. 30. The figures given above are adapted from Hilgard's table; lime (presumably CaO) has been calculated to $CaCO_3$ for comparison with Peter's figures.

The Panola ("Corniferous") soil appears to be exceptionally good and to approach most nearly the high average of the Lexington limestone soils. The Highbridge (Birdseye) and Panola (Upper Silurian) soils have about the same general composition, although derived from rocks which widely differ in age, in appearance, and probably also in composition. It is interesting to note that the Ohio shale (black shale) soils, which have often been considered very poor, approach the average soils in composition. In one of the early reports of the Kentucky Geological Survey[a] Doctor Peter attributed the low productivity of this soil to the presence of too much water and suggested the use of lime to render the clay more porous, so that the excess of moisture could escape. The loess soils, which are fair when measured by the standards of the average soils, are considerably poorer than the Lexington (Trenton) soils.

SURFACE WATERS.

OHIO RIVER.

The Ohio makes a bend northward around the Blue Grass region, flowing north of west from Maysville to Cincinnati and approximately southwest from Cincinnati to the southern boundary of Old-

[a] Peter, Robert, Chemical analyses, A, pt. 2, Kentucky Geol. Survey, 1883, p. 101.

ham County, and forming a partial boundary of 10 out of 30 counties. Only a small portion of the area, however, drains directly into the Ohio, most of the drainage passing first to one of the principal tributaries. Where the river borders this region its channel is a trench cut into the Ordovician rocks to a depth of 350 to 400 feet and varying in width from one-fourth mile to 1½ miles. The variation in width of the Ohio channel is the result of the formation of a single stream channel out of a number of segments of different streams and tributaries.

Between Maysville and Louisville,[a] a distance of 198 miles, the Ohio falls 54 feet, an average fall of 0.27 foot, or somewhat more than 3 inches, to the mile; but the rate of fall of the river is not uniform, varying from 0.2 foot to at least 5 feet to the mile in different parts of its course, increase in fall commonly occurring where the river crosses the old rock divides. The velocity of the stream is variable but is nowhere high.

Most of the small streams of the region are steep walled and have very high gradients, and the consequent rapid run-off causes correspondingly rapid fluctuations in the amount of water entering the main streams. Floods are very common on the Ohio, the gage records at Cincinnati showing that the river has passed the danger line (50-foot stage) just 23 times in the forty-six years previous to 1906. The highest stage during this period was 71.1 feet, in February, 1884, and the lowest was less than 2 feet. The extreme range is therefore nearly 70 feet, but the usual range is probably not much more than 25 feet. The highest floods, as a rule, occur in winter—in February or later—and are caused by the melting of the snow. A second rise, produced by the summer rains and ordinarily less than the one occurring in the winter, takes place in May or June. The autumn rains produce a third rise, which is comparatively small. The date of the autumn rise is uncertain, as it may come in November or not until late in December. The lowest river stages are, as a rule, reached in August or September, and they generally extend into October. As a result of recent work by the United States Government, the Ohio is now navigable along the borders of the Blue Grass region, even at very low water.

KENTUCKY RIVER.

Kentucky River rises in the mountainous part of the State and flows in a general northwesterly direction across the Blue Grass region, passing near the apex of the Jessamine dome. Where the river crosses the resistant Highbridge limestone its gorge is generally but little wider than the stream, and in many places the river flows between

[a] Gannett, H., Profiles of rivers in the United States: Water-Supply Paper U. S. Geol. Survey No. 44, 1901, pp. 41-43.

perpendicular walls of the limestone 300 feet or more in height. A characteristic view of this gorge is shown in Plate III, *A*. At various points above Frankfort the stream is bordered by rock terraces bearing narrow strips of alluvium, in most places composed of fine sand with a few layers of pebbles. Below Frankfort the alluvial deposits are more extensive, locally forming bands more than one-fourth mile wide. In areas where the Kentucky flows through rocks of the Maysville, Eden, and Winchester formations the slope of the channel is as a rule comparatively gentle. The contrast between the precipitous walls formed by the Highbridge limestone and the gentle slopes of the walls in the Maysville formation is beautifully shown on the northern edge of Madison County, where, by reason of the Kentucky River fault, the river passes abruptly from one of these formations to the other. On the one side of the fault the cliffs are so steep that it is impossible to ascend them; on the other side fields of corn extend down the gently sloping walls to the flood plain of the river. This change from one type of valley to the other is repeated several times as the river meanders back and forth across the fault line.

From Frankfort to the mouth of the river, a distance of 65 miles, the Kentucky falls 42 feet, or 7.2 inches to the mile; between Frankfort and Beattyville, a distance of 189 miles, the fall is 184 feet, or at the rate of nearly 1 foot to the mile. Throughout the Blue Grass region the gradient of this stream is comparatively low, but toward the mountains it increases rapidly.

The largest tributaries of the Kentucky in the Blue Grass region are Dix River and Eagle Creek, both of which have higher gradients than the main stream at the points of junction. The fall of Dix River from a point west of Lancaster to the mouth of the stream, a distance of 10 miles in a direct line, is not far from 300 feet. The minor branches of the Kentucky and its principal tributaries have very steep gradients, some of them descending 300 feet or more from the level of the upland to the main stream in a distance of 3 or 4 miles. As a result of the high gradients the streams show quickly the effects of rains, the water reaching maximum heights within a very short time after a storm. Floods are very common on the Kentucky, though the range in stage is probably not great as compared with that of the Ohio at Cincinnati.

LICKING RIVER.

Licking River heads at the edge of the mountains and flows in a direction slightly west of north into Ohio River opposite Cincinnati. This stream has cut through the Ordovician rocks to the Lexington limestone and the channel is in many places steep walled, but it is, as a rule, bordered by deposits of alluvium, especially along the lower course of the stream.

A. KENTUCKY RIVER GORGE SOUTH OF CAMP NELSON, KY.

B. AN OPEN SINK HOLE IN CLARK COUNTY, KY.

The gradient of Licking Valley has not been determined, but it is apparently somewhat greater than that of Kentucky River. The tributaries of the Licking, like those of the other streams of the region, have very steep slopes.

MINOR STREAMS.

A small strip along the western edge of the Blue Grass region is drained by Salt River. The streams belonging to the Salt River system are all small, most of them flow only a part of the year, and all of them fluctuate rapidly with the amount of rainfall.

UNDERGROUND WATERS.

THE SOURCE.

The water that falls upon the land in the form of rain or snow either sinks into the earth or flows off over the surface. The part which sinks into the ground and is held by the rocks is known as ground water; that which flows off over the surface, together with the ground water returned to the surface streams, forms what is called the run-off. A part of both ground water and run-off is returned to the atmosphere and another part is consumed in chemical and organic work.

It is easy to understand that the shallow wells derive their supplies from rainfall, for the process of absorption by the more or less porous soils may be observed, and in many places in the Blue Grass region the storm waters may be seen entering the underground channels through sink holes. The connection between rainfall and the water supplied by deep wells is not, however, so apparent, and it is indeed possible that the saline waters furnished by some of the deep wells were taken into the rocks from the ocean during the process of deposition; but disregarding the origin of the very saline waters, it may be said that all of the water found in shallow wells, and much of that in deep wells, is derived directly from rainfall.

CONDITIONS OF OCCURRENCE.

THE WATER TABLE.

The water that sinks into the earth descends until it reaches a level where the underlying rocks are already completely saturated. This level is known as the water table, and its form and depth beneath the surface vary with the amount of rainfall, the relief of the surface, and the resistance which the rocks offer to the movement of the water. In arid regions of low relief the water table lies far beneath the surface, and its form is only slightly convex, the convexity being greatest in the materials that offer the most resistance to the passage of the water. The variation in convexity, which is due to the resistance offered by the rock to the movement of the ground water, is explained by the fact that a greater slope of the water surface is needed to overcome an increased resistance. In humid regions of considerable relief the water table reproduces with lesser magnitude the inequalities of the land surface. The greater the rainfall and resistance the nearer the approach of the water table to the surface.

Wherever the water table intercepts the surface, as along the valleys of the streams, seeps or springs are formed, and the lowering of the stream channels will depress the water table except where impervious materials, such as shales, are encountered. Where the porous material rests on dense materials, such as shale or clay, the depression of the water table ceases, and as the stream deepens its channel springs are left perched on the side of the valley. Veatch[a] has given the name "perched water tables" to the water tables that are left above the dense materials by the deepening of the stream

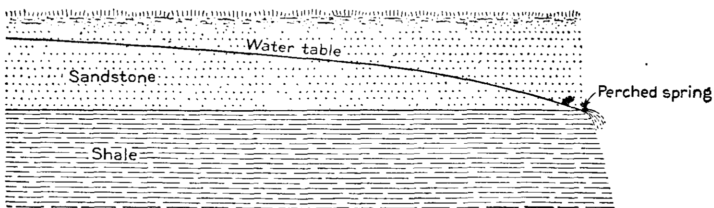

FIGURE 1.—A perched spring.

channels. It is proposed to extend the term "perched" to include springs formed where such water tables intersect or emerge at the surface. Perched springs are common at the contact of some of the sandstone beds of the Waverly shale with the underlying shale beds. They may also occur at certain points along the larger streams where beds of sand and gravel rest on clay.

In a large part of the Blue Grass region there is no general water table, but a water table exists in the sandstones of the Waverly shale, in alluvial materials along the larger streams, and in some partly saturated glacial sands and gravels on the uplands of northern Boone and Kenton counties. Locally, in various parts of the upland, a porous residual soil allows the formation of a ground-water level, but these areas are small and their supply of water is likely to fail during a very dry season.

The passages through which the ground waters move vary with the character of the rock, and in order to understand underground-water conditions it is necessary to consider the mode of occurrence

[a] Veatch, A. C., Underground water resources of Long Island, N. Y.: Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 57-58.

of water in the different kinds of rocks and in rocks of different sorts arranged in alternate layers differing in thickness.

WATER IN SAND, GRAVEL, AND SANDSTONE.

In sand the water moves through the small spaces between the grains; hence the coarser or more porous the material the larger the passages and the greater the amount of water they will transmit.

Slichter[a] explains the effect of the size of the sand grains on the movement of water as follows:

> If the particles of sand or gravel which make up the water-bearing medium are well rounded in form, the pores are somewhat triangular in cross section and the diameter of the individual pores is only one-fourth to one-seventh the diameter of the soil particles themselves. Thus if the individual grains of sand average 1 millimeter in diameter, the pores through which the water must pass will average only one-fourth to one-seventh of a millimeter in diameter. If to a mass of nearly uniform sand particles larger particles be added, the effect on the resistance to the flow of water will be one of two kinds, depending principally upon the ratio which the size of the particles added bears to the average size of grains in the original sand. If the particles added are only slightly larger than the original sand grains, the effect is to increase the capacity of the sand to transmit water, and the more particles of this kind that are added the greater will be the increase in the capacity of the sand to transmit water. If, however, large particles are added, the effect is the reverse. If particles seven to ten times the diameter of the original sand grains be added, each of the new particles tends to block the course of the water. Thus, for example, a large bowlder placed in a mass of fine sand will tend to block the passage of the water. As more and more of the large particles are added to a mass of uniform sand, the rate of flow of water through it will be decreased until the amount of the large particles equals about 30 per cent of the total mass. From this time on the adding of the large particles will increase the capacity of the whole to transmit water, until if a very large quantity of the large particles be added, so that the original mass of fine particles becomes relatively negligible, the capacity to transmit will approach that of the mass of the large particles alone. These facts have an important bearing upon the capacity of gravels to furnish water to wells or to transmit water in the underflow of a river. The presence of large particles is not necessary to be interpreted as indicating a high transmission capacity of the material, for this is indicated only when the large particles constitute a large fractional per cent of the total mass, as would be the case where the large particles equal 40 or 50 per cent of the whole.

Sandstone, having had some of the passages closed by the cementing material that binds the grains together, is less porous than sand composed of grains of the same size and shape. Sandstone therefore offers much greater resistance to the movement of water and transmits a relatively smaller amount than sand. This condition is often partly offset by the joint and bedding planes which may furnish channels for the passage of considerable water.

The motion of underground water is controlled by the factors that govern the motion of surface water—resistance and slope. As the

[a] Slichter, Charles S., Field measurement of the rate of movement of underground waters: Water-Supply Paper U. S. Geol. Survey No. 140, 1895, pp. 10–11.

water which moves in tiny threads between the grains of sand meets with a great deal of resistance it advances but a few feet a day; with the same gradient a surface stream, because of the comparatively slight resistance offered by the channel, will move several miles in the same length of time.

WATER IN LIMESTONE.

JOINTS AND BEDDING PLANES.

Limestone rocks are as a rule traversed by at least two sets of vertical joints which make approximately right angles with each other, and a third set of partings at right angles to these joints form the bedding planes of the rocks. The spacing of joints is ordinarily fairly uniform over considerable areas, and the interval between them is commonly to be measured in feet; but where the rocks have been deformed the joints are more numerous. The bedding planes exhibit very little uniformity of arrangement; an interval of a few inches may be followed by one of much greater magnitude.

Some limestones are sufficiently porous to absorb considerable quantities of water, but most of them are too dense to yield water for wells or springs. The water which comes from limestones is usually that which has found its way in along more or less enlarged joints or bedding planes, the enlargement being due to the solvent action of water. Obviously the places where water circulates most readily will, other things being equal, suffer most loss by solution, but differences in the solubility of the rock may offset the effect of rapid circulation. Doubtless the most common line of rapid solution is at the intersection of a prominent bedding plane and a more or less open joint.

FORMATION OF CAVERNS.

Not only is slight resistance to solution offered along certain lines, but in certain spots, owing to the presence of numerous open joints or to the solubility of the rock, very large chambers—"domes"—are formed. It is noticeable that "domes" are the points at which considerable water enters the underground channel. This water, coming fresh from the surface, is charged with a great amount of carbonic acid and it attacks the limestone about the point of entrance; as it flows farther and farther from the point of entrance it loses its power to dissolve the rock, because it has gradually picked up as large an amount of calcium carbonate as it can carry.

As the belt of rapid solution is restricted to the zone of active water circulation, the formation of caverns takes place largely above the level of the surface streams that receive the underground drainage, but this does not imply that there is no deep-seated solution or that active circulation may not extend slightly below the level of surface drainage. As solution progresses some parts of the walls and roof of the solution cavities collapse and sink holes are formed. If the channel beneath the point of collapse is large in proportion to the amount of material which falls, the sink is usually an open hole; but if the amount of fallen material is sufficient to clog the channel, the sink appears as a rounded depression that has no outlet. The fallen material may obstruct the opening so that the stream appears at the surface, or it may leave a passage which will allow the drainage to continue underground. In this event the gradual wearing of the stream may remove enough of the fallen material to form an open sink.

In the process of deepening its valley a stream lowers the base-level of its tributaries and thus affords them an opportunity to degrade their channels. When the tributaries flow in caverns they lower their channels along some joint plane, and the process goes forward most rapidly along some particular line in the same manner as during the

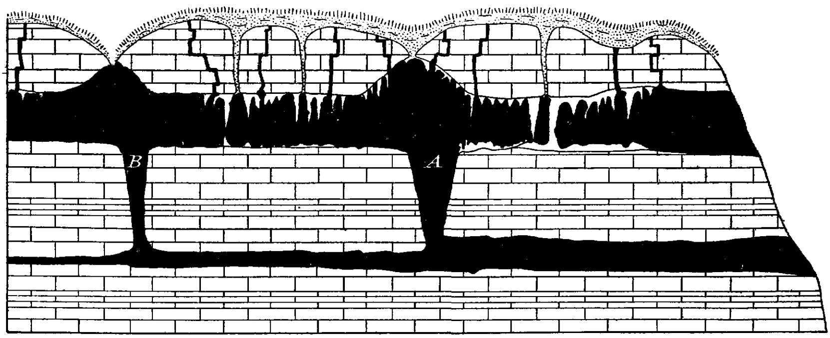

FIGURE 2.—Diagram of a cavern, showing different levels of the underground stream.

formation of the original cavern. At certain places where there is rapid downward movement from the old to the new channel more or less rounded openings develop. These openings provide a passage from the old to the new cavern and are usually called "pits." They often form beneath the domes, their location being determined in part by the presence of initial crevices and in part by the same condition that produced the dome, namely, the entrance of surface water bearing considerable free carbonic acid. (See A, B, fig. 2.) Doubtless the formation of caverns, and especially of pits and domes, is aided by the mechanical action of the water, especially where it contains sediment.

As long as the lower channel or the passages leading to it are comparatively small the old cavern retains a large part of the drainage. With the enlargement of the new cavities the old channel receives less and less of the original drainage, until it is entirely deprived of its original headwaters except during storms, and at last, when the new channels have become sufficiently enlarged, the old channel receives only the drainage of its local tributaries.

Migration from higher to lower levels may take place at successive periods, leaving a series of abandoned channels at different levels. The course of the underground stream at each successive stage probably deviates more or less from the course of the abandoned channel. Moreover, the course may not lie in a single channel, but passages may divide and reunite, forming a more or less extensive network of channels.

After a section of the underground stream has been abandoned the amount of water entering the old channel becomes less and less until it is chiefly confined to small seeps. At this stage much of the water is removed by evaporation, so that solution gives place to deposition, the principal deposit being calcium carbonate. At first deposition is rapid, because the crevices are large enough to supply all the water that can be evaporated; but gradually, as the openings become closed, the rate of deposition decreases. The deposits present a great variety of forms which add to the beauty of the caverns. The most common types, the stalactite and stalagmite, are familiar to all who have visited caverns. The stalactite begins as a thin film of calcium carbonate around the edge of a drop of water which evaporates on the roof of the cavern. Upon this film as a nucleus successive additions are made until the stalactite resembles a giant icicle suspended from the roof of the cavern. The accumulations of calcium carbonate which form where the water evaporates on the floor of the cavern are known as stalagmites. By the union of stalactites and stalagmites pillars are formed.

If a shale bed is encountered by the water in its downward progress a cavern is usually formed above it, and if the shale bed is some distance above the level of the surface stream which receives the drainage from the cavern the water may emerge from the cliff above the surface stream. The mechanical wear of the underground stream may remove the shale at some point, and thus permit the formation of another cavern nearer the level of the surface stream. If the shale bed is of considerable thickness the downward migration of the water may be permanently obstructed. The lowering of the channels of the surface streams usually takes place much more rapidly than the lowering of the underground streams. In consequence of this fact the underground streams may remain considerably above the level of the surface streams even where there are no beds of shale or other dense material to prevent downward migration.

SMALL WATER PASSAGES.

In all limestone regions there are water passages below the levels of the surface streams. In some places the openings are simply small pores in the limestone, but in the Blue Grass region they appear to be channels which closely resemble the caverns. Vein deposits are formed in these passages, and where exposed by erosion they present forms closely resembling those found in ordinary caverns. When penetrated by drilling the small water passages supply an abundance of water which is usually under considerable head, indicating that the channel is covered by impervious rock. The direction of movement in these channels probably conforms roughly to the dip of the rock, which in the Blue Grass region is away from the apex of the Jessamine dome. In this region these channels usually contain water that is more highly mineralized than that of the caverns.

WATER IN SHALE.

Shale, being composed largely of clay, contains practically no available water except that found in the joints and bedding planes. The number and character of the joints and bedding planes in shale vary in different formations and in different parts of the same formation. The water that enters the joints of the shale passes downward to the zone at which these openings practically cease and then moves laterally until it reaches the point of emergence. Near the surface the bedding planes may be sufficiently open to allow the passage of considerable water, but at moderate depths they are closed so that they transmit little or no water.

WATER IN INTERBEDDED LIMESTONE AND SHALE.

The amount and mode of occurrence of underground water in interbedded limestone and shale vary greatly with the relative amounts of the two kinds of rocks and the relations they bear to each other and to the surface. In a formation with a high percentage of limestone and thin scattered beds of shale the underground circulation is essentially the same as that in pure limestone; in a heavy deposit of shale containing thin beds of limestone underground water occurs essentially as in shales. For the sake of simplicity consideration will here be restricted to the occurrence of water in a series consisting of equal parts of shale and limestone arranged in alternating layers not exceeding 6 inches in thickness. Under such conditions the surface water may penetrate the rocks by passing along the joints which cross the beds, or it may follow along a joint in one or more beds, thus conforming to the dip of the rock. Probably in most such formations the actual movement combines these two methods. Water enters a joint near the surface and percolates downward until its course is obstructed by the gradual decrease in the width of the opening. If there were no means of escape laterally the movement would cease as soon as the crevice was filled; but in general a lateral movement along the joint allows a slow movement of the water. The lateral movement naturally follows the largest crevice, and this may lead to frequent change from one series of joints to the other, or the movement may continue along a single joint.

The movement of the water tends to enlarge the joints by mechanical wear, but as the circulation is usually slow the amount of enlargement is slight. The solvent power of the water tends to enlarge the joints along the beds of limestone, but as these beds are thin the height of the channel produced by solution is small.

The tendency of the shale to sink into any cavity which may be formed by solution restricts the width of the channel. The lenticular shape of many of the limestone beds presents another obstacle to the formation of underground passages by solution. As a result of all these factors the underground channels in interbedded shales and limestones are small.

Where the downward movement of the water is checked by a heavy bed of shale the water usually follows the dip of the shale bed, and under some conditions this movement may be away from the surface stream. An example of such movement was noted in northwestern Franklin County. Where the water follows the dip it is generally confined by the overlying shale and it continues its underground course until it reaches some point of escape at lower level.

The occurrence of springs above the level of the main streams was mentioned in connection with the formation of caverns, but it needs special mention here because such springs are very common in formations consisting of interbedded limestones and shales. The water which enters the joints passes downward until it reaches a layer of shale which contains no crevice, and follows this layer to the point at which it emerges at the surface. The most usual course for the water which supplies these springs is along the contact of a limestone layer with the underlying shale. These springs are most common along Ohio River, but they occur also along the other streams in the Blue Grass region. Their height above the streams varies from a few feet on some of the smaller streams to more than 300 feet along the Ohio and other large rivers. These springs have the same topographic position as the perched springs, but the mode of occurrence of the water is different.

SPECIAL CONDITIONS IN THE BLUE GRASS REGION.

WATER IN THE HIGHBRIDGE AND LEXINGTON LIMESTONES.

Water channels.—The Highbridge limestone forms the surface rock in but few localities in the Blue Grass region, and in those areas the topography is rugged and the soils are as a rule thin. The formation therefore contains but few large underground streams; most of the water channels in it are small. Along Kentucky River gorge, however, some of the channels form good-sized caverns, those best known being at Glasses Mill, Valley View, Highbridge, and Camp Nelson.

The Lexington limestone, except in the vicinity of large surface streams, occupies areas having gently rolling topography and a heavy deposit of porous soil. These conditions favor the occurrence of a large amount of underground water and the development of extensive systems of underground drainage, and the formation contains innumerable small channels and many large caverns. Indeed, most of the counties in which this limestone covers a large area can boast one or more caverns. The best known, and probably the largest of these, is the Russell cave, in Fayette County, which is reported to have been explored for nearly a mile. Several of the other caverns in the Lexington limestone have been explored shorter distances. Most of these caverns contain streams, many of which give rise to large springs. Few of the caverns are accessible except in dry weather, and none of them are highly ornamented by stalactites or

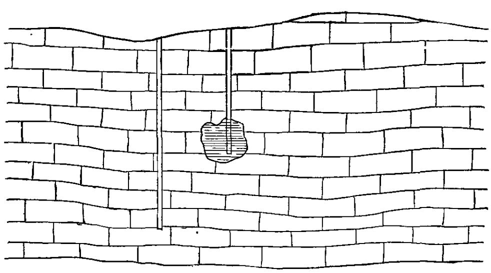

FIGURE 3.—Diagram showing difference in conditions in adjacent wells in limestone.

other deposits. The small underground channels that lie above the level of surface drainage also give rise to many springs. Below the level of the surface drainage the underground channels in the Lexington limestone are apparently small, but most of them seem to be full of water, while the channels nearer the surface are practically never entirely filled.

Wells.—The Highbridge limestone is penetrated by but few shallow wells and most of the deep wells sunk in it obtain mineral water. More than 95 per cent of the drilled wells of the upland obtain water from the Lexington limestone. The possibility of procuring water depends entirely on the chance of encountering one of the underground channels. In some localities few wells fail to procure an adequate supply; in others many failures are reported. The mode of occurrence of the mineralized waters makes it uncertain whether they will be encountered in any particular well, and in two wells located near together they may be found at very different depths (fig. 3).

In general they may be looked for at less depth in the valleys than on the hills, but to this rule there are likely to be many exceptions. Wherever the Lexington and Highbridge limestones are covered by younger formations they yield only the highly mineralized waters. Ignorance of this fact has led to the sinking of deep wells in the areas of Maysville limestone with the hope of obtaining waters for domestic and industrial uses. Such wells are almost certain to be failures.

Quality of the water.—The water in the channels which are situated above the level of the surface drainage is practically always hard, but the hardness varies with the amount of rainfall, being greatest in dry weather and least after heavy rains. This condition is readily explainable, for in dry weather nearly all the water seeps in through the soil and the velocity of the underground stream is low, while during heavy rains much water enters through open sinks and the stream velocity is high. When the water enters from the soil, the subsoil, or the underlying rock it contains carbonic acid, which enables it to dissolve the material in the residual deposits and the limestone. The slow movement in the underground channel facilitates solution, but when the water enters through open sinks it contains less carbonic acid and the rapid movement of the flood waters does not favor solution. The substances most commonly found in the shallow waters are calcium and magnesium, but a number of other substances are present in smaller quantities.

The plane of separation between the shallow and deep waters coincides roughly with the levels of surface drainage, rising slightly above the level of the surface streams toward the divides and sinking slightly below the streams in the valleys. Where the surface streams flow in canyons the deep waters are often found above the levels of the surface streams. The deep waters in the Lexington and Highbridge limestones always contain considerably more mineral matter in solution than the shallow waters, and some of them appear to contain alkaline carbonates. (See analyses Nos. 24 and 25, p. 212.) These highly mineralized waters, which for the sake of brevity will be termed "mineral waters," occur in small areas of porous limestone or in channels that pass below the levels of the surface drainage. Rapid movement of the underground water is prevented by the situation of the channels and porous rock, and in many places the water is probably stationary; thus the water may remain in contact with the rock for a long time and dissolve out much mineral matter. Such waters are especially likely to be brackish or salt and to contain hydrogen sulphide or petroleum.

Practically all the channels are supplied with water from the surface, and when penetrated by wells the mineralized water may be replaced by the ordinary hard limestone water after the well has been pumped for a time. The length of time required to make this change varies from two or three weeks to a year or more, being influenced by the rate of pumping, the size of the channel, and the distance of the well from the point at which the water enters the ground. Rarely the character of the water does not change after long-continued pumping.

The numerous joints in the limestone probably furnish a natural means of escape for the mineral waters, but the amount escaping from a channel must as a rule be less than that taken out by an ordinary well. The almost universal connection of the channels with the surface, which is indicated by the entrance of surface water after pumping, shows that the water is probably derived from meteoric sources, the mineralization being due, as suggested, to the slow circulation of the water and the great length of time it remains in contact with the soluble materials of the limestone.

Within 10 or 15 miles of Kentucky River the shallow waters have been moving downward during the erosion of the gorge of that stream. This movement, which has been accomplished in the manner described under the occurrence of waters in limestone, has made it possible to procure some ordinary hard water below the level of the surface streams. Where the channel containing the mineral water has been severed by the deepening of the main stream and water from the surface allowed to enter, the result has been the same as when one of these channels has been penetrated by a well and the mineral water has been removed by pumping.

The general movement of the deep water appears to be in the direction of the dip of the rocks, and consequently the mineral waters of the region pass outward from the central area of the Highbridge and Lexington limestones. This outward movement carries the mineral waters into those areas where the Lexington and Highbridge limestones lie beneath the younger geologic formations.

WATER IN THE WINCHESTER LIMESTONE.

Water is found in the Winchester limestone under conditions resembling those in the Lexington limestone, except where the formation contains a high percentage of shale. Channels of sufficient size to be called caverns are not known in this formation, but where the limestone layers are exposed at the surface they yield, as a rule, considerable water.

The shallow waters of the Winchester are the ordinary hard waters of limestone rocks; the deep waters are saline and locally contain hydrogen sulphide.

WATER IN THE EDEN SHALE.

The outcrops of Eden shale occur in areas of rugged topography unfavorable for the absorption of large amounts of water. The formation presents three phases: (1) Nearly pure shale, (2) interbedded shale and limestone, and (3) sandstone. All of these rocks except the sandstone yield on weathering a dense residual clay which stores considerable moisture, but allows only a small portion of it to reach the underground channels. The residual materials of the sandstone are porous loams or sandy loams, through which considerable water passes to the underlying rocks.

In the shaly phase of the formation the water occurs in numerous joints, few of which, however, are large. The bedding planes are practically everywhere too compact to yield water. The amount of water afforded by the shale is usually small and the supply is quickly reduced by dry weather. The water is also liable to pollution from surface drainage and much of it is of poor quality.

The interbedded phase varies from nearly pure shale to shale containing numerous limestone layers, and the water conditions vary correspondingly. The most abundant supplies of water are obtained where one or more beds of limestone occur near the surface. In such places the water comes chiefly from the enlarged joints in the beds of limestone.

The sandy phase of the formation—the Garrard sandstone member—varies from slightly sandy shale to nearly pure sandstone, with shaly sandstones predominating. The more shaly parts of the sandstone yield very little water except along the joints, and the amount is variable. The sandstones, where not too firmly cemented, yield moderate quantities of water, and where exceptionally thick the supplies may be large. The concretionary sandstone is, as a rule, too dense to be water bearing.

The joints of the Eden shale seldom present openings which yield water at depths greater than 25 feet, and the depth of wells should not exceed 35 feet. Moreover, experience has shown that the largest supplies occur near the surface. Dug wells are more successful than drilled wells, because they intersect a larger number of joints. No deep wells obtain water from this formation. As the water comes from the immediate vicinity of the well and receives practically no purification, great care should be exercised to guard the wells from pollution.

Springs are numerous in the Eden shale, but none of them are of large volume and few can withstand the effect of drought. Some exceptionally good springs were observed in the sandstones of Garrard County.

The water of the shaly phase of the Eden contains only a small amount of mineral matter and is moderately hard, but where limestone beds occur the mineral content of the water is increased and the hardness may be equal to that of the shallow limestone waters. Much of the water of the sandy phase of the Eden is nearly free from mineral matter and is called "soft," but the presence of lime in the sandstone may cause it to yield hard water.

WATER IN THE MAYSVILLE AND RICHMOND FORMATIONS.

The outcrops of the Maysville and Richmond formations have a gently rolling surface over considerable areas, and the topography thus favors the retention of residual soils and the absorption of large quantities of water. The soils are somewhat porous where they are derived from the limestone layers of the formations, but are dense where they result from the disintegration of the shales, and they therefore have lower storage capacity for water than the soils of most limestone areas.

Underground water occurs in the Maysville formation essentially as in interbedded limestones and shales. The more shaly parts of the formation present conditions much like those in shale; where the formation contains heavy beds of limestone which are near the surface, the underground water conditions resemble those in limestones. Thus, although certain parts of the Maysville contain but little more water than the Eden shale, there are other parts in which small caverns are found, and these parts supply considerable water. The presence of the caverns is usually indicated by a number of small sinks, which are especially noticeable near Burlington, in Boone County, although they may also be found in many other parts of the area. Locally, these heavy beds of limestones are capped by several feet of shale, and where this occurs the limestones receive very little water. Such conditions obtain in the vicinity of Richmond, Madison County.

Water conditions in the Richmond formation are much like those in the Maysville, but as at many places the Richmond carries much shale the amount of its underground water is locally small. The heavy beds of limestone in the upper part of the Richmond afford conditions favorable for the formation of caverns, and numerous sinks and springs indicate the presence of large underground channels. This phase of the Richmond formation is practically restricted to western Trimble and Oldham counties.

Drilled wells in the Maysville and Richmond formations have been remarkably successful in some localities, a well in the vicinity of Flemingsburg, Fleming County, affording a conspicuous example. In general, however, there is small chance of obtaining enough water for a farm from drilled wells in either of these formations. It is seldom advisable to sink a well more than 50 feet, and 100 feet should be the maximum, because in the interlaminated limestones and shales of the two formations the number and size of the openings decrease rapidly with increasing depth. Almost everywhere the water that comes from them from a depth more than a few feet below the bottoms of the neighboring creeks is likely to contain both salt and sulphur in moderate quantities.

Dug wells in the Maysville and Richmond formations usually procure sufficient water for a farm at depths ranging from 10 to 35 feet, the most common depths being 20 to 35 feet. Most of these wells are affected by the weather and many of them fail during a protracted drought.

Springs are numerous in both formations, but few of them are large. Many of the springs are perennial, and during a dry season maintain sufficient volume to furnish water for several families.

Water obtained from these formations above the level of the surface drainage is hard; that obtained below the level of the surface drainage is, as a rule, mineralized. Where the water emerges in some surface stream near the point where it enters the ground the underground circulation is so short that only a moderate quantity of mineral matter is dissolved. Where the dip of the rocks carries the water below the level of the neighboring surface stream the prolonged underground course allows the water to become highly charged with mineral matter, and if the rocks contain much organic matter such water will usually contain hydrogen sulphide, produced by the decomposition of the organic matter. The presence of hydrogen sulphide and large percentages of mineral matter in the water of wells that draw their supplies from depths below the levels of the surface drainage is thus explained. After water has been drawn from such wells for a considerable time the underground circulation may become more rapid and the amount of mineral matter and hydrogen sulphide may be lessened. The same result is brought about by the gradual removal of the amount of available mineral and organic matter along the underground channel. These highly mineralized waters have sometimes been regarded as residual sea water, but this theory is probably incorrect. In some places the Richmond formation contains magnesian limestones, and the water obtained from this phase of the rock contains considerably more magnesia than is usually present in hard waters.

WATER IN THE PANOLA FORMATION.

The limestones and shales of the Panola formation, as a rule, occupy areas of low relief, but in some localities they have been rather deeply dissected. The soils derived from the limestones are generally sufficiently porous to absorb considerable water, but those from the shales are commonly quite dense. Both topography and soils favor the occurrence of considerable underground water.

The limestones of the Panola are the principal water-bearing rocks. In some places, as in Fleming County, these rocks consist in part of single beds of limestone alternating with beds of shale; but in other places, as in Clark, Madison, Oldham, and Trimble counties, the beds of limestone have an aggregate thickness of several feet. Even where the limestone beds are thin they generally yield considerable water. Where the limestone beds are thick the movement of the underground water is essentially the same as in the Lexington and Highbridge limestones. A few caverns have been reported in this formation, but they do not appear to be very numerous. One of the most interesting of these caverns is on Jeptha Knob, in Oldham County.

The shales of the Panola are locally traversed by numerous small joints that permit the entrance of considerable water; hence many shallow wells are successful and small springs are numerous.

Wells dug in the limestones of the Panola usually yield ample supplies of water for household or farm use. Drilled wells have also been successful, especially on the west side of the Jessamine dome in Oldham and Jefferson counties. The water is almost invariably encountered in the crevices of the limestone at its junction with the underlying shale.

The limestones of the Panola are highly magnesian, and the water which they contain is charged with magnesium in addition to the calcium and other salts that all limestone waters carry. Sulphur and salt are entirely lacking in these limestone waters, but zinc has been noted. The character of the water is shown by the analyses of the Anita Spring water and the water of the Royal Magnesian Spring.

The water from the shales of the Panola usually contains a large amount of mineral matter, especially Epsom salts and other sulphates. These waters are not extensively used within the area covered by this report, though there is a resort at Kiddville where an Epsom well obtains its water from this formation. At Crab Orchard, outside the area, the Epsom water has been used in the manufacture of Epsom salts, which have had an extensive sale. The mineral matter in these waters is believed to have been derived in part from the Ohio shale which lies above the limestones.

WATER IN THE OHIO SHALE.

In the Ohio shale water occurs chiefly in the joints, which are especially numerous near the surface and usually afford openings a fraction of an inch wide. The width of the joints diminishes downward, but they have been known to supply water at a depth slightly exceeding 50 feet. The bedding planes probably supply no water, except near the surface.

The soil of the Ohio shale is in most places sufficiently porous to allow considerable water to enter the underlying rock. Where the formation occupies flat or moderately rolling areas it generally receives much of the water which is absorbed by the soil; where the surface is steep very little water enters the rock. On the mountain sides, however, where the sandstones of the Waverly shale overlie the Ohio, some of the water that comes from these sandstones enters the joints of the shale in its passage down the slope.

Wells in the Ohio shale are uniformly successful, the supplies of water being obtained at depths less than 50 feet. Where the formation is exposed many drilled wells have obtained sufficient water for the use of one or more families. Springs are numerous and some of them have been utilized as health resorts.

The water derived from the Ohio shale is highly mineralized, sulphur, alum, and chalybeate waters being especially characteristic types. Springs of Epsom and salt waters also occur.

WATER IN THE WAVERLY SHALE.

The shaly layers of the Waverly shale, which occupy the almost perpendicular sides of the mountains, furnish practically no water; but numerous springs of soft water that occur on the mountain side derive their supplies from the sandstone layers and shallow wells in the areas where the sandstones are exposed at the surface yield an abundance of water, although the rock is, as a rule, rather firmly cemented.

WATER IN THE ALLUVIUM.

Water occurs in the alluvium as in sands and gravels. The deposit is in most places sufficiently coarse to yield an abundance of water, but at one locality in northern Boone County the water-bearing sands are so fine that it is practically impossible to keep them from clogging the pumps.

The water in the alluvium is derived in part directly from rainfall and in part from springs and surface streams, although the rainfall probably furnishes the greater part. Each surface stream which emerges from the upland contributes to the water supply of the alluvium, unless its channel is lined with clay, which prevents the escape of the water, and some of the smaller streams lose a large part of their water in this way. Springs which emerge from the upland formations, either above or below the surface of the alluvium, also contribute to its water supply.

Under normal conditions the water table (see p. 39) of the alluvium slopes toward the main stream, and the water moves toward the stream to emerge in springs and in seeps along the channel. When the river rises the slope of the water table near its channel may be reversed, and the movement of the water may be from the river into the alluvium. This reversal of the normal movement is only temporary, as the supply of water which the alluvium receives from the rainfall and from other sources soon raises the water table and reestablishes its normal slope toward the river. When a well near the river bank is pumped rapidly the slope of the water surface between the well and the river may be reversed so that the well draws some water from the river. This reversal of the slope of the water surface is due to the formation of a cone-shaped depression of the water table in the vicinity of the well. After the pumping ceases the water table rises and the ground water resumes its normal movement toward the river. The effect of the entrance of river water into the gravel along Ohio River has been noted at several points. Its presence may usually be detected in analyses by the small amount of mineral matter obtained in water near the river. The difference is shown by the analyses of the water from the wells of the Augusta steam laundry and the Augusta electric-light plant (p. 212). The steam laundry well is within about 10 rods of the river, and the well of the electric-light plant is several blocks distant. The difference is also illustrated by the behavior of the water in steam boilers. The water from the laundry well causes no scale, but the water from the well of the electric-light plant produces a large amount of scale, even after it has been passed through a heater which removes much of the mineral matter.

The quality of water in the alluvium varies greatly in different localities, and it may be expected to vary at any point as the conditions which govern the source of supply at that point change. The water that falls upon the alluvium percolates downward through the sand and gravel, dissolving lime and other materials which make it slightly hard. Water that is derived from the upland streams enters the gravel bearing whatever materials it has in solution. In the Blue Grass region the streams flow over formations that contain much limestone, and the water naturally carries a considerable amount of material dissolved from these calcareous rocks. The springs emerging from the formations through which the river valley is excavated contribute water carrying mineral matter that has been dissolved from these formations, and springs from different formations or even from different parts of the same formation may yield water differing greatly in quality. An example of the effect of spring water on the composition of the ground water of the alluvium was noted at South Ripley. At this locality Ohio River has cut nearly to the base of the Eden shale, and this formation or the underlying Winchester limestone probably supplies the salt water which gives the ground water in the alluvium at South Ripley a brackish taste.

AMOUNT OF UNDERGROUND WATER.

MODIFYING FACTORS.

RAINFALL.

The amount of underground water is influenced by several important factors, among which may be mentioned the quantity and character of the rainfall, the nature of the topography, the presence or absence of vegetation, and the character, condition, and thickness of the residual soil mantle.

Adequate rainfall is essential to abundance of ground water, but even when the rainfall is heavy the amount of water that enters the ground is greatly influenced by the rate of precipitation. Obviously, the conditions most favorable for absorption of water by the ground are slow precipitation and high temperature. The slow precipitation permits the water to enter the ground, and the high temperature facilitates its downward percolation. With decrease in temperature or increase in the rate of precipitation the percentage of rainfall that is absorbed is decreased and the amount of run-off is increased. If the precipitation takes the form of snow and falls upon a warm earth, its gradual melting may afford especially favorable conditions for the absorption of water; when the snow melts rapidly the amount of water that is absorbed is usually small.

The annual rainfall in the Blue Grass region varies from 40 to 50 inches, the precipitation being greatest in the southwestern part of the region and diminishing gradually toward the northeast corner of the State. A map prepared by Alfred J. Henry[a] shows an annual precipitation of 45 to 50 inches in the southern part of the area and of 40 to 45 inches in the northern part. The line on the map (fig. 4) separating these two belts of unequal rainfall crosses the counties bordering Ohio River in a northeastward direction until it reaches the latitude of Frankfort, and then bears eastward, passing north of Frankfort, to the east side of Licking River, where it turns to the southeast and extends beyond the southern boundary of the region. Lexington and Cincinnati, with mean annual rainfall of 44.38 and 39.87 inches, respectively, typify the conditions prevalent throughout the greater part of these two divisions. These figures represent the average rainfall as deduced from observations carried on over a number of years, but the actual precipitation for a single year may vary widely from the mean. An inspection of the following table (No. 4) shows that in the ten years from 1897 to 1906 the departure from the normal has exceeded 10 inches five times at Lexington and three times at Cincinnati. The maximum departure from the normal for any part of the area was 20.62 inches at Cincinnati in 1901. The

[a] Chart 12, U. S. Weather Bureau.

maximum departure at Lexington was 16.66 inches in 1904. Both of these departures were below the normal and mark periods of drought in their respective sections. The rainfall for the two years of drought

FIGURE 4.—Map showing average rainfall in eastern part of United States, in inches.

and for the two intervening years is given in Table 5. These droughts were not the result of the annual variation from the normal, but were caused by the continuation of a period of marked deficiency in rainfall through three or four consecutive months. The drought of 1901, according to the figures given in Table 5, was most severe locally, but did not cover so wide an area as that of 1904. It was confined to a narrow strip along Ohio River and lasted from August to November. The drought of 1904 extended over much of the upland and was most marked in the last part of November and early part of December. It began as early as August in some parts of the area, and October was the driest month ever recorded in the region.

TABLE 4.—*Annual precipitation, in inches, and departure from the normal for four stations of the United States Weather Bureau, 1896–1906.*

Year.	Lexington.		Cincinnati.		Frankfort.		Shelbyville.	
	Rainfall.	Departure from normal.	Rainfall.	Departure from normal.	Rainfall.	Departure from normal.	Rainfall.	Departure from normal.
1896	43.29	− 1.67	34.48	....	46.73	....	46.54	− 0.15
1897	49.19	+ 2.30	43.89	+ 4.00	42.88	− 2.40	48.58	+ 3.00
1898	59.41	+14.67	38.97	− 0.90	....	....	52.73	+ 7.84
1899	40.24	− 2.76	34.69	− 4.94	....	....	41.14	− 3.73
1900	33.67	−10.58	27.79	−11.20	36.38	− 7.01	48.23	+ 2.12
1901	30.31	−13.29	17.99	−20.62	....	....	34.78	−10.42
1902	36.10	− 8.28	37.30	− 2.57	43.01	+ 1.38	38.35	− 6.12
1903	30.70	−13.68	34.69	− 5.15	38.42	− 3.71	38.46	− 5.84
1904	28.72	−16.66	29.54	−10.33	32.55	−10.65	32.18	−11.54
1905	44.17	− 0.21	38.69	− 1.18	46.91	+ 5.84	....	....
1906	42.59	− 1.79	40.83	+ 0.96	52.39	+11.32	51.64	+ 7.35

TABLE 5.—*Monthly precipitation, in inches, and departure from the normal at Lexington and Cincinnati, from 1901 to 1905.*

[Compiled from the reports of the U. S. Weather Bureau.]

Year.	Station.	January.		February.		March.		April.	
		Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.
1901	Cincinnati	0.87	−2.15	1.35	−2.17	2.01	−1.60	1.93	−0.95
	Lexington	1.49	−2.16	0.62	−2.73	2.23	−2.78	4.52	+1.14
1902	Cincinnati	2.10	−1.36	0.38	−3.31	1.47	−1.83	2.87	−0.33
	Lexington	4.77	+0.95	0.90	−2.80	2.92	−1.98	1.27	−2.45
1903	Cincinnati	2.05	−1.41	5.76	+2.09	4.97	+1.67	3.49	+0.29
	Lexington	1.68	−2.14	6.16	+2.46	3.24	−1.66	3.29	−0.43
1904	Cincinnati	2.66	−0.80	2.66	−1.03	8.17	+4.87	2.28	−0.92
	Lexington	1.92	−2.90	2.38	−1.32	4.75	−0.15	3.08	−0.64
1905	Cincinnati	1.80	−1.66	1.76	−1.93	2.46	−0.84	3.14	−0.06
	Lexington	2.04	−1.78	1.13	−2.57	5.87	+0.97	2.87	−0.85

TABLE 5.—*Monthly precipitation, in inches, and departure from the normal at Lexington and Cincinnati, from 1901 to 1905*—Continued.

Year.	Station.	May.		June.		July.		August.	
		Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.
1901	Cincinnati	1.62	−1.70	2.27	−1.69	1.44	−2.05	0.88	−2.66
	Lexington	2.66	−1.15	3.70	−0.50	2.61	−1.57	3.74	−0.35
1902	Cincinnati	5.54	+2.13	5.25	+0.85	3.47	+0.09	0.65	−3.07
	Lexington	2.43	−1.06	5.19	+0.94	2.33	−2.77	1.89	−1.63
1903	Cincinnati	3.83	+0.42	3.27	−1.13	2.31	−1.07	2.75	−0.97
	Lexington	1.75	−1.74	2.71	−1.54	2.62	−2.48	1.49	−2.03
1904	Cincinnati	3.70	+0.29	2.60	−1.80	0.80	−2.58	0.41	−3.31
	Lexington	2.60	−0.89	2.51	−1.74	3.13	−1.97	2.44	−1.08
1905	Cincinnati	9.52	+6.11	2.36	−2.04	1.04	−2.34	4.66	+0.94
	Lexington	5.54	+2.05	3.31	−0.94	4.94	−0.16	4.11	+0.59

Year.	Station.	September.		October.		November.		December.		Total.	
		Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.
1901	Cincinnati	0.92	−1.43	0.59	−1.68	0.74	−2.59	3.37	+0.41	17.99	−20.62
	Lexington	2.18	−0.41	1.33	−0.78	1.73	−1.05	3.50	+0.40	30.31	−13.29
1902	Cincinnati	4.26	+1.84	2.77	+0.33	3.29	−0.01	5.25	+2.10	37.30	− 2.57
	Lexington	2.60	+0.06	2.11	−0.11	3.09	−0.63	6.60	+3.20	36.10	− 8.28
1903	Cincinnati	1.78	−0.64	1.31	−1.13	1.45	−1.85	1.72	−1.43	34.69	− 5.15
	Lexington	0.81	−1.73	2.12	−0.10	2.84	−0.88	1.99	−1.41	30.70	−13.68
1904	Cincinnati	1.28	−1.14	0.89	−1.55	0.34	−2.96	3.75	+0.60	29.54	−10.33
	Lexington	1.71	−0.83	0.57	−1.68	0.53	−3.19	3.10	−0.30	28.72	−16.66
1905	Cincinnati	1.54	−0.88	4.85	+2.41	2.75	−0.55	2.81	−0.34	38.69	− 1.18
	Lexington	3.20	+0.66	3.45	+1.23	3.58	−0.14	4.13	+0.73	44.17	− 0.21

Deficient precipitation lessens the quantity of water supplied by springs and shallow wells, but does not affect the supplies from deep wells. The effect of low rainfall is especially noticeable in the autumn months, when the precipitation is normally small. The time required for deficiency of rainfall to affect the amount of ground water varies with the quantity of water in the ground at the beginning of the drought, and the effect in different parts of the area varies with the nature of the materials in which the water is stored. In general, it may be said that a drought of two months usually causes a marked diminution in the amount of ground water; and if it continues for three or four months, the water supplies of the area are noticeably depleted.

When the amount of precipitation is much above the normal, the soil becomes saturated and the excess runs off over the surface. As the surface of the Blue Grass region is rolling, this excess moisture escapes readily.

During the spring and summer months much of the rainfall comes in the form of thunder showers. As a rule, these add comparatively little to the underground water supply, because the rapid precipitation favors run-off rather than absorption. In some parts of the area, however, open sinks abound, and in these localities a considerable part of the water falling during thunderstorms may enter the underground channels directly. The frequency of thunderstorms in the Blue Grass region is shown by the fact that in the ten years from 1895 to 1904 the Lexington station reported an average of 21 thundershowers for the three months from June 1 to August 31. Such storms also occur during other parts of the year, but less frequently.

TOPOGRAPHY.

Many investigators have assumed that, aside from its effect on the form of the water table, topography bears no relation to underground-water problems; but in reality the influence of topography on the amount of underground water is so marked that it is often possible to determine with considerable accuracy, from a study of the character of the surface of an area only, whether wells in a given locality are likely to have large or small yields.

A much greater amount of water is absorbed where the surface is level than where it is uneven, the level surface favoring absorption because the water flows off more slowly, and thus remains for a longer time in contact with the soil; a rolling surface favors rapid run-off. The influence of sink-hole topography on the quantity of ground water is especially noticeable, for while this topography is in itself an indication of the presence of underground streams, it also favors the absorption of large amounts of water.

The character of the topography also affects the thickness of the residual materials, for in many places on the rolling areas much of the decomposed rock has been removed by erosion, and wherever the thickness of the soil is reduced its storage capacity is lessened.

SOILS.

The permeability of soil depends largely upon its texture, a coarse-grained soil being, as a rule, much more permeable than a fine-grained. The capacity of the soil to retain moisture also depends upon its texture, the storage capacity of the finer soils being much larger than that of the coarser. The water which enters coarse sand passes through it rapidly, because of the large spaces between the grains; but that which is absorbed by clay is held by the capillary attraction of the small passages.

Although a coarse sand will readily absorb a large amount of water, it will retain only about 15 per cent of its volume; while a clay, which absorbs water more slowly, will retain more than 40 per cent.

By referring to Table 3 (p. 36) it will be seen that the soils of the Blue Grass region are very fine grained and hence have a large capacity for storing moisture. Determinations made by King[a] of the per cent of pore space and the approximate effective diameter of soil particles are given in the following table:

TABLE 6.—*Approximate effective diameter of soil particles.*

Type of soil.	Locality.	Depth of material.	Percentage of pore space.	Approximate effective diameter of soil grains.
				Millimeter.
Prairie loam	Oasis, Wis	Surface	38.83	0.03035
Do	do	Second-foot	34.64	.04777
Clayey loam	Drummond, Wis	Surface	44.87	.02206
Do	do	Second-foot	44.15	.02197
Heavy clay	Ashland, Wis	Surface	45.32	.01402
Do	do	6–18 inches	44.15	.01111
Sandy soil	Minong, Wis	Surface	34.49	.02619
Do	do	6–12 inches	29.96	.0523

These soils are not precisely the same as those of the Blue Grass region, but the table is valuable because it shows the porosity of loam, clay, and sandy soils. Actual measurements of the amount of water in the soils at Lexington and Greendale, Ky., were made by the United States Bureau of Soils.[b] These measurements include the surface soil to a depth of 12 inches and were made daily from May 18 to July 31, 1895. The maximum amount of water in the soils was found to be slightly more than 21 per cent of the total weight. The general range was about 13 to 21 per cent, and the lower limit was about 10 per cent. As these measurements were made at a time when frequent rains insured saturation of the soil, the maximum probably represents nearly the full water capacity of the soil.

The percentage by weight is only about one-half as great as the percentage by volume; hence, if reduced to percentage by volume, the maximum amount of moisture would be about 42 per cent and the range about 20 per cent. An examination of the table shows that the percentage of pore space diminishes in the subsurface materials, so that the average porosity of the residual materials at Lexington and Greendale is probably somewhat less than would be indicated by the table. The amount of reduction might bring the maximum as low as 35 to 40 per cent.

No measurements of the amount of water in other soils have been made, but assuming a porosity approximately the same as that for the soil types given in the table above, the clay would have a pore space of about 40 to 45 per cent of its volume and the sandy

[a] King, F. H., Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897–98, pp. 213–214.

[b] Soils and soil moisture: U. S. Dept. Agr., Bulls. 1, 2, and 3, May, June, and July, 1895.

loam of about 30 to 35 per cent of its volume. As the silt loam has more silt and less clay than loam, its amount of pore space would probably be somewhat smaller than was found in the soils at Lexington and Greendale. The silt loam is of small extent and is underlain by gravelly loam or fine sand. Its porosity is probably slightly greater than that of the sandy loam.

From the above estimates of porosity it appears that even if the amount of water absorbed equaled only three-fourths of the total pore space, the residual deposits of the Blue Grass region would still hold a high percentage of moisture. The fact has an important bearing on the available water supply of the region, for the Ordovician limestones are too dense to yield water, and the water supplied to the shallow wells and springs during dry weather must be derived from the residual materials.

The residual materials in the Blue Grass region range in thickness from a few inches up to about 30 feet, the most common thickness being 3 to 5 feet and the average probably less than 6 feet. From this mantle of decomposed rock the transition to the solid rock below is rather abrupt. The importance of the residual material to the water supply does not depend upon its yielding water directly to wells, for this it does in but few places. Its real function is to store the rainfall and deliver it gradually to the underground channels. If the rocks of the Blue Grass region were laid bare the water from each rainfall would either enter the cracks at once or flow off over the surface at a rate determined by the slope, and in a comparatively short time all the water would have escaped, leaving the surface dry except where small pools were formed in depressions. Under such conditions springs would flow only a short time after each rain, because the rocks of the Ordovician formations have little or no storage capacity for moisture. The capacity of the residual soil to absorb moisture has already been mentioned. The small thickness of the residual mantle, however, prevents the storage of large quantities of water. As the porosity and thickness of the soil vary with the character of the rock from which it is derived, the water capacity of the soils of the different formations or of different parts of the same formation varies widely.

AMOUNT OF WATER IN THE EARTH'S CRUST.

Several attempts have been made to estimate the total amount of water in the earth's crust, but none of the results are universally accepted. To reach a conclusion it is necessary to estimate the average thickness of the various kinds of rock which compose the outer 6 miles of the earth and to compute the average amount of water contained in each kind of rock. The results obtained can not be applied to any particular region, for they represent only the average condition for the whole earth, and as the results are not locally applicable their practical value is small.

The discussion has had, however, a practical bearing, in that it has called attention to the erroneous belief that an abundance of water can be obtained anywhere by drilling deep enough. In many places it has been found that the amount of water diminishes with increase of depth, and probably in nearly all places the amount of water below the first 2,000 or 3,000 feet is very small.

The quantitative estimates of the amount of water in the earth's crust vary from one-hundredth to one-half of the volume of the ocean. The smallest of these estimates was made by Fuller.[a] This estimate may be stated in another way by saying that the one-hundredth of the volume of the ocean means sufficient water to cover the entire surface of the earth to a depth of nearly 100 feet.

ARTESIAN WATER.

GENERAL PRINCIPLES.

The term "artesian" is derived from the name of a town in France, Artois, where the first important flowing wells were sunk. In this country the term has been used in so many different ways that it is often impossible to say just what particular kind of a well is meant. Some authors use artesian to designate only wells that flow; others apply it to any well in which the water is under hydrostatic pressure, so that it will rise above the level at which it is encountered; still others use the term to designate any deep well.

The desirability of securing uniformity of usage for the term "artesian" led Fuller to attempt to give it a precise meaning, and he proposed the following definitions:[b]

The artesian principle (which may be considered as identical with what is often known as the hydrostatic principle) is the principle in virtue of which water confined in the materials of the earth's crust tends to rise to the level of the water surface at the highest point from which pressure is transmitted. Gas as an agent in causing the water to rise is expressly excluded from the definition.

Artesian pressure is the pressure exhibited by water confined in the earth's crust at a level lower than its static head.

Artesian water is that portion of the underground water which is under artesian pressure and will rise if encountered by a well or other passage affording an outlet.

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[a] Fuller, M. L., Total amount of free water in the earth's crust: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 59-72.

[b] Fuller, M. L., The significance of the term "artesian:" Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 14-15.

An artesian system is any combination of geologic structures—such as basins, planes, joints, faults—in which waters are confined under artesian pressure.

An artesian basin is a basin of porous bedded rock in which, as a result of synclinal structure, the water is confined under artesian pressure.

An artesian slope is a monoclinal slope of bedded rocks in which water is confined beneath relatively impervious covers owing to the obstruction of its downward passage by the pinching out of the porous beds, by their change from a pervious to an impervious character, by internal friction, or by dikes or other obstructions.

An artesian area is an area underlain by water under artesian pressure.

An artesian well is any well in which the water, when encountered, rises under artesian pressure.

The conditions commonly producing artesian wells are:

1. A porous bed or an open plane or channel to permit the entrance and passage of water.
2. An impervious cap to prevent the upward escape of the water.
3. An inclination of the water-bearing bed or passage.
4. A suitable exposure of the water-bearing beds or passages above the level of the surface at the well to permit the entrance of water.
5. An adequate rainfall to furnish the water.
6. An absence of openings which will permit the ready escape of water at a level below the well.

It was formerly believed that an impervious bed below the water-bearing horizon was an essential condition, but such a bed is not everywhere necessary because the rocks below may be saturated with water. Under certain conditions, also, the impervious bed above the water horizon may be dispensed with, for the interlocking grains in the layer of sands above the water may offer more resistance to its upward movement than is offered by the well. Even a porous bed may not be necessary to furnish artesian conditions, for artesian wells may be obtained where the water is in joints, solution channels, bedding planes, or other open passages. The inclination of the water-bearing beds may not everywhere be necessary, for the pressure may be supplied by the entrance of the water at a level above that at which it is encountered and by its downward passage through joints or other openings which cross the beds.

ARTESIAN WELLS IN THE BLUE GRASS REGION.

Flowing wells are not common in the Blue Grass region, but artesian wells—wells in which the water is under artesian pressure—are found in many parts of the area. The wells which encounter the mineral water of the limestones are practically all artesian, and in a few localities where the wells are located in stream valleys the mineral water rises above the surface. Flowing wells of this class are found near Lexington, in Fayette County, near Harrodsburg, in Mercer County, and near Smitsonville, in Harrison County. The amount of water yielded by all these wells is small and the water is highly mineralized, being sulphureted and often brackish. The pressure of the escaping hydrogen sulphide gas in these waters may aid in producing the flow, the gas acting in the same manner as air which is forced into a well when an air-lift pump is used, but it is improbable that the gas pressure is sufficient to appreciably affect the height to which the water will rise. It is probable that the water in these wells does not enter at the outcrop of the beds under which it is moving, but finds its way in at various points along the underground streams through joints which reach the surface. The high mineral content of the water indicates that it has had a long underground course.

The shallow water in the limestone areas may be under artesian pressure wherever the underground channels are partly or wholly obstructed below the well, and if the water enters at a point higher than the surface at the well a flow may be obtained. No flows of this kind have been observed in the region.

The region is without large synclinal folds, and therefore contains no artesian basins. The flowing wells in the valleys of the large streams appear to belong to a structure intermediate between an artesian slope and an artesian basin. The rock in which this water occurs—the St. Peter sandstone—has been called both a sandstone and a siliceous limestone. It appears probable that some layers of this rock are very sandy while others are highly calcareous, but as the formation is known in this region only from well records its character is not easy to determine. It transmits water with a facility that suggests that it is either an open sandstone or a very porous limestone.

The effective head of the water in the St. Peter is 580 feet above sea level at the Murray well in Frankfort and 590 feet in the valley of Ohio River near Cincinnati. Flowing wells that reach this formation are located at Covington, Newport, Latonia, Frankfort, Boston, and the Old Crow distillery near the Woodford-Franklin County line. Flowing wells may be obtained in any part of the Ohio River channel where it borders the Blue Grass region and in the valleys of the principal tributaries of the Ohio where they have cut below about 590 feet above sea level. The flowing-well area would therefore include practically all of the gorge of Kentucky River within the Blue Grass region and the channel of Licking River for some distance above Falmouth, as well as the lower parts of some of the smaller valleys tributary to these streams. Flowing wells may also be obtained in the lower part of the small valleys tributary to Ohio River.

The quality of the water from the St. Peter, which is shown b analysis No. 11, page 212, unfits it for domestic or industrial uses The water has been used for cooling in distilleries, but it has bee found to corrode the condensing pipes very rapidly, and their frequen renewal is necessary. It is highly esteemed as a medicinal water an has proved valuable where a strong salt-sulphur water is required It is also a valuable water for stock. The well at Boston is locate in a pasture where ordinary spring water is abundant, but the stoc will, it is reported, drink only the salt-sulphur water. The wate from the well at Frankfort has been used for drinking. Wells shoul not be located near dwellings, for the hydrogen sulphide has a ver disagreeable odor and is injurious if breathed for any considerabl period. It has also an injurious effect on metal and on varnished o painted woodwork. A well located at the Hemingray glass factor in Covington was plugged because the residents of the neighborhoo objected to having their furniture and silverware damaged by th sulphurous gas.

The source of the pressure which causes the water of the St. Pete to flow is not definitely known. It has been suggested that the wate enters from the upland and passes downward through joints and othe open passages into the sandstone, but many facts render this expla nation highly unlikely. The hypothesis that the Jessamine dome o central Kentucky might be the source of the pressure is also inade quate, as the mouths of the flowing wells are from 200 to 300 fee above the top of the St. Peter in the apex of the dome. A third and according to present knowledge, the most reasonable explanation i that the water enters the sandstone in southern Wisconsin and north ern Illinois and that the pressure is transmitted from those areas.

It has been rather generally supposed that the water of the St. Pete is sea water, which was stored in the rocks at the time of their depo sition. Adherents of this theory explain the fact that the St. Pete water is less saline than sea water by assuming that the percentage o salt has been decreased by the addition of surface waters. Althoug this theory has certain points in its favor, it is believed that the lon underground journey of the water through rocks more or less cal careous is quite sufficient to explain its present qualities.

RECOVERY OF UNDERGROUND WATER.

NATURAL RECOVERY.

Much of the water that sinks into the earth returns to the surfac under the influence of gravity, capillarity, and by the action of plant Sometimes one of these forces acts alone, but more often two of the are combined, and under some conditions one of the forces may oppose another. Capillary action, though usually not apparent, is very important, because it brings much water to the surface, where it is returned to the atmosphere by evaporation, or within the reach of the roots of plants, where it is absorbed. The water taken from the soil by plants is built into their tissues or evaporated through their leaves. This last process is usually called transpiration. Here gravity acts against the upward movement of the water caused by capillarity. Gravity combines with capillarity to bring the water to the surface at the foot of a slope. Capillary action causes the water to move more rapidly through the pores of the unconsolidated materials where the movement is downward under the influence of gravitation, the relative importance of gravitation and capillarity depending entirely on the size of the pores through which the water moves. If these pores are small, gravitation is much less important than capillary action; if they are large, gravitation is the principal cause of the movement of the water. Where water comes to the surface through open crevices or caverns, the movement is due wholly to gravity, but the weight of a column of water in the crevice or channel may cause the water to move upward in some parts of its course.

The water which is brought to the surface under the influence of capillarity alone is distributed over such a large area that it is rapidly absorbed by the atmosphere. That which is taken up by plants is given to the atmosphere either directly by transpiration or by evaporation when the plant decays. These processes go on so gradually that most of the water which is removed by them passes off as vapor. This fact has usually caused the influence of plants and capillarity on the amount of underground water to be disregarded, but in many regions the amount which is removed by these agencies probably equals 40 to 50 per cent of all the water absorbed by the soil.

Water which comes to the surface under the influence of gravity or the combined influence of gravity and capillarity emerges either in the form of springs or seeps.

Seepage is supplied by water from the pores of the rock and not from definite channels. It occurs wherever the level of the water table (p. 39) rises above the surface, as along the margins of streams, or where the surface and underground drainage is defective. The seepage which occurs along the margin of the streams forms but a small part of the whole, for the water also enters the channels of the streams below the water level. In the Blue Grass region water may be seen seeping from the rocks along the banks of the Ohio and other streams or in the depressions where the surface is comparatively level and the underlying rock is impervious. Many seeps on the upland are utilized for stock and sometimes for domestic purposes by digging a hole in which the water may collect.

The water which emerges at any point in sufficient volume to form a stream is called a spring. Springs are formed by water coming from underground streams or by the concentration of percolating water at one point. It is difficult to distinguish sharply between seeps and springs supplied by percolating water, for with variations in the amount of ground water the springs may diminish in volume until they become mere seeps, or the seepage may increase in volume until springs are formed. In such cases the name "intermittent spring" has been used, but this term is also applied to certain springs formed by underground streams.

In the Blue Grass region springs form a very important source of water for domestic and industrial uses, but they are especially important as sources of water for stock. They occur in all parts of the region and in all the geological formations, but large springs are numerous only in the Lexington and Highbridge limestones.

A hole excavated about a spring or seep is commonly called a pool. Pools are usually walled with rock or cement and serve as reservoirs for storing ground water. Some of the pools in the Blue Grass region are 10 feet or more in depth. On one side an opening is left through which the animals may enter the water, and the floor of the pool is made to slope from the entrance so that the animals may reach the water as its surface recedes during dry weather.

ARTIFICIAL RECOVERY.

WELLS.

The artificial recovery of underground water is accomplished by means of wells, which may be classified as dug, driven, bored, and drilled.

Wells excavated by pick and shovel or by blasting and removing solid rock are called "dug wells." A well of this type is especially adapted to rock formations whose water supply is scanty or is unevenly distributed, for it furnishes a large surface for the entrance of water and a correspondingly large storage capacity. Dug wells are easily constructed in materials which are sufficiently compact to prevent caving of the sides; in looser materials some sort of wall must be provided. In solid rock the work of excavation is greatly increased by the necessity for blasting. In the Ohio Valley the early wells were dug, some of them to a depth of 50 or 60 feet or even more. On the uplands most of the dug wells are 20 to 30 feet deep, though many are less than 20 feet and a few exceed 30 feet. A few wells were dug and blasted to a depth of 100 feet. Dug wells are especially liable to pollution because it is difficult to entirely exclude impure surface water. The dug wells vary in diameter from 3 to 5 feet, but in some localities, where a large storage capacity is desired, some of the dug wells are 25 to 30 feet in diameter.

Many driven wells have been sunk in the sands and gravels along Ohio River, and a few have been sunk in similar materials in the gorge of Kentucky River. Such wells are adapted only to unconsolidated sands and gravels, and hence there are none on the uplands.

Bored wells are excavated with an auger and, like driven wells, are adapted only to loose materials. A few bored wells have been sunk in the gravels along Ohio River. As the well is deepened an iron pipe the size of the hole is driven into the bore to prevent the walls from caving. In some wells a strainer is placed in the lower end of the pipe; but in others the pipe is driven down to within 8 or 10 feet of the bottom of the hole and the water enters through the sand or gravel below the end of the pipe. This method of sinking wells is slow, and unless the well is cased to the bottom the lower part of the bore is apt to fill in a very short time.

Drilled wells are put down by machinery of various sorts. In the Blue Grass region two types of machinery have been used. In the Ohio Valley at Covington a few wells have been sunk by means of a rotating pipe with loose steel shot at the cutting end. This method gives a core of rock nearly as large as the inside diameter of the pipe and thus enables the driller to judge the nature of the materials. On the uplands the churn drill is used. This drill depends for its effectiveness on the impact of a heavy steel bit which is raised and dropped in the hole. The drills are operated by horse power or by steam or gasoline engines. They are especially adapted to such rocks as are found in the region.

The type known as the diamond drill, which uses diamonds set in the bottom of the pipe instead of the loose shot, is not used in the Blue Grass region.

In unconsolidated materials the jet process is often used. In this process a stream of water is forced into the hole to loosen and wash out the material. An iron casing is forced in as fast as the hole is excavated.

The cost of drilling wells in the Blue Grass region ranges from 50 cents to $2 a foot, depending upon the diameter of the well and the amount of competition between drillers, the average being about $1 a foot. Driven and bored wells also cost about $1 a foot, the range being from 75 cents to $2.50. The cost of dug wells can not be readily ascertained, because few have been sunk within the last thirty years and most of the old ones were excavated by day laborers.

WELL CASINGS.

Dug wells in unconsolidated materials are commonly walled with rock, which is rarely well cemented. Where the wells enter rock the casing is usually used above the rock, but in some places where the residual soil is thin no casing is used. The rock walls would be materially improved by cementing them firmly together and to the rock below, as this would exclude a large amount of surface water. In the Ohio River valley the wells which have been bored, driven, or drilled are all cased with iron pipe.

The drilled wells on the upland are also cased with iron pipe, which extends only to the solid rock. These wells might be rendered safer from pollution by taking greater precaution to make a water-tight joint between the casing and the rock. Where the soil is thin this could be done by digging down to the rock and cementing the casing to it, but where the loose material is several feet thick it would be more convenient and economical to use rubber washers, such as are used in oil wells.

Certain wells might be improved by casing off supplies of polluted surface water from underground streams near the surface; and some of the deep wells which have encountered both fresh and brackish waters could be improved by plugging the well below the supply of fresh water. In a few wells where water escapes through cracks or crevices above the point where the supply was encountered the head would be increased by extending the casing below the opening through which the water escapes.

METHODS OF RAISING WATER.

All artificial recovery of underground water except that by flowing wells requires the use of some method of raising the water to the surface. In some dug wells a bucket is used, the water being drawn up by a rope attached to a windlass. Rarely an old-fashioned well sweep is employed, or the bucket may be raised from the well by hand without the use of any apparatus.

Chain or valve pumps are used in many wells. The chain pump is held in high favor because a great part of the water which it raises falls back into the well and thus affords a certain amount of aeration for the water.

In the drilled, driven, and bored wells force pumps are commonly used. Hand power is the most usual method of pumping, but windmills or engines are used where large supplies are required. Windmills have not everywhere proved satisfactory, especially on the large stock farms, and many of them are being replaced by gasoline engines. Steam engines are used to pump water for industrial plants where a constant supply is needed. A few hot-air engines are also used for raising water in the Blue Grass region, and under certain favorable conditions "air lifts" have been installed.

COLLECTION AND STORAGE OF RAIN WATER.

CISTERNS.

Rain water is collected and stored in cisterns, ponds, and reservoirs. Where a small amount of water is needed it is usually collected from roofs and stored in cisterns. This method of procuring water for domestic use prevails throughout the upland areas of the Blue Grass region, and as cistern water is comparatively free from mineral matter it is usually considered more desirable than underground water.

Cisterns are ordinarily excavated to a depth of 10 to 20 feet, and where the materials are unconsolidated the cisterns are walled. In some parts of the Blue Grass region the wall is made of brick laid in cement, but the wall material most commonly used is stone. A stone wall, however, is satisfactory only where great care is taken to secure a perfect joint. Cisterns in rock are not walled, but the cement is applied to the rock, and if the rock contains water-bearing crevices the cement wall is apt to be too weak to withstand the hydrostatic pressure of the water outside the cistern. Under such circumstances the cistern should be walled just as if it were in unconsolidated materials. In some cisterns where the rock is exceptionally solid no cement is used, but the omission of the cement is hardly safe, because practically all rock admits some ground water into the cistern or allows some of the rain water to escape. Moreover, the rain water which is stored in uncemented cisterns gradually dissolves mineral matter from the rock and becomes hard.

Rain water collected after roofs and spouts have been thoroughly washed is practically free from inorganic matter. The desired washing is usually accomplished by allowing the first water which falls to escape through a waste valve. After the roof and pipes have been cleansed the waste valve is closed and the water is allowed to enter the cistern. This method is inconvenient, especially if the rainfall comes in the night, but it is desirable if the cistern water is to be kept pure and wholesome. During dry weather objectionable material of various sorts, such as dust that may contain germs of dangerous disease, leaves, or twigs, lodges on the roof or in the eaves troughs. Eaves troughs especially need constant attention, for they are frequently the nesting places of birds. Roofs should be kept painted to prevent the growth of moss and the accumulation of filth in the cracks.

Small filters are much used to purify the water before it enters the cistern, but their efficiency has frequently been overestimated.

Filters such as those here described may be used to remove some of the suspended matter which may have been derived from unclean roofs or water spouts, but they can not be depended upon to free the water from the organic matter which is apt to cause disease. The filter in most common use consists of a tin cylinder, 2 to 3 feet high and 18 to 24 inches in diameter, partly filled with alternating layers of charcoal and sand or with charcoal alone. Above this material is a screen which catches the leaves and fragments of wood that may be washed from the roof. Filters of this type are valuable only when they are kept clean and the filtering materials are renewed frequently. A filter of another type is excavated in the ground and walled like a cistern. The filter is made large enough to hold the water from a single storm and is connected with the cistern by a passage placed some distance above the bottom of the filter. The sediment collects below the level of the connecting passage and may be removed through a manhole at the top of the filter chamber. The filtering materials are so arranged that all the water entering the cistern must pass through them. Like the materials used in other filters they should be frequently renewed or they will become filled with foreign matter and their efficiency will be reduced. These large filters are more expensive than the others, but when properly constructed and cared for they are much more effective.

RESERVOIRS.

Reservoirs built to impound surface waters are numerous throughout the upland areas of the Blue Grass region. These reservoirs furnish water of good quality, both for city supplies and for farm use. As a rule the water is not highly mineralized, but it is likely to be turbid, especially where the catchment area is cultivated. In selecting a site for a reservoir it is best to choose some place where the area of the water surface will be reduced to a minimum, as the smaller the area the smaller the loss by evaporation. The best location is in a comparatively narrow valley with a steep gradient, which will permit the construction of a deep and narrow reservoir. In some such places, however, the rock beneath the selected site is found to be so badly fissured that it would be impossible to prevent leakage. Under such conditions another location must be sought. In the country districts these artificial reservoirs, or ponds form a very important source of water for stock.

For city supplies it is often necessary to build more than one reservoir, and such reservoirs may be arranged one above another on the same stream. This arrangement has three distinct advantages: It allows the collection of a supply of water during wet weather amply sufficient to last through a drought; in its passage from one reservoir to another the water receives some aeration; and the upper reservoir catches most of the sediment and thus lowers the turbidity of the water at the point of intake in the lower reservoir.

MUNICIPAL WATER SUPPLIES.

SOURCES OF SUPPLY.

In the Blue Grass region both underground and surface waters are used for city supplies. The surface water is taken from rivers or small streams. The underground water is taken from streams in limestone, the supplies being obtained from wells which penetrate the channel of the stream or from springs at the point where the underground water reaches the surface.

SURFACE WATER.

The important sources of surface water for the region are Ohio River and its principal tributaries, or the small streams that enter these tributaries. Some of the small streams which are utilized for city supplies flow only a part of the year, and hence it is necessary to build storage reservoirs.

The surface water is ordinarily used without attempt to free it from the suspended matter present, though settling basins or filter plants have been constructed in a few places. Where more than one storage reservoir is available it is possible to utilize the uppermost as a settling basin, but the sediment may be so fine that much of it will reach the lower reservoir where the intake is located.

The sanitary character of the surface water varies greatly. Ohio River water is probably the most objectionable, because it receives the sewage of a number of cities above the region. The other rivers receive less sewage, but all of them flow through regions more or less densely populated. The water which is taken from small streams varies in character, according to the local conditions. One supply is from a stream which receives no drainage from farms, but all the other supplies are from streams which are to some extent polluted.

UNDERGROUND WATER.

In some localities the limitations imposed by nature make it impossible to procure enough underground water of a suitable quality for a city supply. Certain geologic formations of the Blue Grass region will not yield enough water at any one place for a city, while others contain water which is too highly mineralized for ordinary use. In fact, there are only two geologic formations—the Lexington limestone and the alluvium of the Ohio Valley—which will furnish enough underground water of suitable quality for a city, and neither can be relied upon to supply a large settlement. Water from the Lexington limestone is fit for use only when it is obtained above the level of surface drainage, and enough water for a public supply can be obtained only in certain localities where underground drainage is extensively developed.

COMPARATIVE VALUE OF UNDERGROUND AND SURFACE SUPPLIES.

Although most people prefer underground water to surface water, the preference is seldom based upon a careful consideration of the relative merits of the two supplies. Water from the alluvial gravels of the Ohio Valley is little utilized as a source of supply, because of its proximity to the river, from which a large quantity of water may be easily obtained. The Lexington limestone supplies considerable water in some localities where surface water can not be obtained without constructing storage reservoirs. The water from the gravels is probably freer from pollution than surface water, because it undergoes filtration in its passage through the sand; but it contains considerable mineral matter, which must be removed before it is suitable for some industrial uses. The surface water is often polluted by sewage and surface drainage, and hence its sanitary condition is doubtful. It also contains a large amount of suspended matter, which unfits it for certain purposes. The polluting substances and suspended matter may be removed from the surface water by filtration, and the dissolved mineral matter in the water from the gravel may be precipitated by the use of softening compounds. As it usually costs more to soften water than to filter it, the surface water may be regarded as more satisfactory for municipal and industrial purposes than the water from the gravels.

Wherever the Lexington limestone yields large supplies, the water is derived from streams flowing in caverns, and these underground streams do not differ from surface streams in any essential particular except that they are partially covered by a roof of limestone capped by a few feet of clay.

As the underground streams are partly covered, they probably receive less objectionable drainage than the surface streams. This is counterbalanced by the fact that the drainage basin of the surface stream is well known, and hence it is possible to discover sources of pollution. The courses of the underground streams and their tributaries are little known, and it is not often possible to protect them against pollution. There is, moreover, small chance for the water in the underground stream to be purified by natural means. Therefore the surface streams usually form a more desirable source of supply than the underground streams. The water from either source should, as a rule, be filtered before it can be regarded as safe.

For industrial uses the surface waters have a decided advantage over those from the limestone, because they contain much less mineral matter in solution. It is true that the underground waters from the Lexington limestone are well adapted to certain industries; but they would need to be softened before they could be utilized for all purposes.

POLLUTION OF UNDERGROUND WATER IN THE LEXINGTON LIMESTONE.

In the preparation of this section on the pollution of underground waters in the Lexington limestone an attempt has been made to avoid, as far as possible, all strictly scientific and technical discussions, such as the efficiency of natural purification of waters and the value of various artificial methods of purification. Because of a desire to make the discussion as useful as possible, stress is placed upon the simple methods of tracing underground streams and determining possible sources of pollution.

The shallow water from the Lexington limestone is used for city supplies, and is fairly satisfactory. Certain features of this aquifer, however, suggest the possibility of pollution. Though it is possible to state certain general facts bearing on the subject of pollution, it is necessary to deal with each individual case strictly on its merits. The most important generalization is that the water which flows in limestone channels is not completely purified by its passage through those channels. There is a popular idea that water is purified by passing a short distance underground, a belief based partly on the effect of sand or sandstone on the water that traverses them. In close-grained, water-bearing rocks the purification is in part mechanical and takes place because the openings between the sand grains are very small; in other words, in removing objectionable matter the sand acts much like a filter. But when water flows through channels in limestone there is no filtration, and probably but little natural purification. The flow of water in limestone channels may be compared with its movement through ordinary water mains, and the chances for purification are about equal in the two cases. As there is little chance for natural purification of limestone waters, it becomes desirable to prevent pollution, and this can best be accomplished after the source of the polluting matter and the methods by which it reaches the water are thoroughly understood.

Persons using underground water are apt to consider its appearance and temperature indications of purity, for it is generally believed that water which is clear and cold is pure. No such belief is warranted by the facts, for some of the most dangerously polluted waters are both clear and cold.

Certain waters will be rejected as unfit for use because of the occurrence in them of straw or other visible materials of organic origin, and the wisdom of such rejection is too apparent to need comment. The presence of suspended matter in water is often taken as an indication of the entrance of surface water through an open sink hole, but such conclusion also may be erroneous.

From an inspection of the accompanying diagrams it will be seen that the presence or absence of sediment can not be considered a safe

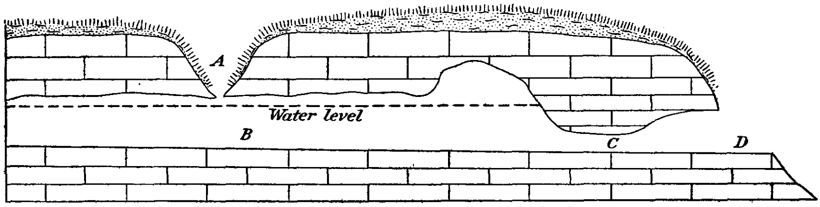

FIGURE 5.—Diagram of cavern showing how sediment may be deposited by the underground stream.

indication of the presence or absence of surface drainage. In the diagram (fig. 5) sediment-laden surface water entering at *A* may be so retarded in the chamber *B* that it deposits its suspended matter and passes through the constricted channel *C*, to emerge at *D* comparatively clear. In this case the water, though free from sediment, may contain considerable surface drainage in some other form. In figure 6, absolutely uncontaminated water in its passage round the fallen material from the closed sink *A* may obtain sediment and emerge at *B* so turbid as to cause the erroneous deduction that there is a direct connection with surface drainage.

The conditions represented by these two figures are transitory, for the chamber *B* (in fig. 5) will soon become partly filled with silt

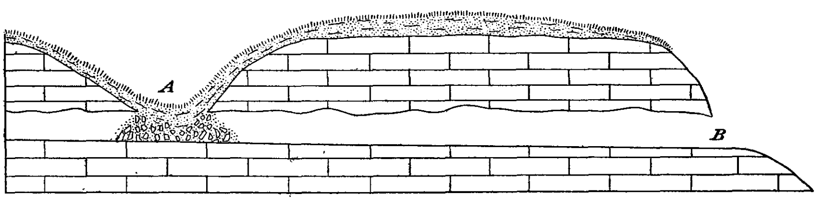

FIGURE 6.—Diagram of cavern showing how sediment may be obtained by the underground stream.

so that the water passing through the channel *C* will transport a considerable amount of sediment, while the gradual removal of material (in fig. 6) from the sink *A* will soon form an open hole. Such conditions may also be intermittent. In any case it is wise to refrain from drinking underground water which contains silt or clay, for while these materials in themselves are seldom injurious, they may indicate the presence of surface drainage which has received little or no natural purification. It must not be inferred that all surface drainage is harmful, but it is well to bear in mind the possibilities of pollution by such drainage, and if any part of the surface drainage comes from a city or from dwellings, the water should be rejected.

It was formerly thought that a sanitary analysis of water was a reliable means of determining its potability, but this dependence upon chemical tests has little by little proved to be unsafe. For this reason a careful examination of the drainage basin to discover possible sources of pollution is recommended as more reliable than chemical or bacteriological examinations of the water. On this subject Dole[a] says:

> In brief summary it may be said that careful study by practical sanitarians of the chemical and bacteriological results of analyses, made not in one small section alone but all over the country, has failed to show that laboratory methods can be depended upon to detect pollution. On the other hand, sanitary survey strikes directly at the source of the evil—pollution—and affords definite bases for its removal or for protection against it.

The futility of sanitary analyses is illustrated by several examples given by Leighton.[b] One citation is of especial interest to inhabitants of the Blue Grass region, because the samples of water were taken from Kentucky River. In this case one sample of water was taken from Kentucky River at the intake of the Frankfort waterworks and another was taken from the same stream below the outlets of the city sewers. Both samples were taken on the same date and were judged by the standards usually employed in determining the potability of water. The conclusion reached by Leighton[c] is:

> The important feature * * * is that here is a water, or a dilute sewage, taken below the sewers of a city of 20,000 inhabitants showing practically the same, if not a better, condition, according to the interpretation standards, than another sample taken from the stream above the sewers.

This conclusion should not be taken as a condemnation of the city supply of Frankfort, for it merely shows the absurdity of relying upon sanitary analyses alone to determine the potability of water.

A satisfactory method of determining the potability of water is by means of a sanitary survey of the watershed from which the supply is drawn. Such survey, including as it does an examination of the entire watershed from which the supply is taken, makes practicable the determination of the sources of polluting matter and the adoption of measures to prevent contamination. Wherever streams flow through inhabited areas considerable objectionable matter is certain to enter the water and pollution can not be entirely pre-

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[a] Dole, R. B., Sanitary inspection versus sanitary analysis: Proc. Am. Pub. Health Assoc., vol. 31, pt. 1, 1905, p. 60.

[b] Leighton, M. O., The futility of a sanitary water analysis as a test of potability: Biological studies by the pupils of Wm. Thompson Sedgwick, Boston, 1906, pp. 36–53.

[c] Idem., p. 43.

vented. For this reason filtration is desirable; but the dangers from such pollution may be minimized by the use of ordinary care in the disposal of sewage and other waste materials.

Sanitary surveys of small surface streams may be made with considerable ease, but similar examinations of underground streams are attended with more or less difficulty. In order to ascertain the possible sources of pollution in an underground stream in limestone, it is first necessary to determine the location of the channels of the main stream and its tributaries. The course of the underground system may usually be inferred from the general slope of the surface and the position of sink holes. The location of minor tributaries is often so uncertain that it is necessary to go over the probable drainage basin with great care. In addition to examining the areas which from their surface slope are associated with the underground stream, it is advisable to survey the territory immediately adjoining them, because some underground streams pass beneath surface divides.

Besides considering the course of the underground stream it is also necessary to know how surface drainage reaches it. The water in the limestones flows in well-defined channels, to which it gains access either by seepage through the soil or directly through open sink holes. A portion of the water which enters the soil is almost certain to find its way to some underground stream, either directly or through some of the numerous crevices which traverse the limestone, and although it may receive some filtration and oxidation in its passage through the soil, reliance can not safely be placed upon this method of purification. The water which passes through the open sink holes carries with it much of the objectionable matter it may have obtained in its passage over the surface of the ground. Whatever purification this water undergoes takes place as the result of oxidation, bacterial action, etc., in the stream; and it is doubtful if the changes to which such objectionable matter is subjected are sufficient to render recently polluted water potable.

In the United States tracing the course of underground streams has received little attention, but in Europe, especially in the vicinity of Paris, much work of this sort has been done. A summary of investigations made by the city of Paris is presented by Dole [a] in Water-Supply Paper No. 160, and the reader is referred to that publication for a discussion of the results.

The common method of tracing underground streams in limestone is to introduce some substance into the underground channel at a convenient place and then to determine the presence or absence of the material thus added by examining samples of water from the underground stream at another place more or less removed from the

[a] Dole, R. B., Use of fluorescein in the study of underground waters: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 73-85.

point of initial introduction. Sometimes chemical salts are dissolved in water and introduced into the underground stream either directly through open holes or by seepage through the soil. Compounds which have been used are chlorides of sodium, calcium, or ammonium, potassium nitrate, and compounds of lithium or of iron. After the introduction of one of these substances chemical tests for its presence are made at frequent intervals in samples of water taken from the well or spring under study. For various reasons sodium chloride has been found to be most satisfactory and it is commonly used in preference to the other compounds. Successful experiments have also been made by coloring the water with solutions of potassium permanganate, fuchsine, Congo red, methylene blue, and fluorescein. Such substances as flour, starch, sawdust, leaves, oil, or cultures of bacteria may be suspended in the water and samples from the suspected spring or well water may be examined to determine their presence or absence. The choice of the material to be used depends largely on local conditions. Oil and other substances which float on the water are satisfactory only where there are no quiet reaches of water and no marked constrictions in the channel to delay their progress. In some streams they have proved satisfactory, while in others they have given negative results, and they are most useful in connection with other tests.

The use of fluorescein, one of the coal-tar products, is especially recommended, because this dye is not easily affected by the substances usually occurring in ground waters, and its color may be detected in very dilute solutions. According to Dole's abstract,[a] solutions containing 1 part of fluorescein to 10 billion parts of water will show, with the proper apparatus, the characteristic color of the fluorescein.

Salt or fluorescein may be placed in the underground stream and tests for their presence made at wells or springs at frequent intervals. In this way the time required for the substance to traverse the distance between the point of introduction and the places where samples are taken may be determined. If desired, the sampling may be continued until the water returns to its normal condition. It is usually best to take samples of water from as many sources as possible in order to determine the underground water conditions over an extended area. After the water has returned to its normal condition the testing materials may be introduced at some new locality and samples taken as before. This process can be repeated until the sources of the underground water are determined. It will usually be found that the stream receives tributaries from different directions in about the same manner as surface streams.

In choosing a spot for the introduction of the testing materials, preference is naturally given to places where there is free access to the underground channels, either through sink holes or through wells.

[a] Op. cit.

In such places the fluorescein solution may be poured into the stream. The most satisfactory method of introducing salt is in the form of a strong brine, which may be allowed to flow into the stream. Where open sink holes or wells are not available, the fluorescein or brine is usually placed in a shallow depression and allowed to enter the underground stream by percolation through the soil. In order to determine whether a cesspool drains into the underground stream, the identifying material is usually placed in the cesspool and tests are then made to determine its presence in the stream.

The use of salt in tracing underground drainage requires a certain amount of chemical knowledge and some skill in the use of chemical apparatus, because it is not usually practicable to introduce enough of the material for recognition except by chemical examination. Fortunately the test for salt is simple enough to be readily understood by those who are not specialists in the subject. It is made by determining the amount of chlorine present in the water both before and after the addition of salt (sodium chloride), and the procedure for this estimate is that in common use among water analysts, namely, titration with silver nitrate solution, using potassium chromate indicator. The method is outlined in detail by Leighton.[a]

The amount of salt necessary for any given test depends largely upon the mode of introduction into the underground channel and the volume of the stream. Where the salt can be poured into open sinks, it is possible to get satisfactory results with a smaller amount than where it is necessary to depend upon percolation through soil. In the examination of the big spring at Georgetown, Ky., from 2 to 4 barrels of salt were used with good results; and as this is one of the largest springs in the Blue Grass region, it appears probable that the maximum amount given above should be ample for the examination of most of the underground streams in the area. However, for such streams as those that emerge at the large spring at Spring Station or at Russell Cave, it might be necessary to use from 6 to 10 barrels in order to procure decisive results.

Fluorescein could doubtless be used in tracing the course of the underground streams in the limestones of the Blue Grass region, and because the test employed in detecting its presence in water is so simple its use is attended with fewer difficulties than the use of salt. It is introduced into the underground streams either directly through wells or open sink holes or by percolation through soil. In alkaline waters a strong solution of fluorescein gives a red color by transmitted light and appears green by reflected light. If the solution is very dilute, the red color is not detectible, but the green color is very powerful. An apparatus called a fluoroscope, described in Water-Supply Paper 160, has been devised for recognizing small

[a] Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905,–50 pp. 49.

quantities of the dye in samples of water. This instrument is very simple, consisting merely of long, colorless glass tubes plugged at one end by stoppers blackened with plumbago. The tubes are filled with the samples of water, and the presence of fluorescein is demonstrated by a greenish tinge of the sample when it is viewed by reflected light.

Oil, fragments of wood, and sodium chloride were used in studying one of the underground streams of the Blue Grass region. The materials were put into the stream through an open sink about one-eighth of a mile from its point of emergence in a spring. The oil appeared at the spring in one hour, the chloride of sodium in seven hours, and the wood fragments had not appeared after a lapse of several days. Salt is satisfactory for use in streams having a daily flow of a few million gallons or less; but its introduction is impracticable in very large streams such as those found in some caverns.

Water from small channels in limestone may generally be considered safe provided care is taken to guard against local pollution; but the source of the water in the streams in large caverns should be sought. Whether an underground stream for a city supply is safe or not depends entirely on the local conditions. The first questions to be decided are the source and the direction of flow of the water. If the underground stream clearly does not receive polluted water, it may be regarded as a safe source of supply; but if the stream passes beneath or near the city, the intake should be located on the upstream side of the town. The importance of taking the supply from above the town is recognized when dealing with surface streams, but it is sometimes disregarded when the stream is beneath the surface. Not infrequently belief in the natural purification of underground water leads to carelessness in locating the intake. Occasionally the fact that there are several feet of solid limestone or beds of "soapstone" above the underground stream gives the impression that local drainage is excluded. Such idea is wholly erroneous, because the so-called solid limestone or the soapstone contains many cracks and crevices, which allow the surface water to enter the underground channel.

If water from limestone caverns is used, a sanitary survey is desirable to determine the course of the stream and the sources from which it obtains its supply. In a question of potability it is much better and far safer to make a practical inspection of the drainage area, as outlined in the preceding pages, than to place reliance upon a chemical analysis of the water.

The practice of putting rubbish, barnyard filth, etc., into sink holes should be abandoned. Still more reprehensible is the custom of running sewage into sink holes, thus converting the underground channels into natural sewers. This practice, by no means uncommon, is often defended by the claim that the water in limestone channels beneath the city is unfit for drinking. The correctness ‹ this claim can not be disputed, but there are persons ignorant of tl danger who continue to use the underground water. Moreove those living at some distance from the city may take water from tl polluted stream.

NOTES ON CITY SUPPLIES.

The Covington water system, which is the largest in the Blı Grass region, takes its supply from Ohio River. The water pumped to a settling reservoir on the upland. From the settlir reservoir it passes to a storage reservoir and thence to the distril uting reservoir. Considerable sediment collects in the settling basi: Ohio River water contains some inorganic matter in solution; but tl amount is not sufficiently large to render the water unfit for indu trial uses.

The Cynthiana water supply is taken from Licking River. Tl water is pumped to a reservoir and distributed under gravity pre sure to the city. The sediment in the water could be readily remove by the use of a mechanical filter. The small amount of inorgan matter held in solution does not render the water objectionable f‹ use in boilers.

The Danville water supply is drawn from Dix River, and is reporte to be satisfactory. There is no great danger of pollution, and as tl water is filtered, its sanitary condition is guarded.

The Falmouth water supply is taken from Licking River. Tl water is so turbid that it is not suitable for domestic uses; but it drunk by stock and utilized in some industries.

Frankfort is the only city which takes its supply from Kentuck River. There are no large cities on the Kentucky above Frankfor but considerable waste from distilleries is allowed to enter the rive The water of the Kentucky, like that of other streams in the regioı is very muddy during a large part of the year, and could be improve by filtration.

The Maysville water supply is pumped from Ohio River. Tl reservoir is situated on the upland above the town, at an altituc sufficient to give a very strong pressure in the city. The qualit of the water is much the same as that of the river above Covingto and Newport.

The Newport Water Company uses Ohio River water. Th water is very turbid and its sanitary quality during a large part ‹ the year is doubtful. The water is pumped to a reservoir on tl upland and distributed to the city by gravity.

Lancaster has constructed an impounding reservoir on a smε stream. The watershed of this stream is not cultivated and uninhabited. The water is pumped directly from this reservoir in the mains.

Lexington has a water supply which gives universal satisfaction. The water is impounded in three reservoirs, placed one above another on the same stream. The upper reservoirs serve as settling basins when the stream is high and the water turbid. Before being pumped into the mains the water is aerated and filtered. The water is used in nearly all of the manufacturing plants of the city.

The water supply of Paris is taken from a creek. A mechanical filter is used to remove sediment from the water. The supply is ample for the prospective needs of the city and should prove very satisfactory.

The Richmond Water Company takes its supply from a small stream which receives very little drainage of an objectionable character.

The water supply of Shelbyville is taken from Clear Creek. Unfortunately, the water is not always as clear as might be expected from the name of the source.

The supply for the city of Winchester is taken from two reservoirs constructed on a small stream. It is ample for all purposes.

The Lawrenceburg supply is taken from wells sunk in the Lexington limestone. The water is reported to be slightly hard, but it is satisfactory for use in boilers.

The Nicholasville supply was formerly taken from a reservoir on a small stream. It is now pumped from wells which are sunk at the edge of the reservoir, and these wells probably draw considerable water from the reservoir. This water is said to be slightly hard and to form a small amount of scale in boilers.

Georgetown is supplied with water from a large spring located on the west edge of the city. The water is moderately hard and forms some scale in boilers. The volume of the spring is always large, but it fluctuates greatly, rising rapidly after a rain and subsiding again in a short time. The water contains considerable sediment after a rain, and the character of the sediment suggests that surface drainage enters through open sinks.

The water supply of Berea College is derived from ten springs issuing from the sandstones of the mountains. Each spring is surrounded by a cement reservoir. The water is conveyed from these reservoirs to a 6-inch main, which conducts it to the college grounds. The combined flow of the ten springs is about 100 gallons per minute, and their altitude above the town gives a gravity pressure of 95 pounds per square inch. The water has been analyzed at the college and is reported to contain less mineral matter than water taken from cisterns. Springs like those that supply Berea College are numerous, and similar supplies could be installed in many of the towns near the mountains.

Table 7 gives the available information concerning the municipal water supplies of this region.

TABLE 7.—*Municipal water supplies of the Blue Grass region.*

SUPPLIES FROM RIVERS.

No.	City.	Owner.	Source.	From what distributed.	Capacity of reservoir or standpipe.	Elevation of reservoir or standpipe in feet. Above source of supply.	Elevation of reservoir or standpipe in feet. Above city.	How distributed.	Length of mains.	Number of taps.	Number of fire hydrants.	Number of people supplied.	Population of city in 1900.	Daily consumption.	Maximum capacity of pumps.	Domestic pressure.	Fire pressure.
					Gallons.				*Miles*					*Gallons.*	*Gallons.*	*Lbs.*	*Lbs.*
1	Covington; Central Covington; Latonia and Ft. Thomas	City	Ohio River	Reservoirs	+31,970,100; 26,622,200; 27,368,800	+353	250	Gravity	+45	+6,436	....	45,000	a42,938; b4,185	2,823,432	....	100	100
2	Cynthiana	do	Licking River	Standpipe	315,000	......	......	do	7	400	75	2,500	3,257	....	....	100	100
3	Danville	do	Dix River	do	225,000	+500	164	do	11	385	112	1,800	4,285	350,000	2,000,000	70	70
4	Falmouth	do	Licking River	Reservoir	1,100,000	......	......	do	⅓	150	27	750	1,134	....	....	100	100
5	Frankfort	Frankfort Water Co.	Kentucky River	Reservoirs	4,000,000; 4,000,000	+320	+390	do	15	1,250	130	10,000	9,487	2,000,000	8,000,000	120	120
6	Harrodsburg	Harrodsburg Water Co.	Salt River	Standpipe	289,000	+100	......	do	8	300	84	....	2,876	90,000	1,000,000	70	70
7	Maysville	Maysville Water Co.	Ohio River	Reservoirs	1,500,000; 1,500,000	+400	365	do	14	1,000	82	8,000	6,423	600,000	2,500,000	150	150
8	Newport and Dayton; Bellvue	City	do	Reservoir	6,000,000	+330	+250	do	35	5,600	265	....	......	1,185,100; 6,505,700	....	......	......

SUPPLIES FROM SMALL STREAMS.

9	Lancaster	City	Springs and creek.	Reservoir	30,000,000	0	−100	Direct pressure.	4¼	135	40	1,000	1,640	15,000	1,000,000	40	100
10	Lexington	Lexington Hydraulic and Manufacturing Co.	Creek	do	640,000,000			do	43½	+2,716	388	+25,000	26,369	1,700,000		45	100
11	Paris	Paris Water Co.	Hinkston Creek	Standpipe	300,000	+ 40		Gravity and direct pressure.	9	725	108	3,750	4,603	500,000	2,500,000	50	100
12	Richmond	Water and Light Co.	Springs and creek.	do		+100	+ 50	do	6	525	90	3,000	4,653	150,000	2,000,000	−80	100
13	Shelbyville	Shelbyville Water and Light Co.	Creek	do	60,000			do	4		56	2,000	3,016	200,000	1,000,000	40	120
14	Winchester	Winchester Water Co.	do	do		+ 65		do	16	513	138	3,000	5,964	375,000		55	100

SUPPLIES FROM WELLS.

15	Lawrenceburg		4 wells	Standpipe		+100	+100	Gravity and direct pressure.	4	140	31	475	1,253	40,000	500,000	55	130
16	Nicholasville	Nicholasville Water Co.	do	do	150,000			do	4	150	50	750	2,393	7,000	500,000	50	75

SUPPLIES FROM SPRINGS.

17	Georgetown	Georgetown Water, Gas, and Electric Light Co.	Big spring					Direct pressure.		550	74	3,000	3,823	250,000	500,000	75	115
18	Berea	Berea College	Springs (10)	A reservoir at each spring.			+300	Gravity	6			1,200–1,500	762	30,000		95	95

a Covington.

b Other cities.

MINERAL WATERS OF THE BLUE GRASS REGION.

CHARACTER OF THE WATERS.

The underground waters of the Blue Grass region vary widely in composition, the amount of inorganic matter in water ranging from a few hundred to several thousand parts per million. Although the kind of mineral matter is determined by the character of the soil and rock through which the water has passed, certain mineral ions, such as calcium, magnesium, sodium, potassium, chlorine, and the carbonate and sulphate radicles, are common to most of the waters of the region. This is to be accounted for by the fact that the substances mentioned are to be found in the soils and rocks of all parts of the region and that they are all more or less soluble in the ground waters. Many of the waters, especially those from the Ordovician rocks, contain small quantities of some of the rarer elements, such as boron, strontium, lithium, and iodine.

The most common type of mineral water in the Blue Grass region is the alkaline water which contains carbonates of lime, magnesia, sodium, and potassium, together with other carbonates and sulphates. These waters are found in nearly all parts of the area and are commonly designated hard waters.

Hydrogen sulphide occurs in most of the deep waters of the Ordovician area and in some of the waters from the Ohio shale. In the waters of the Ordovician rocks the hydrogen sulphide is often accompanied by petroleum or asphaltic material, suggesting that it is derived from the decomposition of organic matter. The sulphuretted waters from the Ohio shale probably derive their hydrogen sulphide from the decomposition of the sulphide of iron, which is abundant in the shale.

Salt is a very common constituent in the deep-seated waters of the Blue Grass region and it also occurs in some of the waters from the Ohio shale. Its frequent association with hydrogen sulphide has led to the use of the term "salt-sulphur" for such waters as those from the St. Peter sandstone and some of the waters from the Highbridge and Lexington limestones. Besides the salt-sulphur waters, salt waters which are free from hydrogen sulphide also occur.

Some of the waters of the Silurian and Devonian formations contain magnesium sulphates and are known as epsom waters. Sodium carbonate (glauber salts) is also common in some of the waters from the Devonian and Silurian shales. Various other mineral substances are known to occur in the waters from the Ohio shale, the most prominent being the iron which occurs in the Chalybeate Springs. The iron appears in the springs in the form of the hydrous oxide, which is probably formed by oxidation of the iron compounds present in the spring water.

The wells which penetrate the St. Peter sandstone obtain strong salt-sulphur water, known locally as "Blue Lick" water. The water is often used for medicinal purposes. The wells which are best known are located at Newport, Boston Station, and Frankfort. At Sanders a well which probably penetrated this formation procured a salt-sulphur water which is said to contain a notable quantity of lithia. This water is sold under the name of the Eagle Valley Lithia Water.

Water is being sold from a number of wells in the Lexington limestone, and, judging from the mode of occurrence and the analyses, there are many others which might supply marketable water. The best known mineral waters from wells in this formation are the Lexington Lithia water and the Renfro water. The former contains considerable lithia and the latter contains both lithia and sulphur.

One of the best known of the medicinal waters is the "Blue Lick" water which comes from the Lower Blue Lick Springs. This water has a large sale and has been known throughout the South for more than half a century. It also has a large sale in the northern half of the country. The composition of the water, as shown by the analyses, has not changed materially in the last fifty years.

Salt-sulphur water is obtained from the Upper Blue Lick Spring, the Big Bone Springs, the Sanders Sulphur Spring, Drennon Springs, and from many other springs in various parts of the region.

So remarkable is the general resemblance between the Blue Lick water and the water of the St. Peter sandstone that it has often been suggested that the Blue Lick water comes from the St. Peter. Aside from the fact that both are salt-sulphur waters, there is little reason to believe that they have the same origin. Their mode of occurrence suggests that the Blue Lick Springs may derive their water from either the Winchester or the Lexington limestone. In support of this idea it may be said that the Blue Lick water resembles somewhat the deep waters of these limestones, though the resemblance is due rather to such constituents as salt, sulphur, and other elements common to many of the Blue Grass waters rather than to the less common compounds, such as are mentioned in the chemical discussion (p. 207) under the head of Lower Blue Lick Springs. No evidence was noted that would suggest that a fault existed at the Blue Lick Springs, and in the absence of faulting it does not appear probable that the waters of the St. Peter sandstone would rise through the Lexington and Highbridge limestones which overlie the St. Peter.

Big Bone Springs supplies a strong salt-sulphur water which, as already stated, resembles the Blue Lick water. There were originally three springs at this locality. A well which was drilled at one of these springs is reported to have encountered salt-sulphur water at depths of 150 and 500 feet. This well now flows through a wooden pipe which rises 4 feet above the ground, and since it has been drilled one of the original springs has nearly ceased to flow. The water which is now being sold comes from this well. From the well logs (see report of Boone County, p. 163) it appears probable that the Big Bone Springs water originally came from the Lexington or High-bridge limestones, and these formations now supply the water which is obtained from the flowing well.

The limestone of the Maysville formation furnishes very little water of commercial value. At Buffington there are three springs, belonging to J. S. Haynes, which supply water for a small health resort, known as Keo-Me-Zu Springs. These springs are situated within a radius of 20 feet, but they present certain differences in composition. The only other locality where the Maysville formation is known to furnish water of commercial value is at Beechwood, Owen County. The Beechwood Spring—really a shallow well—furnishes water containing a large amount of magnesium, apparently in the form of magnesium sulphate.

The Silurian shales furnish mineral waters at Crab Orchard, just outside the area mapped, but they are not important within the Blue Grass region. They are the source of some mineral water in eastern Clark County, and possibly in some of the neighboring counties. The upper limestone beds of this series furnish an abundance of water in localities where they are not deeply buried beneath the Waverly shale. Some of the springs from the limestone of the Panola formation are being extensively used, the most prominent being the Anita and Royal-Magnesian springs. The waters of these springs are not sold as mineral waters, but they find a ready market as pure drinking waters. Other springs from this formation are known near the western margin of the area and at various points on the eastern side of regions in the vicinity of Waco and elsewhere.

The Ohio shale furnishes valuable mineral waters at various points in central Kentucky. Within the area mapped the most important localities are Linietta Springs, at Junction City, and Alum Springs, 4½ miles west of Junction City, Boyle County; Fox Springs, Fleming County; Dripping Springs, Garrard County; Kiddville and Oil Springs, Clark County. Outside the area mapped are some very important springs which have been included in this report—Estill Springs, Olympia Springs, and Crab Orchard Springs. These resorts were not visited by the writer. Both the occurrence and the character of the waters are fully described in several of the reports of the

Kentucky Geological Survey. The Olympia Springs were discussed by Linney in his report on the geology of Bath County, from which the following statement is taken:[a]

> These springs are situated near the head of Mud Lick Creek, 2½ miles from the Chesapeake and Ohio Railroad, at Olympia station, and consist of a salt well, a salt-sulphur well, black-sulphur well, two chalybeate springs, and a well and a spring whose waters are alkaline saline. Some of these have been known and used nearly since the first settlers came to this part of the State. The geological position of these waters is the same which gives rise to the majority of mineral waters in the State. They arise from near the union of the rocks of the Corniferous limestone with the black slate. This is a horizon in which magnesian limestones, clay shales, salt, sulphide, carbonate and other forms of iron, and minute quantities of other minerals are found in close proximity. Water penetrating the rocks dissolves the mineral matters in various proportions, new combinations are formed, and thus originate these various mineral springs.

In his report on the geology of Lincoln County, Linney gives the following facts relating to the source of the Crab Orchard Springs and the Crab Orchard salts:[b]

> In Lincoln County there are a large number of mineral springs. Some of these, situated in and near Crab Orchard, have old and extended reputations. These springs furnish several classes of water.
>
> The black slate everywhere contains more or less of the sulphides of iron. These compounds, by their decomposition, furnish a variety of sulphur, and sulphur and chalybeate waters—among which salt-sulphur and black-sulphur are the most common.
>
> The lower Subcarboniferous shales furnish some weak springs of chalybeate, but the best water of that kind issues from a layer in the Upper Silurian, which contain oxides of iron.
>
> In the Crab Orchard shales are a number of springs and seeps which furnish magnesian waters. Weak alum waters are known at a few places, while salt water has been obtained in the county in boring wells for other purposes.
>
> Crab Orchard salts is a name given to a peculiar variety of epsomite—Epsom salt or magnesian sulphate—which is manufactured from the Crab Orchard shales of the Upper Silurian in Lincoln and Garrard counties. They differ from the common type of other magnesian salts, so well known to commerce as a medicine, in containing a number of other ingredients which enhance their value.
>
> This strip of country, in which these shales predominate, and the manufacture of these salts is conducted, is an irregular one, about 13 miles in length, and from a few hundred yards to 2 miles in breadth. They lie on a slope in the rocks to the southeast, and are from 16 to 40 feet in depth. Through all this line and thickness they are impregnated with the minerals which characterize the salts.
>
> The origin of this deposit is an interesting question, worthy of investigation. That the shales and the minerals contained in them were thrown down from solution during the evaporation of the ocean water in shallow basins, raised above the sea level, is hardly to be accepted, as the differences in the shale and the interstratification of limestone would require other conditions for their formation. It seems more probable that the materials for the shales were swept in and deposited in protected places by currents, and that afterward these minerals, which had been contained in the magnesian layers of the Upper Silurian and Devonian series, were carried down this slope, and found in those shales the conditions for their deposition and preservation.

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[a] Linney, W. M., Reports on the geology of Bath and Fleming counties: Geol. Survey Kentucky, 1886, pp. 36, 37.

[b] Linney, W. M., Report on the geology of Lincoln County, Geol. Survey Kentucky, 1882, pp. 29–32.

A bulletin of the Kentucky Geological Survey, by A. F. Foerste, received after the preparation of the body of this report, discusses the mineral waters of the Ohio shale as follows:[a]

It has been stated that the table of contents of the waters from a mineral spring is but an index of the various geological strata through which its waters have passed and of the mineral bodies with which they have come in contact. In this sense, the Devonian black shales should be of special interest to the people of Kentucky, since a considerable part of the springs which are visited, more or less for their medicinal virtues, issue from the black shales. Among these may be mentioned the Fox Springs, 8 miles east of Flemingsburg, in Fleming County; the Olympian Springs, in the southeastern part of Bath County; the Oil Springs, about a mile northeast of Indian Fields, in the northeastern part of Clark County; the Estill Springs, about a mile north of Irvine, in Estill County; Hale's well, about 4 miles southeast of Stanford, in Lincoln County; the Linietta Springs, northwest of Junction City, in Boyle County; Alum Springs, 2 miles farther west, in Boyle County; the Sulphur Springs, 3 miles southeast of Lebanon, in Marion County; and numerous other springs, less known but with waters containing the same ingredients.

PRODUCTION OF MINERAL WATERS.

The total sales of mineral water from the Blue Grass region approximate $200,000 annually. Of this amount, about one-fourth is derived from the sale of table waters and the remainder from the sale of medicinal waters. Apart from the sales, considerable water is consumed at the springs where there are hotels.

COUNTY CONDITIONS.

ANDERSON COUNTY.

SURFACE FEATURES.

Anderson County is located near the western border of the Blue Grass region. Its western boundary is formed by Kentucky River, which here flows in a trench more than 400 feet below the upland and so narrow that the river occupies nearly the entire width of the gorge.

The surface of the upland near the Kentucky is broken by deep canyons where the tributary streams have cut into the limestone formations. A short distance back from the river the surface becomes gently rolling, exhibiting shallow valleys separated by rounded divides. Toward the western boundary the valleys are deeper and narrower and the areas of level upland are much smaller.

A narrow strip along the eastern edge of the county is drained by small streams tributary to the Kentucky within the county, and a small area in the northern part by streams that join the Kentucky in Franklin County. The central part of Anderson County is drained

[a] Foerste, A. F., The Silurian, Devonian, and Irving formations of east-central Kentucky: Bull. Kentucky Geol. Survey No. 7, 1906, p. 255.

by Salt River, which enters from the south, flows northward to a point a few miles southwest of Lawrenceburg, then takes a southwesterly course to Van Buren, where it leaves the county. This stream receives no large tributaries within the county except Crooked Creek, which flows along the western border of the county and joins the Salt near Van Buren. A small area in the southwestern part of the county is drained by two tributaries of Chaplin River—Beaver and Sulphur creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Anderson County consist of yellow or red clays from 2 to 8 feet thick, the average thickness being probably less than 3 feet. These soils yield water in few localities to wells, but they store considerable quantities and supply it gradually to the crevices in the underlying rock. A deposit of sand containing pebbles of chert—the alluvium which has been transported from the hills to the southward and deposited wherever the gorge was wide enough to permit its accumulation—is found in narrow, discontinuous strips along Kentucky River. Such alluvial deposits supply water in abundance to springs and driven wells.

CONSOLIDATED MATERIALS.

The geologic formations appearing at the surface in Anderson County include the Highbridge limestone, which is exposed in the Kentucky River gorge; the Lexington limestone, which forms a part of the upper walls of the gorge and extends out a short distance on the upland, and which is also exposed in the valley of Salt River from the southern line of the county to the point where the river makes the bend toward the southwest; the Winchester limestone, which lies in narrow strips outside the areas of Lexington limestone and occupies a large area in the central part of the county; and the Eden shale. It is possible that rocks belonging to the Maysville formation may occur on some of the higher hilltops near the western boundary of the county, but no evidence of their presence has been obtained.

In areas where they appear at the surface the Highbridge, Lexington, and Winchester limestones furnish considerable hard water to springs and shallow wells. At depths varying from 50 to 100 feet, however, the Lexington and Highbridge yield salt and salt-sulphur water; and highly mineralized water, usually containing salt and sulphur, is also obtained from wells in the Winchester limestone which have been sunk below the level of the surface streams. The Eden shale usually occurs on the slopes or tops of hills and in such situations that it furnishes only small quantities of water to springs and shallow wells; below depths of 30 to 35 feet it contains practically no water.

The St. Peter sandstone underlies the county and will furnish flowing wells in the gorge of Kentucky River and probably in the lower parts of some of its tributaries. The water from this horizon is, however, highly mineralized, and is in addition saturated with hydrogen sulphide gas.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

The water for city supplies and manufacturing in Anderson County is obtained from drilled or dug wells, cisterns, and springs.

Drilled wells are numerous in the eastern part of the county, especially near Tyrone, McBrayer, and Lawrenceburg, the city last named obtaining its supply from wells sunk in the Lexington limestone. The drilled wells vary in depth from 40 to 80 feet, although a few of them obtain water at 25 feet or less. Sulphur water is encountered at various depths, ranging from 25 to 30 feet in the valleys of some of the tributaries of Salt River to over 100 feet near Kentucky River.

Dug wells are found in all parts of the county, but they are more numerous in the western part. Few of them exceed 30 feet in depth, and they are apt to fail in times of drought. The water is of good quality except where the wells are located too near buildings.

Cisterns also are extensively used in all parts of the county, and in the western part they form the best sources of supply for domestic purposes, but many are in use in the eastern part, where good well water is available.

Springs are numerous throughout the county, but they vary greatly in size, being large in the eastern half of the county and small in the western half. As the spring water is usually hard, it is used but little for domestic purposes. A number of springs are, however, used for manufacturing, and a part of the supply for the village of Tyrone comes from a spring in the Kentucky gorge.

Most of the underground water used for manufacturing comes from the Winchester and Lexington limestones.

BOONE COUNTY.

SURFACE FEATURES.

Boone County, one of the most northerly counties of the Blue Grass region, is bordered on the north and west by Ohio River, whose channel here occupies a steep-sided gorge.

The surface of the county is a plateau, deeply trenched by narrow gorges near the river, but nearly level in the interstream areas, which are occupied in large part by flat-topped divides. Altitudes within the county have an extreme range of over 500 feet—from about 420 feet above sea level along the Ohio to more than 940 feet on the highest parts of the upland. The descent from the level of the upland to the river is usually precipitous, and the small streams, which as a rule make the descent within a distance of 3 or 4 miles, have very steep gradients. The larger tributaries have cut deep channels for a distance of several miles back from the river.

The Ohio receives in this county water from many small tributaries and from three creeks of considerable size—Woolper, Gunpowder, and Big Mud Lick. These creeks not only drain the greater part of Boone County, but small areas outside of it. The drainage basin of Woolper Creek is largely north and west of Burlington; Gunpowder Creek receives the drainage of the south-central part of the county; and the southern end of the county drains into Big Mud Lick Creek, either directly or through Big Bone Creek.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

Above the rock in the southern part of the county is a deposit of residual clay, averaging 5 or 6 feet in thickness, which has been produced by the weathering limestones and shales of the Maysville. It varies in color from yellow to brownish red, and is usually dense where it was derived from the shales and more porous where the original rock was limestone. The porosity of these limestone soils seldom equals that of the loam derived from the Lexington limestone in Fayette County. The residual materials do not furnish water directly to wells and springs in this county, but they store the moisture and give it to the crevices and channels in the rock from which the wells and springs draw their supplies.

The northwestern part of the county is capped by a loesslike silt (see silt-loam soil, p. 33) to an average depth of 2 or 3 feet, with a maximum of about 6 feet. Beneath the silt is glacial drift, a few feet thick, composed largely of residual clay containing fragments of limestone and pebbles of chert, with occasional bowlders of granite. In the vicinity of Bullittsville and Hebron the glacial drift consists of water-deposited sand and gravel, but this phase is apparently restricted to the ancient channel of a small stream which existed before the deposition of the drift.

In the valley of Middle Creek there is a deposit of sand and gravel which locally exceeds 40 feet in thickness and which is not known to extend beyond the boundaries of the drainage basin. Above the gravel of this deposit, which has in some places been cemented into a hard conglomerate, is a layer of sand several feet thick, capped by 5 or 6 feet of loesslike silt. The drift rests upon the original surface, which it has modified very little.

In the Ohio Valley near Bellevue the glacial drift forms well-defined knolls which rise to nearly 250 feet above the gravel terraces which border the river. In some places the residual soil has been very little disturbed. The drift has about the same color as the residual material from which it was largely derived.

The glacial deposits over most of the county serve the same purpose as the residual materials—that is, they store the water and supply it to openings in the rock below. The glacial materials are as a rule somewhat less porous than the residual, but they are much thicker and therefore hold a greater volume of water. Where the drift consists of sand and gravel it supplies water for both wells and springs. Rock springs, from the conglomerate in Middle Creek Valley, are very well known throughout the western part of the county. In the vicinity of Bullittsville and Hebron the glacial gravels supply remarkably pure soft water to half a dozen wells and a number of springs.

The hillside slopes underlain by Eden shale are usually covered by a mass of talus, composed of blocks of limestone with more or less silt or clay. The streams are constantly transporting this material toward the river, but the accumulation usually goes on more rapidly than the removal. The deposition of the material at the points where the tributary streams enter the main valley gives rise to alluvial fans. The talus deposits supply moderate quantities of water to springs and shallow wells.

The alluvium along the small streams is usually made up of coarse angular or subangular fragments mixed with silt or clay, the large fragments predominating to such an extent that the material is very porous. It contains large quantities of water in wet weather, but the supply is apt to be exhausted during periods of drought.

In the Ohio Valley the alluvial deposits are also very porous and they absorb a large amount of water, receiving not only that which falls directly upon the surface of the gravel but much drainage from the upland. These deposits furnish, at depths of 80 to 110 feet, an abundance of water which, although moderately hard, contains less inorganic matter than the water from the limestones.

CONSOLIDATED MATERIALS.

The surface rocks of Boone County include the Winchester limestone, which outcrops in the Ohio Valley and in the lower course of the tributaries of the Ohio; the Eden shale, which is exposed on the stream slopes for a distance of several miles back from the river but which does not reach the surface on the upland; and the Maysville formation, which is at the surface over all the upland portion of the county. It is possible that the Lexington limestone forms a part of the channels of the streams near the southeast corner of the county, but important exposures of this rock are not found in the county.

The Winchester limestone in this region is from 40 to 50 feet thick and is exposed only in the lowest parts of the valleys. In some of the smaller stream valleys it may yield fresh water, but in most localities the water from this horizon is brackish and in many places it is sulphurous. Its quality would in general render it unfit for domestic or industrial uses.

The Eden shale, which overlies the Winchester limestone with a thickness of about 300 feet, furnishes practically no water for either springs or wells.

Overlying the Eden shale are the rocks of the Maysville formation, which comprise a series of interlaminated limestones and shales somewhat exceeding 200 feet in thickness. In the northern half of the county, especially in the vicinity of Burlington and Florence, the heavy bedded limestones of this series contain some caverns, not large enough to permit exploration, but indicated by numerous small sink holes. In this part of the county underground water conditions are greatly favored by the porosity and unusual thickness of the loose materials above the limestone. In the southern part of the county, where the shales of the formation are the predominant surface rock, the amount of underground water is smaller, although locally the occurrence of limestone beds furnishes more favorable conditions. The residual materials in this part of the county, being derived from argillaceous rocks, are rather heavy clays, and although they have great storage capacity they furnish only moderate quantities of water to the underlying rocks.

Wells in the limestone of the Maysville formation obtain water at depths ranging from 10 to 35 feet, but the amount of water varies greatly from time to time. The underground channels fill quickly after a rain, but the supply is soon lessened by dry weather, and during periods of drought the shallow wells and many of the springs may be dry. Where the upland borders the Ohio Valley numerous springs emerge from the contact of the limestone beds with the underlying shale layers. Many of these springs are situated 300 or 400 feet above the river; but there is, of course, no foundation in fact for the popular belief that they lie on the highest points of land, for the water comes from higher areas a short distance back from the river. The water found in the rocks of the Maysville formation contains considerable amounts of inorganic matter, but is not too hard for ordinary uses.

The Highbridge and Lexington limestones are under cover in this county, but where they were penetrated in drilling for oil near Big

Bone Springs some salt water and considerable gas were found. Here, as elsewhere in the Blue Grass region, the water in these formations occurs in channels which may or may not be encountered in drilling; but as neither formation supplies fresh water where it is buried beneath younger rocks, it is useless to drill into them for water for domestic or industrial purposes.

The St. Peter sandstone underlies Boone County at depths varying from less than 900 feet in the deeper valleys to 1,400 feet on the upland, but it has not been reached by any deep wells. It would furnish flowing wells in all the valleys which are cut below about 590 feet above sea level, including the Ohio Valley and the lower courses of its principal tributaries, but it is safe to say that the quality of the water would be the same as at Frankfort and Cincinnati, where the formation furnishes the strong salt-sulphur water commonly known as "blue lick" water.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

In the Ohio Valley wells penetrating the alluvium have been uniormly successful except at Taylorsport, where a fine sand was encountered which caused the abandonment of two wells. The Boone County distillery takes its entire water supply from the alluvium. On the upland, however, drilled wells have been unsuccessful, either failing to obtain any water or finding brines. A well drilled to a depth of 200 or 300 feet at Walton found no water, but encountered considerable gas. At Florence a drilled well between 150 and 200 feet deep obtained a small supply of water, said to be brackish, and attempts to increase the amount by exploding dynamite in the well were unsuccessful.

The following record of one of the three deep wells drilled for oil near Big Bone Springs was supplied by Mr. Geer, the driller:

Record of drilled well near Big Bone Springs.

	Feet.
Soapstone (very white) and limestone	0–100
Hard limestone; strong flow of salt water at 105 feet; small flow of gas at 160 feet	100–160
Limestone (light colored); strong flow of gas at 165 feet, and small flows of gas at 177 and 193 feet	160–500
A few feet of "slate," followed by limestone (alternating light and dark)	500–800

An incomplete set of samples from another well at the same locality was identified by E. O. Ulrich as follows:

	Feet.
Lower Lexington limestone (Hermitage and Logana)	150–240
Curdsville	240–288
Tyrone	288–330

A well drilled at one of the Big Bone Springs is reported to have obtained salt water at 150 and 500 feet. The flow was so strong that drilling was stopped. The water from the well has the same properties as that of the springs and is now being sold as Big Bone Spring water.

Shallow dug wells are numerous on the upland areas of Boone County and afford considerable water, though many of them fail in dry weather. Few wells have been dug in the last quarter of a century, and except in the northern part the old wells are gradually being abandoned in favor of cisterns, which provide most of the water for domestic use, some being in use even in the Ohio Valley where underground water is abundant.

BOURBON COUNTY.

SURFACE FEATURES.

Bourbon County is located in the east-central part of the Blue Grass region. Its surface is a gently rolling plateau, crossed by streams which flow in broad, shallow valleys. Through the central part of the county Stoner Creek, a tributary of Licking River, has cut a channel more than 200 feet deep, but over a large part of the area the relief does not exceed 100 feet. The long, narrow ridge which rises abruptly above the surrounding country in the southeastern part of the county received from the early settlers the name "Cane Ridge."

Stoner Creek receives the drainage from the entire county except small areas near the eastern and northern boundaries. The principal tributaries of this creek in Bourbon County are Strodes Creek, Coopers Run, Flat Run, and Townsend Creek. The northern and eastern parts of the county are drained by Hinkston Creek, which receives within the county several small tributaries, the largest being Boones Creek.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The large streams of Bourbon County are bordered by narrow strips of alluvium, composed of assorted sands and gravels, but the formation covers too small an area to be important as a water bearer.

The residual soils of the county consist of the porous loams and clays common to the Blue Grass region. They are usually about 3 feet thick, but in exceptional localities the thickness may be somewhat greater. These soils store moisture which is transmitted to the underlying rocks and assists in maintaining their water supply during dry weather.

CONSOLIDATED MATERIALS.

The rock formations of Bourbon County include the Lexington and Winchester limestones and the Eden shale.

The Lexington limestone forms the surface rock over a large part of the county west of the east side of Stoner Creek Valley and yields an abundance of hard water for springs and wells. Most of the wells obtain water at depths of 100 feet or less, but those which penetrate below the level of the surface streams or enter the Highbridge limestone may find salt-sulphur waters. Some of the springs in this county are exceptionally large and have fairly uniform flow.

The Winchester limestone is exposed in a narrow strip along the west and northwest boundaries of the county and covers a large area bordering the Lexington limestone in the eastern part of the county. Where this formation is at the surface it furnishes moderate quantities of hard water. It might also furnish water for deep wells, but such water would be too highly charged with salt and sulphur to be fit for ordinary uses.

The Eden shale covers the high ridges and hills in the southeastern part of the county and caps some of the hills in the northwestern part, and small exposures are also found in the northeastern part of the area. It furnishes little water except to springs and shallow wells.

The St. Peter sandstone, which underlies the county, would furnish an abundance of salt-sulphur water, but none of the wells would flow, and except in the bottoms of the valleys the water would probably not come within 200 feet of the surface.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

The water supply of Paris, the county seat, is taken from a stream near the city, and since the installation of a filter plant this supply ranks as one of the best in the Blue Grass region. In addition to the municipal supply, many cisterns and a few drilled wells are in use at Paris, and a large spring in the western part of the city supplies water for a number of families. Since the underground stream which supplies this spring passes under a thickly inhabited part of the city, the water can scarcely be regarded as safe, even though its use does not appear to be injurious.

Several hundred wells, ranging in depth from 30 to more than 100 feet, have been drilled in Bourbon County, and in most localities they have been very successful; but in a few places they have obtained no water, and some wells near Shawhan encountered strong brine which was unfit for use. Salt-sulphur waters are usually found at depths ranging from 30 feet in some of the valleys to 100 feet or more on the hills.

Dug wells are numerous throughout the county, but they are gradually being abandoned in favor of cisterns, from which the water for domestic use is commonly obtained. The average depth of the dug wells does not exceed 35 feet. Two deep wells in this county, one about 80 feet and the other 120 feet, were sunk by digging and blasting. As the residual clay is in few places more than 20 feet thick, the amount of rock which had to be removed must have made the sinking of these wells a difficult task.

The cisterns in general use are as a rule well constructed, and they receive such excellent care that they form very satisfactory sources of supply. The use of cisterns and a small hand engine for fire protection in the small towns of the county is strongly recommended.

Besides the spring at Paris, four other springs in the county supply large quantities of water, and springs of moderate size are found on nearly every farm. Several of the large plantations are supplied with water pumped from springs to reservoirs or standpipes and distributed to the buildings by gravity pressure.

BOYLE COUNTY.

SURFACE FEATURES.

The surface of Boyle County, on the southern border of the Blue Grass region, is greatly diversified. On the eastern boundary of the county is Dix River, flowing between nearly perpendicular walls of limestone in a gorge cut to a depth of more than 300 feet below the level of the gently rolling upland, which extends from the river westward to beyond Perryville and from the northern line of the county southward nearly to the line of the Louisville and Nashville Railroad. South of the Louisville and Nashville and west of the Cincinnati Southern Railroad is a deeply dissected area belonging to the mounainous province. The mountains here are somewhat lower than farther east in the Blue Grass region, and few of them rise more than 250 to 300 feet above the level of the upland. From the upland to the mountains the transition is usually abrupt, though the hills on the upland appear to be highest near the mountains.

Dix River receives the drainage of the eastern part of the county, its principal tributaries being Balls Branch, Wilson Run, and Harrod Branch. A small area in the southeastern part of the county is drained by the tributaries of the Hanging Fork, and the southwestern part drains to Salt River through North Rolling Fork and its tributaries. The northern half of the county, west of Atoka, is drained by Salt and Chaplin rivers, which head in the mountainous area of the county, and, after flowing northward for several miles, turn westward to the Ohio.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Boyle County vary with the character of the underlying rock. On the shales of the Eden, Panola, and Ohio formations they consist of dense, heavy clays, at few places thicker than 2 or 3 feet; on the limestone formations they are usually much lighter and approach loam in texture; on the Waverly shale, which occupies only the mountain tops, they were derived from the sandstone layers, and consequently they have the texture of a sandy loam.

The unconsolidated materials in this county furnish directly little well or spring water; but here as elsewhere in the Blue Grass region the residual soils store considerable moisture and transmit it gradually to the crevices in the underlying rocks. The thin layers of gravelly alluvium found along some of the larger streams supply moderate quantities of water in the neighborhood of the streams.

CONSOLIDATED MATERIALS.

The rocks exposed at the surface in Boyle County include the Highbridge, Lexington, and Winchester limestones, the Eden shale, limestones and shales of the Maysville formation, the blue shales and limestones of the Panola formation, and the Ohio and Waverly shales, and the county is divisible into water provinces depending entirely on the character of the surface rocks.

The Highbridge limestone is exposed in the gorge of Dix River and in the lower parts of some of its tributaries and furnishes fresh water only along that stream.

The Lexington limestone forms the upper part of Dix River gorge, covers a large part of the upland between Dix and Salt rivers, and is also exposed along the headwaters of Chaplin River. The Winchester limestone forms a narrow band south of the Lexington limestone from Dix River to the Cincinnati Southern Railway, and west of this railroad it spreads over broad areas on the upland along the headwaters of Salt and Chaplin rivers and on the divides between these streams. West of Perryville the Winchester limestone reaches nearly to the Washington County line, and northwest of Danville it occupies some small areas near the Mercer County line. The areas underlain by both the Lexington and Winchester limestones present very favorable conditions for springs and wells, and drilled wells usually obtain an abundance of water at depths less than 100 feet. Water found in either formation, however, below the level of the surface streams is occasionally salt and is in many wells sulphurous, sulphur water having been found in some wells 50 feet deep.

Outside of the Winchester limestone is the Eden shale, with the Garrard sandstone member occupying the upper 100 feet. The

Eden shale forms a narrow band north of the mountains and covers considerable areas between the headwaters of Salt and Chaplin rivers and to the south and west of Perryville. The shale layers of the Eden furnish small quantities of water, and the sandstones, which are somewhat better water-bearers than the shales, furnish fair quantities of soft water for both springs and shallow wells. The Eden shale furnishes no water for deep wells.

The limestones and shales of the Maysville formation occupy a narrow strip, 1 to 2 miles wide, along the northern edge of the mountains and some narrow belts along the large streams in the southwestern part of the county. In most localities these rocks furnish enough water for domestic and farm use. They contain few large springs, but small ones are numerous and shallow wells are uniformly successful. They might also yield water for deep wells.

The Panola formation includes blue shales and limestones, which are overlain by the Ohio shale. The principal exposures of these formations in Boyle County lie along the northern side of the mountains and border the valleys of North Rolling Fork and Scrub Grass creeks. The formations are feebly developed, and few of the exposures exceed half a mile in width. At Johnson City, however, the black shale occupies a strip a little over a mile wide. In some parts of the county the Ohio shale is less than 40 feet thick. The water supplied by these formations is abundant, but is usually highly mineralized, alum, sulphur, iron, and magnesia being common constituents. In one locality salt water has been obtained from the Ohio shale.

The Waverly shale covers a large part of the area south of the Louisville and Nashville and west of the Cincinnati Southern railroads, its sandy beds forming the tops of the mountains. The thickness of the formation exceeds 300 feet in but few places in this county. The sandstone layers of the Waverly supply an abundance of soft water where they are exposed at the surface, and it is this formation that furnishes the numerous springs of so-called freestone water in the mountains. Few wells have been sunk in the Waverly, and deep wells in this formation would be unsuccessful.

The St. Peter sandstone underlies all of Boyle County and will probably yield flowing wells in some parts of Dix River gorge. The water from this formation is of the well-known "blue lick" type of the region.

DOMESTIC WATER SUPPLIES.

Springs, drilled or dug wells, and cisterns furnish the water for domestic supplies in this county. Underground water conditions are especially favorable in the valley of Salt River, where there are many drilled wells. In Perryville, for example, there are about 100 drilled wells, ranging in depth from less than 25 to more than 100 feet, with an average depth of less than 50 feet. These wells obtain water from the Winchester and Lexington limestones. At Mitchellsburg two drilled wells, about 100 feet deep, obtain water from the Panola formation, and springs and shallow wells in this formation will in most localities yield sufficient water for farm use. Several different kinds of mineral water are obtained from the Ohio shale at Junction City, Alum Springs, and Shelby City. At Mitchellsburg this shale supplies considerable white sulphur water, but the other types common to the formation have not been found at this place.

Dug wells are common throughout the county, but they are gradually being abandoned in favor of cisterns or drilled wells—a change which would appear to be most desirable, as the drilled wells and cisterns, when properly constructed and cared for, are much less likely to be contaminated by impure surface water than are the dug wells.

BRACKEN COUNTY.

SURFACE FEATURES.

Bracken County borders Ohio River in the southeastern part of the Blue Grass region. The altitude of Ohio River at the northwestern corner of the county is about 440 feet above sea level, and the higher parts of the county rise to a height of about 450 feet above the river. South of Brooksville there are some areas of level land, but elsewhere erosion has carved the surface into steep-walled valleys, separated by narrow divides.

The northern part of the county is drained by Locust Creek and other small tributaries of Ohio River. Licking River touches the southwest corner of the county, and the North Fork of the Licking forms the southern boundary and receives the drainage from nearly all of the southern half of the county. Its principal tributary within the county is Camp Creek. Kindale Creek, which heads near the southwest corner of Bracken County, crosses Harrison County and enters the Licking River north of Falmouth.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Bracken County consist of clays, yellow or reddish, and usually thin and stony on account of the great amount of erosion to which they have been subjected since the removal of the forests. In the northeastern part of the county, where the surface is nearly level, the residual clay is in places more than 3 feet thick. The glacial deposits of the county are restricted to the Ohio Valley, where they are represented by such materials as the conglomerate near Augusta. The terrace gravels rise to an altitude of 75 to 80 feet above the river, and have the same general character here as in other counties of the Blue Grass region. Where they rest on dense rocks which are free from open crevices the residual materials yield a little water to springs and wells; elsewhere they supply water to the crevices in the underlying rock.

The alluvial deposits along the streams furnish an abundance of hard water, which is usually obtained by sinking drilled wells. Many springs issue from the alluvium along the banks of the Ohio, and wells procure large supplies at depths ranging from 80 to 110 feet.

CONSOLIDATED MATERIALS.

The surface rocks of Bracken County include the Lexington limestone, which is exposed in the stream beds and on the lower parts of the slopes, in most places less than 100 feet above the streams; the Winchester limestone, exposed along the main Licking River, North Fork, Ohio River, and along the lower courses of the tributaries which enter these streams; the Eden shale, which occupies the slopes of the valleys and covers a considerable area on the upland, the most extensive exposures being found near the southwestern corner of the county; and the Maysville formation, found capping the highest hills, covering considerable areas of the upland in the northeastern part of the county. The Maysville formation is represented in this county chiefly by the lower members, but some of the limestone beds which outcrop on the eastern edge of the county probably belong near the middle of the group.

The Lexington limestone will probably furnish no fresh water in Bracken County, but it may yield salt or salt-sulphur water.

Where the Winchester limestone is exposed in the valleys of the streams it furnishes moderate quantities of hard water. In most parts of the county, however, it will not yield fresh water, though deep wells may obtain from it salt-sulphur water.

In localities where it forms the surface rock the Eden shale yields moderate quantities of hard water to springs or shallow wells. Deep wells which penetrate this formation obtain either inadequate supplies or none at all.

The St. Peter sandstone underlies this county at depths ranging from less than 1,500 feet on the upland to about 1,000 feet in the Ohio Valley. This formation contains salt-sulphur water under sufficient head to give flowing wells in the valley of Ohio River and the lower parts of some of the large tributary streams. The Highbridge limestone, which rests on the St. Peter, will probably supply nothing but salt or salt-sulphur water in this part of the Blue Grass region.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Water for domestic purposes is obtained in this county from springs, dug, drilled, or bored wells, and from cisterns, the cisterns forming the most satisfactory source of supply.

A few very successful wells have been sunk in the alluvium of the Ohio Valley, the only failure resulting from locating the well too near the valley wall, where rock was encountered. A drilled well at Cummins Brothers' mill furnishes a large supply of water which is very satisfactory for use in the boiler of the mill. At Brooksville several unsuccessful wells have been sunk, and it does not appear probable that much fresh water can be obtained by drilling. An oil well sunk on the outskirts of the town encountered a small amount of hard water near the surface and strong salt-sulphur water at a greater depth.

Dug wells from 20 to 30 feet deep and springs of moderate size are common on the upland, and they furnish an abundance of water during a wet season, but both springs and wells are apt to fail in dry weather. Some of the springs in the valleys of the small streams yield brackish sulphur water. Along the banks of the Ohio springs are numerous when the stream is low, but they are usually submerged during high water.

CAMPBELL COUNTY.

SURFACE FEATURES.

Campbell County, lying between Licking and Ohio rivers, comprises the narrow belt of lowland along these streams and the upland area between them. The upland consists of a deeply dissected plateau with narrow interstream areas. Ohio River, where it borders the county, has an altitude of less than 540 feet above sea level, and the highest points on the upland are about 400 feet above the river. Licking River is somewhat higher than the Ohio, and the valleys of both streams have precipitous sides. Along the Licking, southwest of Alexandria, at a height of nearly 200 feet above the stream, is a rock terrace capped with a few feet of Tertiary sand containing pebbles of chert derived from the younger geologic formations to the south.

The principal streams of the county are Philips Creek, a tributary of Licking River, and Twelvemile Creek, a tributary of the Ohio. A number of smaller tributaries join each of the rivers. These tributary streams have very steep gradients, many of them descending 200 or 300 feet in a distance of 3 or 4 miles.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The rock formations of Campbell County underlie a thin mantle of unconsolidated, yellow or reddish-brown soil. In some places near the Ohio River this material contains fragments of rock and is probably of glacial origin, but over most of the county it has been weathered from the underlying rock. The residual soil is largely clay over the shale areas, but over the limestone areas it has the texture of loam.

These residual clays contain considerable water, but they yield very little directly to wells or springs. They serve, however, a valuable purpose in storing moisture and feeding it to the crevices in the underlying rocks.

Alluvial terraces of sand and gravel with a maximum thickness somewhat exceeding 110 feet, are found along Ohio River, where they reach an altitude of over 550 feet above tide. The alluvium in the Licking Valley also consists of sand and gravel, but the percentage of sand is greater than along the Ohio Valley and the deposit is not so thick. A thin deposit of coarse alluvium containing fragments of limestone with some clay, is usually found bordering the small streams. Along Licking River the rock terraces carry a deposit of porous sandy gravel, which was probably at one time nearly continuous, but much of which has been removed by erosion, so that it now appears only in small isolated patches.

The alluvium of the Ohio Valley is very porous and contains a large amount of water. A number of wells obtain water from these beds at depths of 80 to 110 feet, and the height of the water in the wells usually varies with the stage of the river. The rise and fall of the water is most marked in wells which penetrate coarse gravel near the bank of the stream, and the fluctuations usually lag behind the corresponding stages in the river. Many springs emerge from the alluvium just above the level of the river. The water from these gravels is moderately hard, but the degree of hardness varies considerably.

The alluvium along Licking River supplies water to springs along the river bank, and it would also furnish water to wells. The quality of the water is practically the same as that in the sand and gravel of Ohio River. The alluvium of the small streams furnishes some water in wet weather, but the supply is likely to fail in periods of drought.

CONSOLIDATED MATERIALS.

The Lexington and Winchester limestones are largely under cover in this county. Where exposed in the bottoms of the small valleys they supply moderate quantities of hard water, but where buried under the younger formations they usually furnish only brackish water, which may contain considerable hydrogen sulphide.

The Winchester is overlain by from 250 to 300 feet of shales, with occasional beds of limestone, which represent the Eden shale. These rocks form the lower slopes of the stream valleys and rise to the upland near the borders of the county, and furnish small quantities of hard water to shallow wells and springs.

Above the Eden shale are the interbedded limestones and shales of the Maysville formation, which make the surface rocks over a narrow belt in the center of the upland portion of the county. Near the center of the county the limestone beds of the Maysville are the predominant surface rocks.

The rocks of the Maysville formation furnish the water supplies for shallow wells on the upland. Underground channels are numerous, and hence underground water conditions are good; but near the rivers, where the more shaly portions of the lower part of the Maysville are at the surface, the underground channels are smaller and the water conditions less favorable. In the central part of the county rocks of the Maysville yield water to many good springs and wells, but outside the central area the springs are smaller and the wells as a rule obtain small supplies. All the water from the Maysville formation is hard.

The Highbridge limestone is under cover in this county, but if penetrated by deep wells it would probably yield nothing but strongly mineralized water.

The St. Peter sandstone underlies Campbell County at depths of 900 to 1,000 feet in the Ohio Valley and 1,400 to 1,500 feet on the upland. It yields a strong salt-sulphur water, under head sufficient to give flowing wells in the valleys of Ohio and Licking rivers and in the lower parts of the valleys of the small streams which enter these rivers.

CARROLL COUNTY.

SURFACE FEATURES.

Carroll County is in the western part of the Blue Grass region, with the Ohio River forming its northern boundary. The upland surface of the county is a deeply eroded plateau with narrow divides and steep-sided valleys, the highest parts rising to an elevation of about 900 feet above tide or more than 450 feet above the Ohio. Along Eagle Creek, which forms the southeastern boundary of the county, is a well-developed rock terrace.

Kentucky and Little Kentucky rivers, which enter the Ohio in this county, have cut deep, narrow channels across it. The most important of the numerous smaller streams of the county are McCoots

Creek, a tributary of Ohio River, and Whites Run and Eagle Creek, tributary to the Kentucky.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

A large part of the upland is covered by a few feet of heavy clay derived from the decomposition of the underlying rock, which usually contains much shale. On the upland west of the divide which separates the tributaries of Ohio River from those of other streams, the surface is mantled by glacial deposits consisting of residual clay mixed with fragments of limestone with occasional pebbles and bowlders of other rocks. East of Carrollton, in a gap in the rock ridge which separates the valleys of Ohio and Kentucky rivers, the till forms a well-defined ridge less than one-half a mile wide [a] which appears to be a moraine. This moraine presents a nearly flat top, which is apparently due to a capping of loess like silt. The residual and glacial materials furnish very little water directly to wells, but they serve a valuable purpose in storing water and supplying it to the crevices in the underlying rock.

A heavy deposit of alluvium, consisting of sands and gravels which were deposited by waters from the melting of the Wisconsin ice sheet, is found in the Ohio Valley and fills the valley to a depth of slightly more than 100 feet, its surface forming terraces which rise to a height of nearly 100 feet above the stream. Wells 80 to 120 feet deep obtain an abundance of water in this deposit.

Along Eagle Creek and Kentucky River are thin deposits of alluvial sands and gravel which rise about 80 feet above the streams. The alluvium of Kentucky River furnishes a large quantity of water at depths of 100 feet or less, but that along Eagle Creek is in few places more than 30 feet thick and furnishes only moderate quantities of water. The thin deposits of coarse alluvium found along smaller streams is in most places but a few feet thick, and it yields water only during wet weather. The water obtained from all the alluvial deposits is moderately hard, but it is suitable for domestic use, and along Ohio and Kentucky rivers it is used for industrial purposes.

CONSOLIDATED MATERIALS.

The Winchester limestone is exposed in the valleys of all the principal streams in Carroll County, occupying the lower slopes, and above the Winchester, reaching to the lower parts of the upland, is the Eden shale. Resting on the Eden shale are the limestones and shales of the Maysville formation, which cover all the higher parts of the

[a] Leverett, Frank, Glacial formations of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, p. 257.

upland. The Maysville and Richmond formations of this county contain a high percentage of shale, except in areas south of the Kentucky River, where the upper part of the Richmond consists of several feet of massive limestone.

The Winchester limestone furnishes some fresh water for shallow wells located in the valleys, but over the greater part of the county it will furnish nothing but salt-sulphur water. The water of the salt-sulphur spring at Sanders, which comes from this formation, closely resembles the famous "Blue Lick" water but contains less mineral matter. This may be due to the entrance of surface water.

The Eden shale furnishes little water except near the surface, and wells and springs in this formation are apt to fail in dry weather.

The limestone layers of the Maysville and Richmond formations furnish water for the shallow wells and springs on the upland, the supply usually being ample for a farm, except in very dry weather. Most of the wells obtain water at depths less than 35 feet, and it is practically useless to sink wells deeper than 50 feet in the areas covered by these rocks. The water from the limestones of the Maysville and Richmond formations is hard, but is satisfactory for domestic use. The massive limestone of the Richmond formation supplies considerable water in many places.

Experience has shown that the Lexington and Highbridge limestones, when buried beneath the younger formations, as they are in Carroll County, furnish salt or salt-sulphur water, and it is useless to attempt to obtain fresh water from them.

The St. Peter sandstone, which should be reached at depths of 900 to 1,000 feet in valleys of the streams bordering this county, will furnish flowing wells of salt-sulphur water in the valleys of Eagle Creek and Ohio and Kentucky rivers. On the upland the St. Peter lies deeper, and the water does not have sufficient head to force it to the surface.

CLARK COUNTY.

SURFACE FEATURES.

Clark County is situated on the southern edge of the Blue Grass region. The surface is greatly diversified, varying from the gently rolling, nearly level, areas in the western and northern parts, with the streams flowing in broad shallow valleys and the divides flat topped or slightly rounded, to the rugged area in the southeast corner of the county, where the mountains rise 300 to 400 feet above the level of the upland. Along the southern boundary of the county the surface is cut by the deep narrow gorges of the tributaries of Kentucky River, and local variations in relief are found as that river passes from areas of easily eroded rocks where the slopes are gentle to areas in which the rocks are more resistant and form vertical cliffs.

The drainage of Clark County is divided almost equally between Licking and Kentucky rivers, the watershed which separates the two systems passing nearly east and west through Winchester. From the district north of this line the drainage is carried to Licking River through Stoner Creek, which heads a few miles east of Winchester. The principal tributaries of Stoner Creek in Clark County are Donelson Creek, Pretty Run, and Strodes Creek. The principal tributaries of Kentucky River within the county are Howards Creek, Twomile Creek, Fourmile Creek, and Upper Howards Creek. Boones Creek, on the western boundary of the county, and Lulbegrund Creek, on the eastern boundary, are important tributaries of Kentucky River which drain small areas of Clark County.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials consist of residual clays and loams on the shale and limestone areas of the upland and of alluvial sands and gravels in the gorge of Kentucky River. As in other counties of the region, the residual soils yield no water directly to wells, but they furnish considerable moisture to crevices in the underlying limestone. The alluvial sands and gravels in the gorge of Kentucky River would probably provide excellent supplies for shallow wells.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed in the walls of the gorge of Kentucky River and in the lower parts of the tributary streams in the southwestern part of the county. Where it appears at the surface in the southern part of the county it will supply moderate quantities of hard water for springs and wells, but elsewhere in the county it will yield only salt or salt-sulphur waters.

The Lexington limestone is exposed over large areas along Strodes and Stoner creeks and on the upland in the southwestern part of the county, and some small exposures are also found in the stream valleys south of Winchester. Where this limestone is at the surface it furnishes an abundance of hard water for springs and wells, but at depths of about 50 feet in the valleys and 100 feet on the uplands it furnishes salt or salt-sulphur water. In the northeastern part of the county the salt-sulphur water is encountered in some wells at a depth of less than 50 feet. Some of the springs in this formation in the northwestern part of the county are exceptionally strong, and most of the drilled wells have been successful.

The Winchester limestone occupies a narrow strip along the boundary of the Lexington exposures and covers a large area in the northwestern part of the county, and furnishes moderate quantities of hard water for springs and shallow wells. In wells exceeding 50 feet in depth the water is usually strongly saline, and in some of them it is sulphurous.

The Eden shale occupies a large area in the central and eastern parts of this county, the Garrard sandstone member reaching a thickness of more than 100 feet. The formation furnishes small quantities of hard water to shallow wells, but drilled wells obtain no water from it below a depth of 25 to 30 feet. Most of the springs in the Eden shale are weak, and many of them fail during dry weather.

Rocks of the Maysville formation cover a large part of the southeastern and eastern parts of the county, and the higher hills in the southeastern part of the county are capped by a deposit of sandy shales containing some beds of earthy limestone which may represent the Richmond formation. The Maysville and Richmond rocks furnish considerable water for springs and shallow wells, but few deep wells obtain any large supplies of water from them.

The Panola formation, which outcrops over a large area in the southeastern part of the county, consists of about 50 feet of limestone containing interbedded shale, in many places sandy, overlain by about 5 feet of yellow magnesian limestone. The limestone layers of the Panola yield in some localities considerable water for springs and shallow wells, but the water is usually strongly charged with magnesia.

The Ohio shale occurs in the same localities as the Panola formation, but the areas are somewhat more restricted. The Waverly shale is exposed in the southeastern part of the county, but its areal extent is small. The Ohio shale and the shales of the Panola formation furnish a large variety of mineral waters, the most common types being alum, chalybeate, and sulphur. In the eastern part of the county some of the springs from these shales supply medicinal waters for a health resort.

The St. Peter sandstone underlies Clark County and will probably yield flowing wells in Kentucky River gorge north of the large fault, and possibly in the region south of the fault. On the upland the water would come within 300 or 400 feet of the surface in but few localities. In this county, as elsewhere in the Blue Grass region, the water would be highly saline, and consequently unfit for domestic or industrial uses.

STRUCTURAL FEATURES.

The rocks of Clark County dip gently toward the southeast, the only important structural feature being the large faults in the southern part of the county. One of these extends from about a mile north of Ruckerville in a direction slightly south of west to a point about a mile north of Valley View. Kentucky River crosses this fault six times on the southern line of the county, and thus the fault plane is alternately in Clark and Madison counties. Near Ruckerville this fault is represented by a small fold that gives place to a fault with a gradually increasing displacement toward the west, until it reaches a maximum of nearly 400 feet near Cleveland.

Another fault begins at Kentucky River below Jacksons Ferry and extends northeastward into Montgomery County near Kiddville. The maximum displacement along this fault is less than that of other faults, but it amounts to nearly 300 feet. In both of these faults the rocks on the northern side of the fault plane have been lifted with relation to those on the south. In the fault first mentioned the Highbridge limestone on the north side of the fault has been brought to the level of the Garrard sandstone member of the Eden shale on the south, and in the other fault the upper part of the Lexington limestone on the north side reaches the level of the Garrard sandstone member on the south.

WATER FOR DOMESTIC AND INDUSTRIAL SUPPLIES.

The water for Winchester, the only large city in Clark County, is taken from reservoirs on a small stream a few miles from the city, and the supply is ample for all the prospective needs of the community.

Many good springs are found in all parts of the county, the largest being in the northern half, but few of them supply more water than is needed for a single farm.

Drilled wells, ranging in depth from less than 50 to more than 125 feet, are numerous in the vicinity of the Lexington and Eastern Railroad junction and to the north and west of Winchester. At Winchester and eastward along the Lexington and Eastern Railroad salt and salt-sulphur waters predominate, while to the north and west of Winchester ordinary hard water is usually obtained. In the southern part of the county there are few drilled wells, though some were reported at Kiddville, where they obtain mineral water. The many dug wells in the county are not much used, except when other sources of supply fail.

FAYETTE COUNTY.

SURFACE FEATURES.

Fayette County lies in the very heart of the Blue Grass region. On its southern boundary is the gorge of the Kentucky, and except near this river, where many of the streams have cut narrow channels 200 or 300 feet deep, the country is essentially a plateau with a gently rolling surface, presenting, however, considerable diversity. Variations in altitude of 50 to 100 feet within short distances are many, and the extreme range within the county is more than 500 feet, for there is fully that difference between the surface of the Kentucky and that of the highest parts of the upland.

The drainage of the entire county is into Kentucky River. That of the southeastern corner reaches the river through Boone Creek; that of the south-central part through East Hickman and Little Hickman creeks; and that of the north-central and northern parts through Elkhorn Creek, which is formed by the union of three branches—North Elkhorn, South Elkhorn, and the town branch—and which joins the Kentucky in the northern part of Franklin County. From the source of North Elkhorn Creek to the point where the water enters Kentucky River the distance is nearly twice as great as is the distance from the source of the same stream to Kentucky River on the south. The direction of the streams seems to have been established by the original slope of the surface of the Lexington peneplain and by the course of the underground drainage, which developed before the peneplain was uplifted. The divide between the northward and southward flowing streams extends from Brannon northeastward to Lexington, and thence southeastward past Chilesburg. The flat areas along this divide and along the divides between the other stream valleys form the catchment areas for underground streams. The best defined of these streams flows through Russell Cave, but there are many smaller ones. The presence of the underground channels is indicated by numerous sinks and springs.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The rocks nearest the surface in Fayette County are overlain by residual material, usually red or yellow, varying in thickness from a few inches to more than 25 feet, the average being probably 5 or 6 feet. On the Lexington and Highbridge limestones the soil is made up of the comparatively insoluble constituents of these rocks; on the Eden and Winchester formations it is made up in part of the insoluble constituents of the limestone layers and in part of the fragments into which the many shale layers of these formations break up on being exposed to weathering. The soils on the Lexington and Highbridge limestones are for the most part loamy, but those on the Winchester limestones and Eden shales usually contain a large amount of clay. In the residual clay on the Lexington limestone there are many nodules of chert arranged in bands, much as they were in the original rock. As the underlying limestone has been removed by solution the soil has settled, the most marked settlings taking place along the joints where the water circulated freely and the limestone was dissolved rapidly. This unequal sinking has caused the chert beds to bend down at the joints, leaving a series of arches over the heavy blocks of limestone. Because the solution along the joints was unequal the amount of downward curvature varies, and in some places, where the roof of a cavern has fallen, the chert is entirely gone.

Except in the city of Lexington, few wells obtain water from the residual material, but the material serves a valuable purpose in storing water and feeding it gradually to the underground streams in the limestone.

CONSOLIDATED MATERIALS.

The rocks of Fayette County are all of Ordovician age, the formations ranging from the Eden shale down to and including part of the Highbridge limestone. The greater part of the surface is made up of the Lexington limestone, but the Winchester limestone lies at the surface over considerable areas in the northwestern and southeastern parts of the county. In the extreme southeastern corner the Highbridge limestone is exposed in an area a few square miles in extent. A strip of Eden shale several miles long and less than half a mile wide extends in a northeast-southwest direction through the center of the county. These rocks lie in an almost horizontal position, and except for the faults that have brought the Eden shale into contact with the Lexington limestone they have been subjected to very little disturbance.

The principal water-bearing formation in the county is the Lexington limestone, which supplies many springs, some of them of large size, and most of the drilled and dug wells. The waters of this limestone are of two kinds—hard waters, with short underground courses, yielded by the shallow wells and by practically all of the springs; and mineral waters, usually alkaline, many of them containing salt, sulphur, and other mineral matter in noticeable quantities, supplied by many of the drilled wells in different parts of the county. Of these the flowing well on the Hisle farm is a noteworthy example. Underground drainage is favored by the topography of the area near Lexington and in the north half of the county, and in these areas water is abundant; elsewhere it is found in smaller quantities, but there are few farms on the Lexington limestone area without at least one good spring, and some of the farms have a large number of springs.

The Highbridge limestone furnishes considerable quantities of water for dug and drilled wells and a few springs of moderate size, but its surface is too deeply dissected to allow the formation of large underground streams. In quality the water is practically the same as that in the Lexington limestone, and ordinary hard waters and mineral waters are most important.

The Winchester limestone is of slight importance as a water bearer except in the southeastern part of the county, for the layers of shale separating the limestone beds prevent the formation of extensive underground channels. Shallow wells in this formation yield hard water, but some of the deeper wells penetrating it obtain salt-sulphur water.

The Eden shale is so dense as to be almost impervious, and the water supplied by it is always meager in quantity and often poor in quality.

The St. Peter sandstone underlies Fayette County, but the depth at which it would be reached is not certainly known. The horizon that supplies the flowing well at Frankfort was reached at a depth of 900 feet. In the Kentucky gorge, on the southern boundary of the county, the depth to this horizon would probably be less than 900 feet. It is doubtful if the St. Peter sandstone would furnish a flowing well in the Kentucky River gorge, and as the head of the water from the St. Peter is only about 580 feet above sea level, no wells drilled on the upland to this formation would flow. The water from the St. Peter is too highly mineralized for domestic or industrial uses, but it is considered valuable for medicinal purposes. Its composition is shown by the analysis of the water from the Old 76 distillery. (See p. 212.)

WATER FOR DOMESTIC AND INDUSTRIAL SUPPLIES.

The only public supply in the county is in the city of Lexington (see list on p. 85), but the private supplies of the stock farms rival the best city supplies in efficiency and in detail of construction. Many of the smaller farms provide water for stock by means of ponds constructed to retain surface water, but most of the large farms use underground water, either from springs or wells. In some places the spring water is merely impounded, but in others it is pumped to a tank from which it is distributed to the different parts of the farm. The wells in most common use are of the drilled type and range in depth from 30 to nearly 300 feet. The height to which the water rises varies greatly in different wells, and wide variations in the quantity and quality of the supply are also shown. The only flowing well noted in the county is on the Hisle farm.

The uncertainty of wind power has led to the adoption of the gasoline engine for pumping water on most of the large stock farms.

The water of the shallower drilled wells is apt to be hard, with much lime and magnesia and smaller quantities of other mineral compounds, while that of many of the deeper wells is alkaline, containing more or less salt and sulphur and other less noticeable ingredients. Although these general qualities are ascribed to the shallow and deep wells, respectively, it does not follow that all deep wells contain highly mineralized waters or that shallow wells never supply them. The difference appears to be based on the relation of the underground stream to the surface drainage. Attention is called to the chemical analyses (Nos. 24 and 25, p. 212) of the remarkable alkaline water of the well at the depot of the Cincinnati Southern Railway in Lexington.

A few wells, ranging in depth from 15 to 30 feet, dug and blasted into the rock, are still used in this county to supply water for stock and domestic purposes. The water from these wells is always hard, the supply is apt to fail during periods of drought, and they are subject to pollution by surface water. They can not therefore be regarded as forming an entirely satisfactory source of supply. Most of the rock wells extend down to the solid limestone, and as a rule the water seeps in from the earth or cracks in the rock, although in some wells a definite underground stream is encountered. A good example of this is furnished by a 15-foot well at Athens, in which the water rises nearly to the top within a few hours after each rain and then gradually falls until it reaches its normal level with a depth of 3 feet.

On most farms the water for drinking is obtained from cisterns, and on some of them the entire domestic supply is drawn from this source. The cisterns are as a rule well cemented and many of them are provided with filtering devices. Chain pumps are in high favor because of the aeration resulting from the falling back into the well of much of the water raised. Such aeration is, however, of doubtful value, and the use of chain pumps allows dust and insects to get into the water and increases the possibility of contamination. More effective filtration and the adoption of pumps that will exclude foreign matter are greatly to be desired.

Cisterns also form the chief source of supply for most of the small towns in various parts of the county. In some settlements of more than a hundred people only one or two wells may be in use.

In the city of Lexington, in addition to the public supply, many cisterns and a few wells furnish water for domestic purposes. The danger of pollution of underground waters in a city like Lexington is great, and the use of such waters for domestic supplies can not be too strongly condemned. The underground drainage appears to converge toward the town branch of Elkhorn Creek, and the wells outside the city should be comparatively free from contamination by city sewage. If the custom of allowing city sewage to enter the underground channels were entirely discontinued, the quality of the underground waters would undoubtedly be improved; but the danger of pollution by surface drainage would still remain and the waters would probably never be entirely safe for domestic use.

FLEMING COUNTY.

SURFACE FEATURES.

Fleming County, located on the eastern edge of the Blue Grass region, includes on its eastern border a strip 6 or 8 miles wide belonging to the mountainous part of the State. The topography of this strip is rugged, the flat-topped mountains rising abruptly 400 to 500 feet above the valleys, which are from 1 to 2 miles wide. West of the mountains is a belt of country 10 to 15 miles wide whose gently rolling surface presents broad interstream areas separated by shallow valleys.

The southern and a large part of the western boundary of the county is formed by Licking River, which receives the drainage of the southern part of the county through Fox and Locust creeks and many smaller streams, and of the central part through Fleming Creek, which enters the river just west of the Robertson County line. These streams flow in valleys cut from 100 to 300 feet below the surface of the upland and separated by divides in many places only a few rods wide. The drainage of the northwestern part of the county reaches the Licking through Johnson, Elk, and Buchanan creeks, and that of the northern and northeastern parts enters the North Fork of the Licking through a number of small streams.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Fleming County vary with the geologic formations from which they were derived. On the Eden shale the soil is a thin, stony, yellow or reddish clay; on the rocks of the Maysville and Richmond formations brownish or reddish clays are found, which are usually thicker and more porous than the clays derived from the shale formations; on the Silurian and Devonian shales the deposits are dense, light-colored clays. The Silurian limestones decompose to a rather porous red clay. The Waverly shale occurs only on the slopes of the mountains and is covered with coarse débris which has fallen or been washed down the hillsides; the sandstone of the Waverly disintegrates to a light sandy loam, which is in most places very porous.

The residual materials furnish no water to wells or springs except where they rest on dense rocks like the Eden or Siluro-Devonian shales, but where underlain by limestone formations they may store considerable water, which is, in part, supplied to the crevices in the rock.

CONSOLIDATED MATERIALS.

Along the western edge of the county the Winchester limestone is exposed in the valleys of Licking River and its principal tributaries but not far from Sherburne its eastward dip carries it below the drainage levels. In the valleys of the streams where it forms the surface rock this formation yields some hard water for wells, but in other parts of the county water obtained from it will contain salt and salt-sulphur compounds.

Along the streams and on the upland in the western part of the county the Eden shale forms the surface rock, but few of its exposures are more than 3 or 4 miles wide. This shale furnishes some water for springs and shallow wells, which are, however, apt to fail in dry weather. At depths of 30 feet or more below the surface it yields no water.

East of the exposures of Eden shale is a belt of limestone of the Maysville formation, which passes beneath the Richmond formation along a line extending from a point south of Tilton northeastward to about a mile east of Flemingsburg, and thence northward to the north line of the county. The eastern boundary of the Richmond formation follows Licking River from the east line of the county to a point near Wyoming, Bath County, and thence passes northward in a sinuous line west of Grange City, Millsboro, and Poplar Plains and east of Flemingsburg and Mount Gilead. The Richmond extends much farther east in the valleys than on the uplands, and some narrow bands or isolated exposures of it are found east of the line just mentioned. The limestones of the Maysville formation provide exceptionally good conditions for underground water and in most places furnish an abundance of hard water for springs and shallow wells. Drilled wells may encounter gas or water containing petroleum or hydrogen sulphide gas at depths of 60 to 150 feet. The rocks belonging to the Richmond formation as a rule present less favorable conditions for underground water than those of the Maysville, because of the high percentage of shale they contain; but most of the springs in this formation yield moderate amounts of hard water, and most of the shallow wells obtain good supplies.

Above the rocks of the Richmond formation and covering all the rest of the county except the mountainous areas are the shales and limestones of the Silurian and Devonian periods, consisting, in ascending order, of about 25 feet of yellow magnesian limestones containing beds of shale in the lower and upper parts, nearly 100 feet of blue shale, and 150 feet of black carbonaceous shale. In some localities a thin deposit of concretionary iron ore is found at the top of the lower shale bed, and at one locality about 5 feet of yellow magnesian limestone was observed at the base of the black shale, but neither of these deposits appears to be widely distributed in the county. Linney correlated the lower shales and limestones to within a few feet of the black shale with the Silurian; the black shale with the beds of limestone at the base he considered Devonian.[a] The blue shale of this

[a] Linney, W. M., Geology of Bath and Fleming counties: Geol. Survey Kentucky, 1886, pp. 67-77.

series presents unfavorable conditions for underground water, though some wells derive a little water from the unconsolidated materials above it. The limestones usually furnish shallow wells with an abundance of hard water, commonly containing considerable magnesia. The black (Ohio) shale supplies many springs of highly mineralized water, usually containing either alum or sulphur.

Above the Ohio shale is a greenish, even-bedded sandstone, about 180 feet thick, with many interbedded shale layers. This sandstone caps the mountains, and being more resistant than the shale below, it prevents rounding of the slopes. The sandstone, with its interbedded shale, was called sub-Carboniferous sandstone by Linney[a] and Waverly shale by Campbell.[b] The Waverly shale yields an abundance of soft water, supplying the well-known "freestone" springs so numerous along the mountain sides. It is probable, also, that the spring water of the Ohio shale was originally absorbed by the Waverly shale and became mineralized after emerging from that formation during its passage through the joints in the shale.

The Lexington and Highbridge limestones and the St. Peter sandstone are deeply buried in Fleming County, but would yield salt and salt-sulphur waters to deep wells. The water from the St. Peter would probably rise nearly to the surface in the valley of Licking River at the western boundary of the county, but it is doubtful if surface flows could be obtained except near the northwest corner of the county, where a small area is less than 590 feet above sea level.

FRANKLIN COUNTY.

SURFACE FEATURES.

Franklin County, which lies in the southern part of the Blue Grass region, includes two distinct topographic provinces which coincide closely with the exposures of different geologic formations. That part of the county lying east of Kentucky River and south of a line drawn from Switzer to the Kentucky just north of the mouth of Elkhorn Creek is an upland province, with a gently rolling surface of low relief; the rest of the county, west of the river, is deeply dissected by innumerable valleys separated by narrow ridges. In general, the transition from one of these provinces to the other is gradual. Altitudes within the county have a range exceeding 400 feet.

Kentucky River crosses this area from north to south, receiving the drainage of the county through Elkhorn and Benson creeks and numerous smaller streams. From the south line of the county to the mouth of Elkhorn Creek the walls of the Kentucky gorge are precipitous; from this point to the northern end of the county a well-

[a] Linney, W. M., Geology of Bath and Fleming counties: Geol. Survey Kentucky, 1886, pp. 78, 79.
[b] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

defined rock terrace, from 80 rods to 1 mile wide, rises to an altitude of about 500 feet above sea level. Above this terrace the valley walls rise abruptly to the level of the upland. This broad terrace is well developed along Elkhorn Creek, where it reaches an altitude of over 600 feet above tide. Along the Kentucky south of the mouth of Elkhorn Creek, where the terrace may be observed at several points, it is as a rule less than one-half mile wide. In some places this terrace surrounds hills that have been separated from the upland by the erosion of the streams. Such isolated remnants of the upland may be seen at Bethel Church on Elkhorn Creek and at Gratz and Frankfort on Kentucky River. The separation of these hills from the upland appears to have taken place in part since the formation of the rock terrace, for the channels surrounding them have been excavated below the level of the terrace.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials on the limestone areas of the county comprise brownish or reddish loams derived from the decomposition of the underlying rocks; on areas underlain by shale they consist of stiff yellow or red clays. These materials furnish little water for wells or springs except where they are underlain by relatively impervious rock, and even in such places the supply is small and is apt to fail in dry weather.

Along Kentucky River and on the limestone terraces that border the principal streams are considerable areas of sandy alluvium which yield large quantities of water to springs. Few wells have been sunk in the alluvium in Franklin County, but those drilled obtained an abundance of moderately hard water at depths ranging from 50 to 80 feet. This deposit will furnish large quantities of water only in places where it extends below the level of the river; where it rests upon the limestone terraces the water escapes through channels in the rock.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed along Kentucky River from the southern line of the county to a point about 9 miles beyond Frankfort, where its dip carries it below water level. In localities where it forms the surface rock it furnishes hard water for shallow wells; but where it is covered by other formations it yields brines which are as a rule charged with sulphur.

The Lexington limestone forms most of the surface rock from the southern line of the county to Switzer and on the terraces along the principal streams, and is also exposed along Benson Creek from Kentucky River to the west line of the county. In most places it contains many water-bearing channels which supply an abundance of water for both springs and wells, and nearly all the large springs of the county get their water from this formation. Many of the wells sunk below the level of the surface streams, however, obtain salt or salt-sulphur water, and water of this character may be expected in the Lexington limestone where it is covered by younger formations.

A narrow strip bordering the exposures of Lexington shows the Winchester limestone, and the formation is also exposed in a large area east of Kentucky River in the southern part of the county. In most localities where it forms the surface rock the Winchester furnishes moderate quantities of hard water to springs and shallow wells; but wells which penetrate the limestone to depths below the level of the surface drainage obtain salt or salt-sulphur.

The Eden shale is exposed over a large part of the county west of Kentucky River and north of Elkhorn Creek on the east side of the river, and furnishes small quantities of water for springs and shallow wells. Farther below the surface, however, this rock is too dense to yield water.

The limestone of the Maysville formation may occur on some of the high hills near the Shelby County line, but it is not extensively developed in Franklin County.

The St. Peter sandstone lies at a depth of 790 feet in Kentucky River gorge near the southern line of the county and 900 feet at Frankfort. On the upland the maximum depth to this formation would probably be less than 1,500 feet. Flowing wells of salt-sulphur water can be obtained from the St. Peter wherever the altitude of the surface is less than 580 feet above sea level.

STRUCTURAL FEATURES.

The rocks of Franklin County dip slightly toward the southwest and present no interesting structural features except the faults in the northern and eastern areas. In the eastern part of the county are two faults which extend from south of Stamping Ground northwest into Franklin County. The area between these faults has been dropped so that the Eden shale is brought into contact with the Lexington limestone. Prof. Arthur M. Miller has informed the writer that there is another small fault west of Kentucky River in the northern part of Franklin County.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Dug or drilled wells, springs, and cisterns supply the greater part of the water used in Franklin County. The water supply of Frankfort is taken from Kentucky River, and as no cities are located on the river above that city the supply should be satisfactory. A large amount of sediment in the water renders it somewhat objectionable for some purposes, but this sediment might be removed at comparatively small expense by the use of a mechanical filter.

The alluvium of the Kentucky gorge formerly supplied water for a number of wells at Frankfort, 80 to 110 feet deep, but these wells have nearly all been closed in accordance with the advice of the health officers.

Drilled wells from 50 to 150 feet deep are numerous, and most of them yield excellent supplies, though the water of some of the deeper wells is sulphurous. In the vicinity of Jett there are nearly a score of drilled wells. At Frankfort drilled wells have been less successful, and some absolute failures are reported. The Murray well at Frankfort is 1,250 feet deep and encountered a strong flow of salt-sulphur water in the St. Peter sandstone at a depth of 900 feet. The water from this well was formerly sold for medicinal purposes, but the sales gradually diminished until the enterprise was abandoned. As the water undoubtedly has considerable value in the treatment of certain diseases of the organs of digestion and excretion it should find a ready market.

Many cisterns are used in the areas of the county underlain by the Eden shale, for the water furnished by this formation is in some places poor in quality, is meager in quantity, and the supply is apt to fail entirely in very dry weather.

GALLATIN COUNTY.

SURFACE FEATURES.

Gallatin County occupies a narrow area between Ohio River and Eagle Creek in the northwestern part of the Blue Grass region. Except along the streams, where level strips of alluvium are found, the surface of the county is a deeply dissected plateau, with altitudes ranging from 445 feet above sea level at the Ohio River level to more than 900 feet on the upland. A rock terrace along the valley of Eagle Creek has an altitude of about 530 feet above sea level. Leverett [a] mentions an abandoned valley nearly 650 feet above sea level, which passes from Eagle Creek, 2 miles north of Glencoe, to Ohio River just north of Warsaw, and is closely connected with a similar valley which extends northward to the South Fork of Big Bone Creek.

A narrow belt on the east side of the county drains into Eagle Creek, but the principal drainage is into Ohio River through Stephens Creek, Craigs Creek, the South Fork of Big Bone Creek, and numerous smaller streams. All of these streams descend from the level of the upland to the Ohio within a very few miles, and most of the valleys have precipitous slopes.

[a] Leverett, Frank, Glacial formations of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 114-115.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The glacial deposits in Gallatin County consist of patches of clay containing some pebbles, and are practically restricted to the area draining to Ohio River.

The residual materials that cover so large a part of the county are made up of yellow to reddish clays which have been derived from rocks containing a large percentage of shale, and hence they are usually heavy. Where the residual materials rest on the Eden shale they supply a little water to wells. They also feed water to underlying rocks from whose crevices the wells and springs of the upland draw most of their supplies.

The usual deposit of alluvium, which is here arranged in three terraces lying at altitudes of 450, 470, and 495 feet above tide, is found in the Ohio Valley. An alluvial deposit consisting of sand with a few pebbles occurs in the valley of Eagle Creek, and thin patches of alluvium were observed on the terrace bordering Eagle Creek and in the abandoned channels which extend from this creek to Ohio River and Big Bone Creek. The alluvium of the Ohio Valley supplies large quantities of moderately hard water at depths ranging from 60 to 110 feet, and a number of springs emerge from it along the banks of the river. The alluvium along Eagle Creek furnishes some water for springs and shallow wells, but the supplies from these sources are very little utilized.

CONSOLIDATED MATERIALS.

The Lexington and Highbridge limestones are deeply covered by younger formations over the greater part of Gallatin County, though the Lexington is exposed along Ohio River in the vicinity of Warsaw. At such depths these formations furnish only salt or salt-sulphur water, unfit for any ordinary purposes.

The Winchester limestone occupies the lower slopes of the Ohio Valley and is also exposed along Eagle Creek on the east side of the county and in the valley of Big Bone Creek on the northern boundary. In the valleys of the streams where it is at the surface this limestone yields to shallow wells a supply of ordinary hard water, such as is commonly found in limestones; in localities where it is deeply covered, as over a large part of the county, its water is salt and as a rule contains sulphur.

The Eden shale occurs in the valleys of all the large streams and reaches well up toward the upland over a large part of the county. This formation yields practically no water to deep wells, and the moderate supply for shallow wells enters as a rule at or near the base of the unconsolidated materials.

The lower members of the Maysville formation cover the higher parts of the upland in Gallatin County. These rocks contain much shale and the underground channels are small. Except in very dry weather, however, they supply sufficient water for farm use, most of the wells being less than 35 feet deep. Springs are numerous in this formation, and some of them flow during the driest seasons.

The St. Peter sandstone probably lies 700 to 900 feet deep in the valleys of the principal streams and would undoubtedly yield salt-sulphur water, such as it supplies elsewhere in the region, under sufficient head to flow in the valleys of Ohio River and Eagle Creek where they border Gallatin County.

GARRARD COUNTY.

SURFACE FEATURES.

Garrard County is on the southern edge of the Blue Grass region, its northern boundary being formed by Kentucky River and a part of its western boundary by Dix River. The surface of the northwestern and central parts of the county is gently rolling, except near the boundaries, where the streams have cut deep, narrow gorges from 100 to 400 feet below the level of the upland; that of the northeastern part is deeply dissected by numerous streams, whose deep valleys are separated by narrow divides; and that of the southern end is diversified by mountains which rise abruptly to a height of nearly 500 feet above the level of the broad intervening valleys. Some of the finest blue grass land of the region is found in the northern end of this county.

The drainage of the eastern part of the county passes into Kentucky River through Paint Lick Creek; that of the central part reaches the Kentucky through Sugar, Davis, and Cane creeks and several smaller streams. The drainage of the western and northern parts of the county is to Dix River, chiefly through Boones, Drakes, and Coopers creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials in Garrard County exhibit wide variation in texture, and consequently they differ greatly in water capacity in different parts of the county. On the Lexington and Winchester limestones and the limestones of the Richmond formation they are, as a rule, rather heavy clays, having high storage capacity, but for the most part they supply the water to crevices in the underlying rock rather than directly to wells. On the Eden and Siluro-Devonian shales the residual materials supply small quantities of water directly to springs and wells. On the Garrard sandstone member of the Eden and on the Waverly shale the residual materials consist chiefly of sand, and they absorb considerable moisture, which readily sinks into the underlying rock.

Narrow strips of alluvium, in some places more than 50 feet thick, consisting of coarse sand containing layers of chert pebbles, are found along Kentucky River. The alluvium supplies abundant water for springs. A well sunk into it across the river from Camp Nelson obtained water at a depth of 50 feet.

CONSOLIDATED MATERIALS.

The Highbridge limestone reaches its maximum thickness of 400 feet in the northern part of the county across the river from Camp Nelson, and its upper layers are found near the top of the Kentucky gorge. It is exposed along the northern line of the county to a point about 2 miles above Camp Nelson and along Dix River nearly to the head of the gorge. Some excellent springs are found in this limestone along Kentucky River, and it might also yield water for shallow wells in the bottom of the gorge. On the upland, where it is covered by younger formations, it will yield no fresh water, but salt and salt-sulphur water can be obtained in it in some places.

The Lexington limestone is found in the Kentucky gorge above the Highbridge, and it forms the bottom of the gorge from the eastern end of the Highbridge exposure to the northeast corner of the county. It is also exposed along Dix River, in the valleys of Sugar and Paint Lick creeks, and over a large part of the upland in the western part of the county. This formation supplies water for springs along Kentucky River and in various places where exposed on the upland. Shallow wells on the upland also usually obtain an abundant supply of hard water, but deep wells drilled in it obtain highly mineralized salt and salt-sulphur waters.

The Winchester limestone forms part of the valley slopes in the northeastern part of the county and is exposed in a narrow band bordering the upland areas of the Lexington. Where it forms the surface rock it furnishes moderate quantities of hard water, but below the level of the surface streams and where it is covered by younger geologic formations its waters, as a rule, contain salt or salt and sulphur.

The Eden shale is exposed over a large area in the northeastern part of Garrard County and extends in a narrow band along the eastern edge of the Winchester limestone from about a mile east of Camp Dick Robinson southward to Dix River. The shale member of this formation yields small quantities of water to springs and shallow wells, but none to deep wells. The sandstone member also is in most places rather a poor water bearer, yielding little water except in localities where it is exposed at the surface. In the eastern part of the county, however, some of the more sandy layers furnish considerable water for springs and shallow wells.

The Maysville and Richmond formations are exposed over a large area between the northern edge of the mountains and a sinuous line drawn from Paint Lick to Camp Dick Robinson, and they are seen also in the valleys of some of the streams in the southern part of the county. They include nearly 200 feet of interbedded limestones and shales and about 100 feet of sandy limestones and shales. It seems possible that the sandy shales and possibly some of the upper beds of limestone belong to the Richmond formation. In the south-central part of the county the limestones of the Maysville are in many places very pure and the beds are unusually thick. They contain many subsurface channels, which afford favorable conditions for underground water, springs are numerous, and shallow wells are uniformly successful. The water of some of the deeper wells is, however, brackish or sulphurous.

The rocks of the Richmond formation are more shaly than those of the Maysville, and underground water conditions are less favorable, but springs and wells deriving water from them nevertheless yield ample supplies for farm use.

The Panola formation is exposed in a narrow band on the northern edge of the mountainous district and along some of the streams within it, and it occupies areas of considerable size west of the mountains. The shales of the Panola yield little water, but the limestone layers carry large quantities of water containing lime, magnesia, and other inorganic material.

The Ohio shale forms a narrow belt along the mountainous area and appears on a few isolated hills in the southwestern part of the county. This rock is generally traversed by joints which admit large quantities of water, and consequently numerous springs and shallow wells are supplied by it. The water in this formation is everywhere highly mineralized—alum water, chalybeate water, and sulphur being the most common types furnished by it.

The Waverly shale occupies the tops of the mountains in the southeastern part of the county. It has a maximum thickness exceeding 300 feet. The shale beds of the Waverly contain very little water, but the sandstones which cap nearly all the hills contain abundant supplies of soft water, which emerges in springs at the top of the underlying shale.

The St. Peter sandstone underlies the entire county and will furnish flowing wells in the lower part of Dix River gorge and in the gorge of Kentucky River north of the large fault. Here, as elsewhere in the region, the water of the St. Peter would be of such quality as to unfit it for ordinary purposes.

STRUCTURAL FEATURES.

The only important structural features exhibited by the rocks of Garrard County are the faults which occur in the northern and southern areas. The west end of the Kentucky River fault enters this county just south of Camp Nelson and extends southwestward several miles to the point at which it finally disappears. The displacement along this fault in Garrard County is less than 200 feet. The existence of two faults is shown by Campbell [a] in the southeastern part of the county. The maximum displacement of one of these faults has brought the Waverly shale into contact with the Panola formation. The presence of faults at the base of Burdetts Knob was noted by Owen [b] during the first geologic survey of the State.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Springs and dug or drilled wells form the principal sources of water supply for all domestic purposes in Garrard County. Springs are everywhere numerous, and they present considerable variety in composition. Soft water is reported in the vicinity of Point Leavell and Buckeye and at various places in the mountains; sulphur, chalybeate, epsom, and alum springs are common along the northern side of the mountains, and an alum spring occurs at the foot of Burdetts Knob. Springs of ordinary hard water are found in the northern and central parts of the county, and in the southern part of the county are some magnesian springs.

Sufficient water for a farm is as a rule obtained by dug wells less than 35 feet deep. In the western part of the county and near Paint Lick, Hyattsville, and Cartersville are a number of drilled wells ranging in depth from 60 to 100 feet. Near Cartersville drilled wells obtain sulphur water at depths of 25 to 50 feet. At Lancaster a drilled well sunk to a depth of 1,100 feet in an effort to procure a supply for the city obtained a small supply of fresh water near the surface and a large flow of salt-sulphur water at a depth of several hundred feet. The supply of Lancaster is now taken from a small stream which receives no objectionable drainage, and the water is very satisfactory, but considerable water is still used from shallow wells. It is doubtful if any of the well water is as pure as the city supply.

GRANT COUNTY.

SURFACE FEATURES.

Grant County is in the north-central part of the Blue Grass region. A narrow ridge, known as "Dry Ridge," with a maximum altitude of somewhat more than 950 feet, crosses the county from north to south

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.
[b] Owen, David Dale, Third Rept., Geol. Survey Kentucky, 1877.

and forms the divide between the tributaries of Eagle Creek and those of Licking River. The divides between the smaller streams are as a rule somewhat lower, but have a nearly uniform height, which represents the approximate level of the plateau which has been dissected. The streams all flow in narrow steep-sided valleys which have been carved in the plateau.

Crooked, Fox, and Grassy creeks, tributaries of Licking River, receive practically all the drainage of the area east of Dry Ridge. Eagle Creek, which crosses the western edge of the county, receives the drainage of its western half. Its principal tributaries in Grant County are Tenmile, Clarks, and Grassy creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

Residual soil formed by the breaking up of the underlying rock covers the surface of the county. Near the northern end of the county, where the original rock contained many limestone layers, the soil approaches a loam in texture, but farther south, where shales predominated, the decomposition product is a heavy clay. In but few places is the residual clay more than 3 or 4 feet thick, and in many localities it is only a few inches thick.

Small patches of alluvium occur along all the large streams, but it is for the most part coarse material which was derived from the decomposition of the rocks on the slopes. A rock terrace along Eagle Creek is covered by a thin deposit of sandy alluvium.

Both the alluvium and the residual clay store considerable water and supply it gradually to the underlying rock, but they yield little water directly to wells. An exception to this rule is found where these unconsolidated materials rest on dense shale, for in such places the water is obtained directly from the loose material or from its plane of contact with the underlying rock.

CONSOLIDATED MATERIALS.

The Winchester limestone is exposed in the valleys of Eagle Creek and several small streams, and where it is at the surface it generally furnishes good supplies of hard water. In the bottoms of the valleys, however, wells in this formation obtain a brackish sulphur water, and on the upland, where it might be reached by drilling deep wells, its waters would be salt or salt-sulphur in character.

The Eden shale is exposed over a small area of the upland near the southern end of the county and on the slopes of all the principal streams. Here, as elsewhere in the Blue Grass region, this formation affords practically no water, except near the surface where small cracks have formed in the rock. Moreover, the soil above the shale is so dense that it yields little water. For this reason springs are few and small and wells are not very successful in the areas of its outcrop.

The surface rocks over the greater part of the upland belong to the Maysville formation. The highest rocks of this formation that are exposed in the county are the heavy beds of limestone found north of Crittenden; south of Crittenden the lower and more shaly beds appear at the surface. The limestones of the Maysville near the northern end of the county favor the formation of underground channels whose presence is indicated by small sink holes. Farther south the rocks contain a much larger proportion of shale, and the underground channels are small. The soil over the more shaly areas affords but little water to the underlying rock, and consequently the underground supplies are limited. The water from these rocks is as a rule hard.

The Lexington and Highbridge limestones and the St. Peter sandstone might be reached by deep wells, but they would afford only salt or salt-sulphur waters. The water in the St. Peter is under sufficient head to rise to a height of nearly 600 feet above sea level, but this head would give flowing wells, if at all, only in the lowest part of the valley of Eagle Creek.

WATER FOR DOMESTIC AND INDUSTRIAL SUPPLIES.

The springs of Grant County are nearly all small, and some of them fail in dry weather. The only important mineral spring is Gum Lick Spring, in the southeastern part of the county, which supplies a good quality of salt-sulphur water. This spring was formerly visited by many persons who carried the water away for drinking.

Few dug wells in Grant County are more than 35 feet deep, and in dry weather they yield very little water. None of the drilled wells sunk in this county have been successful. At Williamstown an attempt was made to procure water for the city by drilling a deep well; no fresh water was found, but strong sulphur water was encountered between 700 and 790 feet below the surface.

Cisterns form the principal source of supply for domestic use, both in the towns and on farms. In a few localities where the Eden shale forms the surface rock cistern water is also used for stock. The city of Williamstown depends upon cisterns and hand engines for fire protection. The cisterns are located at various points along the main streets and are filled with water collected from the roofs of warehouses, stores, and churches.

HARRISON COUNTY.

SURFACE FEATURES.

Harrison County is in the east-central part of the Blue Grass region. A strip of country several miles wide, bordering the South

Fork of Licking River, has a gently rolling surface, with shallow valleys and rounded divides; but on the east and west of this area of slight relief the topography is rugged, the surface exhibiting steep-sided valleys separated by narrow divides. Rock terraces which lie slightly below the level of the upland border Licking River and its South Fork, and other terraces just above the level of these streams were observed at several localities.

Licking River forms part of the eastern boundary of the county, and the South Fork of the Licking flows northward through the center of it. Beaver Creek is the only large tributary of Licking River in this county. The greater part of the drainage is to the South Fork, which receives a number of large tributaries, the most important being Coopers Run, Grays Run, and Townsend, Twin, Crooked, and Indian creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Harrison County consist of loams on the areas of Lexington and Winchester limestones and clays on the Eden shale. The loams have an average thickness of about 3 feet, but the clays are in most places thin. These soils yield water only where they rest on dense shales.

A deposit of sandy alluvium, 10 to 20 feet thick, is found in many places on the rock terraces bordering the river and supplies an abundance of water for shallow wells. On the upper terrace are narrow deposits of the sandy alluvium belonging to the Irvine formation, which furnish small quantities of water in some localities; but the Irvine is not, as a rule, an important water-bearer.

CONSOLIDATED MATERIALS.

The Lexington limestone is exposed along the valleys of Licking River and its South Fork and over much of the area of rolling topography of the upland, and where it forms the surface rock it yields an abundance of water for springs and wells. Where it is reached below the levels of the surface drainage, however, it may supply salt-sulphur waters, such as are obtained by many of the drilled wells in this formation.

The Winchester limestone is exposed in a narrow band bordering the Lexington outcrops and furnishes moderate quantities of hard water. In the southwestern part of the county this limestone supplies some salt-sulphur water in springs and shallow wells. A well sunk near Smitsonville obtained a weak flow of sulphur water in this formation. The water rises about 4 feet above the surface, and the well yields less than 1 gallon per minute.

The Eden shale appears at the surface on the upland near the western boundary of the county, where it occupies a strip nearly 10 miles wide, and also on the divide between Licking River and its South Fork. It supplies small quantities of water for springs and shallow wells, but none for deep wells.

The Highbridge limestone is not exposed in Harrison County, and wells sunk to it would probably obtain only highly mineralized water.

Wells drilled to the St. Peter sandstone would probably procure flowing water in some parts of the valley of the South Fork of the Licking, but, as elsewhere in the region, the quality of the water would unfit it for ordinary uses.

DOMESTIC WATER SUPPLIES.

Dug or drilled wells and cisterns are used to obtain water for domestic purposes in this county. Few of the shallow wells exceed 35 feet in depth, and the amount of water which they yield depends on the nature of the rock in which they are dug. Drilled wells which yield water enough for a farm are common in many localities. The quality of the water varies with the depth of the well, many of the shallower wells obtaining hard water and the deeper wells sulphur water. The depth to the sulphur water varies, however, with the location of the wells, being about 50 feet in the valleys and over 100 feet on the hills. In areas where the Eden shale forms the surface rock cisterns form the principal source of supply.

HENRY COUNTY.

SURFACE FEATURES.

Henry County lies near the western edge of the Blue Grass region, south of Kentucky River, whose gorge here presents two steep slopes separated by a rock terrace at an elevation of about 500 feet above sea level. Near the Kentucky gorge the surface of the upland is deeply dissected by many small streams and is practically all reduced to slopes. Most of the divides are but a few rods wide, and the intervening valleys are, as a rule, narrow and steep sided. A few miles back from the Kentucky the surface is gently rolling, with shallow valleys and rounded divides, and topography of this type prevails throughout a large part of the county. The range in altitude within the county is about 200 feet.

Nearly all of the drainage of Henry County passes into Kentucky River, which receives the waters of three streams of considerable size—Mill, Sixmile, and Drennon creeks—and of many small tributaries. Streams flowing to Salt River drain a small area near the southern boundary of the county, and the drainage of an area along the western boundary of the county enters Harrods Creek and Little Kentucky River, whose principal tributary in Henry County is Sulphur Creek.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Henry County are, as a rule, heavy clays on the areas underlain by Eden shale, but on the other formations they are lighter and in some localities they are loamlike in texture. The soils yield moderate quantities of water only where they rest on the Eden shale.

Strips of alluvium, consisting of sand containing some layers of gravel, occur in the gorge of Kentucky River, and in some places a thin layer of alluvium also rests on the rock terrace which borders the river. It is evident that these isolated patches represent the eroded remnants of a deposit which once covered the terrace. The alluvium of the Kentucky gorge supplies some good springs along the river, and it would doubtless yield an abundance of water for wells. Some of the springs at Drennon Springs rise through this alluvium, but the water is probably derived from the Lexington or Winchester limestone.

CONSOLIDATED MATERIALS.

The Lexington limestone underlies the terrace which borders Kentucky River and is exposed in the gorge of the river from the Franklin County line to Drennon Springs, occupying the lower parts of the gorge and rising to about the level of the terrace along the valley for some distance north of the southern line of the county. It contains numerous sink holes and supplies several large springs of hard water. A short distance back from the river this limestone dips under the younger formations, and where it is thus covered it will yield no fresh water. In some places in this county both the Lexington and Highbridge limestones yield salt-sulphur waters when penetrated by deep wells.

The Winchester limestone lies above the Lexington and extends a short distance farther down the stream, but it is exposed only in the gorge of the Kentucky and the lower parts of some of its tributaries and does not rise to the level of the upland. In the areas of its outcrop it yields moderate quantities of hard water, but elsewhere in the county it may yield mineral waters.

The Eden shale outcrops on a small area of the upland near Kentucky River and extends some distance back from the river along the principal streams. Where it lies at the surface it supplies moderate quantities of water for springs and shallow wells, but over a large part of the county it is buried beneath the rocks of the Maysville formation and will yield practically no water.

The Maysville and Richmond formations are found over a large part of the upland, underlying nearly all of the area of rolling topography, and they supply water for many perennial springs. Sufficient water for a farm can generally be obtained by wells 25 to 50 feet deep. A few unsuccessful deep wells have been drilled in Henry County.

Near the western line of the county is a narrow ridge which is underlain by the blue shales and yellow magnesian limestones of the Panola formation. Because of the small area of its outcrop the Panola is not important as a source of underground water.

The St. Peter sandstone will supply flowing wells in the gorge of Kentucky River. The water will be of the highly mineralized type usual in this formation.

STRUCTURAL FEATURES.

The rocks of Henry have a general northwesterly dip of a few feet to the mile, which was produced by the arching that formed the Jessamine dome. The uplift appears not to have been accompanied by any great amount of local disturbance in this county, though some minor folds and displacements have been observed at Drennon Springs.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Henry County has a number of "never-failing" springs, but few of them are large. Springs are commonly used for stock, but some of them also serve household purposes. At Drennon Springs, an important health resort located on Kentucky River, the most important are the sulphur and salt-sulphur springs. Both black and white sulphur springs are reported. At Eminence a chalybeate spring supplies a moderate quantity of water.

Most of the wells of Henry County are shallow, ranging from 20 to 35 feet in depth. Such wells form a satisfactory source of water for domestic use only when they are carefully guarded from pollution. Considerable water is used from these shallow wells both in the towns and in the country. The few deep wells drilled in Henry County have not been very successful.

Both Eminence and Newcastle could procure surface water for municipal supplies by constructing reservoirs on small streams, but underground supplies of suitable quality are not available. This should not, however, be considered a misfortune, for a careful comparison of the best surface and underground supplies of the region indicates that the surface waters are more desirable than those derived from either springs or wells.

JESSAMINE COUNTY.

SURFACE FEATURES.

Jessamine County lies in the great bend of Kentucky River near the southern border of the Blue Grass region. Its surface is gently rolling except near the southern and western boundaries, where the

Kentucky and its tributaries have cut deep channels, and altitudes range from less than 500 feet above sea level in the Kentucky gorge to over 1,000 feet in the highest parts of the upland. Where the streams cross the limestone formations the walls of their valleys are generally nearly perpendicular, but where they flow through shales and shaly limestones the slopes are gentler.

The drainage of the county reaches Kentucky River through Hickman and Jessamine creeks and several smaller streams, and a small area in the northern part of the county is drained by the southern branches of Clear Creek, which unites with the Kentucky in Woodford County. All the streams flow in deep narrow gorges and have very high gradients, making the descent from the upland to the river within a few miles.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The upland of Jessamine County is covered by a mantle of yellow or brownish-red unconsolidated material which has been formed by the decomposition of the underlying rock. On limestone areas this material has the texture of a loam, but on areas where the original rock contained a large proportion of shale it is chiefly a dense clay. Although the residual clay has in some places a thickness of 20 feet or even more, its average thickness probably does not exceed 5 or 6 feet. The soils furnish little water directly to wells, but they have a high storage capacity and feed their supply of water slowly to the crevices in the underlying rock. The loam stores less water than the clay, but it generally contains some free water which is available for the underground channels.

Sandy alluvium occurs in narrow strips along Kentucky River and yields water for numerous springs. It would doubtless also furnish an abundance of water for wells.

CONSOLIDATED MATERIALS.

The apex of the Jessamine dome is located in this county, and the oldest rocks of the region are exposed at Camp Nelson, where Kentucky River passes near the crest of the dome. These rocks belong to the lowest division of the Highbridge limestone. The entire thickness of the Highbridge in Jessamine County is about 400 feet, and the exposures are restricted to the valleys of Kentucky River and its principal tributaries. The Highbridge furnishes large quantities of hard water to springs and to most of the shallow wells, but deep wells and a few of the shallow ones obtain either salt or salt-sulphur water.

The Lexington limestone forms the surface rock over the greater part of the county, overlying the Highbridge limestone without apparent unconformity. The maximum thickness of this limestone is about 200 feet, but the thickness over a large part of Jessamine County probably falls much below the maximum. Where it outcrops at the surface it contains many underground channels and large quantities of hard water. Nearly all of the springs and shallow wells over a large part of the county north of Hickman Creek are supplied with water from this limestone. The wells which penetrate this formation below the level of the surface drainage as a rule find salt or salt-sulphur waters.

The Winchester limestone is exposed along the Kentucky River gorge and on the south side of Hickman Creek, in the southern part of the county, and occupies a long narrow strip and several isolated patches on the upland in the northeastern part of the county. Where it is at the surface it yields moderate quantities of hard water to springs and shallow wells. In the southern part of the county it would be penetrated only by deep wells which would be apt to obtain salt and sulphur waters.

The Eden shale occurs over a large part of the upland between Hickman Creek and Kentucky River, and appears also as a small isolated patch in the northeastern part of the county. In this county the upper portion of the Eden consists of sandy shales and sandstones, which were mapped as the Garrard sandstone by the early workers of the Kentucky Geological Survey. The shale beds of the Eden furnish little water, but some of the limestones contain crevices which supply small quantities of moderately hard water for wells and springs. Some water is also obtained at the contact of the residual clay with the underlying rock. The Garrard sandstone member of the Eden is in most places not porous enough to yield much water, but the residual soil formed from it locally furnishes considerable soft water for both wells and springs.

The St. Peter sandstone will supply flowing wells in the valleys of the large streams north of the Kentucky River fault in this county. On the upland the water will not reach the surface, as the head is only sufficient to cause the water to reach an altitude of about 590 feet above sea level. South of the Kentucky River fault few wells have been drilled to the St. Peter, and definite information as to the head of the water encountered by these wells is not available. It appears probable that the faulting has produced a displacement of the St. Peter which might interrupt the movement of the water.

STRUCTURAL FEATURES.

The only marked structural feature in this county is the Kentucky River fault, which extends along the valley of Hickman Creek, in the southern part of the county. There are really two faults, one entering near the southeast corner of the county and extending southwestward nearly to its western boundary, and another beginning a few miles south of this first fault and running southwestward into Garrard County. The maximum displacement along these faults is probably about 400 feet. At one point near the southeast corner of the county it was sufficient to bring the Garrard sandstone member of the Eden shale into contact with the Highbridge limestone.

UNDERGROUND DRAINAGE.

The presence of caverns along Kentucky River and numerous sink holes and springs on the upland indicate that the underground drainage is very extensive. Some of the sink holes are several acres in extent, and many of the springs give rise to streams of considerable size. The large springs, as a rule, emerge at the heads of small gullies rather than along the river. This peculiar location of the springs is explained by the fact that the gully represents merely the portion of the underground channel where the roof has fallen. Sinking Creek, in the northeastern part of the county, affords an excellent example of a surface stream which enters an underground passage.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Springs and dug or drilled wells supply water for domestic and industrial purposes. One of the largest of the many large springs is Overstreet's, which supplies water enough to run a small mill, and another large spring is utilized at Union Mills.

Dug wells are numerous, but they are not extensively used. Drilled wells have been successful in some localities, but a number of dry holes are reported at Nicholasville, Keene, and Wilmore. Many of the drilled wells have found sulphur water at depths of 50 feet or more, but the amount of sulphur is commonly not great enough to render the water unfit for domestic use. At Union Mills a well sunk in the Highbridge limestone to a depth of 283 feet obtained a little fresh water between 30 and 40 feet below the surface and several supplies of salt-sulphur water at greater depths. At 200 feet the driller reported a stream of this water which was strong enough to remove the pulverized rock produced in drilling.

Nicholasville has the only municipal supply in the county. The water, which is taken from wells located on the edge of a reservoir, probably comes in part from the reservoir. The wells were sunk because some of the consumers objected to the surface water, but the installation of a filtering plant would probably have been a greater improvement.

KENTON COUNTY.

SURFACE FEATURES.

Kenton County occupies a long, narrow area in the northern part of the Blue Grass region, extending northward to Ohio River and eastward to Licking River. Its surface is a plateau which has been deeply trenched by the tributaries of the Ohio and Licking rivers, and the upland areas, which are comparatively level, rise to a height of 900 feet above tide, or more than 500 feet above the Ohio.

The northwestern corner of the county drains into the Ohio through Dry Creek and several other small streams. Bank Lick Creek, which flows diagonally across the northern part of the county and enters Licking River at Latonia, receives the draniage of the central part of the county, and the southern end of the area drains to Licking River through Cruises and Grassy creeks and several smaller streams. All of these streams have high gradients, most of them making the descent from the uplands to the rivers within a few miles.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

A thin mantle of unconsolidated material covers the rock formations. Near the Ohio this loose material is of glacial age and consists in part of sand and in part of clay, containing fragments of limestone and other rocks. Resting on the glacial drift are 2 or 3 feet of loess-like silt, which is also of glacial age. On the upland the glacial drift has an average thickness of less than 10 feet and a maximum thickness of about 20 feet. In the Licking Valley, near Latonia, the drift appears to be somewhat thicker than on the upland. Although the sands of the glacial drift are of small extent, they would probably yield some water for shallow wells at a few localities. The bowlder clay and the overlying silt do not yield water directly to wells, but they are sufficiently porous to absorb some water which they feed to the underlying rocks.

South of the area of glacial drift the unconsolidated material consists of yellowish or reddish clay, in most places less than 5 feet thick, derived from the underlying rock. This clay is porous enough to absorb considerable moisture, but it does not afford sufficient water at any one place to supply a well.

The alluvium of Kenton County consists of terraces of sand and gravel along Ohio River, which rise to a maximum height of about 550 feet above sea level. The thickness of these and similar deposits along Licking River is from 80 to 120 feet, and they yield large quantities of water at depths of 60 to 110 feet. The water is moderately hard, and in the vicinity of Covington contains some sulphur. This sulphur may be supplied by the decomposition of the organic matter in the alluvium or by the sulphur water which comes from the rocks which form the floor of the valley. The alluvium in the Licking Valley should have a thickness of 30 to 50 feet, but few wells have been sunk in this deposit and its exact thickness is unknown. In other parts of the Blue Grass region similar deposits yield large quantities of moderately hard water.

CONSOLIDATED MATERIALS.

The oldest rocks in Kenton County outcrop in the channel of the Ohio between Covington and Ludlow. The exposure consists of about 50 feet of interbedded limestones and shales, at the top of which is a wave-formed bed of limestone containing fragments derived from the underlying rock. These interbedded limestones and shales are believed by E. O. Ulrich to be the equivalents of the lower part of the Lexington limestone. Over all the upland portion of the county the Lexington and Highbridge limestones are deeply covered by younger formations, and under such conditions they supply only salt water, which will in some places be sulphurous.

Above the Lexington limestone and occupying the lower slopes of the valleys are about 300 feet of dark-colored shale belonging to the Eden formation. This shale supplies practically no water for wells, though small quantities of water are in some places obtained from the talus which rests on the valley slopes.

The upland is underlain by rocks belonging to the Maysville formation. In the southwestern and northern parts of the county these rocks are shaly and supply only small quantities of water, but elsewhere the uplands are capped by limestone beds of the formation, which furnish ample supplies of water for farm use. The numerous springs found on the upland derive their water from these limestone beds. Along Ohio River the springs emerge near the tops of the bluffs, where the limestone layers rest on beds of shale.

In this county the St. Peter sandstone lies 800 or 900 feet below the surface in the Ohio Valley and 1,300 to 1,400 feet below the surface of the uplands. It yields a strong salt-sulphur water, which will rise to the surface in places having an altitude of 590 to 600 feet above sea level. Wells drilled in this formation at Covington and Latonia obtained good flows.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Dug wells are still used extensively in Kenton County; in many of them the supply is augmented by permitting rain water from the roof to flow into the well. In some instances water is hauled from a nearby spring and poured into the well. Cisterns are an important source of water for domestic purposes, and they are gradually supplanting the wells.

No deep wells have been drilled on the upland, but driven and drilled wells are numerous in the Ohio Valley. These wells range in depth from about 80 to 120 feet and procure large supplies of water for domestic and industrial uses. Here, as elsewhere in the valley of the Ohio, the water near the river is apt to contain less inorganic matter than at some distance from the stream. Water for city supplies is obtained from Ohio River and is regarded as satisfactory for most purposes.

MADISON COUNTY.

SURFACE FEATURES.

Madison County is situated on the south side of Kentucky River in the extreme southern part of the Blue Grass region. A large part of the county is a broad plateau, deeply cut by narrow, steep-sided valleys near Kentucky River and along the western boundary. In the central part of the county is a belt, 5 to 10 miles wide, in which stream valleys are shallow and the surface is gently rolling. The extreme southern part of the county includes a rugged area, characterized by irregular ridges rising nearly 500 feet above the level of the plateau and separated by broad, level-floored valleys. The slopes of many of these mountains are so precipitous that their ascent is very difficult.

The drainage of Madison County goes to augment Kentucky River. Red River, which receives the drainage of the southeastern part of the county, flows eastward and joins Station Camp Creek, a tributary of the Kentucky, in Estill County. Paint Lick, which flows along the western boundary of the county, receives the drainage of a narrow strip near that boundary. Silver and Tates creeks drain the western and Otter and Muddy creeks the eastern part of the county.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials in Madison County consist of rather dense clays, derived from the limestone and shale formations; of loams, derived from the Garrard sandstone member of the Eden shale and the sandstone of the Waverly shale; and of alluvial sands and gravels in the gorge of Kentucky River.

The residual soils furnish a small amount of water for springs and shallow wells on the areas underlain by shale, but elsewhere they furnish practically no water. The alluvial sands and gravels of the Kentucky gorge furnish an abundance of water for springs along the river bank, and they would doubtless also furnish water for wells.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed along Kentucky River in the four bends which lie north of the Kentucky River fault. Although the upper part of this limestone lies near the top of the gorge, it does not extend out upon the upland. The Lexington limestone is exposed in the same localities as the Highbridge, and it forms also the lower part of the gorge from the last crossing of the fault above Boone Ferry to the northwestern corner of the county, and the lower parts of the valleys of Silver Creek and Paint Lick to the vicinity of Cartersburg. Both the Highbridge and Lexington limestones supply considerable water to springs and shallow wells in the valleys of the streams; but on the uplands they are buried by younger formations, and under such conditions they will yield only salt or salt-sulphur water.

The Winchester limestone is exposed in a narrow area surrounding the Lexington, but it does not rise to the level of the upland except near Kentucky River. It furnishes moderate quantities of hard water where it is exposed at the surface, but where it underlies younger formations its water is generally brackish and somewhat sulphurous.

Outside the area of the Winchester limestone is the Eden shale, its upper portion including 70 to 130 feet of sandy shales and sandstone—the Garrard sandstone member. The lower part of the Eden outcrops in the valleys of the streams in the northern and western parts of the county, and the Garrard sandstone member reaches the level of the upland in the same areas. The Eden shale supplies small quantities of water for springs and shallow wells, but deep wells do not as a rule obtain water in this formation. The Garrard sandstone member supplies more water than the shale member, but it contains so large a proportion of clay that it is unimportant as a water horizon.

The Maysville formation underlies a large part of the rolling surface of the upland. East of Richmond some of the higher hills are capped by about 50 feet of green sandy shales, which may represent the Richmond formation. The limestone beds of the Maysville present favorable conditions for the occurrence of moderate quantities of water, but conditions somewhat less favorable are afforded by the Richmond rocks. A number of good-sized springs occur in the limestones of the Maysville, and shallow wells are ordinarily successful in both the Maysville and Richmond formations.

The blue shales and heavy-bedded yellow limestones of the Panola formation, as mapped by Campbell,[a] occupy considerable areas in the eastern and southern parts of the county. The shales of the lower part

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

of the Panola supply practically no water, but the limestone beds generally furnish enough water for domestic use. As the limestones of this formation are magnesian, much of the water contains magnesia.

The Ohio shale, which in this county has a thickness of 110 to 150 feet, is exposed in many places above the limestones of the Panola formation and it generally rims the mountains. It supplies an abundance of highly mineralized water for springs and shallow wells, the most common types being alum, sulphur, and chalybeate waters.

The sandy beds at the top of the Waverly shale, which caps the mountains in the southern part of the county, yield an abundance of soft water, and numerous springs emerge from these sandstones where they rest on the shale beds.

Along the southern line of the county is a small and unimportant area of later Mississippian limestone.

The St. Peter sandstone underlies the entire county and will probably supply flowing wells in the gorge of Kentucky River north of the large fault. It is possible that a flow might also be obtained in some of the deeper stream valleys south of the fault. The water from this formation is so highly charged with salt and sulphur that it is unfit for ordinary uses.

STRUCTURAL FEATURES.

The rocks of Madison County dip gently toward the southeast and present no important structural features except the faults which have produced displacements of the Ordovician formations. The major fault of the region—the Kentucky River fault—crosses the northern part of the county. Kentucky River crosses this fault eight times on the northern boundary of the county, and thus the fault plane is alternately in Madison and Clark counties. The maximum displacement in Madison County, as given by Campbell[a] is 400 feet, and this has brought the Highbridge limestone to the same altitude as the Garrard sandstone member of the Eden shale. The Richmond folio shows also two small faults in the southern part of the county which are roughly parallel to the direction of the Kentucky River fault. East of Richmond is a fault which is almost at right angles to the other faults of the region. None of these faults are of great magnitude, the maximum displacement having brought the Ohio shale into contact with the limestone of the Maysville formation.

WATER FOR DOMESTIC AND INDUSTRIAL USES.

Both surface and underground waters are used in Madison County.

Richmond obtains its water supply from a small stream. Attempts to get water by drilling wells in the city have not been successful.

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[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

One well, sunk to a depth of nearly 1,800 feet, is said to have obtained water highly charged with sulphur.

Many good springs are found in various parts of the county. Between Kentucky River and Richmond and for some distance eastward most of the springs yield moderately hard water. Sulphur springs occur at Boonesboro and at various points in the area of the Ohio shale, and this shale also furnishes springs of epsom, alum, and chalybeate water. Springs of soft (freestone) water are found near Elliston and at various points in the mountains, and Berea College has an excellent water supply derived from such springs.

Dug wells 20 to 35 feet deep are common on the upland, and an ordinary well affords sufficient water for a household. Besides the wells at Richmond, a number of wells have been drilled at Berea and Wallacetown. Few of these wells exceed 50 feet in depth and most of them yield sulphur water. A few wells have been drilled in other parts of the county, but these as a rule have not found large supplies of fresh water.

MASON COUNTY.

SURFACE FEATURES.

This county borders Ohio River at the eastern edge of the Blue Grass region. The surface is a deeply dissected plateau, with a range of altitude exceeding 450 feet. The amount of dissection varies considerably, being greatest near the large streams and diminishing rapidly a short distance from these streams. In the southern part of the county variations in altitude are smaller and the slopes gentler, and another area of rolling topography occupies a strip several miles wide between Maysville and Germantown. In the Ohio Valley alluvial gravels form flat terraces which rise about 80 feet above the river.

The northern part of the county drains into Ohio River through Limestone Creek and a number of other small streams. The North Fork of Licking River, which flows westward through the central part of the county, receives the drainage of a wide area. Johnson Creek, a tributary of the Licking, receives several small tributaries from the southern part of the county.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The upland of Mason County is covered by a deposit of residual material varying in thickness from 6 to 8 feet and in character with the nature of the underlying rock. On sandy shales the material is a loam; on denser shales a heavy clay, and on the limestones clay or loam, as sand or clay were prominent constituents of the original rock. These residual materials furnish little water directly to wells, but they store considerable moisture, which they feed slowly to crevices in the underlying rocks.

The terraces of the Ohio Valley consist of 80 to 120 feet of coarse sand and gravel. These deposits furnish an abundance of moderately hard water.

CONSOLIDATED MATERIALS.

The Winchester limestone is exposed at the foot of the bluff bordering the Ohio Valley from the Bracken County line southward beyond Maysville, along the North Fork of Licking River, and along some of the tributaries of both the Ohio and the Licking. Where it is exposed in the valleys of the streams it furnishes, as a rule, moderate quantities of hard water. Saline and sulphur springs are also found in this formation at several localities. No deep wells have been drilled in the Winchester on the upland, but it is quite certain such wells would not find fresh water.

The Eden shale forms a large part of the valleys of the principal streams and extends out upon the upland in the western part of the county. The formation is more sandy here than in the more northern counties, but it does not contain enough sand to be classed as a sandstone. It yields small quantities of hard water to both springs and shallow wells, but no water to deep wells.

The Maysville formation is most typically developed in this county. It forms the surface rock over large areas and is well exposed in the vicinity of Maysville, where the entire formation is represented. The limestones of the Maysville as a rule furnish an abundance of hard water for springs and shallow wells, and the drilled wells of the upland usually obtain water in these rocks.

The Richmond formation is at the surface over a small area extending from Ohio River east of Maysville to the southern line of the county. In this county the lower part of the Richmond consists of sandy shales with some thin beds of limestone; the upper part is generally more calcareous and contains a number of beds of limestone. The rocks of the Richmond supply less water than those of the Maysville formation, but the quantity is usually sufficient for farm use.

The tops of the highest ridges and hills in Mason County are capped by gray cherty limestones and blue shales belonging to the Panola formation. Where the shales are at the surface this formation yields only a small supply of water, but where the limestones are exposed enough water for a farm can usually be obtained.

The Lexington and Highbridge limestones and the St. Peter sandstone are in this county buried beneath younger formations and will yield only salt or salt-sulphur water. The well-known "Blue Lick" water of the St. Peter should be reached at a depth of less than 1,000 feet in the Ohio Valley, and it would flow at the surface. Flows could also be obtained in the valleys of the smaller streams where the altitude of the surface does not exceed 580 feet above sea level.

MERCER COUNTY.

SURFACE FEATURES.

Mercer County is located near the southwest corner of the Blue Grass region, on the west side of Kentucky and Dix rivers, which here flow in narrow gorges with perpendicular walls. The difference between the altitude of the Kentucky and the higher parts of the upland is more than 400 feet. Near the rivers the upland is deeply trenched by a number of small streams, but a few miles back the slopes become gentler and the variations in altitude smaller, as a rule not exceeding 100 to 200 feet. In the western part of the county the surface is more rugged, the slopes being moderately steep and differences in altitude amounting to 200 feet or more.

The eastern edge of the county drains into Kentucky and Dix rivers through a number of small streams less than 5 miles long. The principal stream within the county is Salt River, which, flowing northward, separates the area of low relief from that of more rugged topography. This river, which unites with the Ohio south of Louisville, flows within a few miles of the Kentucky. In this county the divide between the tributaries of the two streams is in few places more than 4 miles from the Kentucky. The southwestern part of the county is drained by Chaplin River, the chief tributary of Salt River in the Blue Grass region.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIAL.

The upland portion of the county is covered with a mantle of residual material, which varies in texture from a loam to a clay. The loams occur where the material was derived from limestone and the clay where the original rock contained a large amount of shale. The residual materials furnish very little water for either springs or wells, although in general the water conditions are more favorable in localities where the soils are loamy than where clays are found, and in a few places, as at Harrodsburg, the loam may supply considerable water during a wet season.

Narrow strips of sandy alluvium, which supply large quantities of water to springs on the river bank, occupy the wider parts of the gorge in the Kentucky River valley. The few wells that have been sunk in this formation have obtained an abundance of water.

CONSOLIDATED MATERIALS.

The Highbridge limestone outcrops in the gorges of Kentucky and Dix rivers and along the lower courses of some of the tributaries of these streams, but it does not reach the level of the upland. Near Highbridge it is about 300 feet thick, but its northward dip carries its lower portion below the level of Kentucky River in this county, and at the northern boundary the thickness exposed does not exceed 150 feet. In the river gorges and in some of the creeks where it forms the surface rocks the Highbridge furnishes ordinary hard water for springs, but wells which penetrate it below the level of the surface streams as a rule encounter salt or sulphurous waters. On the upland this limestone lies from 150 to 500 feet below the surface, and wells sunk to it will not obtain fresh water.

The Lexington limestone outcrops along Kentucky and Dix rivers, forms the surface rock on the upland near these streams, and is exposed in the valleys of Chaplin and Salt rivers and over considerable areas east and northeast of Harrodsburg. Where it forms the surface rock it appears to afford conditions unusually favorable for underground water; springs are numerous, very few wells have been unsuccessful, and many of the wells obtain large supplies. Water encountered in this limestone below the level of the surface drainage is, as a rule, salt and may be sulphurous.

The Winchester limestone is found on the highest parts of the divide between Kentucky and Salt rivers, where it furnishes an abundance of hard water for springs and shallow wells, and it also yields small quantities of water for springs and shallow wells in the valleys of Chaplin and Salt rivers. Many of the wells that penetrate this limestone below drainage levels obtain salt-sulphur water. It is probable that some of the sulphur springs found in the county come from this formation.

The Eden shale outcrops on the divide west of Salt River, but it yields very little water and this only in small springs or shallow wells, which are apt to fail during dry weather.

Near the western edge of the county is a belt capped by rocks belonging to the Maysville formation, but they contain here so large an amount of shale that they yield little more water than the Eden shale. Near the northwestern part of the county, however, they furnish fair supplies for a number of shallow wells.

The St. Peter sandstone underlies the county at depths of from 700 feet in the gorge of Kentucky River to 1,100 feet or more on the upland, the depth being least near the southeast corner of the county and diminishing toward the north and west. This formation will yield flowing wells of salt-sulphur water in the gorges of Kentucky and Dix rivers and of some of the other streams at altitudes of less than 580 feet above sea level.

NICHOLAS COUNTY.

SURFACE FEATURES.

Nicholas County is situated in the east-central part of the Blue Grass region. Along its western side is a belt of gently rolling upland, with shallow valleys and rounded interstream spaces, but the rugged topography of the rest of the county shows differences in altitude amounting in many places to 200 to 300 feet, the areas of level land consisting of winding divides, as a rule, only a few rods wide.

Licking River, which flows along the east edge of the county, receives the drainage of a strip of land a few miles in width, but the drainage of the greater part of the county enters Hinkston Creek, a stream which forms part of the southern boundary. The streams of Nicholas County are all small—few of them exceeding 6 miles in length—and they flow in narrow V-shaped trenches whose slopes are in many places too steep for cultivation.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Nicholas County include heavy loams on the Lexington and Winchester limestones and heavy clays on rocks belonging to the Eden shale and the Maysville formations. These soils furnish little water to wells except where they are underlain by impervious rocks.

CONSOLIDATED MATERIALS.

The Lexington and Winchester limestones are exposed in the valley of Licking River and on the upland near the western edge of the county, and they underlie nearly all of the areas of rolling upland. In the western part of the county they furnish an abundance of hard water for springs and shallow wells; the Lexington, as a rule, yields somewhat more water than the Winchester, but sufficient water for a farm can be obtained from either formation. Wells sunk in these formations below the level of the surface streams are apt to find salt-sulphur waters.

The Eden shale forms the surface rock over a large part of the upland and furnishes small quantities of water for springs and shallow wells but none for deep wells. The water is moderately hard, but is entirely satisfactory for domestic use.

The Maysville formation is represented in Nicholas County by a series of interbedded limestones and shales which cap the higher hills in the south-central part of the county. The formation, as a rule, affords somewhat more favorable conditions for the occurrence of underground water than the underlying Eden shale, and in this county it furnishes moderate quantities of hard water for springs and shallow wells.

The Highbridge limestone and the underlying St. Peter sandstone yield some salt-sulphur water for deep-drilled wells in this county. The St. Peter will supply flowing wells in the valley of Licking Creek, below Upper Blue Lick Springs, where the altitude of the river is 596 feet above sea level.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

The Upper and Lower Blue Lick Springs of Nicholas County furnish a large amount of excellent salt-sulphur water. Bottling works have been established at both of these springs and a great deal of the water is placed on the market. At the Lower Blue Lick Spring a hotel has been opened for the accommodation of those who prefer to use the water at the spring.

On the upland, springs are of moderate size and most of them yield hard water. In some localities they furnish water for domestic use, but ordinarily they are used only for stock.

Dug wells 15 to 30 feet in depth are common, but they are little used except during dry weather when other sources of supply fail. Drilled wells have been sunk at a few localities, but they have, as a rule, obtained water too highly mineralized for ordinary use.

Carlisle is the only city in the county large enough to warrant the installation of a public supply. Underground water suitable in quality and sufficient in quantity is not available for such purpose, but a surface supply might be obtained by constructing a reservoir on some of the small streams near the city. As none of these streams flow during dry weather, a large reservoir would be needed.

OLDHAM COUNTY.

SURFACE FEATURES.

Oldham County is in the western part of the Blue Grass region, and Ohio River flows along its border. In the southeastern part of the county the streams flow in shallow, gently sloping valleys, separated by rounded divides which in few places exceed 100 feet in height. Farther west the valleys are narrow and steep sided and the interstream spaces are for the most part flat. The relief increases toward Ohio River, and the descent from the upland to the river is in most places abrupt, the difference in altitude between the river and the upland amounting to more than 350 feet.

Southeast of La Grange the surface drains to Floyds Fork of Salt River, the principal tributaries of the stream in Oldham County being East, North, and Rodmans forks. Harrods Creek, the chief tributary of the Ohio in this county, heads in Henry County and flows southeastward, joining the Ohio below the Oldham County line. The Ohio also receives several small tributaries in this county, the largest—Patton Creek—being less than 10 miles long.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The western half of the county is covered by a few feet of reddish till, containing numerous pebbles of chert and limestone, with occasional fragments of granitic rock; the eastern half is covered by a thin deposit of residual material, varying in texture from loam to clay. The residual materials are not important as a source of water for either wells or springs. The alluvium of the Ohio Valley will furnish an abundance of moderately hard water at depths of 60 to 100 feet, but, as many of the people who reside in the valley prefer cistern water, few wells have been sunk in this deposit.

CONSOLIDATED MATERIALS.

Rocks belonging to the Maysville and Richmond formations are exposed in the valleys of all the large streams and occupy considerable areas on the upland in the eastern and northern portions of the county. In the eastern part of the county these rocks supply numerous springs and shallow wells. Few of the wells and springs yield large quantities, but in many localities the springs do not fail even in the dryest weather. The most successful wells are less than 40 feet deep. The upper part of the Richmond formation in Oldham County comprises over 40 feet of heavy-bedded calcareous rock, resembling sandstone and containing many concretions.

The gray magnesian limestones of the Panola formation present very favorable conditions for the occurrence of underground water in Oldham County. Springs in this formation are numerous, the most important being the Anita and Royal Magnesian springs, and drilled wells obtain water at depths of 40 to 60 feet. The water is usually found at the top of the shale beds which underlie the limestones. The average yield of a single well is about 10 gallons a minute. The quality of the water is shown by the analysis of the water from Anita Spring. (See p. 211.)

The Eden shale will supply little water in Oldham County.

The Highbridge, Lexington, and Winchester limestones and the St. Peter sandstone are deeply buried in Oldham County. The limestone formations may furnish saline or saline-sulphur water when reached by deep wells. The St. Peter will supply flowing wells of salt-sulphur water in the Ohio Valley. A well drilled at La Grange about twenty years ago obtained a flow of slightly sulphurous saline water. The exact horizon from which the water was obtained is not known, but from the fact that the well was about 1,200 feet deep it seems probable that the water may come from either the Lexington or the Highbridge limestone.

OWEN COUNTY.

SURFACE FEATURES.

Owen County is in the west-central part of the Blue Grass region. Topographically, it comprises a gently rolling upland area in its central part, with broad, flat-topped divides and narrow, shallow valleys, and elsewhere more rugged areas, deeply trenched by narrow valleys separated by winding ridges. A narrow rock terrace extends along the valleys of Kentucky River and Eagle Creek, and at Gratz an abandoned channel of the Kentucky stands at about the same level as the rock terrace. This channel evidently represents the course of the Kentucky at the time of the formation of the terrace; in changing to its present course past Lockport the river evidently followed the channels of Sixmile Creek and some of its tributaries.

The Kentucky forms the western boundary of the county and receives all of the drainage, chiefly through Eagle, Clear, Severn, and Big Twin creeks. Eagle Creek, whose principal tributaries are Caney, Stephens, and Brush creeks, crosses the western edge of the county and forms the northern boundary.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soil of Owen County is chiefly clay, as a rule very thin on the Eden shale, but having an average thickness of 2½ to 3 feet where rocks of the Maysville formation form the level areas of the upland. These soils are not important as a source of water.

The terrace along Kentucky River and Eagle Creek has in most places a thin coating of sandy alluvium, which should supply some water for shallow wells.

CONSOLIDATED MATERIALS.

The Lexington limestone is exposed in the gorge of Kentucky River from the Franklin County line to Drennon Springs, in Henry County. The Winchester limestone outcrops in the gorges of Kentucky River and Eagle Creek and extends a short distance back from these streams along their principal tributaries. Both of these limestones furnish hard water in a number of the streams, and saline springs emerge from them at several places in the southern part of the county. Over a large part of the county the Winchester, Lexington, and Highbridge limestones are deeply buried by younger formations and will not supply fresh water.

The Eden shale outcrops along the valleys of the principal streams and on the upland in the southern part of the county and furnishes small quantities of water for springs and for wells 30 to 35 feet deep.

These rocks are, however, too dense to yield water except near the surface.

Rocks belonging to the Maysville formation occupy a large part of the upland surface of the county and yield considerable moderately hard water for shallow wells—in most of the wells sufficient for a farm. The best springs in this formation are in the central part of the county, where the formation contains some heavy beds of limestone. Some of the best wells and springs of the Maysville formation are found near the city of Owenton, and the possibility of obtaining an underground supply for the city has been discussed. None of the wells in the vicinity are, however, strong enough to afford more than a small part of the water that would be needed for the municipal supply. Deep wells would doubtless obtain an abundance of water, but it would be too highly mineralized for ordinary use, and if a city supply is to be installed the water must be taken from a stream. One of the spring-fed branches near the city would probably furnish the most satisfactory supply of surface water.

Flowing wells of strong salt-sulphur water may be obtained from the St. Peter sandstone in the gorge of Kentucky River, in the valley of Eagle Creek where it borders the west side of the county, and in the lower parts of some of the other tributaries of the Kentucky.

PENDLETON COUNTY.

SURFACE FEATURES.

Pendleton County is situated in the northeastern part of the Blue Grass region. Its surface presents many steep-sided valleys separated by narrow, winding divides, the surface of the upland being so uneven that roads ordinarily follow either divides or valleys. Two rock terraces—the upper but little below the level of the upland and the lower less than 50 feet above the level of the stream—extend along the valleys of the rivers. The lower terrace is in but few places more than a mile wide, but the upper terrace is much wider.

Licking River is joined by its South Fork near the center of the county, and these two streams receive the entire drainage, but the tributaries of both are small. The most important of the tributary streams are Kindale, Grassy, Fork, Lick, and Crooked creeks. All of these except Kindale Creek head in Grant County and flow eastward across western Pendleton County. Kindale Creek rises in Bracken County, and flows northwestward to join the Licking north of Falmouth.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Pendleton County consist of thin deposits of heavy clay, which furnish practically no water except where they rest on the dense shales of the Eden formation.

On the lower terrace in the river valleys are deposits of sandy gravel which locally exceed 30 feet in thickness; one record of drilling in the northern part of the county gives the alluvium a thickness of 80 feet, but this is probably too great. The upper terrace bears thin patches of sand and gravel belonging to the Irvine formation. The alluvium supplies an abundance of water for springs along the river banks and should be a satisfactory source of water for wells.

CONSOLIDATED MATERIALS.

The Lexington limestone is exposed in this county along the rivers, where it occupies the bottoms and lower slopes of the valleys. It furnishes an abundance of hard water in the valleys of the Licking and its South Fork. No deep wells have been drilled for water in this formation and none have penetrated the Highbridge limestone; but water obtained in either of these formations at depths greater than 75 to 100 feet, would probably be highly mineralized.

A strip of Winchester limestone is found above the Lexington. This formation, however, occurs not only along the river bottoms, but extends considerable distances up the valleys of the principal tributaries. It furnishes moderate quantities of hard water where it is at the surface, and the formation also supplies some springs of salt-sulphur water in the valleys of the streams. Where the Winchester is buried beneath the Eden shale its water would be too highly mineralized for ordinary uses.

Above the Winchester limestone, forming most of the surface of the county except in the valleys of the large streams, is the Eden shale, which supplies small quantities of water for springs and shallow wells but will yield no water to deep wells.

Narrow belts of limestone belonging to the Maysville formation cap the divides in the western part of the county. These rocks contain some excellent springs and supply considerable water for shallow wells.

Flowing wells may be obtained from the St. Peter sandstone in the valley of Licking River. The well at Boston Station obtains its supply from this formation. The water contains a large amount of salt and is highly charged with hydrogen sulphide. It has proved entirely satisfactory for stock, but is unfit for other uses.

ROBERTSON COUNTY.

SURFACE FEATURES.

Robertson County is near the southeast corner of the Blue Grass region, on the east side of Licking River. Its surface is a deeply dissected plateau, whose steep-sided valleys, 100 to 300 feet deep, are separated by narrow divides with even, sinuous crests. An abandoned stream channel passes near Kentontown and joins Licking River Valley below Claysville. The rock floor of this valley is in many places covered with 5 to 10 feet of sand containing a few pebbles of chert.

The surface drains toward the west or north into Licking River or its North Fork. The principal stream, Johnson Creek, crosses the county south of Mount Olivet, and there are also many small streams, most of which are less than 10 miles long.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soil of Robertson County is a yellow or reddish clay, which as a rule forms a thin deposit on the uplands. On the slopes it contains many slabs of limestone which have been left as the soil has washed, and in some parts of the county these slabs are so numerous that they furnish enough rock to construct the pikes. The soil yields very little water for either springs or wells.

Some small, unimportant patches of sandy alluvium are found in the valleys of the large streams. The alluvium of the Licking Valley supplies water for some springs, and wells sunk in it would probably be successful. A few wells in the abandoned stream valley near Kentontown procure a plentiful supply of soft water from sand and gravel at depths of 10 to 15 feet.

CONSOLIDATED MATERIALS.

The Lexington limestone outcrops in the valleys of the streams in the western part of the county, but a short distance back from the main streams it is overlain by younger formations, and its eastward dip carries it down to the water level near the eastern boundary of the county. Where it is exposed in the stream valleys wells and springs obtain from it considerable potable water, but elsewhere it will yield only salt and salt-sulphur waters. Such waters might also be encountered in deep wells near the river.

The Winchester limestone appears at the surface in a narrow area near Licking River and its tributaries, where it yields moderate quantities of water for springs and shallow wells. In other parts of the county it is buried beneath younger geologic formations and may be expected to furnish only salt or salt-sulphur water. Some of the deeper wells in the area where the limestone is exposed may also encounter mineral water.

The Eden shale forms the surface rock over a large part of the county, and in most places it furnishes small quantities of water for shallow wells and springs, though the supply is apt to fail in very dry weather. It supplies no water to deep drilled wells.

The lower members of the Maysville formation may cap some of the higher parts of the county, but these members contain a high percentage of shale, and their water capacity is about the same as that of the Eden shale.

The Highbridge limestone will furnish only salt or salt-sulphur water in this county.

Wells sunk on the upland of the county would probably reach the salt-sulphur water of the St. Peter sandstone at a depth of about 900 feet. In the valley of Licking River flowing wells might possibly be obtained from this formation, as the bed of the river was found by aneroid measurement to have an altitude of 580 feet above sea level. As aneroid measurements are subject to considerable error, the determination of altitude is questionable.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

Dug wells, ranging in depth from 10 to 25 feet, supply water for domestic use over a large part of the county, but their use in the towns is attended by some risk, as they are liable to be more or less contaminated by surface drainage.

Drilled wells have been sunk at Mount Olivet and Piqua. At Mount Olivet two wells, 107 feet deep, were drilled, one of which obtained a moderate supply of mineral water and the other was dry. At Piqua a drilled well encountered sulphur water at a depth of about 75 feet.

The springs of Robertson County are all small, and many of them can not be relied upon to furnish water during very dry seasons. The original Lower Blue Lick Spring was located on the north side of Licking River in this county, but this spring ceased to flow some years ago, and attempts to obtain the water by drilling have been unsuccessful. A spring with water of similar character on the other side of the river is now utilized by the company. In the table of analyses (p. 210) the first three samples were taken from the old spring and the fourth and fifth from the one now in use.

SCOTT COUNTY.

SURFACE FEATURES.

Scott County is situated in the south-central part of the Blue Grass region. A gently rolling surface, with variations in altitude of 100 to 200 feet, characterizes the southern part of the county, the inter-stream areas showing, as a rule, slight relief and being marked by numerous sink holes. In the northern part of the county the surface has been greatly dissected and presents steep-sided valleys separated by narrow divides. The highest points in the county are nearly 1,000 feet above sea level; the lowest are between 600 and 700 feet above; and the maximum variation is therefore between 300 and 400 feet.

The northern part of the county drains into Eagle Creek and the southern part into Elkhorn Creek. Several tributaries of Licking River head near the eastern boundary and receive the drainage of the eastern part of the county.

The underground drainage of the southern part of the county is extensive, and some of the underground streams may be traced for a distance of 3 or 4 miles by the lines of sink holes that mark their courses. As a rule, an underground stream emerges in a spring at the head of a small branch.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials of Scott County form a thin mantle of residual soil, consisting of 3 to 8 feet of brown or red loam on areas underlain by limestone, and 3 feet or less of yellow or red clay where the underlying rock is shale. These materials yield little water except where they rest on a dense rock, like the Eden shale, and even in such places the supply is small.

CONSOLIDATED MATERIALS.

The Lexington limestone is the surface rock over nearly all the southern part of the county, its outcrop coinciding very closely with the area of well-developed underground drainage and rolling topography. The northern boundary of this limestone is a sinuous line extending in an east-west direction across the county about 5 miles north of Georgetown. The formation furnishes an abundance of hard water for springs and wells, and it contains all the large underground streams that supply the important springs of the county. Below drainage levels, however, the water contains salt, and in some places sulphur, and where the limestone is covered by younger formations it will yield no fresh water.

A narrow band of Winchester limestone occurs along the northern border of the area of Lexington limestone, and another extends from the western boundary of the county near Switzer to Greendale in Fayette County. Where this rock is at the surface it furnishes moderate quantities of water for springs and shallow wells, but below drainage levels the water is brackish and is, as a rule, charged with hydrogen sulphide. In localities where it is covered by the Eden shale the water found in it will probably contain both salt and sulphur.

The Eden shale outcrops in the northern part of the county and over a small area in the western part. The rocks of this formation have been deeply eroded and their outcrop coincides very closely with the area of rugged topography. In some places this shale yields small quantities of water for springs and shallow wells, but it yields no water for deep wells, and the supply obtained by the shallow ones is apt to fail in dry weather.

The Highbridge limestone lies about 200 feet below the surface in the southern part of the county, but it is probably nearly 500 feet below the tops of the highest hills in the northern part. It will yield only brine in this county.

The St. Peter sandstone, with its salt-sulphur water, underlies the entire county, but flowing wells are precluded by the altitude of the surface. In the lowest parts of the county the water should rise to within less than 100 feet of the surface. At Georgetown and Rogers Gap strong salt-sulphur was reported in two deep wells at depths of 700 and 900 feet, respectively. At Georgetown this water was said to have sufficient head to rise within 15 feet of the surface. If this is the water from the St. Peter sandstone, it was encountered at a less depth and rose higher than the water from the same formation at Frankfort.

STRUCTURAL FEATURES.

The rocks of Scott County have a general dip toward the north, and there are some evidences of slight local disturbances. The most marked structural features are found southwest of Stamping Ground, where two nearly parallel faults have brought a block of Eden shale into contact with the Lexington limestone. Near Georgetown a slight deformation has produced a small fold.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

Dug wells are used to a limited extent in Scott County, but they are rapidly being supplanted by drilled wells except in the areas underlain by the Eden shale. Most of the drilled wells obtain their waters from the Lexington and Winchester limestones at depths of 50 to 125 feet. The depth to the sulphur water in Scott County varies locally, but it is in few places more than 100 feet.

The Georgetown water supply, which is taken from a large spring on the edge of the city, is the only large underground supply of the region. The fact that this water is usually turbid after a rain suggests that some water enters the underground stream through open sinks. The spring is supplied by a good-sized underground stream, and the amount of water is usually much greater than is needed by the town. Many other large springs are found in various parts of the county.

Sadieville and Stamping Ground have drilled wells belonging to the towns, and these wells supply water for the families that do not use cistern water. At Newtown the underground water conditions appear to be very favorable, and a large number of successful wells have been drilled.

SHELBY COUNTY.

SURFACE FEATURES.

Shelby County is on the western edge of the Blue Grass region. Except near its eastern boundary, where some of the streams have cut narrow valleys 200 to 300 feet below the level of the upland, it has a gently rolling surface, with variations in altitude exceeding 100 feet in but few places. Near the northwestern corner of the county is a high ridge which forms the divide east of Floyds Fork, and a high hill, known as the "Jeptha Knob," is situated near the village of Claysville.

A small area near the eastern margin of the county drains to Kentucky River through Sixmile and Benson creeks, whose principal tributaries are Backbone Creek (to Sixmile) and Collets Creek (to Benson). The rest of the county is drained by tributaries of the North Fork of Salt River, the largest being Big Beech, Guests, and Brashears creeks, and Floyds Fork. The southeastern corner of the county, south of Harrisonville and Southville, is drained by the Middle Fork of Crooked Creek and Big Beech Creek and its tributaries; a large area east of Shelbyville and south of Christiansburg is drained by Guests Creek and its tributaries, Jeptha and Lick creeks and Breton Run; and the central part of the county is drained by Brashears Creek, to which Clear and Big Bullskin creeks are tributary. Floyds Fork of Salt River receives no large streams from Shelby County, but the drainage of the northern part of the county reaches it through several small streams. Plum Creek, a direct tributary of Salt River, drains the southeastern corner of the county.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Shelby County resemble those of Fayette County, ncluding dense red or yellow clays on the areas of Eden shale and loams rather than clays on the limestones of the Maysville and Richmond formations. The residual soils from the Eden shale furnish small quantities of water during wet weather. In a few localities the soils on the Maysville formation contain so much water that tile draining is necessary, and in such places they should furnish some water for wells.

CONSOLIDATED MATERIALS.

The Highbridge, Lexington, and Winchester limestones underlie the entire county, and the Lexington and Winchester are exposed near Graefenburg in the valley of Benson Creek. The Winchester limestone appears also in the channels of several other streams near the eastern edge of the county. Where these limestones are at the surface sufficient hard water for a farm is usually obtainable, but in some places they yield salt-sulphur water like that of the mineral spring at Graefenburg. These formations might be reached by deep wells sunk on the upland, but the water of such wells would probably be saline or saline-sulphur in character.

The Eden shale forms the surface rock over a belt 2 to 6 miles wide along the eastern boundary of the county, and outcrops also in the valley of Brashears Creek and in the valleys of Guests Creek and its principal tributaries. In the eastern part of the county this formation supplies small quantities of water for springs and shallow wells, but farther west it is covered by younger rocks and is not water bearing.

Rocks belonging to the Maysville and Richmond formations occupy nearly all of the surface west of the exposures of Eden shale and furnish moderate quantities of hard water for springs and shallow wells. The undergound water conditions appear to be most favorable in the western half of the county, but perennial springs occur in all parts of the area where these formations are at the surface.

The Panola formation caps the ridge east of Floyds Fork in the nothwestern part of the county. On Jeptha Knob, and near the northwest corner of the county, it furnishes ample supplies of hard water for farm use. A cavern containing a stream of water is reported on Jeptha Knob.

The St. Peter sandstone will supply an abundance of water for deep wells in this county, but it is improbable that the water will flow at the surface. The quality of this water is shown by the analysis of the water from the Old 76 distillery at Newport (p. 212). The water is too highly mineralized for domestic or industrial uses.

STRUCTURAL FEATURES.

The rocks of Shelby County dip gently toward the northwest. They show no marked dislocations except near Jeptha Knob, where they are broken by faults which have brought limestones of Niagaran age into contact with some of the older rocks of the Maysville formation.

WATER FOR DOMESTIC AND INDUSTRIAL USES.

In the western part of this county some drilled wells, 50 to 100 feet deep, have obtained good supplies, but over a large part of the county drilled wells may yield very little water. A conspicuous example of a failure to find water is the well on Mr. Goodloe's farm, northeast of Shelbyville, which was carried to a depth of about 750 feet. Another well a short distance away obtained a good supply at less than 70 feet. In this county drilling should not, as a rule, be carried beyond 100 feet, and 150 feet should be the maximum depth unless mineral water is desired.

None of the formations exposed in Shelby County will supply sufficient water for a city system except the Lexington limestone, and even this formation may be expected to yield large supplies in only a few localities where conditions are especially favorable.

In Shelbyville, which is situated on rocks of the Maysville formation, it is practically certain that underground water of suitable quality and sufficient in quantity for a city supply is unobtainable, and the only alternative is the use of surface water. Filtered surface water, however, would compare very favorably with the underground water of the region.

TRIMBLE COUNTY.

SURFACE FEATURES.

Trimble County is in the western part of the Blue Grass region and is bordered by Ohio River. The eastern part of the county has a gently rolling surface with broad shallow valleys separated by rounded divides, except near Little Kentucky River, which has cut a narrow trench 200 to 300 feet below the level of the upland. West of Bedford the streams flow in deep, narrow valleys which are separated by broad, flat, interstream spaces. The amount of relief increases toward Ohio River, where it approximates 400 feet.

The Little Kentucky, which crosses the eastern part of the county, receives the drainage of the area east of Bedford. The area west of Bedford is drained by several small tributaries of the Ohio, the most important being Pattons, Barebone, Corn, Spring, and Cooper creeks. None of these streams exceed 10 miles in length and all of them have very high gradients.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials of Trimble County include a mantle of glacial deposits in the western part of the county and of residual soils in the eastern part, with a deposit of alluvium 80 to 120 feet or more in thickness in the Ohio Valley.

The eastern boundary of the glacial deposits extends northward from the Oldham County line, passing about 5 miles east of Bedford and entering Carroll County west of Little Kentucky River. The material of these deposits is a red clay containing many fragments of chert and some pebbles of limestone. A few small fragments of igneous rocks occur in the till, but most of the pebbles are of local origin.

The residual soils of the eastern part of the county consist of dense clays, in few places more than 3 feet thick, which furnish little water directly to wells or springs except where they rest on the Eden shale.

The alluvium of the Ohio Valley consists of coarse sands and gravels capped in many places by a few feet of buff silt. These materials supply an abundance of hard water for drilled or driven wells at depths of 60 to 110 feet. The water is not so hard as that derived from the consolidated materials on the upland.

CONSOLIDATED MATERIALS.

The oldest rock appearing at the surface in Trimble County is the Eden shale, which is exposed at the foot of the bluff bordering the Ohio and in the valleys of Little Kentucky River and some of the smaller streams in the northeastern part of the county. In these valleys it furnishes small quantities of water for springs and shallow wells, but elsewhere in the county it is buried by younger formations and is not water bearing. The quality of much of the water from this shale is poor.

The eastern half of the county is underlain by rocks belonging to the Maysville and Richmond formations, which furnish moderate quantities of hard water for springs and shallow wells. The Richmond is especially well developed, more than 150 feet of interbedded limestones and shales belonging to this formation being exposed near Bedford. The upper part of the Richmond presents exceptionally favorable conditions for underground water and contains some very good springs. In some drilled wells the water is slightly brackish.

A large part of the upland near the Ohio is occupied by the blue shale and gray to buff heavy-bedded limestones belonging to the Panola formation. The limestone beds of this formation yield ample supplies of water containing considerable lime and magnesia. Some of the layers that rest on shale beds present unusually favorable conditions for underground water. Northwest of Bedford some large sink holes suggest the presence of good-sized caverns.

The Winchester, Lexington, and Highbridge limestones and the St. Peter sandstone are all buried beneath younger rocks in this county and will not yield fresh water, but any of them may yield salt-sulphur water in deep drilled wells. In the Ohio Valley flowing wells could be obtained by drilling into the St. Peter, but the quality of the water in this formation renders it unfit for ordinary uses.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

A number of good springs are found in the western part of Trimble County, but from Bedford eastward the springs are small and many of them fail during dry seasons. The Bedford mineral spring was formerly a summer resort of considerable note.

Dug wells from 10 to 30 feet deep are a common source of supply for farms and villages. During recent years many of these wells have been supplanted by cisterns.

Drilled wells are usually successful on the upland west of Bedford, but few of them procure large supplies. At Bedford two unsuccessful wells have been drilled.

WOODFORD COUNTY.

SURFACE FEATURES.

Woodford County lies in the southern part of the Blue Grass region, on the east side of Kentucky River, which is here less than 500 feet above sea level; the highest parts of the upland have an altitude of nearly 1,000 feet.

The drainage of the county reaches the Kentucky through Clear, Glen, and South Elkhorn creeks and many small streams. All the surface streams receive large quantities of water from springs fed by underground streams. Such underground streams occur in all parts of the county, but they appear to be especially large and numerous on the divide northeast of Versailles. On this divide are many sink holes which receive the drainage from considerable areas. An example of this is the big sink northeast of Versailles, which receives the drainage from a surface stream more than a mile in length and which is said to be connected by an underground channel with the Big Spring. This spring, which is probably the largest in the Blue Grass region, emerges from a cavern, flows for some distance as a surface stream, and then enters an underground channel through a sink hole. Other examples of sinking streams are to be found on the Woodburn farm, near Spring Station, and at Childer's place, near Versailles. In this county, as elsewhere in the region, most of the large springs emerge in small gullies. Caverns of considerable size exist in various parts of the county, and some of them have been explored for short distances.

Most of the surface streams tributary to the Kentucky have broad valleys on the upland and descend to the river in narrow canyons.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials in Woodford County consist of yellowish or reddish loams and clays which were formed by the decomposition of limestones and shales and which probably have an average thickness of less than 6 feet, although in some places the maximum thickness may exceed 20 feet. These materials furnish little water directly to wells or springs, but they store large quantities of water and supply it gradually to the channels in the limestone.

Thin strips of sandy alluvium, which supplies large quantities of water to springs on the banks of the river and might also furnish an abundance of water for wells, are found in the wider parts of the gorge of Kentucky River. The thickness of this alluvium has not been determined by borings, but it probably does not exceed 50 to 60 feet.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed in the gorge of Kentucky River, but it dips steeply northward and the thickness of the exposure decreases toward the northern end of the county. Where it forms the surface rock it furnishes hard water for springs and shallow wells, but elsewhere it yields water which is highly mineralized.

The Lexington limestone is exposed above the Highbridge along the valleys of the large streams and it forms the surface rock over a large portion of the upland. It is this limestone that contains the large underground streams referred to in a previous paragraph. In the localities of its outcrop it furnishes an abundance of hard water, but wells which penetrate it below the level of the surface drainage are apt to obtain salt or salt-sulphur water.

The Winchester limestone outcrops over considerable areas in the northern half of the county and supplies moderate quantities of hard water. It may also supply some of the sulphur water which is encountered in the drilled wells of the northern part of the county.

The Eden shale, which caps some of the hills in the northwestern part of the county, furnishes small quantities of water to springs and shallow dug wells, but none for deep wells.

The St. Peter sandstone will supply salt-sulphur water at depths ranging from 700 to 800 feet in the gorge of Kentucky River to 1,200 feet or 1,300 feet on the upland. The water is under sufficient pressure to cause it to flow at the surface in the Kentucky gorge and in the lower parts of some of the tributary streams.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Dug wells are used to a moderate extent in Woodford County, but they are not held in great favor. Drilled wells are numerous in all parts of the county, and the water conditions are so favorable that many drillers agree to obtain water or make no charge for drilling. At Versailles about 100 wells have been drilled and none of them have failed to get water, while some have yielded over 100 gallons per minute.

The large spring at Spring Station probably has a greater volume than any other spring in the Blue Grass region. The flow of this spring was not determined, but it must amount to several million gallons per day.

WELLS AND WELL RECORDS.

The following list of well records (Table 8) includes about 75 per cent of the number that was collected during the progress of the field work. No attempt has been made to obtain records of all the wells in the region, but the list is believed to represent the underground water conditions and to indicate what may be expected by those who contemplate drilling.

The wells in the alluvium are all located in the Ohio Valley. Wells sunk in this formation always procure water, unless they are located so close to the upland that they encounter rock near the surface. The water is entirely satisfactory for ordinary use and the supply ample.

The wells on the upland have been sunk in various formations, but it will be noted that none of the deep wells obtain water from the Eden shale. In the other formations the water supply varies in amount and character in different localities. Large supplies are encountered in many places in the Lexington limestone, while few wells in the Maysville and Richmond formations obtain more water than is needed for a single household. In the Winchester limestone underground water conditions are somewhat less favorable than in the Lexington. The Panola formation is seldom thick enough to warrant deep drilling, but near the western edge of Oldham and Trimble counties it supplies a number of good drilled wells.

In all of these formations, except the Panola, the deeper wells are apt to encounter the highly mineralized water which is designated sulphur water in the table. The depth to this mineral water varies from place to place and in different wells in the same locality; but in general the table will form a safe guide to the approximate depth of the ordinary limestone water, beyond which mineralized waters are probable.

In consulting the table it is well to remember that a well in any locality may fail to obtain water. In the Blue Grass region the number of unsuccessful wells is about 4 per cent of the whole number drilled. For the region as a whole, therefore, the probability of success in seeking water is very good, but the percentage of dry holes is much higher in some localities than in others. It may happen that some wells find water while others a few feet away are dry. This is explained by the fact that the water occurs in channels in the rock, and to be successful a well must encounter one of the water-bearing channels. The accompanying diagram, figure 5, shows two wells side by side—one successful, the other dry.

About 100 records were collected by Dr. Chase Palmer and the remainder by the author. Much valuable information in regard to the occurrence of underground water in the region was also furnished by the drillers whose names are given below:

J. B. Bonta.
E. C. Cox.
W. M. Cox.
E. C. Griggs.
George Icenhower.
John Kearney.
W. S. May.
Patton & Bailey.
W. R. Renfro.
Robinson & Moon.
George Sallee.
S. Wells.
Robert Smith.
E. M. Spence.
John O. Rogers.
W. B. Tadlock.

TABLE 8.—*Wells in the Blue Grass region.*

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Anderson County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Lawrenceburg	2 blocks W	City	8	75–100 240	40–45	Small streams				Hard; trace sulphur.		Lexington	Domestic, stock, boilers, manufacturing.	3 wells.
Do	200 yards NW	do	12–4	125	125	50	−110	150	Steam	Sulphur	Lowered	do	Domestic, stock.	
Do	150 yards W	do	8	245	45	None.	− 8	60	Deep well.	Hard	do	do	do	
Do	5 miles N	Kentucky Distillery and Warehouse Co.; Blakemore Distillery.	6	50	48		− 5	100	Steam	Hard; sulphur.	None.	do	Boilers, manufacturing.	
Do	½ mile S	Lawrenceburg Electric Light Co.	6	135			− 10	15	do	Hard		do	Manufacturing.	
Do	2 miles NW	W. B. Saffell	6	105	30		− 4		do	Sulphur		do	Drinking, manufacturing.	
McBrayer	4½ miles S	J. T. S. Brown & Sons.	8	65	60	None.	− 14			do		do	Stock, manufacturing.	
Do	½ mile SW	do	3, 6	70	70	None.	− ½		do		None	do	Domestic, manufacturing, stock.	
Tyrone		City	6	80					Hand	Hard, and one white sulphur.	do	Highbridge	Domestic, stock.	11 wells.

Boone County.														
Bellevue	1 or 2 blocks	Bellevue		130	120–130	Above 120.			Hand	Hard	do	Alluvium	Stock	
Petersburg	3 blocks W	Boone County Distilling Co.		110	90–100	Small, above 90.			Steam	do	do	do	Manufacturing.	
Do.	1 block E	F. M. Morgan	2	80	40				do	do		do	Boilers	
Do.	1½ miles S	Frank D. Smith		100	80				Windmill	do		do	Drinking, stock.	
Do.	1 block S	Town	4	115	100	None.			Hand	do	Varies, but plenty.	do	Domestic, stock.	
Do.	½ mile N	J. I. McWorthey	3	132	95	None.			Windmill	do	None	do	Stock	
Rabbit Hash	1 mile S	John McConnell	4	95	60	None.	– 60	4	do	do	do	do	do	
Taylorsport	½ mile E	P. Grubbs	3	110	32		– 18			Sulphur	do	do	do	
Bourbon County.														
Centerville	1 mile W	J. B. Haggin	5¼	125	85		– 50	50?	Gasoline engine.	Hard; sulphur		Lexington	Stock	
Clintonville	1 mile N	S. L. Weathers	8–6	50	45	25		30	Meyer's hand.	Sulphur	None	do	Domestic, stock.	
Elizabeth Station.	1 block N	John M. Leach	6	55	50	None.		4	Hand	Hard; some sulphur.	Lowers.	do	Stock	
Hutchison	100 yards W	M. R. Jacoby	6	72	72	None.	– 52		Windmill	Sulphur	None	do	Domestic	
Do.	3 miles W	do	6	68	68	None.	– 15	8	Hand	Hard	do	do	do	
Millersburg		Millersburg Female College.	6	60	None.									
Do.		do	6	120	None.									
North Middletown.	2 miles N	William Thomason.		40	40				Gasoline engine.	Slight sulphur.		do	Domestic, stock.	
Paris	1 mile S	Bourbon County Fair Association.	6	113	103	67	– 52		Hand	Hard; some sulphur.		do	Drinking	
Do.	5 blocks W	Bourbon Steam Laundry.	8	90+			– 25		Hand, force.	Hard; slight sulphur.		do	Domestic, stock, manufacturing.	
Do.	1 mile NE	Paris Distilling Co.	6	120			– 30			Hard; strong sulphur.		do		Not used.
Do.	7 miles SE	Benj. Woodford		168		None.	– 40		Hand			do		
Do.	5 miles S	W. B. Woodford	6	50	40	None.	– 20		Suction	Soft		do	Drinking	
Boyle County.														
Danville	2½ miles NW	Charles P. Cecil	5	90	85		– 35		Windmill	Sulphur		do	Domestic, stock.	
Do.	2 miles	W. W. Johnson	4	180	90	None.		½	do	Hard	Lowered	Lexington	Washing, stock.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks
Boyle County—Continued.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Danville	3 miles E	D. F. Slavin	4	125	125	None.	− 50		Windmill	Hard	None	Lexington	Domestic, stock.	
Enido	¼ mile W	J. L. Crain	6-4	65	62	38	− 45	1	Force	Soft; sulphur			do	
Hankla	½ mile W	George Gordon	6	51	51		− 27			Sulphur	None		do	
Do	1½ miles W	W. F. Powers	6	58			− 32				do		do	
Mitchellsburg	200 yards E	School district	6	72	72	40±			Hand	Hard; sulphur	do	Chattanooga.	Drinking.	
Do	East	L. R. Wharton	6	73	73		− 33		do	Sulphur	do	do (?)	Domestic, stock.	
Parksville	50 yards W	Lapp Ewing	6	100			− 8						Domestic, stock, boilers.	
Do	200 yards NE	J. D. Minor	6	57			− 30				Weak supply.		Domestic, stock.	
Perryville	4 blocks E	Samuel Bonta	4	60	60	None.	− 40		Force	Soft; black sulphur.		Lexington	do	
Do	1¼ miles SW	J. W. Broghs	4	56		None.	− 25		Hand	Slight sulphur.	None	do		
Do	250 yards W	J. A. Carpenter	6	67	67	None.	− 45		Force	Sulphur		do	Domestic, stock.	
Do	2½ miles N	J. W. Moss	6	100	100				Windmill	Hard; possibly oil.		do	Stock	
Do	2½ miles E	R. A. Walker	6	125	125	None.	− 93		Deep well.	Hard; salt, oil, and iron.		do	Cooking, stock.	
Do	300 yards W	George Warren	6	82	82	None.			Force	Slight sulphur.		do	Domestic, stock.	
Do	3 miles W	Richard G. White.	6	70	70	None.	− 40			Slight sulphur and gas.		do	Domestic	
Bracken County.														
Augusta	1 block S	Augusta Milling Co.	4	85	40		− 40	45	Steam	Hard	None	Alluvium	Boilers	

Do	3 blocks E	Augusta Steam Laundry.	2	80	60			25+	do	do	Not lowered when 25 gallons were pumped.	do	do	
Do	2 squares W	J. R. Carter	6	86	80	50	− 40	Unlimited.	Hand	do		do	Drinking, stock.	
Do		City	3	90-115	40-50	10, 40-50	− 50±		do	do		do	Domestic, stock, boilers.	
Do	2 blocks NW	do	6	96	50±		− 46	60+	Steam	do	None	do	Boilers	
Do	1½ miles W	E. F. Frolicher	6	170	170	None.	− 60+		Hand; gasoline engine.	Mineral		Winchester (?)	Drinking	
Foster	1 block N	Town	6	106	102	30	− 70±		Hand	Hard	Slight	Lexington	Domestic, stock.	Abandoned.
Wellsburg	15 rods	Noble Stair		68	35				Steam	do		Alluvium	Drinking, washing, boilers.	
Campbell County.														
Newport	4 miles S	Bastian dairy	4	101	− 65	Several veins.	− 40	15	Hand	do	None		Stock	
Do	Evergreen Cemetery.	Evergreen Cemetery Co.	4	600	200	None.	−194	1$\frac{2}{3}$	do	Slight sulphur.	do	Maysville and Eden.		Probably entered Trenton.
Do	Berry ave between 2d and 3d.	Frigid Ice Co	10	122	52	122	− 52	209	Steam	Hard	do	Alluvium	Manufacturing.	Uses water for cooling.
Do		Old 76 Distilling Co.	3	1250		A little fresh water.		34+		Sulphur	do	St. Peter	Drinking, manufacturing.	Very strong salt-sulphur.
Do		George Weidemann Brewing Co.	10	110, 275	80	None.	− 70	350	Air lift	Hard	do	Alluvium	Manufacturing.	Uses several wells for cooling purposes.
Carroll County.														
Carrollton	½ mile W	Atkinson Bros. Co.	3	70	45		40			do		do	Boilers	
Do	½ mile S	Carrollton Furniture Manufacturing Co.	3	98					Steam	do	None	do	Drinking	
Do	5 miles NE	G. H. Conway	8-6	540	20	540	− 90							
Do	½ mile S	Jett Bros. Distillery Co.	5,8	80-90	40		− 40	300	Steam	Hard		Alluvium	Boilers, manufacturing.	Six wells.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply	Geologic horizon of water beds.	Use.	Remarks.
Carroll Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Ghent		City of Ghent	4	108, 94	70		− 80	2	Hand	Hard	None	Alluvium	Domestic, stock.	
Do	1½ miles NE	H. M. Froman	2	114	85	114	− 35	1	Windmill	do	do	do	do	
Do	1½ miles N	do		150					do			do	Stock	
Milton	4 miles E	C. S. Tandy	3	82	60		− 60		Hand	Hard		do	do	
Sanders	4 miles NE	F. B. McDonald	8¼	841	840					Hard; sulphur		Lexington		
Clark County.														
Dodge	Across road S	S. D. Chism	6	58	54	None.	− 38		Hand	Sulphur	None	Winchester	Domestic, stock.	
Do	40 rods W	G. T. Roland	6	50	44	None.	− 15		do	Sulphur; salt	do	do	Drinking, stock.	
Hedges	1½ miles SE	L. T. Bush	5	113	75–80	None.	− 70		do	Salt; sulphur	do	Lexington	Domestic	
Pine Grove	1½ miles S	A. Younger Jones.	4½	90	80–85	50–55	− 65		Gasoline engine.	Hard	do	do	Domestic, stock.	
Do	100 yards NE	D. W. Scott	4½	134	127	None.	− 90+		Hand	Hard; magnesia.	Slight	do	do	
Winchester	5½ miles N	Oscar Johnson	5	70–75					Windmill	Strong sulphur	None	Winchester	Stock	
Do	½ mile E	Reliance Manufacturing Co.	4½	55+	35	42				Sulphur		do		
Do	½ mile S. of E	R. P. Scroble	6	100										No water of importance
Do	¼ mile N	Winchester Electric Light and Ice Plant.	6	132, 112								Lexington		Salt water, unfit for use.
Do	6 miles N	N. H. Witherspoon.	5	146	140				Hand	Sulphur	None	do	Drinking	
Wyandott	2 miles	B. M. Renick	4	145, 165	100	None.			Force		do		Domestic, stock.	
Fayette County.														
Chilesburg	2 miles N	Rev. W. H. Felix		75		do			Gasoline engine.	Salt, iron, and sulphur bearing.		Lexington	Drinking, stock.	

Elizabeth	1½ miles S	Abram Jones	6-4	150	150	60	− 50		Force	Soft		do	Domestic, stock.	
Greendale	½ mile W	Kentucky Reform school.	5	214, 212					Steam			Highbridge	Domestic, stock, boilers.	
Do	½ mile E	S. C. Nunnelly		230		Above 30.			Hand	Sulphur	Strong supply.	Lexington (?).		Not used now.
Do	1 mile NW	State	5	214, 212	60, 75	101, 175	− 75 to − 60	35	Steam and gas.	do		Highbridge (?)	Domestic, manufacturing.	
Lexington	5½ miles Georgetown Pike.	Dr. Aiken	4	200	94	40			Windmill.	Hard	None	Lexington	Stock	
Do	¾ mile NW	Blue Grass Stock Yards.	6	84, 124			− 40+		Horse-power.	do	do	do	do	
Do	1½ miles NE	Boice & Grogan Lumber Co.	8	116	50	20		40	Deep well.	do	Varies	do	Boilers	
Do		City Ice Co.	6	190					Steam			do		Not used.
Do	1½ miles N	Benj. M. Cole	4½	95	95	None.			Force	Alkaline	None	do	Domestic, stock.	Mineral water.
Do	¾ mile W	Consumers' Ice Co.	8, 5, 5	400, 150, 100	274			100		Sulphur		do	Manufacturing.	450-foot well enters Highbridge limestone.
Do	10 miles N	B. S. Coyle	4¼	100	80	None.	− 35	3	Force	Hard	Lowered	do	Drinking, stock.	
Do	do	do	4¼	112	110	70	−100	60	do	Limestone	None	do	Domestic, stock.	
Do	10 miles	do	4¼	142	80-130	None.	− 30	7	do	do	do	do	do	
Do	5 miles SE	R. C. Estill	5-4	225	150	25, 65	− 45		Hand	Salt; sulphur.		Highbridge (?)	Stock	
Do	5½ miles SW	Alex. Foley	6	71	71				do	Hard	None	Lexington		Not used.
Do	1½ miles W	G. R. Foster	4½	200	90		+ 0			do	Varies	do	Drinking, manufacturing.	
Do	3 miles N	John N. Foster	4½	100	−5, −65			66	Steam	do		do	Irrigation	
Do	¾ mile SW	Gentry heirs	4	85					Windmill, electric motor.	do	None	do	Stock	
Do	12 miles E of S.	Dr. D. J. Gibson.	5	52	40	None.	− 27		Hand	Slight sulphur	do	do	Domestic, stock.	
Do	10 miles NE	J. B. Haggin		165					Windmill.	Sulphur	do	do	Stock	Has several other wells
Do	7½ miles S	do	6	198			− 90		do	Salt; sulphur		do		Very highly mineralized.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Fayette Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Lexington	1½ miles W	J. R. Hughes	6	85				6+	Gasoline engine, windmill.	Hard	None	Lexington	Stock	
Do	5 miles NW	Ed. Kane	4	78			−40		Hand			do	Domestic, stock.	
Do		Lexington Brewery Co.	5	143	142	30, 80			Steam	Hard		do	Manufacturing.	
Do		do	8	150	142	30, 80	−8 to −15	230	do	do		do	do	
Do	1¼ miles E	Lexington Brick Co.	4	180	12	None.	−8 to −30+		do	do	Varies	do	Drinking, manufacturing.	
Do	1¼ miles NE	L. and E. R. R.	8	187	45 or 50	None.	−21	6+	Deep well	do	do	do	Stock, boilers.	
Do	1 block W	Lexington Laundry.	8	175	170	14, 75	−12½	80	Steam	do	None noted.	do	Laundry	
Do	4 miles SE	J. E. Madden	5	60	30			9+	Gasoline engine.	Slight sulphur.	Strong stream.	do	Domestic, stock.	
Do	do	do	5	90				9+	do	Considerable sulphur.		do	do	
Do	do	do	5	125				6+	Windmill	Strong sulphur		do	do	
Do	1½ miles NW	Meadowthorpe Stock Farm.	6	105	95	None.			do	Sulphur	None	do	do	
Do	8 miles S	Z. T. Newman	4	95	70		−65		Hand	Little sulphur	do	do	do	
Do	12 miles SW	James E. Pepper Distilling Co.	6	50, 100, 100, 130	90	15-16, 49	−7	173	Air lift			do	Distillery	
Do	1 mile SE	William Pettit	4	51	51	None.	−11		Hand		Strong flow.	do	Domestic, stock.	
Do	1¼ miles S	do		65			−10		do	Hard		do	do	
Do		W. R. Renfro	4¼	66	60		−40	5	do	White sulphur and lithia.	None	do	Drinking	Mineral water.

Do	1½ miles N	Alfred Ruh	5½	140	140	62	−60		Force, gasoline engine.	Sulphur	do	do	Domestic, stock, irrigation.	
Do	2 miles SW	Mrs. J. W. Sayre.	4	168	168	48	−70		Windmill.			do	Drinking, stock.	
Do	1 mile SW	Albert Shuler	6	85	83	None.			do	Hard; sulphur.	None	do	Domestic, stock.	
Do	2 miles NW	Dr. J. W. Wilson.	4½–4	126	126	None.	−76		Hand	Sulphur		do	do	
Nicholasville	7 miles E	Baptist Church	4	80	78				do	do	None	do	do	
Do	8 miles S	County farm	4	120				4+	do	do		do	Drinking	
Do	7 miles NE	East Hickman Church.	6	150	125	90	−40		do	do		do	Domestic, stock.	
Do	7½ miles SE	Mrs. Keith	4	100+					do	Hard		do	do	
Do	7 miles SE	E. E. Price	4	110	100					Gas		do		Not used.
Do	8 miles SE	Mrs. J. W. Strode	4	100+					Hand	Hard		do	Drinking, stock.	
Walnut Hall		Spring										do		Spring supplies farm.
Fleming County.														
Flemingsburg	1 mile SE	William H. Belt.	6	100			−80		Hand	Hard		Maysville	Drinking, stock.	
Do	¼ mile E	City	6	70								do		Little oil at 65 feet.
Do	½ block N	do	6	125	69	69–73	−30	6	Hand	Hard; slight sulphur.		do	Domestic, stock.	
Do	½ block S	A. H. Evans	6	75	25		−18	20		do	None	do	Drinking, stock.	
Do	⅛ mile E	Henderson & O'Bannon.	6	80	57	None.	−36	15–18	Hand and steam.	Salt, alkaline, iron, sulphur.	Lowers	do	Domestic, manufacturing.	
Do	do	do	6	102	45	Several.	−14	18–20	Steam	do	None	do	Drinking, manufacturing.	Used in ice plant.
Do	2 miles SW	W. J. Hendrix	6	72+	30	18	−40		Hand	Hard	do	do	Domestic.	
Hillsboro	3 miles E	J. W. Gilmore	6	65	60	25	−15		do	do		Panola	Domestic, stock.	Supply easily exhausted.
Do	1 block W	J. H. Shepard	6	140	20					Oil at 100 feet.				Never used, on account of oil.
Muses Mills	2 miles W	W. H. Means	6	1,000	18–20	None.								Very little water.
Poplar Plains	1 mile N	R. F. Deering	6	100+	95					Oil and gas		Maysville(?)	Cooking	Now closed.
Do	400 yards E	E. P. Maggard	6	100	70	10			Hand			Maysville	Stock	Used but little.
Do	do	do	6	120	60	10			do			do	do	Do.
Do		J. W. Patrick	6	100	90+	30, 25	−15		do	Hard	Slight	do	Domestic.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Fleming Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Poplar Plains		Town	6	100								Slight		
Sunset	½ mile W	O. B. Graham	6	71½	35		−3 to −5					do	Stock	Flow caused by gas; stopped in 1 week.
Do	do	do	6	150	120		−3 to −5				Fluctuates	do		
Do	do	do	6	196	40		−3 to −5			Salt; some sulphur.		do	Stock, cooking.	
Tilton (?)		Town	6	80	60	None.	−1½		(?)	Hard; little salt.	Easily drawn dry.			Well never used
Franklin County.														
Forks of Elkhorn	200 yards N	Albert Hockensmith.	5	70	60+	Small seeps.			Hand	Only strong sulphur when well pumped out.	Empties in 2 hours, but fills in 24.	Lexington	Domestic, stock.	
Frankfort	¾ mile SE	W. A. Gaines & Co.	6–10	70	52	None.	−30	400	Deep well.	Hard		Highbridge	Manufacturing.	
Do	2 miles W	S. C. Herbst	8–6	300	None.	None.		None.						No water.
Do	4 miles SE	S. French Hogue.	5	80						Hard		Lexington	Stock	
Do	1 mile N	James A. Murray	6	1,300	900	None.	+80			Sulphur		St. Peter	Domestic, stock.	
Do	3½ N	E. B. Weitzel		90						Hard		Lexington	Stock	
Do	4 blocks E	do	6	200	100	150 (?)	−40					Highbridge		Supply too small for use.
Grafenburg	½ mile E	Elias Herndon	6	50	45				Hand	Hard	Varies		Drinking, cooking.	
Jett	½ mile W	T. K. Jett	6	65	65		−45		Windmill.	Very strong sulphur.	None	Lexington	Domestic, stock.	Can not pump dry.
Do	do	do	5½	72	72		−58		do	do		do	do	Not used.
Do	½ mile S	W. B. Jones	6	50	16+	None.	−5	All necessary.	Hand	Rather soft		do	Domestic, stock.	

Do	300 yards N	L. A. Owen		85						Hard	Pumped dry in 15 minutes.	do		Do.
Do	50 feet W	Lee A. Owen	5	107	107	50+	− 50		Windmill	Strong sulphur at first, none now.		do	Domestic.	
Do	150 feet E	W. B. Quin	6-5	54	30	52	− 20		Hand	Hard	Lowered some.	do	Domestic, stock.	
Do	1 block NE	J. R. Shaw	4½	54	50	None.	− 14		Gasoline engine.	Trace of sulphur at first, slight now.	None	do	Domestic, stock.	
Do	½ mile S	do	6	60	55		− 40		Windmill	Hard		do	Domestic, stock.	
Gallatin County.														
Brashear	1½ miles S	J. S. Peyton	2	100	100	65	− 20		Windmill	Soft (?)			do	
Gex	1 block S	Thomas Mylor	3	96	50				Hand	Hard		Alluvium	do	
Ghent	2 blocks NW	Parker & Deane	2	80					Steam	do	None	do	Stock	
Sanders	4 miles W	G. Cox	8¼	352						Salt water and gas.				
Do	do	Mrs. William Roswell.	8¼	550	15					Hard				
Do	250 yards S	Sanders Oil and Gas Co.	8	741	741		+ 75	−1		Sulphur; salt				
Warsaw	¾ mile E	Arch Bell		125	100±		−100	5	Hand	Hard	None	Alluvium	Domestic, stock.	
Do	1 mile S	Samuel Bledsoe		90±					Windmill	do		do	Stock	
Do	2 blocks W	City of Warsaw	2, 3	60	50		− 50	8	Hand	do	None	do	Domestic, stock.	
Do	Within 3 or 4 blocks.	do	3	90-100	85±		−85 to −90	8	do	do	do	do	do	
Do	3 miles S	Ashton Craig		103	45			−45	do	do		do	Stock	
Do	6 miles S	G. A. Ghex	3	90+	60		− 60		Windmill	do		do	do	Unlimited supply. Hardness low.
Do	2 blocks N	Warsaw Furniture Co.	4	90	80		− 30±	30	Steam	do	None	do	Boilers	
Garrard County.														
Bryantsville	¼ mile S	C. M. Jenkins	4	60	45	18	− 4	2	Windmill	do		Lexington	Stock	
Hyattsville	1 mile E	James N. Denny	4	104	104			Small seep.				Maysville		Not used.
Marcellus	3 miles W	I. M. Dunn	4	54	40	None.	− 40	5	Windmill	White sulphur		Lexington	Domestic, stock.	
Do	½ mile E	A. B. Montgomery.	6	60	35		− 6		Hand		None	do	do	
Do	A few rods SW.	C. K. Poindexter	4	129	100±				do	Hard and iron.	Easily pumped dry.	do	do	
Point Leavell	20 rods SE	O. T. Wallace	4	70	25	None.			do	Sulphur	None	Winchester	Stock	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Harrison County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls*						
Berry	1 block W	Berry	6	130	120	None.	−24	2	Hand		None	Lexington	Domestic, stock.	
Do	1 block S	J. W. Haley	6	85	78	None.	−40	30	do		Lowered when pumped.	do	do	
Boyd	2 blocks SE	J. S. Baskett	6	100	90		−60			Hard; gas with water.	None	do		
Do	½ mile W	J. H. Knox	4	70	60	None.	−40		Hand	Hard	Low in dry weather.	do	Stock	
Claysville	3½ miles SW	George B. Duckworth.	6	117	100+		− 0		do	Hard; some sulphur.		do		Never used.
Do	¼ mile NW	Foster McDowell	6	131	65		−25	2	do	Hard; sulphur.	None	do	Domestic, stock.	
Colville	¾ mile S. of E.	L. W. Diltz	6	90	75–80	20	−10		Force	Hard; sulphur and oil.	do	do	Drinking, stock.	
Cynthiana	1½ miles N	A. Keller Distillery.	6	160			−14		Hand	Hard; sulphur.		do		
Do	¾ mile N	F. S. Ashbrook Distilleries Co.	8	280	90–100		−15		Steam	Hard; slight sulphur.	None	do	Manufacturing.	
Do	3 blocks SE	W. M. Cox	6	50	45	None.	−30		Gasoline engine.			do	Domestic, stock.	
Do	2 blocks S	J. W. Daniel	6	90			−30		Hand	Hard; some sulphur.	None	do	Boilers, manufacturing.	The amount of sulphur increases in dry weather.
Do	4½ miles NW	S. O. Ecker	6	119	119	30–40	−59	4	do	Hard; slight sulphur.		do	Domestic, stock.	
Do	4½ miles S	Edgewater Distillery.	6	168	140–150		+ 8			Sulphur water at 100 feet; less at 168 feet.		do	do	
Do	4 miles W	John K. Gray	6	120	No water.							do		No water.

Do	4 miles SE	M. S. McKee	6	150	100	20	−10		Hand	Hard; sulphur; tastes of oil.	Slight	do	Drinking, stock.	Tastes of oil.
Do	3½ miles E	M. J. Rankin	6	90	80	None.				Sulphur water; gas.		do		Not used.
Do	3 miles SE	Wohlender Bros.	6	74+	68	None.	−35	8+	Hand	Slight sulphur.	None	do	Drinking	
Hooktown	1¼ miles NW	Wm. Florence	6	88	25		−30		Force	Gas; salt	Lowers	do	Domestic	
Jacksonville	200 yards E	J. Rose	6	98	81	16	−48		Hand	Strong sulphur water.	Slight	do	Drinking, stock.	
Lair	Across river E.	Edgewater Distillery.	6	150	125				Steam	Sulphur	None	do	Manufacturing.	Distillery abandoned.
Do	do	do	6	175	125				do	do	do	do	Drinking, manufacturing.	Do.
Do	do	Old Lewis Hunter Distillery	6	110	90	None.	−50		do	Some sulphur	do	do	Manufacturing.	
Leesburg	1½ miles SE	R. J. Lucas	6	68		10, 20, 60	−12		Hand	Hard	In dry weather gets below −50 feet.	do	Domestic	
Paris	8 miles NW	J. Crombie	6	70	68		−48		do	Sulphur	None	do	Stock	
Henry County.														
Eminence	⅛ mile SE	Charles S. Knight	6	68					do	Hard		Maysville	Domestic	
Jessamine County.														
Brannon	2 miles NW	William Sale		60				½	Force	Iron		Lexington	do	
Camp Nelson	200 yards +N.	Kentucky Distilleries and Warehouse Co.	8	100					Steam	Hard	Lowered 7 or 8 feet.	do	Manufacturing.	
Do	8½ miles south of Nicholasville.	do	6, 8	196			−20	100	Air lift	Mild black sulphur water.		Below Highbridge.	do	
Hano	1¼ miles S.	H. B. Sand	6	74	70	None.	−34		Hand	Hard	None		Stock	
Keene	3 miles E	J. J. Gormley	6–4½	152	115	50	−50		Deep well and windmill.	Slightly sulphur.		Lexington	Drinking, stock.	
Do	2½ miles NE	R. R. Henderson.	4	100	99	None.	−57	0	Hand	Strong sulphur water; salt.		do	Domestic, stock.	
Do	2 miles N	Wharton Brothers.	4	80			−55		Hand	Sulphur		do	do	
Nicholasville	4 miles SE	City	4	85	85	None.	− 6		Wooden suction.	do	None	do	do	
Do	3¾ miles SE	J. W. Cobb and Steven Snowden.	5½–4	80	80	18	− 5	6	Hand suction.	do	do	do	do	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Jessamine Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Nicholasville	$8\frac{1}{2}$ miles NW	R. R. Henderson.	5-4	100	99	None.	−57		Hand	Sulphur; soft		Lexington	Domestic, stock.	
Do	100 feet N	Jessamine County.	5-3	110	100	60-80	−20	10	Deep well.	Hard	None	do	do	
Do	50 yards S	do	4	120	120		−20			do		do	do	
Do	1,400 feet N	C. A. Kenney	6	77	62		−22	25	Steam	Fairly hard	None	do	Domestic, stock, boilers.	
Do	3 blocks N	do	6	75	62	50	−20	27	do	Hard	do	do	Domestic, boilers, manufacturing.	
Do	do	C. A. Kenney Laundry.	8	75	62	50	−20	14	do	do	do	do	do	
Do	50 feet S. of C. A. Kenney's.	Nicholasville Ice Co.	8	71	62	None.						do	Ice plant	
Do	$2\frac{1}{2}$ miles W	Nicholasville Water Co.	8	130	65		− 3	200	Air lift	Hard		do	Domestic, stock, boilers, manufacturing, irrigation.	
Do	do	do	8	135	65		− 6	200	do	do		do	do	
Do		W. D. Sharp		75						Salt, iron, sulphur.		Highbridge.	Drinking	
Wilmore	10 rods S	City	4±	100					Hand	Hard		do	Domestic, stock.	Supply small.
Do	$2\frac{1}{2}$ miles NE	Stephen Grow	4	140					Windmill.	Sulphur		do	Domestic, stock.	
Do	$\frac{1}{8}$ mile SE		4	62		None.	−15		Hand	Hard		do	do	

Kenton County.														
Bromley	2 blocks SW	G. H. Hackladt	6	90	60			1	do	Hard; some sulphur.	None	Alluvium	do	
Do		C. Lagee	6	70	18			1	do	do	do	do	Drinking, stock.	
Do		William Shafer	6	71	60			1	do	do	do	do	do	
Do		Webber	3	80			−30				do	do	Domestic, stock.	
Covington		Bavarian Brewing Co.	6, 8	69–73	62		−60	50	Cook, McGowan, Laidlaw-Dunne.	Hard; some sulphur.	Lowers	do	Manufacturing.	
Do	3 blocks S	John Brenner Brewing Co.	8	80	60		−50	100	Steam	Hard; slight sulphur.		do	do	
Do	2 blocks NW	Cincinnati Ice Co.	8	200	65		−40	250	Air lift	do		do	do	
Do	S	Consumers' Ice Manufacturing and Cold Storage Co.	4–8	110	80		−75	182	Dunne-Gordon.	do	None	do	Drinking, manufacturing.	
Do	Central avenue and Dayton street.	John Hancks Brewing Co.	8	140–165			−60	80+		Hard	do	do	Manufacturing.	Several wells.
Do		New England Distilling Co.	8	110			−20		Laidlaw-Dunne-Gordon.	Hard; some sulphur.	do	do	Manufacturing, irrigation.	
Latonia	½ mile E	Latonia Distillery.	4	1,100	1,000					Strong sulphur.	do	St. Peter	Drinking, manufacturing.	
Do		Latonia Ice Co	8, 6	105	90+	Beds of sand.	−25		Steam	Hard	do	Alluvium	Manufacturing.	Uses 2 wells for cooling.
Do	1 mile S	George Smith		275										No water.
Madison County.														
Paint Lick	500 yards NE	R. N. Beasley	6	51	51	None.	− 5			Salt alkaline		Lexington		Too salt to use.
Richmond		Cooperage plant		300	40	do				Hard		Maysville		Small supply.
Mason County.														
Dover	In village	Dover City	3	70–85					Hand	do		Alluvium	Domestic, stock.	
Do	1 mile N	Fred Kelch	2	60					do			do	do	
Do	¼ mile S	Henry Schubert	6	157	65		−20		do	Iron		do	Domestic, stock.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Mason Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Dover	1¼ miles SE.	Wilson Smith	1½	70	55		−55	6	Hand	Moderately hard.	Unaffected when pumped 5 gallons per minute.	Alluvium	Domestic, stock.	
Do	6 blocks S.	J. J. Thomas	2	80	60		−60	10	do	Hard	Unaffected when pumped 10 gallons per minute.	do	do	
Do	1 block SE.	W. H. Thomas	2	76	65		−55–60	10	do	do	do	do	Domestic, boilers, stock.	
Fernleaf	3 miles E.	E. C. Slack	6	98	95+	None.	−27	Few.	Hand, windmill.	do	Slight	Maysville	Domestic, stock.	Slight odor of petroleum.
Maysville	Same block	R. A. Carr	7–8	108					Steam	do		Alluvium	Boilers, manufacturing.	
Do	1 mile E.	Pearce Foster	8	91, 92	40	16 to bottom.	−40	20	do	do	Unaffected when pumped 20 gallons per minute.	do	do	2 wells.
Do	4 miles N.	Elisha Moran	6	70	70	35	−35		Force	do		do	Drinking, stock.	
Do	3 blocks E.	William Sprombурge.	3	75				30	Steam	do	None	do	Drinking, washing.	
South Ripley	Across railroad W.	Chesapeake & Ohio Ry.	2(?)	80	65		−65		Hand	Hard; brackish.		do	Drinking	
Tuckahoe	1 mile W. of S.	John E. Bouldin	6	315	315	20	− 3			Soft				Not used.

Mercer County.														
Burgin	1 block SW	Gillam & Tully	5½	60	50				Force	Hard	None	Lexington	Manufacturing.	
Do	do	J. W. Giliam	5½	90	80±				Steam	do		do	Drinking, boilers.	
Do	½ mile	Public	8	40–100			−20 to −80		Force	do		do	Domestic, manufacturing, stock.	
Harrodsburg	2 miles E	Brown & True	5		90	90	−20		Windmill	Hard; black sulphur.	None	do	Drinking, stock.	
Do	do	William Brown	5	90	90	None.	−20		do	Hard; strong sulphur.	do	do	do	
Do	2 miles N	George Chinn	6	85	75				Hand	White sulphur water.		do	Domestic, stock.	
Do	3½ miles E	Scott Covert	5	103			−63		do	Hard	None	do	do	
Do	4 miles S	Judge John Hughes.		97			−10			White sulphur water.		do	Stock	Inexhaustible.
Do	3½ miles S	do		101	101		− 2	50±		do		do	do	
Do	½ mile NW	Ice factory	3¾	55	Near bottom.	10		80	Steam	Hard	Lowers	do	Boilers, manufacturing.	
Do	1¼ miles SW	Minor L. Ransdell.	5	85	40±	None.	−40		Hand	do	None	do	Drinking, stock.	
Do	½ mile NW	John B. Thompson's Distillery.	6, 4	35 or 40			−15 to −20	100+	Steam	do	Varies	do	Manufacturing.	
Kirkwood	1 mile SE	California-Kentucky Oil Co.	8¼–6¼	1,400	15		−35		do	Mineral	None			Not used.
Nevada		Schoolhouse		85	80				Hand	Hard; sulphur		do	Drinking	
Salvisa	⅛ mile S	G. H. Fallis	6½–6	90	60	None.	−60			Salt and sulphur.		do		Do.
Do	At	F. I. James	6	68	65	None.	−62		Hand	Hard		do	Domestic, stock.	
Do	1/32 mile SE	do	6	72	72	None.			Force	do		do	do	
Do	1 mile N	D. E. Nichols		110					Hand	do		do	Stock	
Do	500 yards NW	H. J. Trimble	4	65					Suction	Salt and iron		do	Domestic, stock.	
Do	¼ mile N	K. S. Wood	5, 7	86, 52	48				Hand, windmill.	Hard	None	do	do	
Nicholas Co'y.														
Carlisle	SE	Carlisle Milling Co.	6	155	150			3	Steam		do	do	Domestic, stock.	Not used except in dry weather.
Do	1,500 feet SE	City	6	135	40 or 50				Force	Hard		Winchester	do	

TABLE 8.—*Wells in the Blue Gress region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Oldham County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Beards	1 block W	Public well	6	50	40	50	− 12	½ to 1	Hand	Hard	None	Panola	Domestic, stock.	
Do	½ block N	M. A. Stoess	6	50	20	None.			do	do	do	do	do	
La Grange	¼ mile S	J. W. Barrickman.		1,200	1,200					Sulphur			Drinking	
Do	4 blocks E	Stock Company	6	1,000	Dry hole.									
Do	3 blocks E	do	6	1,500	1,200	1,100	− 25							
Pewee Valley		Mrs. L. T. Cleland.	6	65	45	None.			Hand	Hard		Panola	Domestic	
Do	1 block W	Foley Bros	6	60	25	40+				do		do	do	
Do	200 yards NE	Kentucky Confederate Veterans' Home.	6	200	−23	None.	− 23		Hand	do	Lowers	do	do	
Pendleton Co'y.														
		J. M. Booher	6	90	85	21			Force	Salt		Lexington	Stock	
Boston Station	½ mile S	Mollie A. Edwards.	8-6	1,600	800	None.				Iron and sulphur.		St. Peter	Drinking, stock.	
Robertson Co'y.														
Mount Olivet	2½ miles S	D. R. Wells	5	54			− 30		Force	Hard		Winchester	Drinking, stock.	
Do		John W. Zoller	6	103	80	36, 59, 80	− 24		Hand	do			Drinking	
Piqua	200 yards SE	W. J. Curtis	4	68	30	None.	− 27	7	do	Hard; some sulphur.	None	Winchester	Domestic	
Scott County.														
Donerail	1¼ miles W	Sidney S. Moore	4	127			− 80		Force	Mild sulphur	None	Lexington	Domestic, stock.	
Georgetown		Judge Askew	5	70	70				Hand	Hard		do	do	Large supply.
Do	1 mile N	do	4	127	127		− 37		Windmill		None	do	do	
Do	1 mile NE	John H. De Garis.	8-6	700			− 12			Sulphur				Not used.
Do		Warren Dennis	6	90+	85	28	− 45		Gasoline engine.	Hard	None	Lexington	Domestic, stock.	
Do	1 mile S	Georgetown Cemetery.		92					do	Hard; some sulphur.		do	Stock, irrigation.	

Do.	6½ to 9 miles N.	Buford Hall	3	59.57			− 40±		do	Hard; sulphur.		Winchester (?).	Stock	
Do.	do	do	3	160 70 50+			− 40±		do	do		do	do	
Do.	4 miles NW	Norman Hambrick.	8	100	93	None.	− 65		Hand	do	Large supply.	Lexington	Domestic, stock.	
Do.	4 miles N	Uriah Hambrick	4½	98		None.	− 18		do	Sulphur	None	do	do	
Do.	1 mile N	Nuns of Visitation.	12	107	107		− 20	60		Slight sulphur.		do	Domestic	
Do.	1 mile S	R. B. Thomas	4	141	137	None.	− 55	6	Windmill	Hard	None	do	Stock	
Do.	1 mile SW	do	4	141	141	None.	− 85		do			do	Drinking, stock.	
Newtown	2 miles W. of S.	H. S. Booker	5	65			− 12	2	do	Hard, sulphur.		do	Domestic, stock.	
Do.	2½ miles E	Elbert Hall	6	180	180	None.			Hand	Soft		do	do	
Do.	1½ miles W	Reuben Offutt	6	112	100	None.			do	Sulphur		do	Stock	
Do.	100 yards E	Public well	7	70	65	None.	− 30		do	do		do	Domestic, stock.	
Do.	100 yards W	George D. Sallee	6	50	35	None.	− 30		do	Hard	None	do	Domestic, stock, boilers.	
Do.	do	do	6	70	60	None.	− 40		do	do	do	do	Domestic, stock.	
Do.	75 yards E	H. D. Williams	6	57	50	40	− 30		do	Sulphur	do	do	do	
Paynes Depot	3 miles NE	J. C. Cantrell	4	133	120			60		Hard		do	do	
Sadieville	30 yards SW	Town	6	188			−112	3+	Hand	Hard, iron, sulphur.		Winchester	do	
Stamping Ground.	5½ miles NE	D. S. Alsop	4	106	100	15	− 26		do	Salt and sulphur.		Lexington	Drinking, stock.	
Do.	4 miles NW	J. O. Fluke	5	110						Hard, strong sulphur.		do		
Do.	2 miles NW	Joseph Foree	5	70	60	None.	− 53		do	Hard, sulphur	Large supply.	do	Domestic, stock.	
Do.	2 miles NE	John T. Noel	6	60	52	None.	− 18		do	Strong sulphur.		Winchester (?).	do	
Do.	1½ miles NW	do	5	60	52	None.	− 18	6	do	do	None	Winchester	do	
Do.	2½ miles NW	Dr. R. S. Payne	5	70	65	None.			do	Hard		Lexington	do	
Do.	Opposite center.	George D. Sallee	6	60	55	None.	− 25			do	Slight	do	Drinking	
Do.	¼ mile E	do	6	85	80	None.	− 25		Hand	do		do	Domestic	
Shelby County.														
Shelbyville	1¾ miles W	John A. Middleton.	4½	155	90	None.			do	do		Maysville	Drinking	Well dynamited, but no increase in supply.
Do.	2 blocks SW	Shelbyville Steam Laundry.	5	60	15	None.		1+		do	Varies	do	Washing, manufacturing.	
Simpsonville	2 miles W	Claude Buckley	5½	225		None.	− 25					do		Not used.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Trimble County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Cottage Hill	1 mile E	Z. T. Bore	6	81	50	50	− 15		Hand	Hard			Drinking, stock.	
Milton	$\frac{1}{3}$ mile S	Willis Barth	6	96+	44		− 12		do	do		Richmond	Domestic, stock.	
Do	$\frac{1}{2}$ block N	City	3	80+	35		− 35		do	do		Alluvium	Domestic	
Do	3 miles E	Dr. S. E. Hampton.	4	86	66		− 66±	5	Windmill	do	None	do	Drinking, stock.	
Do	3 blocks NE	A. W. Lane	3	80+	40		− 20	5	do	do	do	do	Domestic, irrigation.	
Do	2 blocks E	J. W. Lane	3	80					do	Moderately hard.		Richmond.	Domestic, manufacturing, stock.	
Do	$3\frac{1}{2}$ miles W	H. N. McIntire	6	96	40	None.	− 40	4	Deep well	do		do	Domestic, stock.	
Do	4 miles S	R. M. Overton	6–5	80	60		− 20		Suction	do		do	do	
Do		Richwood Distillery, H. M. Levy.	5, 6, 8	96±	65		−60 to −65		Steam	do		do	Boilers, manufacturing.	
Do	$2\frac{1}{2}$ miles E	Charles Schurmeier.	6	56	49		−. 26		Hand	Hard; slight sulphur and salt.	Lowered slightly.	do	Stock	
Do	$\frac{1}{2}$ block N	Trimble Milling Co.	4	80					Steam	Hard	None	do	Boilers	
Wodford County.														
Frankfort	5 miles S	W. A. Gaines & Co.	6	779						Hard; salt, sulphur.	do	Highbridge	Drinking, stock	
Jett	$2\frac{1}{2}$ miles S	Pat O'Brien	6	60	20	40	−30 to −40		Windmill and gasoline engine.	Hard		Lexington	Domestic, stock.	

Do.	1 mile S.	Mrs. V. Thompson.	5	60	60		— 30		Hand	do.		do.	Domestic.	Lowered in dry weather.
Do.	do.	do.	5	89	89		— 50		do.	do.		do.	Stock	Never dry.
Midway	2 blocks SE	Belle of Anderson.	6	96	96		— 20	20	Steam	Hard; some sulphur.			Manufacturing.	
Do.	4 blocks W.	City	4	90	70				Force	Hard	None	Lexington	Domestic.	
Do.	Across street, Main street.	do.	4	95					Hand	Some sulphur.		do.	do.	
Do.	5 blocks W.	do.	4	100								do.	Domestic, stock.	
Do.	2¼ miles S.	Frank H. Hawkins.		110						Salt		do.	Stock	
Do.	3 blocks SW	D. Lehman	4	102						Hard		do.	Domestic, stock.	
Do.	3½ blocks W.	R. J. McMullen		95						Sulphur		do.	Stock	
Do.	2¼ miles S.	Nugent Bros	6	118	118		— 58		Hand	Hard; sulphur.		do.	Drinking	Sold for medicinal purposes.
Millville	2 miles N.	E. B. Cutt	5	59			Varies,			Hard		do.	do.	
Mortonsville	¾ mile N.	J. G. Boone	6	50+	48	None.	— 30	18	Hand	do.	Unaffected when pumped 18 gallons per minute.	Highbridge	Domestic, stock.	
Do.	At north	Ed. Boston	6	51	49	None.	— 33	20+	do.	do.	Unaffected when pumped 20 gallons per minute.	do.	do.	
Do.	½ mile W.	Marion Johnson.	5	53	50	13	— 38		Force	Sulphur	None	do.	Domestic, stock.	
Do.	do.	E. S. Sillard	6	115	75	40	— 35			Hard		do.		Gas at 50 feet; never used.
Do.	50 yards E.	Dr. S. C. Sublett.	5 or 6	75					Hand	Sulphur		do.	Drinking	
Do.	A few rods east.	Dr. S. Q. Sublett	6	68	68				do.	Hard		do.	Drinking, stock.	
Nonesuch	300 yards S.	J. R. Bond	4	65	45		— 45		Bucket	do.		do.	Domestic, stock.	
Pinckard	½ mile N.	W. Sippert	5	85	80	30+	— 37		Hand	Hard; sulphur.	None	Lexington	do.	
Spring Station.	3 miles SE.	A. J. A. Alexander.		86	86	None.	— 86		Windmill.	Hard		do.		Not used.
Do.		do.	4-3	95	95				Deep well, windmill, and gasoline engine.	do.		do.	Drinking, stock.	Do.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Woodford Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Spring Station.	2 miles SE	A. J. A. Alexander.		140	140	None.	−110			Strong white sulphur.		Lexington		Not used.
Do	3½ miles W	Thomas W. Hackney.	5	200	200	100	−100		Elevator	Salt, sulphur		do	Medicinal.	
Versailles	1 mile NW	Charles Alexander.	5	90+	90+				Windmill.	Hard, sulphur.	Weak stream.	do	Domestic, stock, irrigation.	
Do	½ mile E	J. C. S. Blackburn.	5	124					Gasoline engine.	Sulphur	None	do	Washing, stock.	The water contained both salt and sulphur. The sulphur has gradually disappeared.
Do	800 feet N	J. Andrew Cain.	4¼	134	132	65	− 70	20	Steam	Lime, magnesia, and zinc, alkaline.	do	do	Drinking, stock.	
Do	2 miles N	J. N. Camden, jr.	5	190	170	60	− 70		Windmill.	Hard		do	Domestic, stock.	
Do	do	do	5	200	175	60, 100			do	Hard, sulphur.		do	do	
Do	100 feet W	City	6	90								do		
Do		Fair grounds		104	102	32			Hand	Hard		do	Drinking, stock.	
Do	4 miles N	Jesse Graddy	2½–6	62	10	30	− 32		Force	Limestone	Lowered some.	do	Domestic, stock.	
Do	½ mile NW	A. T. McLeod	5	149+		30		18	Gasoline engine.	Hard	None	do	Domestic.	
Do	½ mile S	Joe S. Minary	5	163	160		− 80		Hand	Hard; slight sulphur.	do		Stock	
Do	½ mile SE	H. P. Morancy		130	130	None.	−130		Force	Hard		Lexington	Domestic, stock.	Medicinal.

Do	½ mile NW	G. B. Mosely	5	101	96	26	— 50	15	Force and gasoline engine.	do	None	do	do
Do	4 miles SE	J. W. Newman	6	134	120				Hand	do		do	Domestic.
Do	¼ mile N	C. L. Ryley	5	180	170	75		70+	Gasoline			do	do
Do	150 yards W	Shotwell Bros	5	75	40	26	— 26	85+	Steam	Hard	None	do	Domestic, stock, boilers, manufacturing.
Do	¼ mile S	H. C. Taylor	5	128	120	40	— 40		Gasoline engine.	Sulphur water		do	Domestic, stock.
Do	2 blocks S	Thompson-Childers-Minary Co.	5	93	50	20	— 40		do				do
Do	½ mile NW	I. W. Wilson	5½	98	92	30			Suction	Hard	None	Lexington	do

QUALITY OF THE UNDERGROUND WATERS IN THE BLUE GRASS REGION.

By Chase Palmer.

INTRODUCTION.

In the summer of 1903 the writer undertook an investigation of the quality of the waters of Kentucky River in cooperation with the United States Geological Survey. The tests were continued for one year, during which period a similar study was made of the headwaters of Dix, Green, and Salt rivers, which rise in the upland near the southern limits of the Blue Grass region. A few results of this early study of Kentucky and Dix rivers are presented in this report to illustrate the hardness of two important surface streams of the Blue Grass region in comparison with that of the underground waters.

In the spring of 1905, under a similar arrangement, field assays of waters from wells and springs were made in several Blue Grass counties, and the results of that work are also embodied in this report.

In July, 1906, a more extended investigation of the underground waters of the Blue Grass region was begun, jointly with George C. Matson, of the Geological Survey. The subsurface waters from a much larger area were subjected to complete chemical analysis at Lexington, Ky., and the results of the examinations are recorded in the table of analyses on page 212.

ACKNOWLEDGMENTS.

Thanks are due to Dr. M. A. Scovell, director of the Kentucky Agricultural Experiment Station at Lexington, for affording the facilities of the chemical laboratory of the station, so that the analytical work could be carried on expeditiously within the State. It is also desired to express to Dr. A. M. Peter, chemist of the experiment station, appreciation for his uniform courtesy and hospitality while the chemical work of this investigation was in progress. The publications of the Kentucky Geological Survey and of Kentucky Agricultural Experiment Station have been consulted and use has been made of the information contained therein and originally obtained by Dr. Robert Peter and Dr. A. M. Peter, chemists of those two state institutions, respectively.

INDUSTRIAL USES OF WATER.

IMPORTANCE OF QUALITY.

The quantity of water used in modern human industry is so vast, its applications are so varied, and its essential characteristics are so distinctive that water may be considered the most important mineral used in the industrial arts. Immense quantities of water are necessary for many manufacturing operations. Every pound of writing paper made, for instance, has required the use of no less than 40 pounds of water, and in some paper mills as much as 1,600 pounds. In selecting a location for a paper mill, therefore, it is important to see that a liberal supply of water is assured.

The quality of the water best suited for use in any particular industry is also a matter of considerable moment. An iron-bearing water can not be used in a bleachery without previous purification. A calcic carbonate water is undesirable in leather making, as it causes brown stains on the hides and may also produce a reddish leather which has a low market value. The manufacture of tanning and dyewood extracts is another important industry involving the use of enormous quantities of water. These extracts, being easily fermentable, do not keep well if made with polluted water, or water containing putrefactive bacteria.

In the arid regions of the West the scarcity of water makes it a high-priced commodity which is valued accordingly; in the East, where a plentiful supply of water may usually be obtained, little attention was formerly given to its quality, on which its real value so largely depends. Eastern manufacturers have, however, begun to realize that water used in the manufacture of products for which its quality is unsuited is expensive. Its cost may not appear in the price paid for it, but is apparent rather in the smaller yield of the products which it has helped to make, or in the low prices which they command when put upon the market. The benefits derived from the use of water which is naturally suited for a specific purpose or which has been properly treated to meet the requirements of a special operation are quickly realized in the increased quantity and value of the products obtained.

STEAM MAKING.

The engine which turns into mechanical work the energy possessed by steam has given to water a new industrial value, and the rapid advance of modern civilization is due largely to the use of water as a motive power in the form of steam. Steam making may be regarded as an industry in which the raw material is water and the finished product is steam. The quality of the water used in the boiler is of interest to the engineer because upon it the profitable production of steam in large measure depends. The life of the boiler also is in no small degree determined by the care taken to supply it with proper feed water. With a noncorrosive water which does not form hard scale a stationary boiler may last thirty to thirty-five years, but a corrosive water may make it useless in five years. Prevention of corrosion means protection of the boiler; prevention of scale means saving of labor, repairs, and fuel.

CORROSION AND SCALE.

The use of impure water in a steam boiler results usually in corrosion and the deposition of scale. Many waters, especially spring waters, that are comparatively free from mineral matter in solution are known to be strongly corrosive when used in steam boilers. Free acids, such as hydrochloric, sulphuric, and nitric, are very corrosive, attacking iron easily, and waters containing them must therefore be neutralized before they can safely be used for steam making. Water showing no sign of acidity before it enters the boiler sometimes develops corrosive properties when it is heated. Water containing magnesium chloride in solution, for instance, may be neutral under ordinary conditions, but at high temperatures and under increased pressure of the boiler hydrolysis occurs, forming free hydrochloric acid, which vigorously attacks the boiler shell and tubes. The magnesium oxide also formed in this action finds its way to the boiler shell where it may add itself to any scale there forming.

Scale is an incrustation deposited within the boiler during the evaporation of hard waters. The scale from calcic carbonate waters is loose and can be removed by blowing off. Calcic sulphate waters, on the other hand, form a hard tenaceous scale, the removal of which is sometimes very difficult. Hard scale conducts heat poorly, so that a hotter fire is necessary to keep up steam in a boiler thus coated. A waste of 15 to 20 per cent of fuel has been known to be caused by hard scale only 7 to 8 millimeters thick. Boilers thus overheated are liable to blister and to crack, and many serious explosions have resulted from overheating scale-lined boilers.

SALUTARY EFFECT OF SCALE.

Though a thick, hard scale is detrimental to a boiler, a thin coating of scale is often distinctly advantageous. This is especially noticeable where corrosive waters are used for making steam. Kent[a] calls attention to the fact that rain water, and even melted snow, cause pitting of the plates and more or less general corrosion. As a protection against the ravages of waters of this kind he recommends the occasional addition of a little limewater, so that a thin coating of scale may be formed. In certain parts of the United States, especially

[a] Kent, William, Corrosion produced by rain water in steam boilers: Eng. News, vol. 52, 1904, p. 198.

in the West, the waters available for use in locomotives are not only hard but are also high in sulphates of the alkali metals. The usual practice has been to soften such waters before use by precipitating the calcium and magnesium with soda ash, and the formation of scale is prevented by this treatment, but at the same time an equivalent amount of alkaline sulphates is added to the water. Excessive quantities of alkalies in water cause foaming, and on western railroads waters softened in the manner just mentioned have made much trouble. The harder a water is before it is softened by soda ash, the larger is the quantity of alkali sulphates in the water after treatment, and consequently the greater is its tendency to foam in the boiler. M. E. Wells[a], chief boiler inspector of the Burlington and Missouri River Railroad, deprecates the practice in vogue on several railroads of softening such waters for locomotive use by adding soda ash. He quotes the following figures to show the increase in alkalies caused by treating with sodium carbonate a water used by the Chicago and Northwestern Railway from a well 70 feet deep at Council Bluffs, Iowa:

Result of treating water with sodium carbonate.

	Parts per million.
Incrustants:	
Before treatment	813
After treatment	66
Nonincrustants, mostly alkalies:	
Before treatment	106
After treatment	472

Here a hard incrusting water is changed to a foaming water. Wells states that on the Burlington and Missouri River Railroad better results are obtained with incrusting than with foaming waters. He also recommends the use of limewater as a substitute for caustic soda to remove calcium and magnesium from alkaline carbonate waters, because limewater causes no addition of alkali to the water. According to Wells, a moderate amount of scale serves to protect boilers, and this impression seems to be gaining ground among engineers who are compelled to use hard, alkali sulphate waters for steaming.

The sulphate water used in the boilers of the Hoffmann distillery, in Anderson County (see Table 14, p. 201) would probably form hard scale if precautionary measures were not taken. The boilers are cleaned frequently, care being taken to let them cool before washing them, and the scale is easily detached. The scale is not allowed to become thick or to bake into a hard, difficultly removable crust. The water from this well was used continuously during two long runs aggregating thirty-five months, and affords an excellent illustration

[a] Wells, M. E., Foaming waters and scaling waters for locomotive boilers: Eng. News, vol. 52, 1904, p. 198.

of the favorable results that may be obtained from a hard water if intelligent care is exercised in its use.

ACTION ON BOILERS OF ORDINARY CONSTITUENTS OF WATER.

Silica and iron are both found in boiler scale and may be regarded as incrustants. Silica, however, causes very little trouble, as it is present in water in very small quantities, and the same may be said of iron, although iron derived from corrosion of the boiler is sometimes added to the scale. Aluminum also is an incrustant present in most waters in quantities so small that it is not necessary to consider it; but when too much aluminum sulphate, a substance frequently used as a coagulant in filtering water, is added in the process of filtering, the excess passes through the filter and may cause trouble in the boiler, where it hydrolyzes, forming free sulphuric acid. Sodium carbonate will correct the acidity due to an excess of aluminum sulphate, and it can be used to precipitate the aluminum as a harmless solid. Barium carbonate is a better remedy, but it is too expensive for general use. Owing to the poisonous quality of barium compounds, their use should probably be restricted to waters intended only for industrial purposes.

Calcium is the chief constituent of both hard and soft scale, but a water containing as much as 50 parts per million of calcium may be used under certain conditions without bad results. Carbonate waters containing as much as 150 parts of calcium per million might profitably be softened, but carbonate waters with that amount of calcium are usually also high in sulphates and chlorides, and it is doubtful whether such waters can be successfully treated for boiler use.

Magnesium is an incrustant appearing in boiler scale as magnesium oxide, hydroxide, and carbonate. This metal accompanies calcium in waters, but the calcium usually predominates. Magnesium can be economically removed from magnesic carbonate waters containing less than 60 parts per million of magnesium. Magnesic chloride and sulphate waters are highly corrosive because they are easily hydrolyzed in the boiler, forming respectively free hydrochloric and sulphuric acids.

The alkali metals, sodium, potassium, and lithium, are all found in water, but only sodium occurs in quantities large enough to merit consideration. As compounds of the alkalies are readily soluble they can form no permanent scale, but on the other hand they are easily hydrolyzed, forming free acids which corrode the iron. Alkali carbonate and alkali sulphate waters have, moreover, a tendency to foam and thereby interfere with the uniform production of steam. No method is known by which alkalies may be economically removed, so that their presence in any water in large quantity is a permanent detriment to its use in boilers.

The bicarbonate radicle (HCO_3) in carbonate waters is usually related to calcium and magnesium. These metals are supposed to be held in solution by the bicarbonate radicle, appearing respectively as $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. When a calcic magnesic carbonate water is heated the equilibrium of the two soluble constituents is disturbed; carbon dioxide (CO_2) escapes with the steam, and calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) are deposited. The calcium carbonate, soon after it is formed, becomes crystalline and incapable of adhering firmly to hot iron, so that water containing considerable quantities of these bicarbonates, unaccompanied by other incrusting constituents, may be used without danger of forming a hard crust on the boiler.

Carbon dioxide (CO_2), whether present in the free state in the water or released by the decomposition of bicarbonates, is not without corrosive action on iron. It has a tendency to cause pitting of the boiler, so that highly carbonated waters are treated more effectively before they enter the boiler than afterwards. Lime water added in proper quantity to carbonate waters eliminates both calcium and magnesium as well as the bicarbonate radicle. After allowing time enough for the precipitate to settle, the softened water may be fed to the boiler. Carbonate and bicarbonate waters of the alkalies, that is, waters containing the carbonate and bicarbonate radicles in equilibrium with sodium, are occasionally found in Kentucky and in other States farther west. When these waters are heated the alkaline carbonates react chemically with the alkaline earth constituents, causing removal of the latter. Chlorides in water are simply corrosive. Excessive amounts of chlorides are undesirable, and waters containing over 100 parts per million of chlorine are unsuitable for boiler use. Organic matter causes foaming and sometimes it acts corrosively. Its corrosive action is due to the formation of free organic acids to which iron is susceptiible.

Calcic sulphate waters deposit a hard scale, the chief component of which is calcium sulphate. Magnesium sulphate waters are objectionable because they not only corrode the boiler by producing free sulphuric acid in the water, but they also deposit magnesia in the scale, thereby increasing its hardness and making it very refractory. As sulphates of the alkalies, besides hydrolyzing and causing corrosion, also induce foaming in boilers, large quantities of such sulphates are undesirable. No perfectly satisfactory method has yet been devised for removing the sulphate radicle from waters of this character.

Deep-seated waters are usually so highly mineralized that they corrode iron rapidly or form scale in boilers; occasionally, however, such waters are found to be very satisfactory. The water from a well at the Lexington station of the Cincinnati Southern Railway (analyses 23 and 24, p. 212) affords a good illustration of a highly mineralized deep water containing also correctives of hard scale.

This water was found on analysis to contain sufficient calcium, magnesium, and sulphates to form a hard, refractory scale under ordinary conditions, but it was also charged with carbonates of the alkalies. The analyst, Dr. Robert Peter, predicted that these carbonates would precipitate the incrustants in powdery form, thus preventing the deposition of calcium sulphate as a hard scale on the boiler shell,[a] and his assertion that the water could be used in boilers without harmful effect was verified by experience. Another example of water of similar character is furnished by the well at Hope Mills. This well, 134 feet deep, yields water from two horizons, one at a depth of 65 feet and the other at 132 feet. During wet weather, while the 65-foot stream flows, the water forms hard scale in the boilers; during dry weather, when the water is drawn from the lower stratum, the scale formed is soft. The water from the 132-foot vein is not only soft but is said to loosen boiler scale caused by the hard water from the upper vein. Water from a well at Paint Lick, in Madison County (analysis 56, p. 214), though much more highly mineralized than that from the well of the Cincinnati Southern Railway at Lexington, has been used for many years in a steam boiler without forming much scale. The presence of carbonates of the alkalies in the water at Paint Lick probably accounts for the small amount of boiler scale. A well water in Gallatin County (analysis 49, p. 212) illustrates the character of waters found in some places in the alluvium. It contains 16 parts per million of sulphates—a quantity which should cause little trouble in boilers—and it carries also carbonates of the alkalies which precipitate the incrustants, so that when heated the water should completely soften itself and should form no bad boiler scale.

CORRECTIVES OF SCALES.

Hard scales formed by sulphate waters may be prevented by treating the waters with certain substances which precipitate the incrusting constituents in a loose, powdery condition. Sodium carbonate, an agent frequently employed for this purpose, precipitates the calcium as calcium carbonate, which forms a loosely adhering scale if the water is treated after it enters the boiler. As soda ash does not remove the sulphate radicle, the presence of which is undesirable in boiler water, the use of this chemical is only a partial remedy in waters naturally forming hard scale. Barium

[a] Peter, Robert, Well water: Geol. Survey Kentucky, vol. 5, new ser., 1880, pp. 188-190.

chloride may be used instead of sodium carbonate in the treatment of sulphate waters. Although this compound causes the precipitation of the sulphate radicle in a form that does not produce scale, it leaves chlorides in the water, and owing to their corrosive action, high chlorides are undesirable in boiler waters. Barium carbonate is especially suited for removing iron, aluminum, and sulphates from waters, but it is rather too expensive for general use. Hard carbonate waters are most satisfactorily softened by means of milk of lime, which precipitates both calcium and magnesium in powdery form.

Not uncommonly scale preventive is added to the water in the boiler, but it is always better to soften water in tanks before it enters the boiler and to allow sufficient time for the precipitate to settle. Water softened in this way is used to better advantage in making steam, and the boiler is relieved of the extra duty of serving as a water-softening plant.

Many specifics for preventing and removing boiler scale are on the market, some of them being helpful, but others of little value, though the vendors use persuasive arguments in presenting the merits of their wares. Care should be exercised, however, not to use the wrong kind of boiler compound, as more harm may be caused by it than by the untreated water itself.

SOAP MAKING.

In the processes most commonly used soap is made by the chemical action of soda lye (caustic soda) on melted fat. The soap, being easily soluble, is dissolved by water as soon as it is formed, so that a fresh layer of fat is exposed uninterruptedly to the soda-lye solution. The value of soap as a cleansing agent is due to the fact that it forms in water a solution capable of producing suds; therefore anything that changes soap into an insoluble substance reduces just so far its value as a cleansing agent. Hard waters—calcium and magnesium waters—produce with ordinary soap a curdy precipitate of calcium and magnesium compounds that are insoluble in water and incapable of forming suds, and consequently are valueless as cleansing agents. If hard water is used in soap making the calcium and magnesium present react with the soap as soon as it is formed, making an abundant precipitate, which retards the further action of the soda lye on the fat and wastes soap. The precipitate will continue to be formed at the expense of the soluble soap until the calcium and magnesium in the water are entirely removed. Small quantities of the hardening constituents of water can decompose a large quantity of soap.

One requisite, therefore, for a large yield of soap is soft water. If hard water is the only kind available for soap making, it should be softened before use in the works; if not softened beforehand, it will be softened afterwards by the soap, and soap is an expensive water softener.

Sodic chloride waters are undesirable in soap making, because soap is not soluble in solutions of sodium chloride, and briny waters also prevent the free access of the lye to the melted fat. Indeed, advantage is taken of the insolubility of soap in brine when it is desired to remove the soap from solution. Salt is added to the soap solution and the soap then separates out as a solid mass.

Clear water must be used in the manufacture of soap. Suspended matter of all kinds must be removed from the water by filtration to insure the production of a pure, fine-grained product.

LAUNDERING.

The development of the steam-laundry industry has been rapid in recent years, and public service of this character is becoming more and more general. The most important laundry supplies are water and soap, for the combined cost of all other materials consumed in scouring, brightening, and sizing is less than the total cost of soap and water. The prudent launderer buys high-grade soap, because he knows that not only are better results obtained with soap of good quality than with that of inferior grade, but also that his soap bill is correspondingly reduced. It is just as important in laundering to use water of good quality as it is to use good soap. The water should be clear, soft, and free from iron and suspended matter. If the water is muddy or turbid it must be filtered before it can be used.

After the goods are received at the laundry they are soaked in cold water for a short time to remove stains and loosen the starch. At the end of the soaking period steam is admitted to raise the water to the boiling point, the necessary quantity of soap is added, suds are formed, and the washing begins. If the water is hard a wasteful expenditure of soap takes place at this stage. The calcium and magnesium in solution react with the fat acids of the soap, precipitating the insoluble curdy soaps of calcium and magnesium. No suds are formed, and the whole operation of cleansing is delayed until the calcium and magnesium are completely precipitated.

The loss of soap is not the only evil effect of hard water. The precipitated earthy soaps act as coagulants, seizing mechanically upon impurities which are thus often deposited on the fiber of the goods. These plasters adhere to the goods, appearing finally as greasy spots on the laundered material. Hard water is therefore undesirable for laundry use, economically as well as æsthetically.

The water used in all stages of the cleansing process must be as free as possible from iron, as brown stains on the finished product are likely to result from the use of water containing iron to the extent of even one part per million.

The hardness due to calcium and magnesium bicarbonates may be removed by a judicious use of lime water, but the permanent hardness is not reduced in this way. Soda ash (sodium carbonate) is well suited for this purpose, and may be applied after the water has been treated with lime. Hardness due to compounds of calcium and magnesium other than the bicarbonates is thus removed. After sufficient time has been allowed for settling the clear water may be used for washing. The tendency of waters containing alkalies to foam in boilers—a feature that makes carbonates of these metals so undesirable in feed water—is of decided advantage to the laundry water. Carbonates of the alkalies are said to "thicken" the soap, increasing its power to emulsify oily material, thus adding to its cleansing qualities. For this reason the usual practice is to add sodium carbonate to the water with the soap merely to strengthen the soap.

The hardness of water is usually expressed as parts per million by weight of calcium carbonate; water having a hardness of 100 parts per million, for instance, is understood to be water containing 100 pounds of calcium carbonate in 1,000,000 pounds of water. Theoretically 100 pounds of calcium carbonate require for removal 61 pounds of high-grade commercial quicklime, 112 pounds of soda ash, or 860 pounds of soap. Assuming the cost of these reagents to be, quicklime, 0.3 cent; soda ash, 1.25 cents; and soap, 5 cents per pound, the cost of softening a quantity of water containing 100 pounds of calcium carbonate would be, with quicklime, $0.18; with soda ash, $1.40; with soap, $43.

Whipple[a] has experimented on waters of different degrees of hardness to determine their effect on the quantity of soap used in bathing and for general household purposes. He finds that 1 pound of the average soap used in the household will soften 167 gallons of water having a hardness of 20 parts per million. This is equivalent to about 5,990 pounds of soap per million gallons, which, at a cost of 5 cents a pound, would amount to $300 per million gallons. He also finds that the cost increases about $10 per million gallons of water softened for each increase of one part per million of hardness.

It is often asked whether the quantity of soap consumed by a hard water is an item of expense worthy of serious consideration in laundries, which require daily many thousands of gallons of water in which soap is used. This question is best answered by a practical illustration. Let it be assumed that a laundry is using daily 10,000 gallons of water having a hardness of 96 parts per million—the average hard-

[a] Whipple, G. C., The value of pure water: Wiley & Sons, 1907, p. 24.

ness of Kentucky River below Tyrone. According to Whipple's experiments, the hard water causes a loss of average soap amounting to about $10.70 a day. In three hundred working days the annual consumption of soap by the hard water alone would amount to $3,210. If, however, the water were previously softened with lime to reduce its hardness to 30 parts per million (the average permanent hardness of the river), then the daily cost of soap consumed by the laundry water would be only $4.10. After adding to this amount 1 cent for the lime required for the softening, the total daily cost of the partly softened water becomes approximately $4.11. This partial softening of the water, therefore, results in a saving of soap cost of $6.59 a day, or a total annual saving of $1,977. No claim is here made for the absolute accuracy of these figures in estimating the cost of softening water. The size and capacity of the softening plant, cost of labor and fuel, attendance at the works, difficulties arising from turbidity, variable content of magnesium, and other conditions of the water to be softened, must be considered. The computations indicate, however, that there is much room for economy by softening the water before its use, and they suggest, moreover, the practicability of installing mechanical devices to make the natural water more economical in its consumption of soap.

ICE MANUFACTURE.

The rapid gain in popular favor which artificial ice has made in this country in recent years is shown by the reports of the United States Census. In 1870 there were in the United States only four ice factories, with a total capitalization of $434,000, and the total ice output for that year was valued at $258,250. In 1905 reports were recived from 1,320 establishments, indicating a capitalization of $66,592,001, and the total output of ice was valued at $23,790,045. These figures do not include 163 establishments engaged primarily in manufacturing other products, which are reported to have made $1,899,912 worth of ice.

It is important that the water used in the manufacture of ice for household purposes and for cooling beverages should meet all the requirements of potable water in respect to cleanliness and freedom from organic matter and disease germs. Most American manufacturers use distilled water in making ice, in order to get a pure, transparent product.

Two systems are employed in making artificial ice in this country. These are the can and the plate systems. Though cakes of ice frozen from impure water by the can system may be for the most part clear, the center of the block is likely to be opaque. Drown[a] has shown that the interior of the block contains most of the impurities that

[a] Drown, T. M., Ann. Rept. Massachusetts State Board of Health, 1892, p. 592.

were originally distributed through the water. At a certain ice factory known to the writer the core containing the concentrated impurities is cut from the block and allowed to melt, and the liquid product is served to the employees as a preventive of intestinal disorders! It is needless to say that this ice factory is not in Kentucky.

In the plate system, which is becoming more and more popular in this country, it is not necessary to use distilled water in order to obtain clear ice if suitable appliances are installed to prevent the occlusion of air and solid particles. Though it is true that the greater part of the bacteria and mineral matters in the raw water are excluded from the frozen plate, there is insufficient ground for assuming that perfectly harmless ice can be made directly from dangerously polluted water. And while it may be conceded that water pure enough for drinking is pure enough for making ice, it is nevertheless true that too much dependence should not be placed upon the natural purifying powers of the freezing process.

Water serves another purpose in the ice factory beside that of being the raw material for the ice and the steam. Much heat is absorbed by the ammonia which has been used for freezing the water, and advantage is taken of the cooling effect of water to assist in recovering the exhaust ammonia for subsequent use. In the compression system the pipes containing compressed gaseous ammonia are surrounded by cold water constantly flowing in large tanks, or the cold water is sprinkled directly upon the ammonia pipes. In both processes the water absorbs heat from the ammonia, changing it from the gaseous to the liquid form. Water charged with incrustants deposits on the hot ammonia pipes a scale closely resembling the scale formed by the same water in a boiler. Sometimes this scale is very hard and tenacious, and if it is allowed to remain on the pipes, it may become so thick as practically to nullify the cooling effect of the water.

BREWING AND DISTILLING.

The water used in breweries should receive careful attention, because the quality of the beer depends largely upon the quality of the water. In general, a good potable water, free from color, odor, and decomposing organic matter may be used to advantage for brewing. Clean water is indispensable in a brewery. Waters polluted with sewage or putrefactive bacteria should be avoided, for they prevent the beer from keeping well and give it a disagreeable taste. Great care must also be taken to use perfectly clean water in washing the kegs and barrels in which the beer is to be stored. Organic matter in the water is objectionable, as it is likely to promote the growth of mold in the barley, thus preventing a proper development of diastase in the malted grain. In the later stages of the brewing process organic matter in the water is undesirable, because it not only lessens the activity of the yeast, but also forms putrefaction products that seriously affect the quality of the beer.

Water used in brewing should be as free as possible from iron, which combines directly with diastase, forming an insoluble compound and thus reducing the efficiency of the ferment; moreover, iron waters impart an unpleasant taste to the beer. Iron may be removed from water easily and cheaply by forcing air through the water and then filtering it through sand and gravel. The iron hydroxide, which is precipitated by the aeration, is retained completely on the filter. Sodic chloride waters, if not too strong, favor the development of diastase and are therefore of decided advantage in malting. Magnesic chloride waters act similarly. On the other hand, calcic chloride waters are to be avoided because they retard the development of yeast. Calcic and magnesic sulphate waters, which are undesirable for boiler supplies, soap works, and certain other industries, are of distinct advantage to the brewer. Such waters assist the development of the yeast and produce beers of agreeable flavor and good keeping qualities. Soft waters dissolve from the hops a resin which darkens the color of the beer. Calcium sulphate waters do not dissolve hop resin, and thus produce a light-colored beer. Many brewers who have no supply of natural calcium sulphate waters treat with calcium sulphate the waters used in fermentation, regulating the quantity of the mineral to the kind of beer to be brewed.

Table 9 shows the amounts of some of the important constituents in the waters used in brewing three famous kinds of beer—the light Burton ales, the dark Dublin porters, and the beer of the Hofbräuhaus in Munich. Probably the chemical composition of the water supplies influences the essential characteristics of these beverages.

TABLE 9.—*Composition of waters used for brewing.*

[Parts per million.]

	Burton-on-Trent, England.	Dublin, Ireland.	Munich, Germany.
Iron (Fe)	....	2	Trace.
Calcium (Ca)	370	100	72
Magnesium (Mg)	88	3.7	53
Sulphate (radicle (SO_4))	895	44	55
Chlorine (Cl)	34	16	35

In distilleries the malting and fermenting processes are carried much farther than in brewing. What has been said regarding the effects produced by waters of different kinds in brewing applies with equal force to the corresponding processes in a distillery; but since the object of the distiller is to get the largest possible yield of alcohol from the grain, it is important that the water used in the fermentation vats should contain in proper quantities only those substances which are favorable to a vigorous growth and a high efficiency of the yeast plant. The waters of the Blue Grass region, which have long been recognized as being specially suited for making whisky, also produce beer of superior grade.

COMPARATIVE HARDNESS OF BLUE GRASS WATERS.

Economically, hardness is an important quality of water, whether it is used industrially or in the household. The chief difference in the character of the hardness of underground and river waters of the Blue Grass region lies in the excessive alkalinity of the ground water, while the permanent hardness of the water in the lower part of Kentucky River and in Ohio River at Cincinnati closely approximates the permanent hardness of the waters of the Lexington limestone and of the alluvial deposits. The hardness of 16 waters from springs and shallow wells occurring in the Lexington limestone and from 7 wells in the alluvium of Ohio and Licking rivers is shown in Tables 10 and 11. The alkalinity was determined in the regular course of analysis, while the permanent hardness has been calculated from the amounts of calcium and magnesium in the form of salts other than carbonates. The figures indicate that the alluvial waters are somewhat harder than the waters of the Lexington limestone, both in respect of permanent hardness and of alkalinity.

TABLE 10.—*Hardness of the water from springs and shallow wells in Lexington limestone*

[Parts per million as $CaCO_3$. Analyst, Chase Palmer.]

No. (a)	County.	Locality.	Owner.	Source.	Alkalinity.	Permanent hardness.	Total hardness.
1	Anderson	Tyrone		Spring	224	22	246
2	do	do		do	226	35	261
20	Fayette	Lexington	Ed. Kane	Well	189	33	222
21	do	do	Aug. Belmont	Spring	234	24	258
22	do	do	Boice Grogan Co	Well	286	37	323
26	do	do	W. W. Estill	do	295	46	341
28	do	do	W. M. Field	Spring	136	20	156
32	do	do	Harkness	do	189	6	195
36	do	do	Mrs. Israel	Well	232	18	250
37	do	do	Lexington Brewing Co	do	233	18	251
40	do	do	J. E. Pepper	Spring	194	14	208
41	do	do	do	Well	238	40	278
42	do	do	Pettit	do	166	40	206
66	Scott	Georgetown	Askew	do	197	41	238
68	do	Stamping Ground.	Distillery	Spring	177	9	186
74	Woodford	Versailles	Brodhead	Well	198	24	222
	Average				213	27	240

a These numbers refer to the numbers of the analysis in the table on pp. 212-215, from which additional details may be obtained.

TABLE 11.—*Hardness of water from alluvial wells.*

[Parts per million as $CaCO_3$. Analyst, Chase Palmer.]

No. (*a*)	County.	Locality.	Owner.	Source.	Alkalinity.	Permanent hardness.	Total hardness.
5	Boone	Petersburg	Boone County Distillery	90 ft. well	235	43	278
8	Bracken	Augusta	Electric Light Co	90 and 50 ft. wells.	361	55	416
9	do	do	Steam laundry	80 and 60 ft. wells.	287	20	307
12	Carroll	Carrollton	Furniture factory	Well	306	28	334
49	Gallatin	Warsaw	do	do	296	0	296
53	Kenton	Covington	Cincinnati Ice Co	do	332	51	383
71	Trimble	Melton	Richwood Distillery	do	235	23	258
	Average				293	31	324

a These numbers refer to the analysis numbers in the table on pp. 212-215, to which reference is made for further details.

The following table gives the amounts of hardening constituents found in Ohio River water at Cincinnati under varying conditions and at different stages of the river:

TABLE 12.—*Hardness of water from Ohio River at Cincinnati, Ohio.*

[Parts per million as $CaCO_3$.]

Authority.	Conditions.	Alkalinity.	Permanent hardness.	Total hardness.
G. W. Fuller *a*	Normal for 1898	45	33	78
Do *a*	Average (March 13-April 25) 1899	40	29	69
J. W. Ellms	March 21, 1902 (high water)	21	21	42
Do	September 16, 1902 (low water)	72	41	113
Average		44	31	75

a Purification of the Ohio River water, Cincinnati, 1899, p. 493.

During the period from August, 1903, to June, 1904, the waters of Kentucky River were studied by the writer at monthly intervals Eight stations were established along the river at convenient shipping points, the highest station being at Jackson, in Breathitt County, and the lowest at Worthville, in Carroll County. The collections at all stations were made from midstream except those at the Government locks at Highbridge, Tyrone, and Frankfort. The samples from the waterworks at Frankfort were collected at the intake. In this way it was sought to secure typical samples of the river water from its head waters in Breathitt County along its entire course.

TABLE 13.—*Average hardness of water from Kentucky River, August 20, 1903, to June 3, 1904.*

[Parts per million as $CaCO_3$.]

	Alkalinity.	Permanent hardness.	Total hardness.
Jackson (11 months)	32	18	50
Beattyville (11 months)	33	19	52
Irvine (11 months)	36	26	62
Highbridge, Lock No. 7 (9 months)	55	27	82
Tyrone, Lock No. 5 (9 months)	67	33	100
Frankfort waterworks (10 months)	66	31	97
Frankfort, Lock No. 4 (10 months)	66	30	96
Worthville (11 months)	67	30	97

During the same period a similar study was made of the quality of the headwaters of Dix River at Gum Sulphur in Rockcastle County, showing alkalinity, 78; permanent hardness, 18; and total hardness, 96 parts per million as $CaCO_3$.

The progressive increase both in alkalinity and in permanent hardness in the water of Kentucky River from the mountains at Jackson until after it passes Irvine is noteworthy. The initial alkalinity of Dix River at its source in the upland of Rockcastle County is higher than the alkalinity of Kentucky River at any point in its course, and the sudden increase in the alkalinity of Kentucky River at Highbridge is probably due largely to the mingling of the more highly alkaline waters of Dix River, which enters Kentucky River a short distance above the lock at that place. Dix River is evidently an important factor in determining the mineral character of the water of lower Kentucky River, because the new degree of permanent hardness and alkalinity acquired by Kentucky River, shown by the results at Tyrone, remains practically constant throughout the rest of its course in the Blue Grass region until the Kentucky unites with the Ohio.

FIELD ASSAYS OF WATER.

During the spring of 1905 a series of assays of water from wells and springs in the Blue Grass region was undertaken to obtain general information concerning the industrial value of the underground waters in the district. An assay of water is not a complete chemical analysis, because the determinations in an assay are confined mainly to those constituents which are regarded as having an important bearing on the fitness of a water for special purposes. The methods used in making the assays are in general those devised for the U. S. Geological Survey by Leighton.[a]

[a] Leighton, M. O., Field assay of water: Water Supply Paper U. S. Geol. Survey No. 151, 1905.

Field determinations of the constituents of waters are not altogether a novelty. As early as 1854 Dr. David Dale Owen, director of the first Geological Survey of Kentucky, made many tests of waters in the field. Recognizing at that early period the importance of gaining positive information concerning the water resources of the Commonwealth, he provided himself with chemicals and apparatus for making quick tests of water. He carried these with him on his expeditions, and was thus enabled to ascertain on the spot the important characteristics of many waters of the State. In this way a much wider area was covered than would otherwise have been possible, and though the field examinations were merely qualitative, much information concerning the waters of Kentucky was obtained at a minimum cost.

When the samples of water were taken by the writer for field assay, the records of the wells were obtained and as much information as possible was gathered concerning the character of the rock through which the borings were made. Seven counties in the Blue Grass region were visited, and the results of the assays made in these counties are given in Table 14. The estimated incrustants probably approximate the total incrustants in these waters. Considering the sulphates as forming hard scale, these waters are classified in a general way according to a scale suggested by the American Master Mechanics' Association for classifying waters for locomotives boilers. Though this classification has not been generally adopted, it serves fairly well as a means of judging, within tolerably wide limits, the fitness of a water for steam making. The classification refers in no wise to the value of these waters for ordinary domestic purposes.

Classification of waters.

Incrustants:

Below 250 parts per million	Good.
250 to 350 parts per million	Fair.
350 to 500 parts per million	Poor.
500 to 700 parts per million	Bad.

Of the 60 waters represented in the table of assays, 25 are designated good, 18 fair, 16 poor, and only 1 water is apparently so highly mineralized as to be considered unsuitable for boiler service. These results indicate that the waters in the region covered by the investigation are fairly good for industrial uses, and that with preliminary treatment they may profitably be softened so as to yield favorable results in steam boilers.

TABLE 14.—*Field assays of water in Blue Grass region.*

[Parts per million.]

Date.	County.	Location.	Owner.	Source.	Depth of well.	Depth of water.	Turbidity.	Color.	Iron.	Chlorine.	Sulphate radicle (SO_4).	SO_4 calculated to $CaSO_4$.	Alkalinity as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
1905.					*Feet.*	*Feet.*									
Apr. 12	Anderson	Hammond Creek	Hoffman Distilling Co.	Well	36	29	0	0	1.2	26	86	21	255	376	Fair. [a]
12	do	Lawrenceburg	City	3 wells	90	45	0	2	0	29	59	82	194	276	Good. [a]
15	do	County	Old Prentice Distillery	Well	65	60	0	4	0	55	Low.	50	265	315	Good. [a]
15	do	Lawrenceburg	Dowling Distillery	do	40	40	0	4	0	4	Low.	25	155	280	Good.
15	do	Tyrone	Waterfill & Frazier Distillery.	Spring			0	4	Trace.	17	59	82	259	341	Fair.
4	Boyle	Danville	Gentry & Kenney	Well	104	40	0	0	.2	93	127	178	279	457	Poor.
Mar. 4	do	do	Charles Orman	do	8	8	0	17	0	4	Trace.		71	75	Good.
3	do	do	Mrs. Emma Hazelton	do	60	50	0	4	.4	11	105	147	203	350	Poor.
3	do	do	Charles Hardesty	Spring			0	4	.3	58	13	18	197	215	Good.
16	do	do	D. F. Slavin	Well	125	125	0	7	.3	27			263	263	Good.
8	do	Forkland	A. B. Minor	do	27	26	0	6	.6	196	52	72	253	325	Fair.
8	do	do	T. M. Purdom	do	27	26	0	6	0	283	91	127	221	348	Poor.
8	do	Hankla	W. F. Powers	do	58		0	4	0	40	124	172	288	460	Poor.
16	do	Junction City	Mrs. W. T. Richardson	do	24	24	0	6	.1	97	31	44	102	146	Good.
7	do	Mitchellsburg	Town	do	25		0	9	.4	212	92	129	221	350	Poor.
8	do	Parksville	J. D. Minor	do	57		0	4	.3	762	97	136	190	326	Poor.
8	do	do	Lapp Ewing	do	100		0	2	.3	42	168	234	245	379	Poor.
1	do	Perryville	Town	do	47	47	0	4	.1	33	43	94	170	264	Fair. [a]
1	do	do	do	do	63	63	0	4	.3	30	66	93	192	285	Fair. [a]
1	do	do	J. W. Brogles	do	56	56	0	4	.2	13	55	77	189	266	Fair. [a]
4	do	Shelby City	J. S. Figg	do	22	22	0	7	.1	48	94	130	146	275	Fair.
Apr. 4	Garrard	Camp Dick Robinson	A. B. Montgomery	do	60	35	0	4	.3	6	25	35	118	153	Good.
Mar. 16	do	Boone Cave Spring		Spring			0	5	.2	8			84	84	Good.
13	do	Lancaster	Mrs. J. West	Well	8	7				44	83	116	129	315	Fair.
13	do	do	Walden Bros.	do	20		0	9	.3	71	22	30	296	326	Fair. [a]
Apr. 4	do	Marcellus	C. K. Poindexter	do	120	100	0	4	.1	57	71	99	156	255	Fair. [a]
May 20	Jessamine	Nicholasville	Town	do	120	120	2	2	.6	44	98	137	272	409	Poor.
20	do	do	C. A. Kenney	do	77	62	0	2	.5	54	113	127	2 6	393	Poor.
20	do	do	Speais & McKay	do	14	10	5	9	.3	17	42	59	188	247	Fair.
Mar. 29	Mercer	Harrodsburg	Old Jordan Distillery	do	35		0	3	.1	54	120	168	214	382	Poor.

[a] Faint odor of hydrogen sulphide.

TABLE 14.—*Field assays of water in Blue Grass region*—Continued.

Date.	County.	Location.	Owner.	Source.	Depth of well.	Depth of water.	Turbidity.	Color.	Iron.	Chlorine.	Sulphate radicle (SO_4).	SO_4 calculated to $CaSO_4$.	Alkalinity as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
1905.					*Feet.*	*Feet.*									
Mar. 29	Mercer	Harrodsburg	Electric-light plant (outside).	Well	26		0	4	Trace.	371	186	260	293	553	Poor.
29	do	do	Electric-light plant (inside).	do	23		0	0	0	11	43	60	176	236	Good.[a]
May 18	do	do	H. C. Smith & Sons	do	30		0	2	.1	19	50	70	206	276	Good.
18	do	do	G. W. Miles	do	35	35	10	2	.2	12	64	89	252	341	Fair.[a]
18	do	do	Allen & Buster	do	40	20	8	5	.2	47	113	147	203	360	Poor.
Apr. 26	Scott	Georgetown	J. N. Moreland	do	52	42	0	2	2	4	34	47	166	213	Good.
26	do	do	J. C. Porter	do	71	61	5	2	.5	9	30	42	172	214	Good.
26	do	Stamping Ground	Town (schoolhouse)	do	85	80	5	9	2.5	30	18	25	306	331	Fair.
26	do	do	Town (center)	do	60	55	5	9	2	111	43	60	327	387	Poor.
26	do	do	C. T. Duvall	do	40	35	0	4	1.2	27	61	85	179	234	Fair.
26	do	do	J. T. Noel	do	60	52	15	77	2	264	30	42	440	482	Poor.[b]
27	do	Newtown	Mrs. C. P. Pribble	do	59	54	10	6	2	278	83	116	252	368	Poor.
27	do	do	Public	do	48	40	10	4	2	80	30	42	261	303	Fair.[a]
27	do	do	H. D. Williams	do	57	40 and 50	0	19	8	42	30	42	224	236	Fair.[a]
27	do	do	G. W. Murphy	do	84	60	0	2	2	128	54	75	146	221	Good.[a]
27	do	do	Geo. D. Sallee	do	50	35	0	2	2	30	112	156	163	319	Fair.
27	do	do	do	do	70	60	0	2	2	55	124	169	414	583	Bad.
27	do	do	R. Offutt	do	112	100	0	4	8	479	24	34	166	200	Good.
May 19	Woodford	Midway	Town	do	90	70	0	0	.3	42	103	144	216	360	Poor.
19	do	do	do	do	100		0	2	.2	12	Trace.		216	216	Good.
19	do	do	M. C. Kaselbaum	do	80		0	2	.7	32	77	107	137	244	Good.
19	do	do	D. Lehman	do	102		5	2	.2	32	54	75	196	271	Fair.
1906.															
May 18	do	Versailles	Childer's Place	Spring			0	3	Trace.	6	24	34	88	122	Good.
18	do	do	D. M. Bowmar	Well	45		0	3	Trace.	12	35	49	178	247	Good.
18	do	do	Steam Laundry	do	57		0	4	Trace.	37	71	99	192	291	Fair.
18	do	do	J. T. Wilhoit	do	100		2	5	Trace.	9	50	70	145	215	Good.
18	do	do	Fair Grounds	do	107		0	24	Trace.	6	60	84	148	232	Good.
18	do	do	Edwards Spring	Spring			0	2	Trace.	9	35	49	88	137	Good.
18	do	do	Big Spring (town)	do			0	2	Trace.	9	35	49	92	141	Good.
18	do	do	Chapman	do			0	2	Trace.	9	35	49	88	137	Good.

[a] Faint odor of hydrogen sulphide.

[b] Black sulphur water.

MEDICINAL WATERS.

GENERAL CHARACTERS.

Kentucky has long been famous for the number and great variety of its mineral springs, many of which are located in and about the Blue Grass region. A few of the well-known medicinal waters of central Kentucky deserve special mention.

Bromide waters have been recommended as sedatives and have been used successfully in the treatment of epilepsy and ulcerous affections. Iodine is a more active alterative than bromine, though, like bromine, iodine is never present in waters in large quantities. Iodide waters often produce rapid cures and find extensive application in the treatment of a wide range of chronic diseases. The Lower Blue Lick spring waters and several other iodide waters acquired fame for the cure of goitre, scrofula, and other diseases long before it was known that they contained iodine. Bromine and iodine impart to water such valuable medicinal qualities that a list of well-known springs containing these elements is given here for comparison with some of the medicinal waters of Kentucky.

TABLE 15.—*Bromine and iodine in water from various sources.*

[Parts per million.]

	Bromine.	Iodine.
Deep sea water	2,077	....
Average ocean water	414	....
Congress Spring, Saratoga, N. Y.	115	2
Champion Spring, Saratoga, N. Y.	48	3.2
Franklin Lithia, Ballston, N. Y.	48	1.7
Sans Souci, Ballston, N. Y.	....	20
Jordan Alum, Va.	....	10
Iodin Spring, W. Va.	11	11
Brown's Magnesian Well, Independence, Kans.	182	1
Kreuznack, Germany	200	.9
Kissingen, Bitterwasser, Germany	99	....
Lower Blue Lick, Ky.	23	.14
Upper Blue Lick, Ky.	51	.13
Salt Sulphur Spring, Olympian Springs, Ky.	13	Traces.

Sulphur waters are important medicinal agents, the sulphur obtained from them having a powerful effect on the liver, the mucous membranes, and the skin. An admirable description of the therapeutics of sulphur waters is given by Schweitzer,[a] who recognizes that the value of a sulphur water as a curative agent depends largely on the character of the sulphur compounds present. Free hydrogen sulphide, although, on account of its disagreeable odor, the most prominently noticeable sulphur constituent of water, appears incapable of entering the circulation, and leaves the body without having produced any material effect; on the other hand, the sulphides of the alkalies are readily taken up by the blood, where they release

[a] Schweitzer, P., Geol. Survey Missouri Rept., vol. 3, p. 36.

hydrogen sulphide, which under these conditions produces a powerful effect upon the entire system. In a medicinal sulphur water, therefore, the sulphur should be associated with elements other than hydrogen. The Blue Lick waters of Kentucky and the Stachelberg waters of Switzerland, to both of which reference is made in the following pages, are types of medicinal sulphur waters.

CRAB ORCHARD SPRINGS.

Sulphate waters are very common in the Blue Grass region. When they are strongly sulphated, and are also highly charged with magnesium, such waters acquire decidedly medicinal properties. Waters of this kind abound at Crab Orchard, in Lincoln County, and for this reason the Crab Orchard Springs have maintained their popularity as a health resort for more than half a century. The composition of the water from Sowder's Spring was determined by Dr. Robert Peter.[a] It is analogous to that of the world-famous water at Carlsbad, Bohemia. The following comparative table shows the composition of these two waters. The Carlsbad water is somewhat weaker than the Crab Orchard water, and it is also deficient in magnesium, to which the special virtue of the American spring may be attributed.

TABLE 16.—*Composition of water from Sowder's Spring, Crab Orchard, Ky., and from the Sprudel Spring, Carlsbad, Bohemia.*

[Parts per million.[a]]

	Sowder's (Peter).	Sprudel (Gottl.).
Silica (SiO_2)	12	144
Iron (Fe)	Trace.	1.9
Aluminium (Al)	....	6.4
Calcium (Ca)	664	110
Magnesium (Mg)	969	16
Sodium (Na)	523	1,874
Potassium (K)	134	23
Bicarbonate radicle (HCO_3)	1,159	1,839
Sulphate radicle (SO_4)	3,666	1,898
Phosphate radicle (PO_4)	....	23
Chlorine (Cl)	606	724
Bromine (Br)	Trace.	....
	7,153	6,661

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

The action of the Crab Orchard waters is analogous to that of a simple solution of magnesium sulphate (Epsom salt), which is a strong cathartic. Physicians found in practice, at an early date, that the waters from these springs are not so severe in their effects as magnesium sulphate alone; they act rather as laxatives than as purgatives. It appears that the other constituents present in the natural waters so temper the magnesium and the sulphates as materially to

[a] Kentucky Geol. Survey, 1857, vol. 2, p. 239.

reduce their activity. Owing to the mildness of their action, the epsom spring waters are applicable to the treatment of a greater variety of diseases than is the case with the simple solution of magnesium sulphate.

The epsom spring waters of Crab Orchard have been used extensively in the manufacture of salts at one time sold as a cathartic. The composition of the salts from Sowder's Spring, as determined by Dr. Robert Peter,[a] shows the general character of the salts obtainable from the epsom springs of this locality.

Composition of salts from Sowder's Spring.

Magnesium sulphate	63.19
Sodium sulphate	4.20
Potassium sulphate	1.80
Calcium sulphate	2.54
Sodium chloride	4.77
Calcium, magnesium, and iron carbonates and silica	.89
Bromine	Trace.
Waste and loss	22.61
	100.00

KIDDVILLE EPSOM WATER.

A magnesic water bearing a close resemblance to the epsom waters at Crab Orchard occurs at Kiddville in Clark County (analysis 14, p. 212). The Kiddville magnesium water is more highly sulphated and contains magnesium and calcium in larger proportions.

OLYMPIAN SPRINGS.

Olympian Springs, in Bath County, have long been famous as a watering place, and the locality is still held in high esteem as a health resort. In general, the waters at Olympian Springs are distinctly ferruginous, and one water combines the qualities of a magnesic sulphate water with ferruginous properties. Among these springs are black-sulphur waters, white-sulphur waters, and a very strong salt-sulphur water. The salt-sulphur spring water, analyzed by Robert Peter in 1877,[b] was found to be alkaline and borated, and to contain as much as 13 parts per million of bromine and traces of iodine.

The Olympian Springs salt-sulphur water is used advantageously in the bath, and it is recommended as a valuable remedy in the treatment of skin diseases. A close resemblance between the quality of this Olympian Spring water and that of the Kaiserquelle at Aix la Chapelle was observed by Peter, and the composition of these two waters is reproduced for comparison.

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[a] Loc. cit.

[b] Kentucky Geol. Survey, Chemical Analysis A, vol. 1, 1884, p. 365.

TABLE 17.—*Composition of water from salt-sulphur springs at Olympian Springs, Ky., and Aix la Chapelle, Germany.*

[Parts per million.[a] Analysts: Peter (Olympian Springs) and Liebig (Aix la Chappelle).]

	Olympian Springs.	Aix la Chapelle.
Silica (SiO_2)	23	66
Iron (Fe)	1.2	4.4
Aluminum (Al)	.4	Trace.
Barium (Ba)	9	....
Strontium (Sr)	2.6	.1
Calcium (Ca)	89	63
Magnesium (Mg)	42	15
Sodium (Na)	1,934	1,421
Potassium (K)	19	69
Lithium (Li)	.1	0.03
Carbonate radicle (CO_3)	Trace.	....
Bicarbonate radicle (HCO_3)	329	1,023
Sulphate radicle (SO_4)	5.8	276
Chlorine (Cl)	3,081	1,599
Bromine (Br)	13	3.3
Iodine (I)	Trace.	Trace.
Borate radicle (B_4O_7)	Trace.	....
Sulphide radicle (S)	Trace.	14
Organic matter	34	75
	5,584	4,628

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

ESTILL SPRINGS.

The Estill Springs, at Irvine, Estill County, are situated in one of the most picturesque localities of the State. Within easy reach of Kentucky River and close to the mountains, the surroundings are unusually attractive. A commodious hotel and well-kept grounds add to the natural advantages of the place. The several springs supply red-sulphur, white-sulphur, black-sulphur, and chalybeate waters, all of which, except the last, are reported to contain hydrogen sulphide. The iron is deposited from these waters soon after collection, so that their full virtue is realized only by treatment at the springs.

The red-sulphur water deposits ferric hydrate, the color of which has given the name to the water. Black ferrous sulphide is deposited from the black-sulphur water, and from the white-sulphur water a white deposit of sulphur is formed.

TABLE 18.—*Composition of Estill Springs waters.*[a]

[Parts per million.[b] Analyst, Dr. Robert Peter.]

	Red sulphur.	White sulphur.	Black sulphur.	Chalybeate.
Silica (SiO_2)	6.8	4.0	13	32
Iron (Fe)	....	....	48	15
Aluminum (Al)	....	8.5	3.6	....
Calcium (Ca)	81	121	45	148
Magnesium (Mg)	26	25	11	47
Sodium (Na)	99	52	26	7.4
Potassium (K)	42	32	7.6	4.9
Carbonate radicle (CO_3)	197	24	108	72
Sulphate radicle (SO_4)	176	152	67	350
Phosphate radicle (PO_4)	....	Trace.	....	....
Chlorine (Cl)	5	5.5	22	5.5
Organic and volatile matter	40	50	59	141
	715	696	410	896
Free carbondioxide (CO_2)	325	360	263	269
Free hydrogen sulphide (H_2S)	4.5	3	35	0

[a] Geol. Survey Kentucky, 1st ser., vol. 4, p. 143.
[b] Obtained by computation to ionic form; results orginally stated in hypothetical combinations.

KEO-ME-ZU SPRINGS.

The Keo-Me-Zu Springs, located in Kenton County, about 10 miles south of Cincinnati, have recently attracted favorable consideration as affording excellent mineral waters. They consist of three springs, all of the alum-chalybeate variety, and are well charged with free carbon dioxide. The composition of the Keo-Me-Zu Spring waters is given in the following table:

TABLE 19.—*Composition of Keo-Me-Zu Spring waters.*

[Parts per million.[a] Analysts, Karl Langenbeck and Louis Schmidt.]

	Alpha Spring.	Bonanza Spring.	Climax Spring.
Silica (SiO_2)	26	90	15
Iron (Fe)	12	12	0.8
Aluminum (Al)	3.8	32	7.7
Manganese (Mn)	....	.2	Trace.
Calcium (Ca)	115	282	167
Magnesium (Mg)	23	18	19
Sodium (Na)	63	20	22
Potassium (K)	7.7	2.1	4.6
Carbonate radicle (CO_3)	248	388	260
Sulphate radicle (SO_4)	125	370	114
Nitrate radicle (NO_3)	4.4	....	....
Chlorine (Cl)	7	6.5	2.2
Organic and loss	....	2.2	Trace.
	632	1,257	610

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

LOWER BLUE LICK SPRINGS.

These celebrated saline-sulphur springs, located near the north bank of Licking River in Nicholas County, were known to the first settlers of Kentucky. The Indians and the pioneers of the State were in the habit of visiting the springs in order to procure the salt with which their waters were richly impregnated. The medicinal virtues of these waters were also recognized at an early date, and they have been regarded as efficacious in the treatment of scrofula, chronic rheumatism, gout, engorgements of the liver, and chronic skin diseases.

The first quantitative analysis of the Lower Blue Lick waters was made by Robert Peter, and the report of the first Geological Survey of Kentucky, published in 1850, contains an interesting account of his elaborate investigation of the composition of these remarkable spring waters. Several important characteristics of these waters were disclosed by this early study. They were found to be not only strongly saline, but alkaline, and to have the additional value of being moderately strong alkaline sulphated waters. The presence of bromine and iodine was also discovered, and quantitative determinations of these two elements were made.

This early analysis includes also determinations of the gaseous constituents of the waters. Free carbon dioxide and hydrogen sulphide dissolved in spring waters begin to escape as soon as the water is exposed to the air, and, in order to ascertain the quantities of these two gases present in the water when it reaches the surface, it is necessary to make the determinations at the spring.

By the improved volumetric methods and with the modern appliances now in daily use, determinations of these gases may be made in the field as rapidly and as accurately as in the chemical laboratory. At the time, however, when this analysis was made, such refinements were unknown, and the manner in which Peter was enabled to ascertain the exact quantities of hydrogen sulphide and carbon dioxide present in the waters at the fountain head exemplifies his resourcefulness in procuring accurate chemical results under the most unfavorable conditions.

The method used by him was to add to a measured volume of the water at the spring a solution of a chemical capable of acting at once upon the gas, forming with it an insoluble powder; then to seal the bottle and subsequently to determine in the laboratory the quantity of the precipitate formed in the water at the spring.

The hydrogen sulphide was fixed by means of a solution of arsenious acid in hydrochloric acid, and the carbon dioxide was similarly precipitated as calcium carbonate by an ammoniacal solution of calcium chloride.

A second analysis of the Lower Blue Lick waters was made by Peter in 1877. The object of his examination at this later date was to ascertain whether these waters had undergone any essential change in their character during the twenty-seven years since the first analysis, and to discover, if possible, the presence of elements more rarely occurring in waters. The second analysis developed the fact that the waters had suffered no material change since the time of the first analysis, and disclosed the presence of minute amounts of barium, strontium, and lithium, also notable quantities of borates and alkaline sulphides, the latter indicating that sulphur is present in these waters in at least two different conditions. The results of this analysis appear in the second column of Table 20.

According to a recent classification of mineral waters proposed by Haywood, the Lower Blue Lick water may be designated as a sodic, muriated, saline, alkaline (sulphide), borated (bromide, iodide), carbondioxated, sulphureted water.

The alkaline sulphide character of the Lower Blue Lick water is comparable with that of the water of the Stachelberg Spring in Switzerland, one of the famous healing springs of Europe. On account of its remarkable curative power, its waters have been prescribed by physicians ever since the latter part of the eighteenth century. The analytical results of an exhaustive study of the

Stachelberg Spring water, made in 1854 by Simmler,[a] are reproduced in the sixth column of Table 20. To simplify the comparison of the waters of these springs, the results obtained by Simmler are reduced to ionic form. Simmler observed that the quantity of sulphur in the form of hepatic sulphur, or alkaline sulphide, in the Stachelberg water is not constant, but varies within tolerably wide limits. For instance, he found that the sulphur present in the alkaline sulphides on four different occasions was, summer 1853, 57; winter 1853, 54; spring 1854, 63; summer 1854, 61 parts per million. The Stachelberg Spring water contains notable quantities of this sulphide sulphur, which makes this water still more powerful as a sulphur water; though the Stachelberg water contains more absorptive sulphur than has been observed in the Lower Blue Lick, the latter is far more highly mineralized and appears to have additional curative power on account of other saline constituents.

For several years past the supply of Blue Lick waters for shipment is reported to have been obtained from a spring on the south side of Licking River. In 1900 A. M. Peter made partial analyses of the waters obtained simultaneously from the Old Spring on the north bank and of the New Spring on the south bank of the river. The results of these analyses, recorded respectively in the third and fourth columns of Table 20, indicate that, although the waters from both springs appear to be somewhat weaker than the waters of the Old Spring were in 1877, they still possess the same general characteristics, even in regard to the presence of alkaline sulphides, by which both samples were colored slightly yellow. Although the alkaline sulphides are more permanent than hydrogen sulphide in water, they decompose gradually unless the water is kept in tightly sealed bottles. In the fifth column of the same table is reproduced an analysis of a sample of the Lower Blue Lick water which had been kept about three years in a wooden barrel.[b] The results of this analysis demonstrate the inadequacy of wooden containers to preserve the alkaline sulphides for any great length of time, for at the time of the analysis every vestige of hydrogen sulphide and of the alkaline sulphides had disappeared, indicating that during the storage in wood the water had wholly lost the medicinal qualities which are peculiar to an alkaline sulphide water. The Blue Lick waters are applicable to the treatment of so many diseases that they have a wide range of usefulness.

[a] Simmler, Theodor, Comprehensive study of the Stachelberg Spring water: Jour. prak. Chemie, old ser., vol. 71, 1857, p. 1.

[b] Haywood, J. K., Mineral waters of the United States: Bureau of Chemistry, U. S. Dept. of Agri., Bull. 91, p. 50.

TABLE 20.—*Composition of water of Lower Blue Lick Springs, Kentucky, and of Stachelberg Spring, Switzerland.* [a]

[Parts per million.]

	Old Spring, north bank of Licking River.			New Spring, south bank of Licking River.		Stachelberg Spring (Simmler 1854).
	R. Peter, 1850.	R. Peter, 1877.	A. M. Peter, 1900.	A. M. Peter, 1900.	J. K. Haywood, 1905.	
Silica (SiO_2)	14	12	....	....	18	9.7
Iron (Fe)	[b] 5.8 (Fe and Al)	[b] 3.8 (Fe and Al)	....	....	1	....
Aluminum (Al)			....	....		1
Manganese (Mn)	Trace.	....	....	....	2.6	....
Calcium (Ca)	317	307	302	308	343	40
Magnesium (Mg)	135	133	132	133	179	44
Barium (Ba)	....	.1	....	....	....	....
Strontium (Sr)	....	.5	....	....	....	....
Sodium (Na)	3,289	3,324			2,718	80
Potassium (K)	80	98	2,746 (Na, K, Li)	2,812	81	1.9
Lithium (Li)	....	1			1.8	.6
Ammonium (NH_4)	....	....	....	....	.8	....
Bicarbonate radicle (HCO_3)	473	434	....	....	412	278
Sulphate radicle (SO_4)	474	390	413	380	340	100
Nitrate radicle (NO_3)	....	....	....	....	2.2	....
Nitrite radicle (NO_2)	....	....	....	....	Trace.	....
Borate radicle (B_4O_7)	....	23	....	....	Small.	....
Phosphate radicle (PO_4)	Trace.	Trace.	....	....	Trace.	3.6
Chlorine (Cl)	5,462	5,558	4,925	5,120	4,900	3.4
Bromine (Br)	3.4	17	....	....	23	
Iodine (I)	.6	.3	....	....	.14	....
Alkaline sulphides (S)	....	13	Present.	Present.	([c])	58
Thiosulphate radicle (S_2O_3)	....	....	....	....	....	12
Organic and loss	282	457	427	377	1.4	84
Total solids	10,296	10,558	9,026	9,315	9,022	580
Hydrogen sulphide (H_2S)	39	28	34	16	([c])	2.2
Carbon dioxide (CO_2)	355	([c])	....	....	257	114

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.
[b] Includes ferric and aluminic oxides and calcium phosphate.
[c] Not reported.

UPPER BLUE LICK SPRINGS.

The waters of the Upper Blue Lick Springs, which are also situated in Nicholas County, closely resemble the waters of Lower Blue Lick. They are recommended as remedies for the same diseases as those for which the Lower Blue Lick water is prescribed. They are extensively sold.

TABLE WATERS.

In the territory covered by this investigation there are numerous other sources of wholesome water which might be made of commercial importance. Pure, safe water is wanted for table use in large cities, where a widespread prejudice exists against the city waters supplied from sewage polluted streams; and country districts, remote from congested population, are naturally regarded as the most favorable localities from which daily supplies of such water may be obtained. The ordinary pure spring waters of the Blue Grass, being but slightly mineralized, are well adapted for use as table waters, for, besides being palatable, they contain a moderate quantity of various saline ingredients conducive to health, and have therefore a distinctly dietetic value.

The Anita Spring and Royal Magnesian Spring in Oldham County have already acquired considerable reputation as table waters in cities where their waters have been put upon the market. The composition of the waters of these two springs is given in the following table:

TABLE 21.—*Analyses of table waters from Anita and Royal Magnesian springs.* [a]

[Parts per million.]

	Anita (L. D. Kastenbein).	Royal Magnesian (A. M. Peter).
Silica (SiO_2)	16	7.6
Iron (Fe)	.4	.6
Aluminium (Al)	.6	....
Calcium (Ca)	35	48
Magnesium (Mg)	21	28
Strontium (Sr)	....	Trace.
Zinc (Zn)	....	.3
Sodium and potassium (Na+K)	2.9	1.4
Lithium (Li)	....	Trace
Carbonate radicle (CO_3)	110	142
Borate radicle (B_4O_7)	....	Trace
Phosphate radicle (PO_4)	Trace.	....
Sulphate radicle (SO_4)	Trace.	9.4
Chlorine (Cl)	2.8	2.1
Total solids	191	242

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

The following waters are mentioned merely as representative of such as might find a ready market in the cities as table waters. Many others might be included in the list. The numbers at the left correspond with the numbers in Table 22, where the composition of these waters is given.

Possible table waters in the Blue Grass region.

1, 2, and 3. Springs, Anderson County.
4. Riddell well, Boone County.
6. Clark spring, Bourbon County.
12. Furniture Mfg. Co. well, Carroll County.
21. Belmont spring, Fayette County.
29. Wilson well, Fayette County.
32. Harkness well, Fayette County.
38. Madden well, Fayette County.
50. Cox well, Harrison County.
52. Kenney well, Jessamine County.

Table waters can be bottled and shipped to the cities as easily as country milk. By taking advantage of the preference in the cities for pure country waters, the owners of many Blue Grass spring waters could build up a city trade that would yield satisfactory returns.

TABLE 22.—*Analyses of*

[Parts per

No.	County.	Locality.	Owner.	Source.	Analyst.	Date.	Depth of well (feet).
1	Anderson	Tyrone		Spring	Palmer	Oct. 15, 1906	
2	Do	do		do	do	do	
3	Do	do		do	do	do	
4	Boone	Hebron	James Riddell	Well	do	July 31, 1906	30
5	Do	Petersburg	Boone County Distillery.	do	do	Nov. —, 1906	110
6	Bourbon	Paris	W. H. Clark	Spring	do	Sept. 5, 1906	
7	Do	do	Ben Woodford	Well[a,b]	do	Nov. —, 1906	50
8	Bracken	Augusta	Electric light plant	do	do	Aug. 26, 1906	96
9	Do	do	Steam laundry	do	do	do	80
10	Do	Brooksville	Cummings Brothers	do	do	do	75
11	Campbell	Newport	Old 76 Distillery	do	R. B. Dole	Apr. 8, 1907	1,250
12	Carroll	Carrollton	Carrollton Furniture Manufacturing Co.	do	Palmer	Sept. 15, 1906	98
13	Do	Sanders	Mrs. Ella Jacobs	Spring[a,c]	do	do	
*14	Clark	Kiddville	J. E. Groves	Spring(?)	R. Peter	July —, 1884	
15	Do	Pine Grove	Yunger Jones	Well	Palmer	Nov. —, 1906	90
16	Do	Winchester	Reliance Manufacturing Co.	do[a,b]	do	do	55
17	Fayette	Chilesburg	Dr. W. H. Felix	do[a,b,d]	do	Nov. 24, 1906	75
*18	Do	Donerail	G. F. Bateman	do[e]	A. M. Peter	—— —, 1898	125
19	Do	East of Hickman.	Fayette County Farm	Spring[b]	Palmer	Nov. 16, 1906	
20	Do	Lexington	Ed. Kane	Well[a,b]	do	Nov. 9, 1906	76
21	Do	do	August Belmont	Spring	do	do	
22	Do	do	Boice Grogan Lumber Co.	Well	do	Oct. 24, 1906	116
*23	Do	do	Cincinnati Southern Ry.	do	R. Peter	—— —, 1884	80-90
*24	Do	do	do	Well (same).	do	—— —, 1884	153
*25	Do	do	do	do	do	—— —, 1885	800
26	Do	do	W. W. Estill	Well[b]	Palmer	Nov. 22, 1906	40
27	Do	do	R. C. Estill	do[a,b,d]	do	Nov. 25, 1906	225
28	Do	do	Wm. Fields	Spring[e]	do	Nov. 19, 1906	
29	Do	do	Dr. J. W. Wilson	Well[a,b,d]	do	Nov. 6, 1906	126
30	Do	do	J. B. Haggin	do[a,b]	do	Nov. 25, 1906	198
31	Do	do	H. P. Headley	do	do	Nov. 15, 1906	50
32	Do	do	L. V. Harkness	Spring[b]	do	Nov. 2, 1906	
33	Do	do	J. H. Hisle	Well[d,b]	do	Nov. 22, 1906	
34	Do	do	Mrs. Columbia Innes	do[a,b]	do	Nov. 18, 1906	225
35	Do	do	Mrs. E. L. Israel	do[d]	do	Nov. 2, 1906	28
36	Do	do	do	do	do	do	28
37	Do	do	Lexington Brewing Co.	do	do	Oct. 23, 1906	150
38	Do	do	J. E. Madden	do.[a]	do	Oct. 2, 1906	
39	Do	do	Old Tarr Distillery	Spring	do	Nov. —, 1906	
40	Do	do	Jas. E. Pepper Distillery.	do	do	Nov. 18, 1906	
41	Do	do	Jas. E. Pepper estate	Well	do	Oct. 22, 1906	105
42	Do	do	Wm. Pettit	do	do	Nov. 9, 1906	65
*43	Do	do	Phoenix Hotel Co	do.[b]	A. M. Peter	June 26, 1900	
44	Do	do	Mrs. J. Will Sayre	do.[b]	Palmer	Nov. —, 1906	168
45	Do	do	W. H. Means	Spring	do	Aug. 23, 1906	
46	Fleming	Flemingsburg	Henderson & O'Bannon ice factory.	Well[a,d]	do	Nov. —, 1906	102
*47	Franklin	Frankfort	Old Crow Distillery (W. A. Gaines & Co.).	do.[d]	A. Lasche	Aug. 4, 1903	790
48	Do	do	do	do.[d]	R. B. Dole	Apr. 8, 1907	790
49	Gallatin	Warsaw	Warsaw furniture factory.	do	Palmer	Aug 10, 1906	90
50	Harrison	Cynthiana	W. M. Cox	do	do	July 26, 1906	50

* Computed from hypothetical combinations.
a Trace of the borate radicle (B_4O_7).
b Trace of strontium (Sr).
c Much hydrogen sulphide (H_2S).
d Hydrogen sulphide (H_2S) present.
e No hydrogen sulphide (H_2S).
f Hydrogen sulphide (H_2S), 4.5 parts.

waters in Blue Grass region.

million.]

Depth to water (feet).	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Lithium (Li).	Bicarbonate Radicle (HCO_3).	Carbonate Radicle (CO_3).	Sulphate Radicle (SO_4).	Chlorine (Cl).	Total solids.	Geologic formation.	No.
......	9.8	Trace.	0.8	89	5.4	4.3		....	280	0.0	16	3.5	289	Lexington.	1
......	6.2	Trace.	1	93	6.1	4.7		....	283	......	25	5	296	Highbridge	2
......	7	Trace.	1	90	7.2	6.9		....	303	7.4	11	3.5	298	.....do.....	3
......	13	Trace.	10	50	3.2	60		....	274	.0	10	21	318	Glacial.....	4
90	8	Trace.	.6	76	25	9.4		Trace.	294	.0	41	5	330	Alluvium..	5
......	1.2	Trace.	1.6	32	9.1	27		Trace.	191	.0	9.5	2	193	Lexington.	6
40	10	1.3	.5	238	36	2,990		Trace.	321	21	12	5,415	8,961	.....do.....	7
50	10	....	.1	149	17	21		Trace.	451	.0	53	44	493	Alluvium..	8
60	17	....	.4	101	14	17		Trace.	359	.0	14	26	350	.....do.....	9
25	6.4	Trace.	.3	76	38	169		Trace.	328	.0	88	250	857	Winchester	10
......	14	.3	4	360	182	3,700		....	581	.0	456	6,400	11,680	St. Peter...	11
......	11	Trace.	.5	90	27	14		Trace.	382	.0	27	19	390	Alluvium..	12
......	20	Trace.	.8	132	65	1,570		....	460	.0	349	2,560	5,379	Winchester	13
......	10	....	....	1,108	971	315	22	2.2	......	243	6,622	139	9,430	Chattanooga.	*14
80	5.8	1	.3	46	20	25		Trace.	242	.0	23	14	259	Lexington.	15
......	11	2.8	1	271	188	2,813	63	Trace.	374	.0	85	6,700	11,770	Winchester (?).	16
......	23	1.9	3.9	81	45	421		Trace.	356	.0	21	803	1,583	Lexington (?).	17
......	......	....	....	1,433	791	10,280	188	3.7	......	......	302	20,610	33,667	Lexington.	*18
......	7.2	Trace.	4.2	91	2.1	7.7		....	254	.0	19	18	350	.....do.....	19
......	4.8	Trace.	.6	60	14	22		Trace.	236	.0	60	6.2	295	.....do.....	20
......	6.2	Trace.	.5	96	6.7	6.4		Trace.	292	.0	29	9.2	336	.....do.....	21
20, 50	6.2	Trace.	2	98	20	12		Trace.	357	.0	40	17	394	.....do.....	22
......	36	Trace.	....	20	4.4	87	5.3	....	......	102	41	38	332	.....do.....	*23
......	9.4	....	....	21	18	92	9.2	....	......	124	32	74	379	.....do.....	*24
......	4	1.5	....	47	32	64	19	....	......	147	46	91	451	Highbridge	*25
35	7.8	Trace.	.4	79	37	26		....	369	.0	66	24	424	Lexington.	26
......	8.6	2.4	.0	114	78	1,705		Trace.	390	.0	11	2,950	5,360	.....do.....	27
......	9.4	Trace.	2	58	4.7	6.5		Trace.	170	.0	16	10	219	.....do...—	28
126	6	.8	1.6	32	20	61		Trace.	259	5.9	28	31	335	.....do.....	29
......	8.8	.7	1.7	29	12	340		Trace.	149	.0	12	540	1,035	Lexington (?).	30
......	6	Trace.	2	54	23	19		Trace.	235	7.7	38	13	284	Lexington.	31
......	5.8	Trace.	1.5	74	5.1	4		Trace.	236	.0	8.5	4	266	.....do.....	32
......	8.4	1.7	....	44	16	27		Trace.	220	.0	24	30	291	.....do.....	33
......	5	1.4	3	95	63	241		Trace.	632	.0	267	160	1,343	Lexington (?).	34
......	11	4.5	.7	51	34	95		Trace.	376	.0	62	73	577	Lexington.	35
......	5.4	1	.0	86	9.1	28		Trace.	290	.0	58	14	376	.....do.....	36
11, 147	7.6	1	.0	96	8.8	17		....	302	.0	46	5	428	.....do.....	37
......	4.6	Trace.	.5	65	20	55		Trace.	312	.0	22	57	482	.....do.....	38
......	6	1.1	.0	105	11	18		....	333	.0	43	23	456	.....do.....	39
......	9.4	Trace.	1.3	76	5.7	4.8		....	242	.0	13	5	255	.....do.....	40
95	5.4	1	1.4	86	16	7		....	297	.0	42	8.5	343	.....do.....	41
65	5.4	Trace.	1.3	49	20	6.8		Trace.	208	.0	39	7.1	243	.....do.....	42
......	8	2.8	....	92	34	67		....	......	166	95	104	640	.....do.....	*43
48, 168	3.8	1	1.6	86	6.7	4.4		Trace.	292	.0	4.6	6.7	315	.....do.....	44
......	22	4.2	1.6	41	20	32		Trace.	236	.0	41	18	361	Ohio.......	45
65	7.8	1	.2	43	24	263		Trace.	349	.0	76	284	910	Maysville..	46
......	......	1.1	....	57	28	410	......	....	65	......	195	620	1,610	St. Peter(?)	*47
......	12	.1	....	54	26	501		....	305	.0	204	640	1,596	.....do.....	48
80	13	Trace.	.6	82	19	19		Trace.	345	12	16	5	336	Alluvium..	49
45	12	Trace.	3	114	28	23		....	351	.0	76	64	540	Lexington.	50

TABLE 22.—*Analyses of water*

No.	County.	Locality.	Owner.	Source.	Analyst.	Date.	Depth of well (feet).
51	Harrison	Leesburg	Jas. Crombie	Well	Palmer	July 26, 1906	76
52	Jessamine	Nicholasville	C. A. Kenney	do	do	Oct. 13, 1906	75
53	Kenton	Covington	Cincinnati Ice Co	do. [a]	do	July 11, 1906	200
54	Do	Independence	Dr. F. J. Metcalf	do	do	July 13, 1906	45
*55	Madison	Clear Creek Station.	John R. Proctor	do	R. Peter	—— —, 1880	126
*56	Do	Paint Lick	J. H. Spilman	do	do	—— —, 1858	18
57	Mason	Maysville	R. A. Carr	do	Palmer	Aug. 27, 1906	108
58	Do	Sardis	Town	do. [b] [c]	do	Oct. —, 1906	300
59	Nicholas	Carlisle	Carlisle Milling Co	do. [c]	do	Aug. 13, 1906	155
60	Do	do	City	do	do	do	35
61	Owen	Owenton	Thomas & Ruth	do. [c]	do	Sept. 13, 1906	17
62	Pendleton	Butler	Doctor Huddleston	do	do	Sept. 7, 1906	30
63	Do	Falmouth	H. W. Faber	do	do	July 21, 1906	39
64	Do	Morgan	S. F. Fornash	do	do	July 24, 1906	37
65	Robertson	Mount Olivet	John Zoller	do	do	Aug. 10, 1906	103
66	Scott	Georgetown	Judge James Askew	do	do	Oct. 4, 1906	70
67	Do	Sadieville	City	do. [b]	do	Oct. 1, 1906	188
68	Do	Stamping Ground.	J. L. Turnbull	Spring [c]	do	Oct. —, 1906	......
69	Shelby	Shelbyville	T. J. Ramsay	do	do	Sept. 18, 1906	......
70	Trimble	Bedford	Mrs. Mary J. Bell	Well	do	do	22
71	Do	Milton	Richwood Distillery	do	do	Nov. —, 1906	96
72	Woodford	Mortonsville	E. Boston	do. [c]	do	Oct. 10, 1906	51
73	Do	Nonesuch	B. Bond	do. [a]	do	do	40
74	Do	Versailles	Lucas Brodhead	do	do	Oct. 2, 1906	63

* Computed from hypothetical combinations.
[a] Hydrogen sulphide (H_2S) present.
[b] Trace of the borate radicle (B_4O_7
[c] Trace of strontium (Sr).

in Blue Grass region—Continued.

Depth to water (feet).	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Lithium (Li).	Bicarbonate Radicle (HCO_3).	Carbonate Radicle (CO_3).	Sulphate Radicle (SO_4).	Chlorine (Cl).	Total solids.	Geologic formation.	No.
68	17	5	2.1	80	45	14		Trace.	361	.0	104	14	479	Lexington.	51
62	6.8	Trace.	1.1	102	19	30		Trace.	315	.0	82	38	469	.....do.....	52
65	9.6	Trace.	.8	130	16	16		....	415	.0	49	25	479	Alluvium..	53
16	13	Trace.	4.8	110	34	35		Trace.	185	.0	184	105	669	Maysville..	54
......	6	....	....	72	14	61	56	....	262	.0	38	89	466	Upper Cincinnatian.	*55
......	44	Trace.	....	22	4.2	311	33	....	363	.0	97	276	966	Lower Silurian.	*56
......	14	Trace.	1.4	116	17	63		Trace.	398	.0	99	50	662	Alluvium..	57
......	9.2	3.8	.0	160	89	3,260		Trace.	206	14	54	6,800	12,106	Winchester (?)	58
150	5	9.8	3.7	107	21	765		Trace.	454	.0	3.3	1,800	3,222	Winchester	59
......	10	Trace.	2.1	184	36	29		....	377	.0	176	130	875	.....do.....	60
......	17	Trace.	2.2	200	24	127		Trace.	478	.0	105	264	1,202	Maysville..	61
......	9.8	Trace.	2	71	2.8	26		....	216	.0	35	23	296	Alluvium..	62
......	15	Trace.	3.4	122	41	39		....	490	.0	30	88	748		63
......	15	Trace.	12	121	35	37		....	430	.0	75	73	703	Maysville..	64
80	11	Trace.	.8	32	17	204		....	539	.0	136	9.6	720		65
70	8	Trace.	1.5	73	14	6.5		....	246	.0	39	10	373	Lexington.	66
......	4.8	.5	2.5	48	30	280		Trace.	328	29	8.9	396	1,050	Winchester	67
......	8.8	Trace.	1.6	69	4.4	3.8		Trace.	221	.0	9	4.7	222	Lexington.	68
......	16	Trace.	.7	264	31	398		Trace.	600	.0	28	802	1,914	Maysville..	69
......	17	Trace.	.4	91	20	37		....	337	.0	11	71	465	Panola.....	70
±65	6	Trace.	.8	76	18	6.2		Trace.	294	.0	22	9.3	311	Alluvium..	71
51	7.8	Trace.	.7	59	22	54		Trace.	251	.0	87	40	439	Lexington.	72
......	6.2	1	....	42	16	66		Trace.	248	.0	26	60	351	Highbridge	73
50	6.4	Trace.	1.2	74	8.6	7.7		....	242	.0	28	7.7	258	Lexington.	74

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