Cretaceous Aquifers in the Mississippi Embayment

By E. H. BOSWELL, G. K. MOORE, L. M. MacCARY, *and others*

With discussions of QUALITY OF THE WATER

By H. G. JEFFERY

WATER RESOURCES OF THE MISSISSIPPI EMBAYMENT

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CRETACEOUS AQUIFERS IN THE MISSISSIPPI EMBAYMENT

By E. H. Boswell, G. K. Moore, L. M. MacCary, and others

ABSTRACT

To define and describe the many water-bearing units in the Mississippi embayment, these units have been grouped by geologic age into pre-Cretaceous, Cretaceous, Tertiary, and Quaternary aquifers.

The pre-Cretaceous aquifers are in Paleozoic rocks and primarily supply ground water near the periphery of the embayment where the Cretaceous aquifers are thin. The area of use of these aquifers is about 6,500 square miles. Defining the area of potential use and delineating the individual aquifers of pre-Cretaceous age are beyond the scope of the present study.

The aquifers of Cretaceous age supply water in an area of about 30,000 square miles and are potential sources of supply in an additional 15,000 square miles where many of the units contain water having less than 1,000 parts per million dissolved solids. The more extensive aquifers occur in the eastern and northern parts of the embayment and are in the Ripley, Eutaw, and Gordo Formations.

Generally the aquifers are not intensively developed; the total withdrawal and flow from them is about 90 million gallons per day. In many places only the shallowest aquifer is used, although one or more deeper aquifers are present.

The aquifers are recharged primarily by precipitation on the outcrop. Because the aquifers are saturated, most of the streams crossing the Cretaceous outcrop area receive water from the aquifers during periods of no precipitation; therefore, most of the streams are perennial. This condition will continue until large ground-water withdrawals in areas close to the outcrop of the aquifers cause the hydraulic gradient to steepen sufficiently to make additional water move downdip rather than discharge into streams.

Analysis of test data shows that the hydrologic characteristics of the Cretaceous aquifers vary from aquifer to aquifer and from place to place within each aquifer. The aquifers in the Tuscaloosa Group are the most productive.

The temperature of the water from the Cretaceous aquifers ranges from about 60° to 95° F. Water from most of the aquifers is of good chemical quality; it is a calcium or sodium bicarbonate type, the calcium bicarbonate type being predominant in the outcrop area and at shallow depths. Iron is the most troublesome chemical constituent; the higher iron concentrations occur in the outcrop areas and at shallow depths. As the water moves downdip, it changes to a sodium bicarbonate type, and the iron content decreases. The Trinity Group and Ripley Formation yield calcium magnesium bicarbonate water locally, and the Eutaw Formation yields sodium chloride water in part of Alabama and Mississippi. Both the Coffee Sand and the Ozan Formation yield moderately hard water. Water from the Ozan Formation generally has a dissolved-solids content of more than 1,000 ppm and is used mostly in areas where no other water is available.

Most of the general water-level declines in the Cretaceous aquifers are the result of unrestricted flow from wells and of municipal and industrial withdrawals and are not indicative of overdevelopment of the aquifers. As additional supplies are developed, the water levels will continue to decline, and many of the wells which now flow will then have to be pumped.

INTRODUCTION

The future economy of the Mississippi embayment (fig. 1) is largely dependent upon wise utilization and management of the region's water resources. Proper development, use, and conservation of these water resources can be achieved only after the hydrologic system has been defined and the manner in which the system operates has been determined.

Within the embayment, aquifers (water-bearing units) in geologic formations ranging in age from Ordovician to Quaternary are used as sources of water supply. For the purpose of defining and describing these aquifers, they are grouped by geologic age into pre-Cretaceous, Cretaceous, Tertiary, and Quaternary aquifers. Many of these aquifers crop out within the areas shown on figure 2.

This report defines and describes the Cretaceous aquifers where they contain water having a dissolved-solids content of less than 1,000 ppm (parts per million). It also includes a brief description of the pre-Cretaceous aquifers. The area of study for the report is shown in figure 3, which delineates the areas of outcrop, use, and potential use of the Cretaceous aquifers. Pre-Cretaceous aquifers yield water to numerous wells near the periphery of the embayment where Cretaceous aquifers are thin and do not yield desired quantities of water.

The Cretaceous System is subdivided into the Lower Cretaceous Series and the Upper Cretaceous Series.

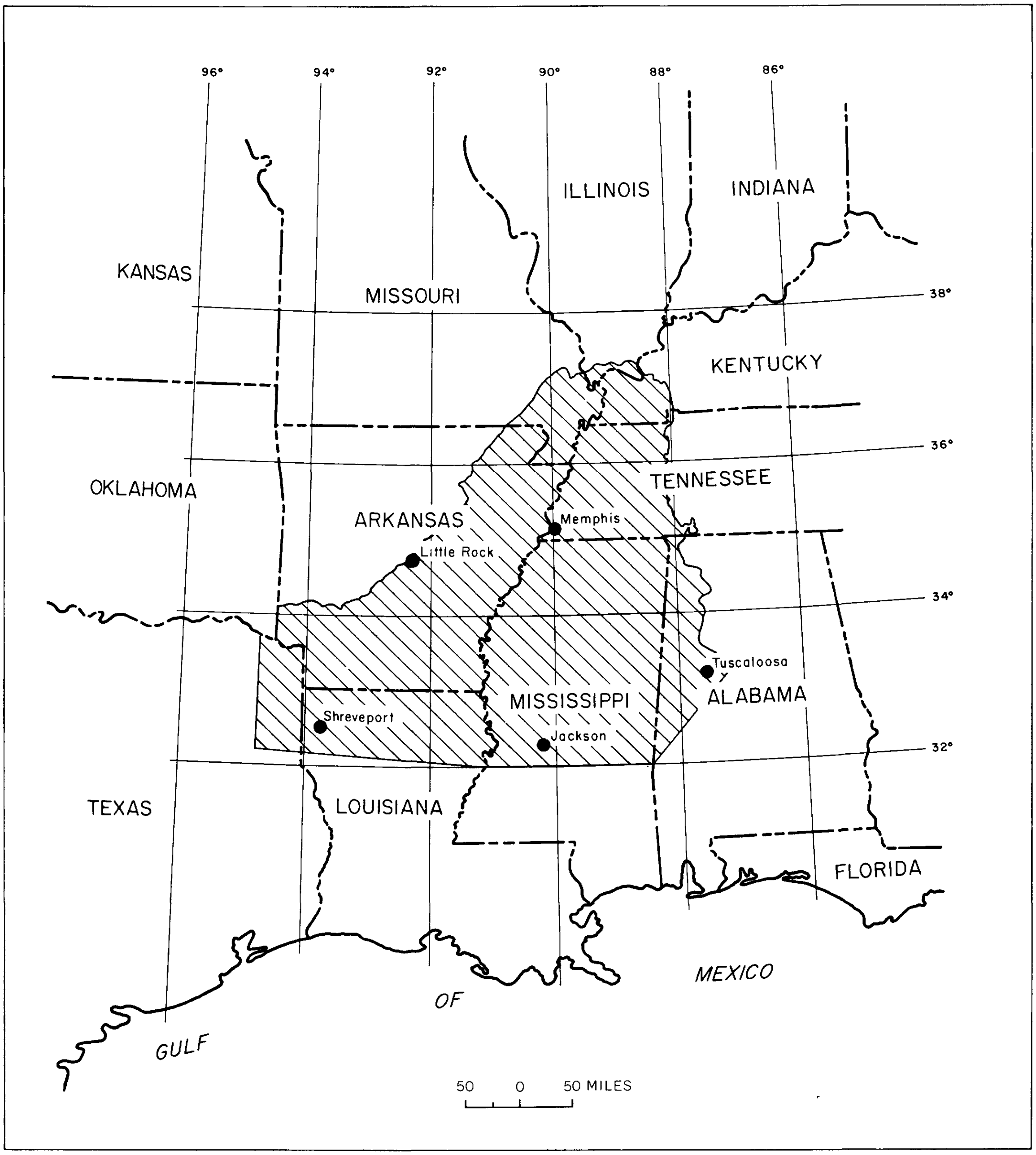

FIGURE 1.—Area of embayment study.

Lower Cretaceous deposits in the embayment crop out only in southwestern Arkansas and underlie only the southern part of the region (fig. 8). Upper Cretaceous deposits crop out or are covered by thin Quaternary deposits near the periphery of the embayment (fig. 3), and they underlie most of the region.

The depth to the top of the Cretaceous System ranges from 0 feet in the outcrop area to more than 7,000 feet near the axis of the embayment at the southern limit of the region. The configuration of the top of the Cretaceous System in the subsurface is shown in figure 4. The thickness of the Cretaceous System is shown in figure 5. The stratigraphic positions and the relative thicknesses of the various geologic units are shown by five geologic sections. (See pl. 1; table 1, p. C7.) The units generally dip toward the axis of the embayment except in the southern part of the region, where they dip toward the Gulf of Mexico.

Southwestern Arkansas is the only area in the Mississippi embayment where fresh ground water is obtained from wells tapping Lower Cretaceous deposits, although analysis of electric logs indicates that the deposits probably contain fresh water in east-central Mississippi and the adjacent part of Alabama. The wells in southwestern Arkansas tap aquifers of the Trinity Group. In Mississippi and Alabama the Lower Cretaceous deposits are not differentiated.

Wells in Alabama, Mississippi, Tennessee, Kentucky, Illinois, Missouri, Arkansas, and Texas obtain fresh water from aquifers in the Upper Cretaceous Series. Table 2 (p. C7) shows the stratigraphic columns used by the U.S. Geological Survey for the Upper Cretaceous Series and the groups or formations that are fresh-water aquifers or include fresh-water aquifers.

Data used in the preparation of the contour maps, thickness maps, maps showing percentage of sand, and maps showing the areal extent of fresh water were obtained from interpretation of electric logs of water wells and oil-test wells. Chemical analyses were used to verify the areas of fresh and mineralized water. Drillers' logs were used in areas where electric logs were not available, and microscopic and micropaleontologic examinations of well cuttings were made to verify the geologic interpretations. Maps showing percentage of sand indicate generally the water-bearing potential of each unit, the higher percentage being associated with the more favorable areas. Maps showing isotransmissibilities would be more useful, but the data necessary to prepare them are not available.

The area of use of each aquifer is delimited by existing water-supply wells. The area of potential use is that area where the aquifer apparently contains water having a dissolved-solids content of less than 1,000 ppm, but no water wells have been drilled into it. In southwestern Arkansas, northeastern Texas, and east-central Mississippi and adjoining part of Alabama, the area of

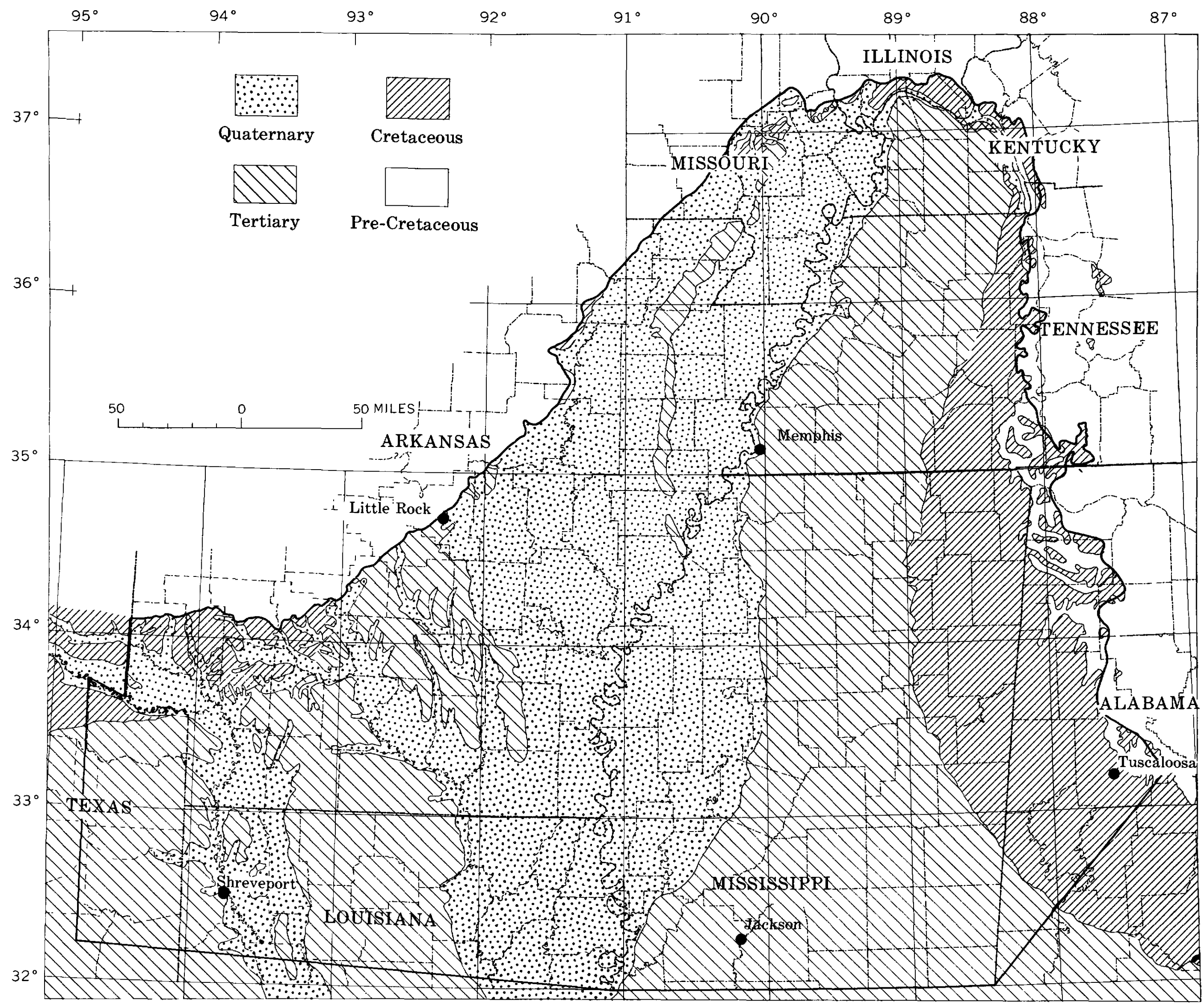

FIGURE 2.—Generalized geology of the Mississippi embayment.

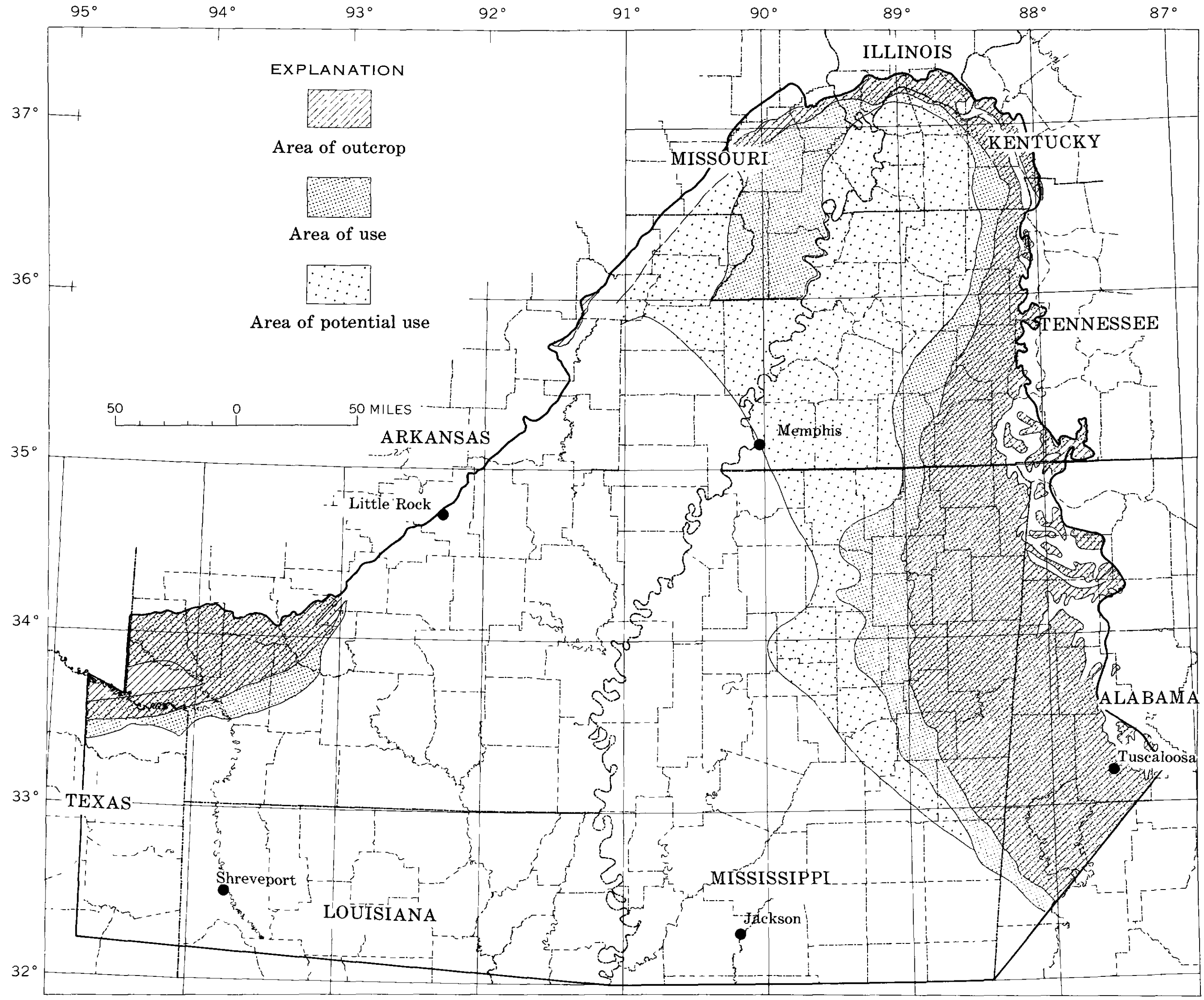

FIGURE 3.—Areas of outcrop, use, and potential use of Cretaceous aquifers.

use of some aquifers includes areas where the mineralization of the water exceeds 1,000 ppm dissolved solids.

Temperatures of water from wells in the Cretaceous aquifers range from 60° to 95°F. The temperature increases about 1°F for each 80 feet of depth (fig. 6).

This investigation and the preparation of the report were under the direction of E. M. Cushing. Fieldwork and data synthesis and analysis for the report were by J. G. Newton for Alabama, R. L. Hosman for Arkansas, L. M. MacCary for Kentucky, Illinois, and Missouri, E. H. Boswell for Mississippi, G. K. Moore for Tennessee, and A. T. Long for Texas. Lithologic and micropaleontologic studies were by S. M. Herrick, and interpretation of quality-of-water data was by H. G. Jeffery.

The cooperation of the following State officials and members of their staffs is gratefully appreciated: Philip E. LaMoreaux, State Geologist, Geological Survey of Alabama; Norman F. Williams, Geologist-Director, Arkansas Geological and Conservation Commission; John C. Frye, Chief, Illinois Geological Survey; William C. Ackermann, Chief, Illinois State Water Survey; Wallace W. Hagan, Director and State Geologist, Kentucky Geological Survey; Frederic F. Mellen, Director and State Geologist, Mississippi Geological, Economic, and Topographical Survey; Thomas R. Beveridge, Director and State Geologist, Missouri Geological Survey; William D. Hardeman, State Geologist, Tennessee Division of Geology; and Joe D. Carter, Chairman, Texas Water Commission. These officials furnished geologic and hydrologic information, many electric logs, and sets of well cuttings for this study. Pumping and water-level information supplied by Carloss Well

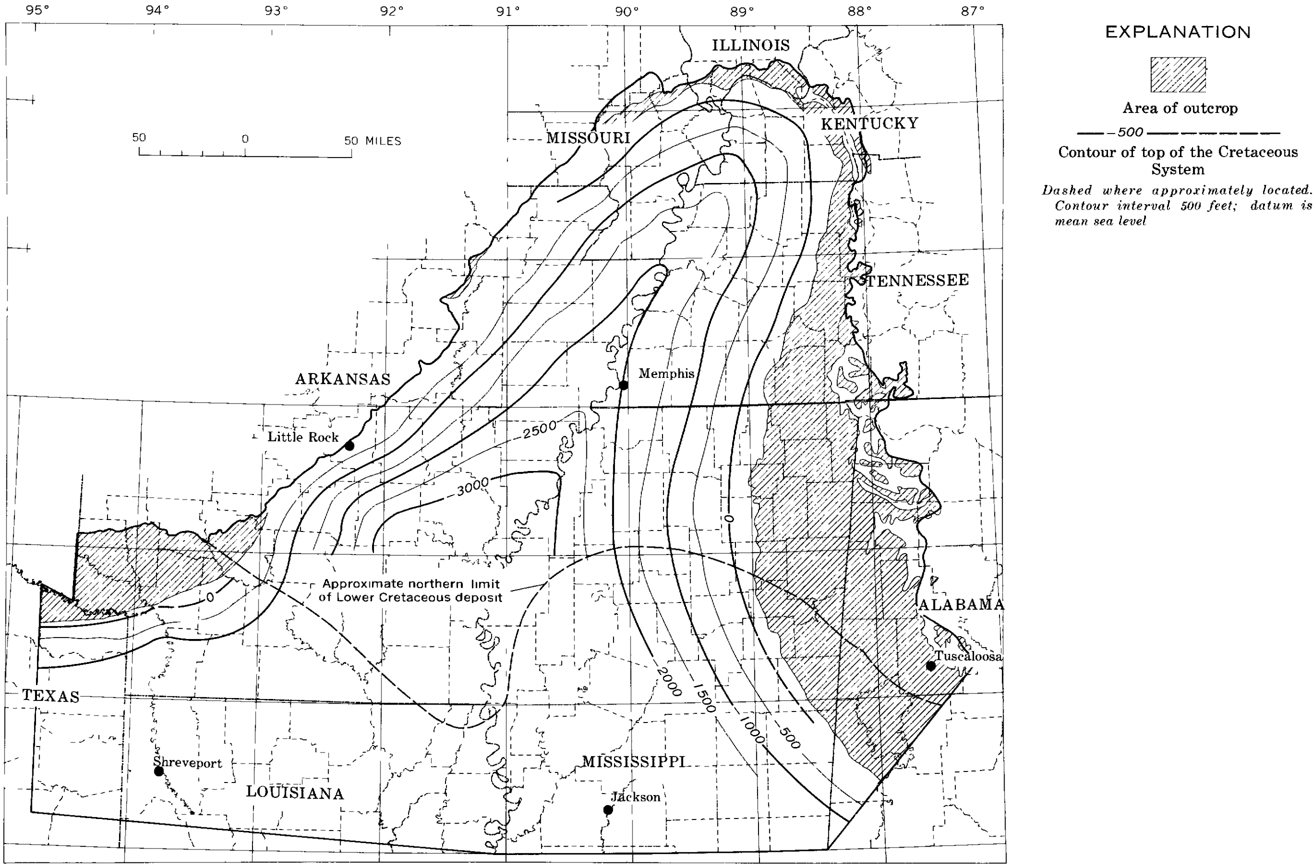

FIGURE 4.—Areas of outcrop and configuration of the top of the Cretaceous System.

Supply Co., Layne-Arkansas Co., and Layne-Central Co., are appreciated.

PRE-CRETACEOUS AQUIFERS

The pre-Cretaceous aquifers are in consolidated Paleozoic rocks which crop out around the edge of the Mississippi embayment (fig. 2). They range in age from Ordovician to Pennsylvanian. These formations are truncated in the subsurface, and Cretaceous beds overlie progessively older rocks toward the center of the Pascola arch (Grohskopf, 1955, p. 25) in southeastern Missouri and northwestern Tennessee. The eroded upper surface of the Paleozoic rocks slopes toward the axis of the embayment at an average of about 35 feet per mile.

The Paleozoic formations consist chiefly of limestone and chert, but sandstone and shale units compose the younger strata. The Ordovician rocks in the subsurface generally are gray to brown hard fine-grained limestones. The Silurian limestones are generally gray or green and are usually soft. Both Devonian and Lower Mississippian formations are predominantly gray limy cherts. Upper Mississippian and Pennsylvanian units consist of alternating sequences of limestone, shale, and sandstone.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Paleozoic aquifers are recharged in the outcrop areas, most of which are outside the embayment. The water moves downdip and probably is discharged by vertical leakage into overlying Cretaceous aquifers. Data are not available to define adequately the piezometric surface of the Paleozoic aquifers. Flowing wells have been obtained, however, in Henderson County, Tenn., southern Pulaski County, Ill., New Madrid and Mississippi Counties, Mo., and some lowland areas in Alabama and Mississippi.

Pumpage from the Paleozoic rocks in the embayment is about 10 mgd (million gallons per day). Data are not available to estimate discharge from flowing wells in the region.

AQUIFER CHARACTERISTICS

Paleozoic aquifers yield sufficent amounts of water for domestic use in most of the area where they occur at shallow depths beneath the Cretaceous deposits. Moderate or large quantities of water are difficult to obtain from formations other than those of Devonian and Early Mississippian age. Wells yielding 200–1,500 gpm (gallons per minute) have been developed in De-

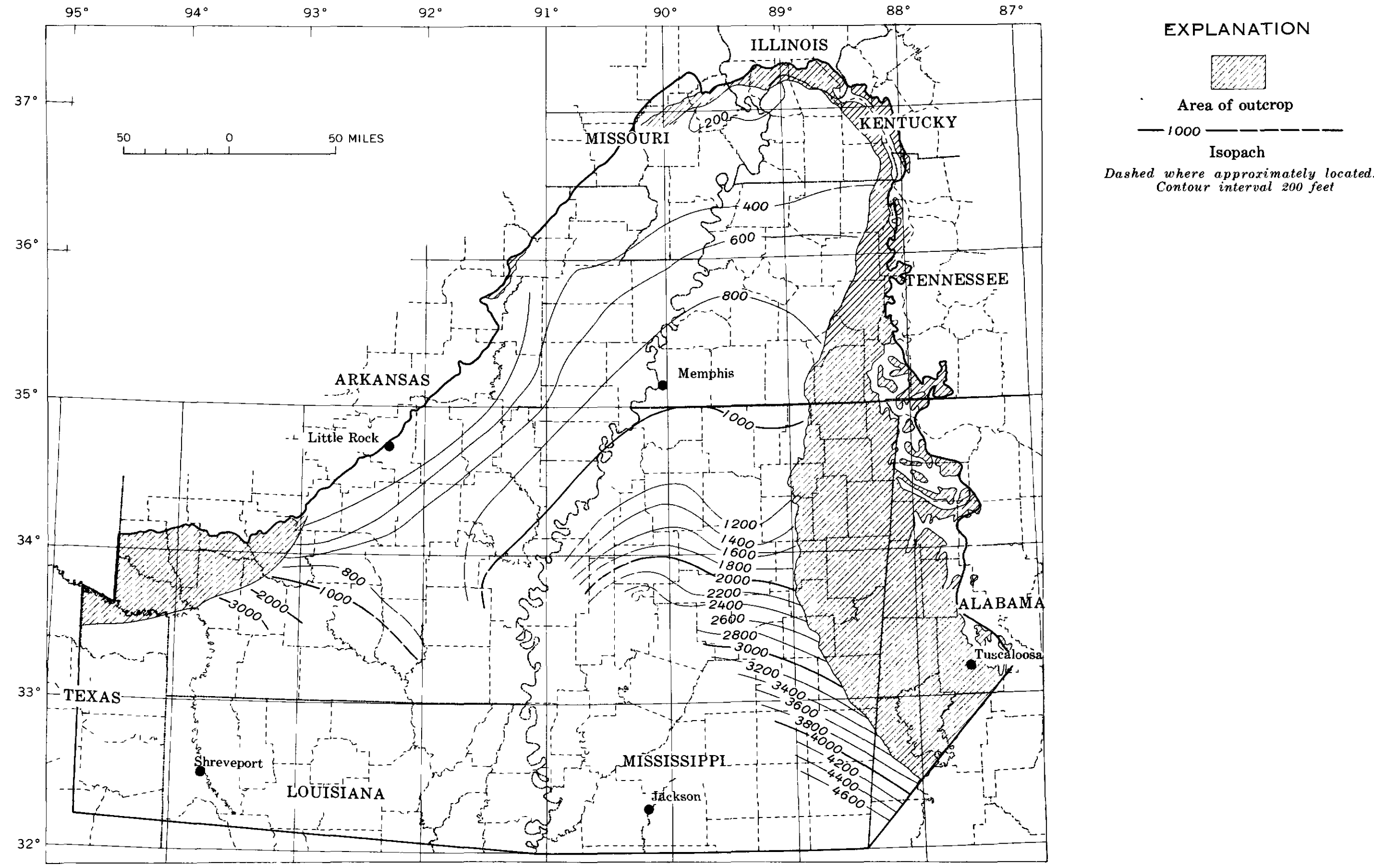

FIGURE 5.—Area of outcrop and thickness of the Cretaceous System.

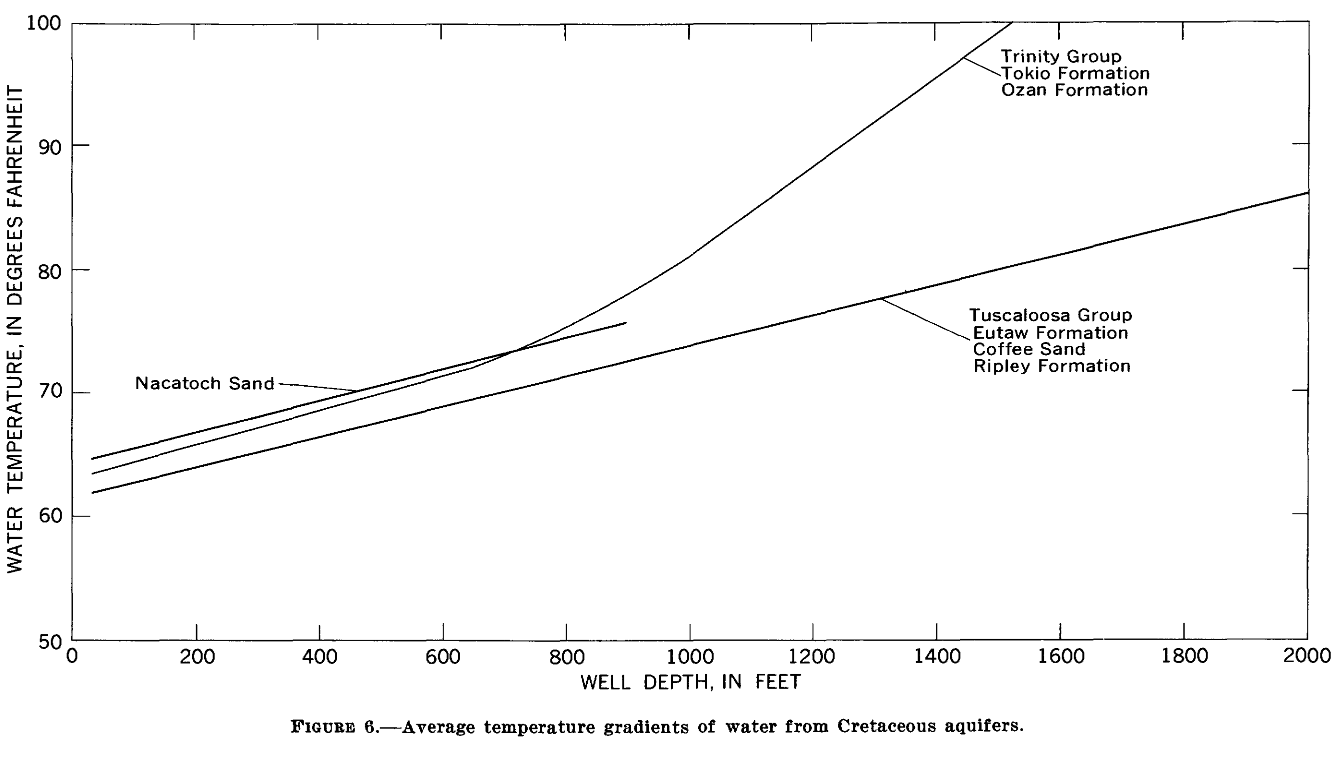

FIGURE 6.—Average temperature gradients of water from Cretaceous aquifers.

TABLE 1.—*Oil tests and wells shown on geologic sections*

State and county	Well	Company or driller	Name
Alabama			
Tuscaloosa	FF-35	Causey Drilling Co	U.S. Geological Survey test well.
Do	SS-24	do	Do.
Greene	G-35	E. C. Johnson	Willis 1.
Sumter	S-20	George Marott	M. G. Larkin 1.
Do	S-21	Diffy and Guin	Allison Lumber Co. 1.
Pickens	P-24	Sonat, Inc	J. G. Lee 1.
Arkansas			
Crittenden	3	S. J. Tucker	McKnight 1.
Do	70	M. E. Davis	De Manze 1.
Do	88	Ramsey Petroleum Co	Sanderson 1.
Cross	15	Seaboard Oil Co	F. S. Tilley 1.
Do	69	Ramsey Petroleum Co	Singer 1.
Howard	36	William James (L. E. Simmons, and others).	Rooks 3.
Do	37	R. M. Crabtree Producing Co.	Barton 1.
Little River	20	Burnett Producing Co	Archie Hale A-1.
Do	38	Lee & Burnett	Troth A-1.
Miller	39	Deep Rock Oil Co	McClouth 1.
Kentucky			
Carlisle	S 1022.4-206.3	Sterett Drilling Co	T. J. Wilson 1.
Fulton	S 946.1-92.3	Mt. Carmel Drilling Co	Florence Smith 1.
Mississippi			
Alcorn	4	Ratliff Drilling Co	Kossuth School (water well).
Do	16	Layne-Central Co	City of Corinth (water well).
Chickasaw	6	Union Producing Co	Dinsmore 1.
Do	17	Phillips Petroleum Co	Crawford C-1.
Choctaw	2	Henson and Rife Co	W. J. & T. W. Green 1.
Clay	25	Carloss Well Co	City of West Point (test hole).
DeSoto	1	Union Producing Co	Withers Estate 1.
Lowndes	9	Layne-Central Co	Columbus Air Force Base (test hole).
Noxubee	2	Hope & Thompson	Donohoe 1.
Oktibbeha	1	John Allen	W. C. Howell 1.
Do	32	Layne-Central Co	Town of Maben (water well).
Pontotoc	14	do	City of Pontotoc (water well).
Tippah	4	do	Ripley Shoe Co. (water well).
Union	9	Carloss Well Co	Biltrite Manufacturing Co. (water well).
Tennessee			
Dyer	Dy:G-1	Henderson Oil Co	Field 1.
Fayette	Fa:J-1	Lazarov & Robillio Oil Co	Beasley 1.
Do	Fa:T-2	Hay-Fay Oil Co	Morrison 1.
Haywood	Ha:B-1	C. L. Maguire, Inc	Moore 1.
Lake	Lk:E-17	Jack W. Frazier & Carl Benz.	Sam Hayes 1.
Lauderdale	Ld:O-4	Raymond Gear	T. A. Lee 1.
Shelby	Sh:L-5	E. R. Owen, Trustee	Crumpler 1.

vonian or Early Mississippian formations in Kentucky, Tennessee, Mississippi, and Alabama. A flowing well in Ordovician rocks in New Madrid County, Mo., yields 200 gpm. In Arkansas, Mississippi, and Alabama, wells which yield 25–100 gpm have been developed in Pennsylvanian sandstone. Yields of as much as several hundred gallons per minute probably can be developed from Paleozoic rocks at many places in the area of use (fig. 7), which is about 6,500 square miles.

TABLE 2.—*Stratigraphic columns of the Upper Cretaceous Series in the Mississippi embayment*

NORTHEASTERN TEXAS
[Bowie, Cass, Marion, and Harrison Counties]

Navarro Group undifferentiated [1]
Taylor Marl
Annona Chalk
Brownstown Marl
Blossom Sand
Bonham Marl
Eagle Ford Shale
Woodbine Formation

NORTHERN LOUISIANA
[North of 32d parallel]

Arkadelphia Marl
Nacatoch Sand
Saratoga Clay
Marlbrook Marl
Annona Chalk
Brownstown Marl
Tokio Formation
Eagle Ford Shale
Woodbine Formation

ARKANSAS

Arkadelphia Marl
Nacatoch Sand [1]
Saratoga Chalk
Marlbrook Marl
Annona Chalk
Ozan Formation [1]
Brownstown Marl
Tokio Formation [1]
Woodbine Formation [1]

MISSOURI

Owl Creek Formation
McNairy Sand [1]

ILLINOIS

McNairy Sand [1]

KENTUCKY

McNairy Sand [1]
Tuscaloosa Formation [1]

TENNESSEE

Owl Creek Formation
Ripley Formation [1]
  McNairy Sand Member [1]
  Coon Creek Tongue
Demopolis Formation
Coffee Sand [1]
Eutaw Formation [1]
Tuscaloosa Formation [1]

See footnotes at end of table.

TABLE 2.—*Stratigraphic columns of the Upper Cretaceous Series in the Mississippi embayment*—Continued

NORTHERN MISSISSIPPI
Northern part

Selma Group
- Owl Creek Formation
- Ripley Formation [1]
  - Chiwapa Member [1]
  - McNairy Sand Member [1]
  - Coon Creek Tongue
  - Transitional clay
- Demopolis Chalk
- Coffee Sand [1]

Eutaw Formation [1]
- Tombigbee Sand Member [1]

McShan Formation [1]
Tuscaloosa Group undifferentiated [1]

Southern part

Selma Group
- Prairie Bluff Chalk
- Ripley Formation [1]
- Demopolis Chalk
  - Bluffport Marl Member
- Mooreville Chalk
  - Arcola Limestone Member

Eutaw Formation [1]
- Tombigbee Sand Member [1]

McShan Formation [1]
Tuscaloosa Group undifferentiated [1]

CENTRAL MISSISSIPPI

Selma Group
- Prairie Bluff Chalk
- Ripley Formation
- Demopolis Chalk
  - Bluffport Marl Member
- Mooreville Chalk
  - Arcola Limestone Member

Eutaw Formation [1]
McShan Formation [1]
Tuscaloosa Group
- Gordo Formation [1]
- Coker Formation [1]
- Massive sand [1]

WESTERN ALABAMA

Selma Group
- Prairie Bluff Chalk
- Ripley Formation
- Demopolis Chalk
  - Bluffport Marl Member
- Mooreville Chalk
  - Arcola Limestone Member

Eutaw Formation [1]
- Tombigbee Sand Member [1]

McShan Formation [1]
Tuscaloosa Group
- Gordo Formation [1]
- Coker Formation [1]
  - Upper unnamed member
  - Eoline Member [1]
- Massive sand [1]

[1] Unit is fresh-water aquifer or contains fresh-water aquifer(s).

QUALITY OF THE WATER

Utilization of water is governed to a large extent by the chemical and physical properties of the water (table 3, p. C10). Water from Paleozoic limestones and cherts in Alabama, Mississippi, Tennessee, Kentucky, and Illinois generally is moderately mineralized, calcium and bicarbonate being the principal chemical constituents. Dissolved-solids contents usually are less than 300 ppm (table 4, p. C12) but increase with depth. In water containing less than 300 ppm dissolved solids, the concentrations of constituents other than calcium and bicarbonate are low. Increases in the dissolved-solids content in water containing more than 300 ppm are primarily increases in sodium, chloride, and sulfate contents. Water from Paleozoic rocks in these States generally is hard, but is suitable for many uses.

Water from Paleozoic dolomite and sandstone in Missouri is a calcium magnesium bicarbonate type. The dissolved-solids content of the water is generally less than 300 ppm. Dissolved-solids contents increase down the dip, and the increases in excess of about 300 ppm are principally in sodium and chloride contents. Water from a well in New Madrid County, Mo., has a chloride content of 1,340 ppm.

Water from Pennsylvanian sandstone in Arkansas is generally of good quality. Dissolved-solids contents range from 82 to 288 ppm and increase with depth. Water from shallower wells is a calcium bicarbonate type, whereas water from deeper wells is predominantly a sodium bicarbonate type.

POTENTIAL USE

The pre-Cretaceous aquifers probably are potential sources of water throughout large areas in the embayment. The delineation of these areas is beyond the scope of the present embayment study, however.

CONCLUSIONS

Wells in pre-Cretaceous aquifers yield sufficient amounts of water for domestic use at many places in the embayment. Moderate to large quantities of water are difficult to obtain from aquifers other than those of Devonian and Early Mississippian age. The area of use within the embayment is about 6,500 square miles and the estimated withdrawal is about 10 mgd. Water obtained from pre-Cretaceous aquifers is generally of good quality, but locally it is hard and may require treatment for some uses.

CRETACEOUS AQUIFERS

LOWER CRETACEOUS SERIES OF ALABAMA AND MISSISSIPPI

By J. G. NEWTON and E. H. BOSWELL

All beds that occur between the Paleozoic rocks and the base of the Tuscaloosa Group of Late Cretaceous age are included in the Lower Cretaceous Series in the area of this report. These beds consist of thick deposits of massive sands and clays similar to those in the overlying Tuscaloosa Group. The series is overlapped by the Tuscaloosa Group and does not crop out at the land surface. The northern margin of the Lower Cretaceous Series is estimated to be about 600 feet below mean sea level along the eastern margin of the report area in central Alabama. Westward, the northern limit of the Lower Cretaceous occurs at progressively greater depths; and, in northwestern Mississippi, it is at a depth of about 5,000 feet. The series in Alabama and Mississippi strikes northwestward and dips southwestward about 40 feet per mile (fig. 8). The series thickens abruptly down the dip, and exceeds 1,000 feet in thickness in the southern part of the study area.

POTENTIAL USE

Interpretation of electric logs indicates that water in sands in the Lower Cretaceous Series is high in dissolved-solids content in some places and low in others. The area, about 4,000 square miles, where the water seems to be low in dissolved-solids content is considered the area of potential use (fig. 8). Because electric-log data are not sufficient to outline the areal extent of the fresh-water sands, and because water wells do not tap these sands, test drilling and sampling will be required to determine the physical and chemical quality of the water and the quantity of water available. In the area of potential use, large amounts of water probably are available in the Lower Cretaceous Series.

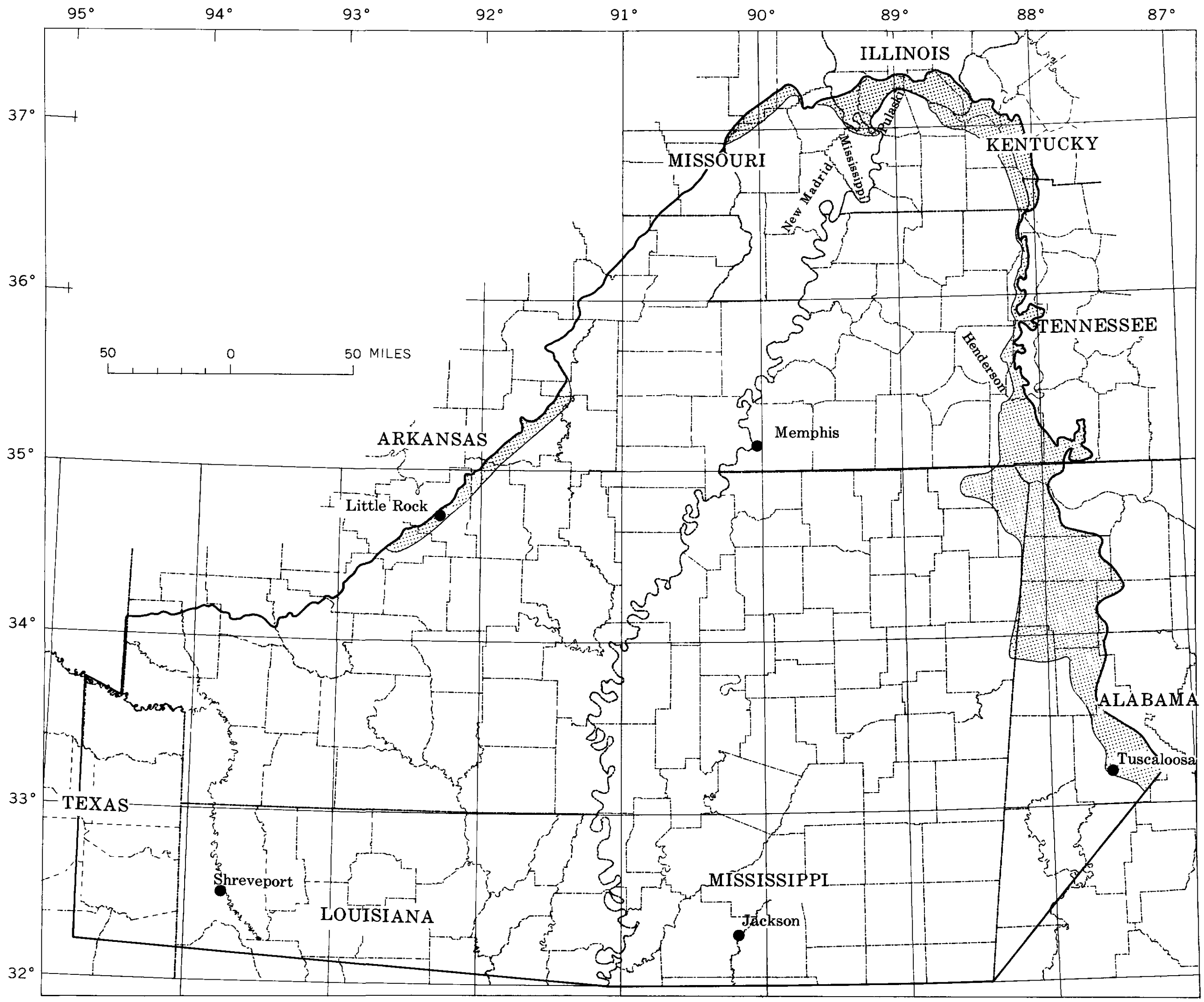

FIGURE 7.—Areas where wells tap pre-Cretaceous rocks.

TABLE 3.—*Source and significance of dissolved mineral constitutents and physical properties of natural waters*

Constituent or physical property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, generally in small amounts from 1 to 30 ppm. Higher concentrations generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. Waters having a low pH tend to be corrosive and may dissolve iron in objectionable quantities from pipe, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacturing, brewing, and other processes. Large quantities cause unpleasant taste and favor the growth of iron bacteria. On exposure to air, iron in ground water usually is oxidized and forms a reddish-brown precipitate. "Public Health Service Drinking Water Standards" (1962)[1] recommend that iron in water supplies not exceed 0.3 ppm.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities commonly associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark brown or black stain. Maximum concentration recommended by the drinking water standards is 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see Hardness). Waters low in calcium and magnesium are desired in electroplating, tanning, and dyeing, and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. High sodium content commonly limits use of water for irrigation. Sodium salts may cause foaming in steam boilers.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Large amounts have a laxative effect on some people and, in combination with other ions, gives a bitter taste. Sulfate in water containing calcium forms a hard scale in steam boilers. The drinking water standards recommend that sulfate in water supplies not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	Large quantities increase the corrosiveness of water and, in combination with sodium, give salty taste. The drinking water standards recommend that chloride in water supplies not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, the amount of drinking water consumed, and the susceptibility of the individual. The maximum concentration of fluoride recommended by drinking water standards varies with the annual average of maximum daily air temperatures and ranges downward from 1.7 ppm for an average maximum daily temperature of 50.0° F to 0.8 ppm for an average maximum daily temperature of 90.5° F. Optimum concentrations for these ranges are from 1.2 to 0.7 ppm.
Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soil.	Nitrate encourages growth of algae and other organisms that cause undesirable tastes and odors. Concentrations much greater than the local average may suggest pollution. The drinking water standards recommend that the nitrate content not exceed 45 ppm as there is evidence that higher concentrations may cause methemoglobinemia in infants.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	The drinking water standards recommend that the dissolved solids not exceed 500 ppm. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form, and deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. In general, waters of hardness as much as 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 180 ppm, hard; more than 180 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water	Specific conductance is a measure of the capacity of the water to conduct an electric current. This property varies with concentration and degree of ionization of the constituents, and with temperature (therefore reported at 25° C).
Hydrogen-ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Temperature		Affects usefulness of water for many purposes. Most users desire water of uniformly low temperature. In general, temperatures of shallow ground waters show some seasonal fluctuation, whereas temperatures of ground waters from moderate depths remain near the mean annual air temperature of the area. In deep wells the water temperature generally increases 1° F for each 60 to 80 feet of depth.

[1] "Public Health Service Drinking Water Standards," revised 1962, apply to drinking water and water-supply systems used by carriers and others subject to Federal Quarantine regulations.

TRINITY GROUP OF ARKANSAS

By R. L. Hosman

On the western side of the Mississippi embayment, the Trinity Group in the Lower Cretaceous Series overlies rocks of Paleozoic age and is overlain by Upper Cretaceous strata. The group includes three aquifers, the Pike Gravel, the Ultima Thule Gravel Member of the Holly Creek Formation, and the Paluxy Sand. The Lower Cretaceous Series crops out in a belt 5–10 miles wide that extends westward from Pike County, Ark., through Howard and Sevier Counties, Ark., into southeastern Oklahoma. The strike of the beds is generally westward, and the dip is southward about 50 feet per mile (fig. 8). The thickness of the Trinity Group exceeds 2,500 feet in the subsurface.

The Pike Gravel, the basal unit of the Trinity Group in the area of outcrop, is overlain by the Delight Sand. It consists of rounded pebbles and cobbles and has a maximum thickness of about 100 feet.

The Holly Creek Formation, including the Ultima Thule Gravel Members, overlies the Dierks Limestone and is overlain by the De Queen Limestone. The Ultima Thule Gravel Member is lithologically similar

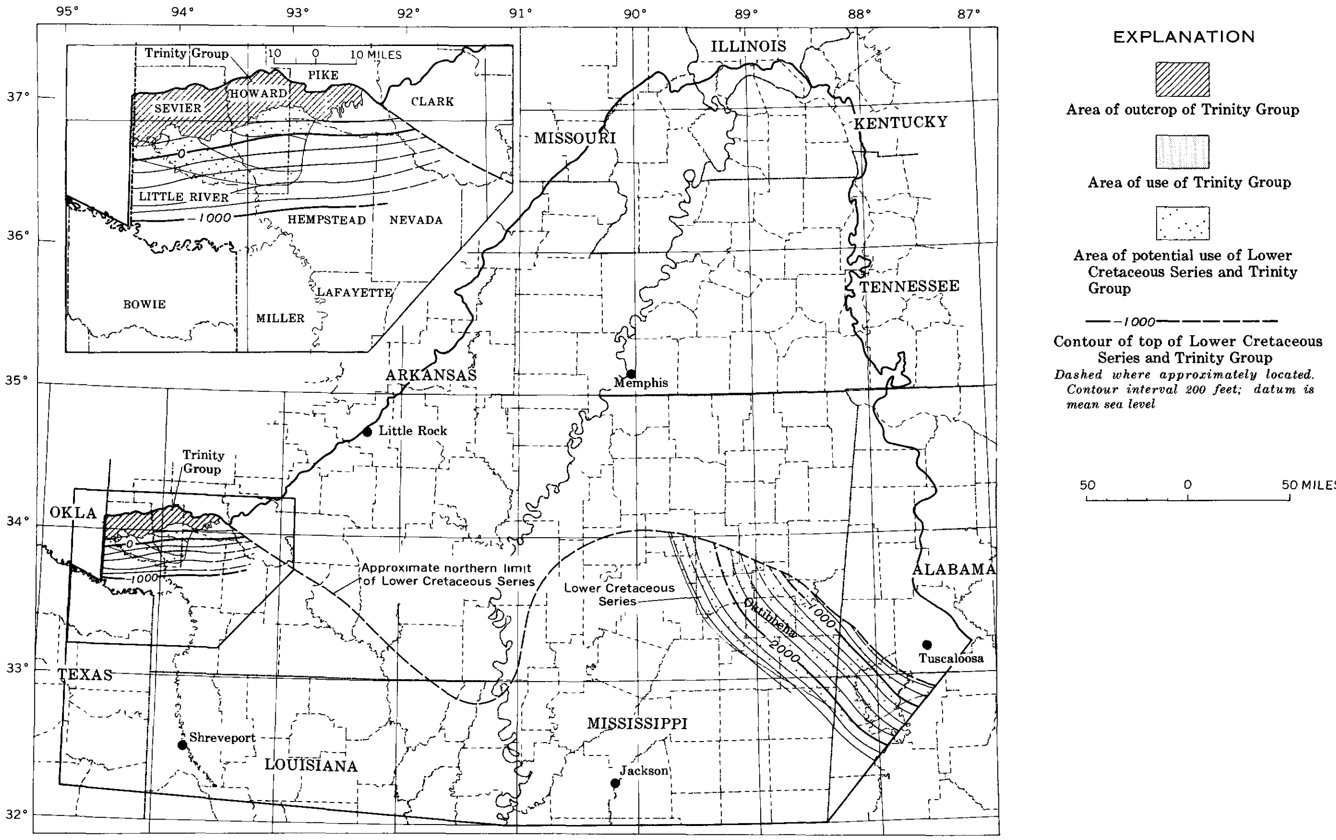

FIGURE 8.—Areas of outcrop, configuration of the top, and areas of use and of potential use of the Lower Cretaceous Series and Trinity Group. Outcrop area modified from Arkansas Geol. Survey (1929).

to the Pike Gravel but consists of finer materials. This member has a maximum thickness of about 40 feet.

The Paluxy Sand, the upper unit of the Trinity Group, overlies the De Queen Limestone. It has a maximum thickness of about 900 feet and is generally composed of well-sorted fine white sand interbedded with clay and limestone and locally may contain gravel lenses. The Paluxy Sand is present in southern Howard and Sevier Counties, Ark.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Aquifers in the Trinity Group receive recharge in the outcrop area. The direction of ground-water movement is southward.

The Paluxy Sand is the most productive and most extensive aquifer of the Trinity; but, with the exception of shallow dug wells, it is not widely used as a source of water. In lowland areas many wells tapping the Paluxy are flowing wells.

Neither the Pike Gravel nor the Ultima Thule Member is widely used as a source of water. Wells screened in the Pike Gravel in southern Pike County, Ark., were formerly flowing, but large withdrawals by municipal and industrial wells have lowered water levels as much as 40 feet below land surface. Total withdrawal from aquifers in the Trinity Group is about 0.4 mgd.

AQUIFER CHARACTERISTICS

Most wells tapping Trinity aquifers are designed for small capacity, but yields of 200 gpm have been reported. The results of an aquifer test using wells screened in the Pike Gravel show a coefficient of transmissibility [1] of about 10,000 gpd per ft (gallons per day per foot) and a coefficient of storage [2] of about 0.00004.

[1] The worth of an aquifer as a fully developed source of water depends largely on two hydrologic characteristics—the capacity of the aquifer to transmit water (the coefficient of transmissibility) and the capacity of the aquifer to store water (the coefficient of storage).

The coefficient of transmissibility (T) is the rate of flow of water, in gallons per day, at the prevailing temperature, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer, under a hydraulic gradient of 100 percent. (A hydraulic gradient of 100 percent means a 1-foot drop in water level or head in a 1-foot flow distance.) For example, an aquifer has a coefficient of transmissibility of 26,400 gpd per ft. If the hydraulic gradient were 100 percent, during each 24-hour period, 26,400 gallons of water would move through each vertical strip of the aquifer 1 foot wide. Assuming a line 100 feet in length perpendicular to the direction of flow in the aquifer, 26,400 gpd per ft times 100 feet or 2,640,000 gpd would move past the line. If the hydraulic gradient were only 10 feet per mile, then only 5,000 gpd $\left(26{,}400\times100\times\frac{10}{5{,}280}\right)$ would move past the line in a day.

[2] The coefficient of storage (S) is the volume of water the aquifer releases or takes into storage per unit surface area of the aquifer per

TABLE 4.—*Maximum, minimum, and median concentrations of constituents determined in water from the Paleozoic rocks*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Silica (SiO_2)	13	0.8	8.9
Iron (Fe)	16	.00	.28
Calcium (Ca)	174	24	35
Magnesium (Mg)	18	2.6	7.9
Sodium (Na)	81	1.7	10
Potassium (K)	10	.2	1.1
Bicarbonate plus carbonate (HCO_3+CO_3)	392	18	170
Sulfate (SO_4)	150	.4	8.2
Chloride (Cl)	123	1.0	4.0
Fluoride (F)	.9	.0	.1
Nitrate (NO_3)	22	.1	3.5
Dissolved solids (residue at 180°C)	590	90	208
Hardness as $CaCO_3$	453	12	152
Specific conductance (micromhos at 25°C)	869	30	325
pH	8.2	6.1	----------

QUALITY OF THE WATER

Water from the Trinity Group is variable in its chemical composition, being a calcium magnesium bicarbonate type in some places and a sodium bicarbonate type in other places. Based on specific conductance (fig. 9, and table 5), the dissolved-solids content usually is less than 300 ppm. When it is more than 300 ppm, the excess is mostly sodium chloride or, in some waters, sodium sulfate. The waters are soft to moderately hard, but when calcium and magnesium are the principal cations, the hardness may be as much as 200 ppm. Water from the Trinity Group may require treatment for some uses.

POTENTIAL USE

Ground-water supplies probably can be developed from the Pike Gravel in most of the Trinity outcrop area in southwestern Arkansas. The area of potential use of the Ultima Thule Gravel Member is restricted by its occurrence to western Sevier County, Ark. The Paluxy Sand has not been used extensively in southern Sevier County because shallower ground-water supplies have been sufficient to meet the demand. The Paluxy will probably supply usable water to wells in the area extending south from the outcrop belt for about 10 miles (fig. 8). The area of use and of potential use of aquifers in the Trinity Group is about 1,000 square miles.

TABLE 5.—*Maximum, minimum, and median concentrations of constituents determined in water from the Trinity Group*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Iron (Fe)	11	0.01	0.50
Bicarbonate plus carbonate (HCO_3+CO_3)	580	20	260
Sulfate (SO_4)	560	1.0	18
Chloride (Cl)	365	3.0	6.0
Nitrate (NO_3)	2.8	.0	1.1
Hardness as $CaCO_3$	200	4	22
Specific conductance (micromhos at 25°C)	3,340	49	462
pH	9.2	6.1	----------

CONCLUSIONS

Aquifers in the Trinity Group are the major source of ground water in an area of about 1,000 square miles in southwestern Arkansas. The aquifers yield small to moderate quantities of water and are the source of domestic and several public and industrial water supplies. The Paluxy Sand is the major aquifer, the Ultima Thule Gravel Member of the Holly Creek Formation and the Pike Gravel being the other aquifers. Water levels in the aquifers are high enough to permit flowing wells in the lowlands. Much of this flow is wasted.

Total withdrawal and flow from aquifers in the Trinity Group is about 0.4 mgd. The water is generally of good quality, but treatment may be necessary for some uses.

COKER FORMATION

By E. H. BOSWELL and J. G. NEWTON

The Coker Formation of the Tuscaloosa Group overlies the Paleozoic rocks in the subsurface of the Mississippi embayment except where beds of Early Cretaceous age intervene (pl. 1). It is overlapped by the Gordo Formation and does not crop out in northernmost Alabama and north-central Mississippi (fig. 10). The Coker strikes northwestward, and dips southwestward about 40 feet per mile.

unit change in the component of head normal to that surface. The coefficient can be expressed as the quantity of water, in cubic feet, that is discharged from each vertical prism of the aquifer having a basal area of 1 square foot and a height equal to that of the aquifer, when the water level falls 1 foot. For an artesian aquifer the water released from or taken into storage in response to a change in water level is attributed solely to the compressibility of the aquifer material and of the water. The volume of water thus released or stored, divided by the product of the water-level change and the area of the aquifer surface over which it is effective, is the coefficient of storage of the aquifer. For example, the coefficient of storage of an aquifer is 0.00016. If the water level drops 2 feet over an area of 10,000 square feet, the amount of water released from storage would be 3.2 cubic feet. ($0.00016 \times 10{,}000 \times 2$.)

For artesian aquifers the storage coefficients generally range from about 0.00001 to about 0.001, and for water-table aquifers they range from about 0.05 to about 0.3.

When the coefficients of transmissibility and storage are known, the theoretical drawdown for any time at any point in an area of pumping for any given rate and distribution of pumping from wells can be computed. (See figs. 25–27.)

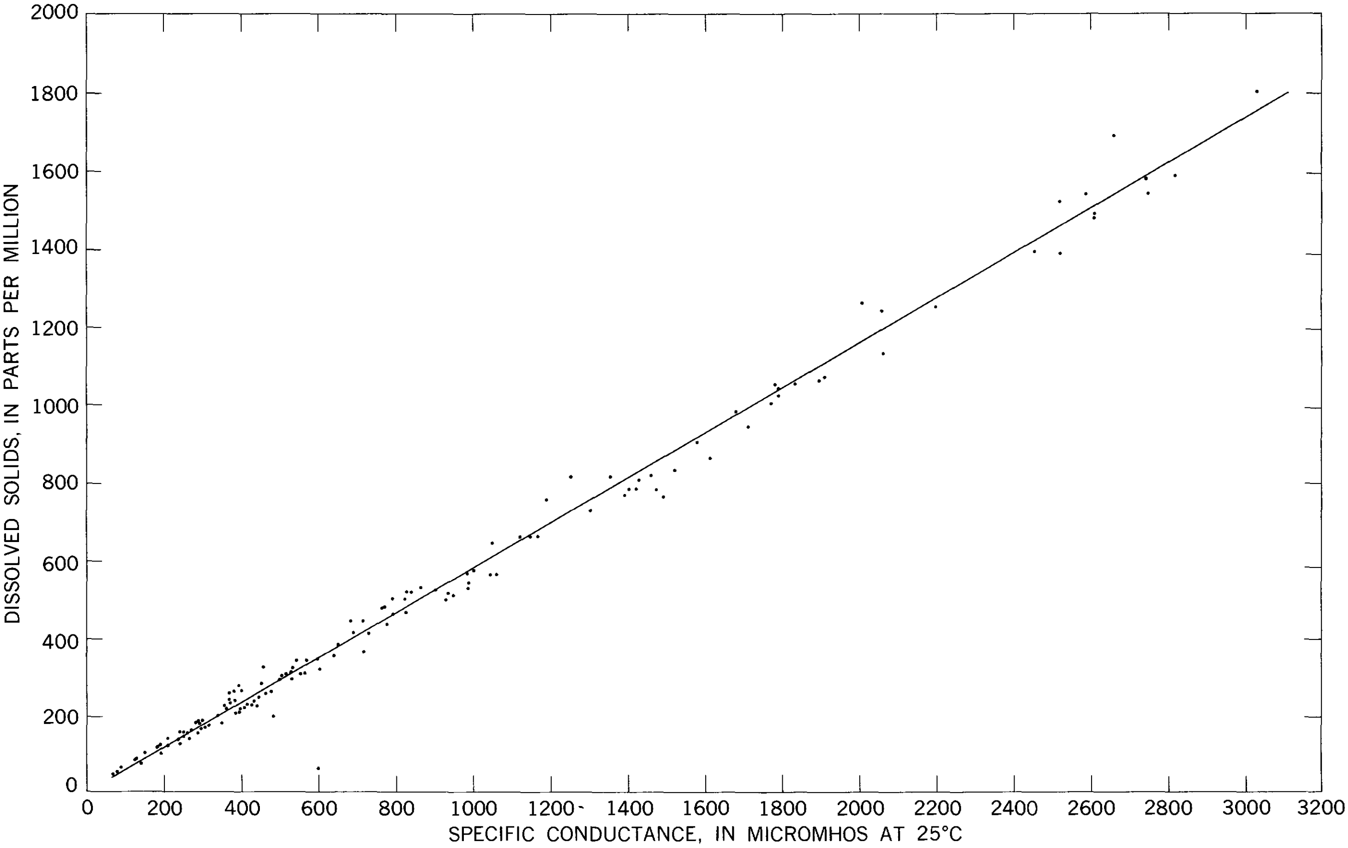

FIGURE 9.—Relation between specific conductance and dissolved-solids content of water from Cretaceous aquifers.

The Coker Formation comprises the Eoline Member at the bottom and an unnamed member at the top. The massive sand (McGlothlin, 1944, p. 46) as used in this report underlies and is included in the Eoline Member of the formation.

The Eoline Member is predominatly sand, whereas the upper unnamed member is predominantly clay and shale. This division is recognized on most electric logs by the contrast of electrical properties recorded opposite the rock types in the formation.

The Coker Formation thickens considerably in the subsurface southwest of the area of outcrop and is 800 feet thick in Sumter County, Ala. (fig. 11).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Coker Formation receives most of its recharge where permeable sands in the lower part of the formation crop out at the land surface. The belt of outcrop (fig. 10) narrows northwestward from Tuscaloosa County, Ala., where it is generally 10–20 miles wide.

Locally, the Coker receives recharge in the area of outcrop from overlying terrace deposits and in places from underlying rocks of Paleozoic age. Where the formation is overlapped in northern Alabama and in Mississippi, the Coker receives some recharge from aquifers in the overlying Gordo Formation. Recharge from Paleozoic rocks probably occurs in southern Tuscaloosa County where sands in the Coker overlie the Paleozoic Pottsville Formation which contains water having a high chloride content. Lowering of artesian pressures by flowing wells in the Coker probably has induced recharge from the underlying Pottsville Formation as some of these wells now yield water having a high chloride content.

The area of use by wells tapping the Coker extends southwestward from the outcrop area as much as 10 miles in Alabama and as much as 70 miles in northeastern Mississippi. Numerous flowing wells (Paulson and others, 1962, p. 27) tap the formation in southern Tuscaloosa County, Ala., and the discharge from these wells in 1956–57 ranged from less than 1 to 285 gpm and averaged 30 gpm. The total discharge from these wells in 1962 was estimated to be slightly more than 3 mgd. In the area of use in Alabama, the total amount of water withdrawn or discharged from the Coker is about 5 mgd. In Mississippi about 2.5 mgd is pumped from two industrial and four municipal wells. An estimated 0.5 mgd is discharged or pumped from other wells in the Coker. In the area of use, about

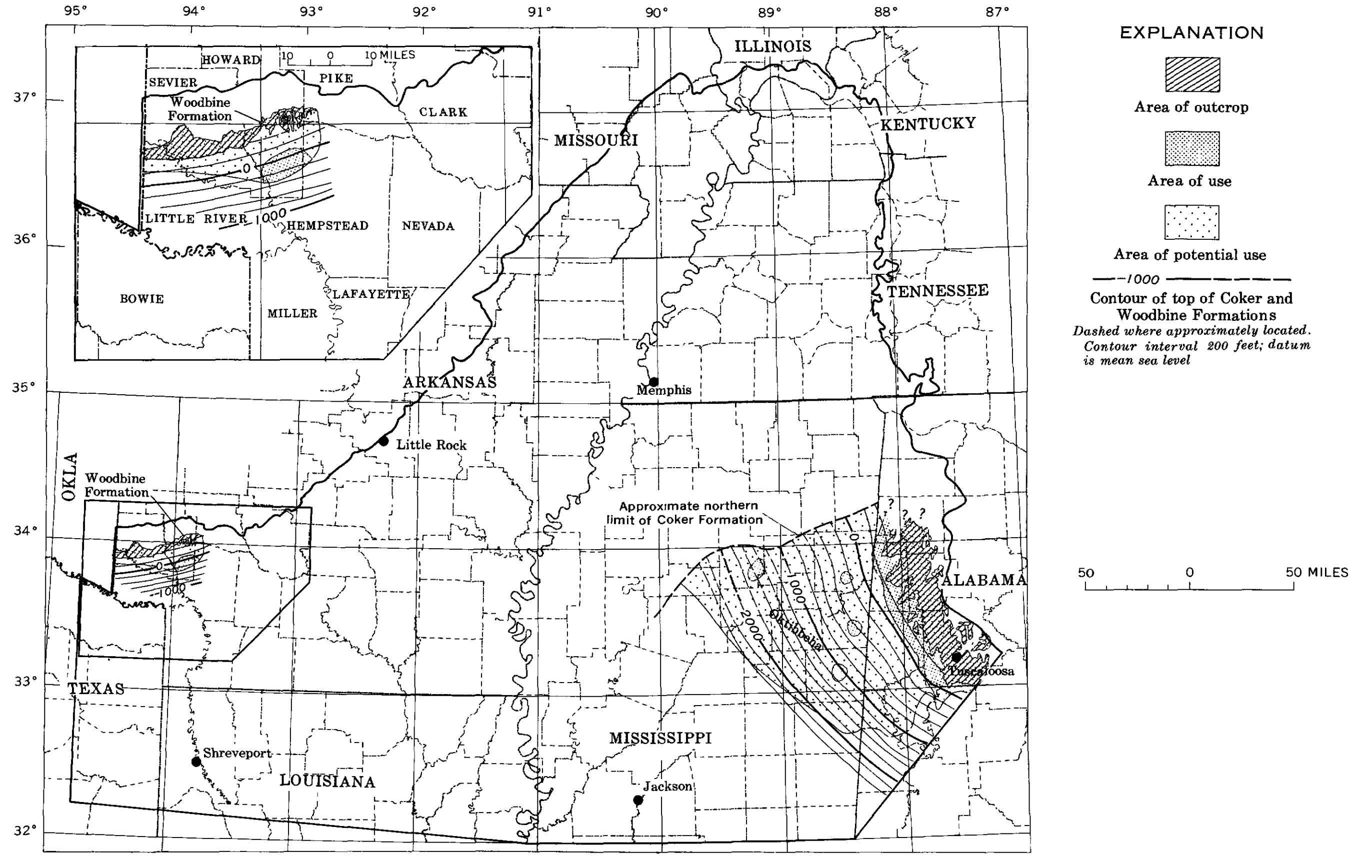

FIGURE 10.—Areas of outcrop, configuration of the top, and areas of use and of potential use of the Coker and Woodbine Formations. Outcrop areas are modified from Alabama Geol. Survey (1926) and Arkansas Geol. Survey (1919).

2,500 square miles, and in the area of potential use, about 6,500 square miles, the quantity of water available from the Coker probably exceed that available from all of the overlying aquifers combined.

The regional movement of water in the Coker Formation is toward the southwest. Near the eastern margin of the embayment the movement is toward the lowlands along the Black Warrior and Sipsey Rivers where flowing wells have lowered the piezometric surface (fig. 12).

AQUIFER CHARACTERISTICS

Most wells tapping the Coker Formation in the area of study are constructed to obtain small yields and data are not available to determine the aquifer characteristics on a regional basis.

The specific capacities [3] of seven wells in Tuscaloosa County, Ala., range from 1 to 15 gpm per foot of drawdown and averaged 6 gpm per ft. The coefficients of transmissibility calculated from five tests range from 3,000 to 77,000 gpd per ft, and the coefficient of storage from one test is 0.00022. A well in northern Hale County, Ala., reportedly had a drawdown of 32 feet after pumping at 500 gpm for 1 hour. The specific capacity is about 16 gpm per foot of drawdown for this short interval of pumping.

Results of an aquifer test using wells tapping the Coker at a depth of 940 feet below land surface in Lowndes County, Miss., indicate a coefficient of transmissibility of 250,000 gpd per ft, a coefficient of storage of 0.0003, and a specific capacity of 71 gpm per foot of drawdown for the pumped well. The saturated thickness of the aquifer was 120 feet.

Yields of several hundred gallons per minute can be obtained from the Coker Formation in many places, and 1,000 gpm or more is probably available in downdip areas where the saturated thickness is more than

[3] Specific capacity defines the capacity of a well to yield water and is expressed as gallons of water discharged in 1 minute for each foot of decline in the water level in the well. If it were not for many extraneous factors such as the size of well, the depth of penetration of the well into the aquifer, the length of screen, the size of screen openings and the relation of the size of these openings to size and assortment of aquifer materials, and the amount of development of the well, specific capacity would be a measure of the capacity of the aquifer in the vicinity of the well to transmit water.

Specific capacity is used to compare the yields of wells and as a means of determining how deep in the well the pump bowls (turbine) should be set. For example, if a well has a specific capacity of 5 gpm per ft and is capable of yielding 500 gpm, then the drawdown for this discharge will be about 100 feet $\left(\frac{500}{5}\right)$, and the pump bowls must be set at least 100 feet below the static water level in the well in order to pump 500 gpm.

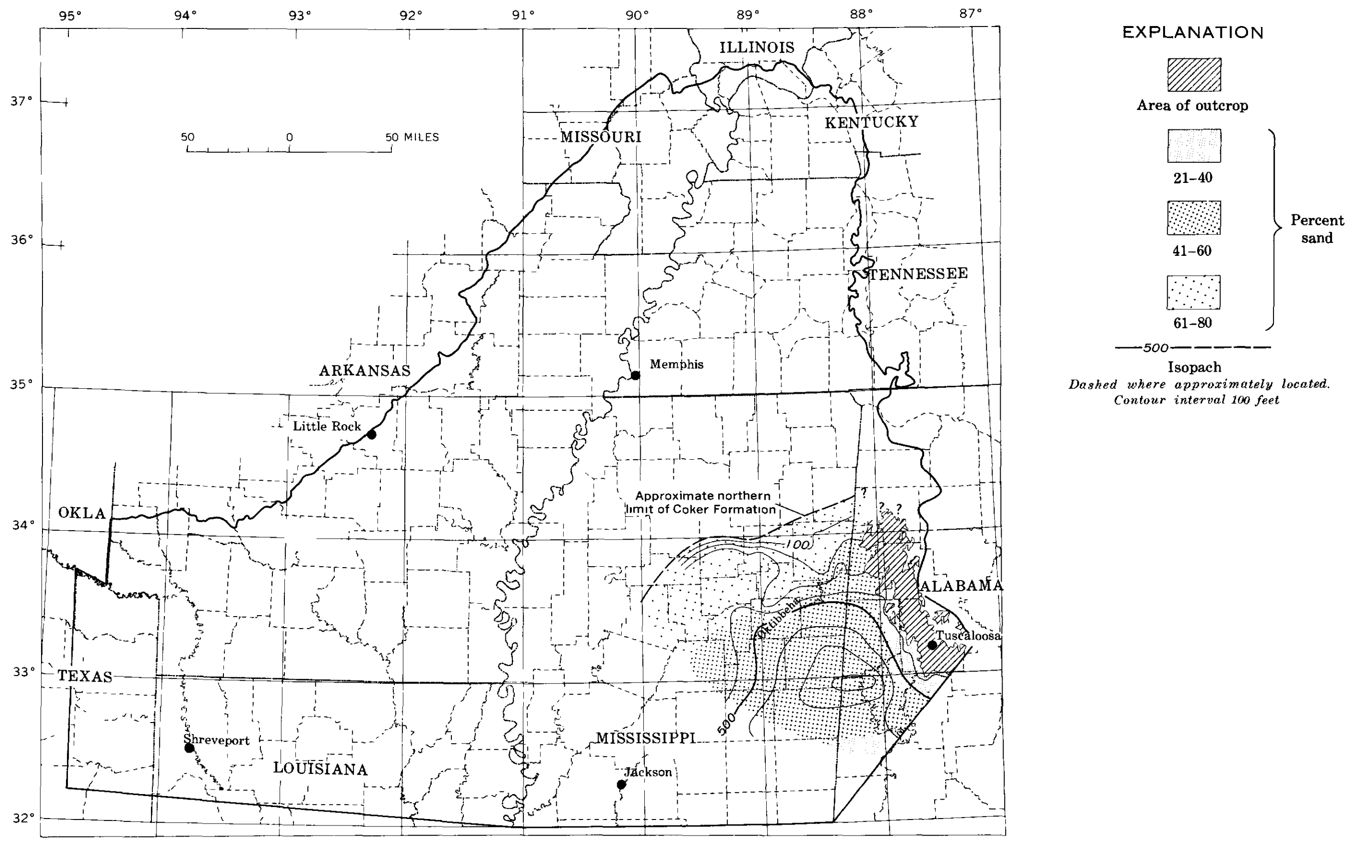

FIGURE 11.—Area of outcrop, thickness, and percentage of sand of the Coker Formation. Outcrop area modified from Alabama Geol. Survey (1926).

100 feet. The sand thickness in the formation exceeds 100 feet in most areas south of the belt of outcrop (fig. 11).

QUALITY OF THE WATER

Water from all aquifers in the Tuscaloosa Group is similar in chemical quality (table 6; pl. 2). Water in the outcrop (zone 1, pl. 2) is generally low in dissolved-solids content. Bicarbonate is the principal anion, and calcium and sodium, present in about equal amounts, are the principal cations. An exception to this occurrence is in southern Tuscaloosa County, Ala., where recharge to the Coker Formaton in an area of artesian flow may be from underlying Paleozoic rocks that contain water high in chloride content. Water from aquifers in the Tuscaloosa Group becomes progressively more mineralized down the dip (pl. 2). In some areas potable water in the Coker Formation occurs farther downdip than in the overlying Gordo Formation.

Water from the Coker Formation in the area of use (fig. 10) is generally of good chemical quality and is suitable for most purposes with little or no treatment. The maximum values determined for most constituents (table 6) are for water in downdip areas. The higher values for iron, however, occur in water from the belt of outcrop and adjacent areas.

TABLE 6.—*Maximum, minimum, and median concentrations of constituents determined in water from the Tuscaloosa Group*

[Data in parts per million except as indicated]

Constituent	Water-bearing formations						Median for group
	Tuscaloosa undifferentiated		Coker		Gordo		
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
Silica (SiO_2)	22	0.8	6.8	4.4	27	1.9	6.7
Iron (Fe)	4.9	.00	15	.37	20	.00	.45
Calcium (Ca)	129	1.2	35	1.7	62	1.5	8.0
Magnesium (Mg)	26	.3	12	1.0	9.1	.4	2.5
Sodium (Na)	680	1.2	165	1.5	321	.9	12
Bicarbonate plus carbonate (HCO_3+CO_3)	165	0	150	8	496	20	74
Sulfate (SO_4)	18	.0	9.0	.2	16	.0	2.0
Chloride (Cl)	1,380	1.0	220	1.2	370	1.0	4.9
Fluoride (F)	.4	.0	.6	.0	2.0	.0	.1
Nitrate (NO_3)	20	.2	28	.0	3.9	.0	.4
Dissolved solids (residue at 180°C)	2,450	17	512	43	865	28	105
Hardness as $CaCO_3$	429	4	124	10	110	5	31
Specific conductance (micromhos at 25° C)	4,180	19	949	27	1,610	61	167
pH	8.0	5.2	8.5	5.5	8.5	6.0	--------

Water in the Coker becomes more mineralized as it moves down the dip through zones 1 and 2, and changes

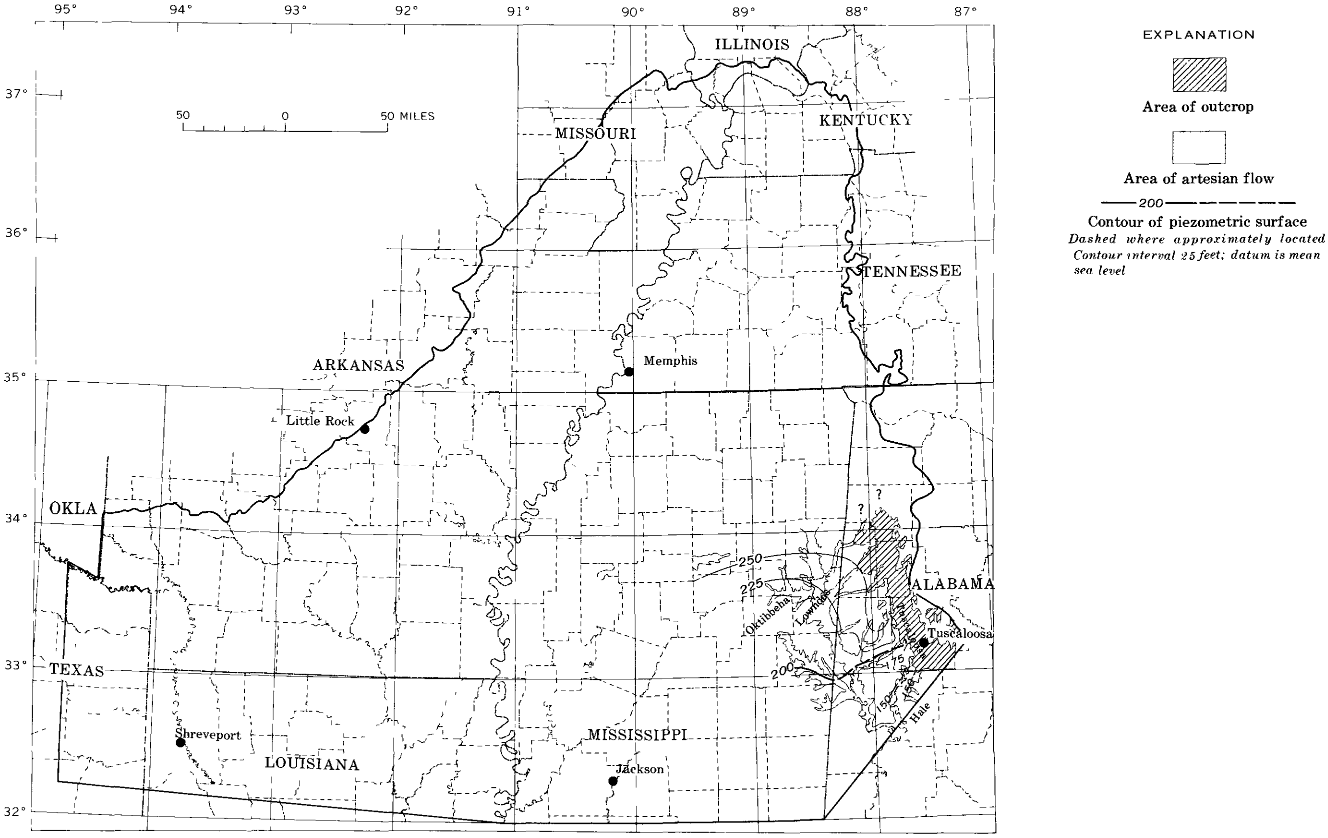

FIGURE 12.—Area of outcrop, piezometric surface of the water, and area of artesian flow in the Coker Formation. Outcrop area modified from Alabama Geol. Survey (1926).

to a sodium bicarbonate type in zone 3 (pl. 2). Downdip from zone 3 the dissolved-solids content increases rapidly over short distances, the main increases being sodium and chloride contents.

POTENTIAL USE

Aquifers in the Coker in the area of potential use (fig. 10) are not tapped because adequate quantities of water are available in overlying aquifers. Large quantities of water are available from the Coker, but test drilling and pumping will be required to determine the maximum quantity and the quality of the water at a particular location.

CONCLUSIONS

The Coker Formation, except near the northern margin of the outcrop area in Alabama and near its northern extremity in the subsurface of Mississippi where it is thin, will yield as much as several hundred gallons per minute of water to wells. Where the saturated thickness of the sands is greater than 100 feet, the Coker generally will yield 1,000 gpm or more.

Discharge from wells tapping the formation in Alabama and Mississippi is about 8 mgd. The quantity of water available from the Coker is believed to be greater than the quantity available in all overlying Cretaceous aquifers combined.

GORDO FORMATION

By E. H. BOSWELL and J. G. NEWTON

The Gordo Formation of the Tuscaloosa Group overlies the Coker Formation and is overlain by the Eutaw Formation. The Gordo strikes northwestward and dips southwestward about 40 feet per mile (fig. 13). The formation consists chiefly of sand and gravel in the lower part and clay and shale in the upper part.

The formation thickens from about 300 feet near the outcrop to more than 450 feet in some downdip areas (fig. 14). The percentage of sand decreases southwestward.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Gordo Formation receives most of its recharge where permeable sands in the lower part of the formation crop out. The belt of outcrop, 8–15 miles wide, trends northwestward (fig. 13).

Although the amount of water withdrawn or discharged from the Gordo by wells has not been accurately determined, it is estimated to be about 25 mgd.

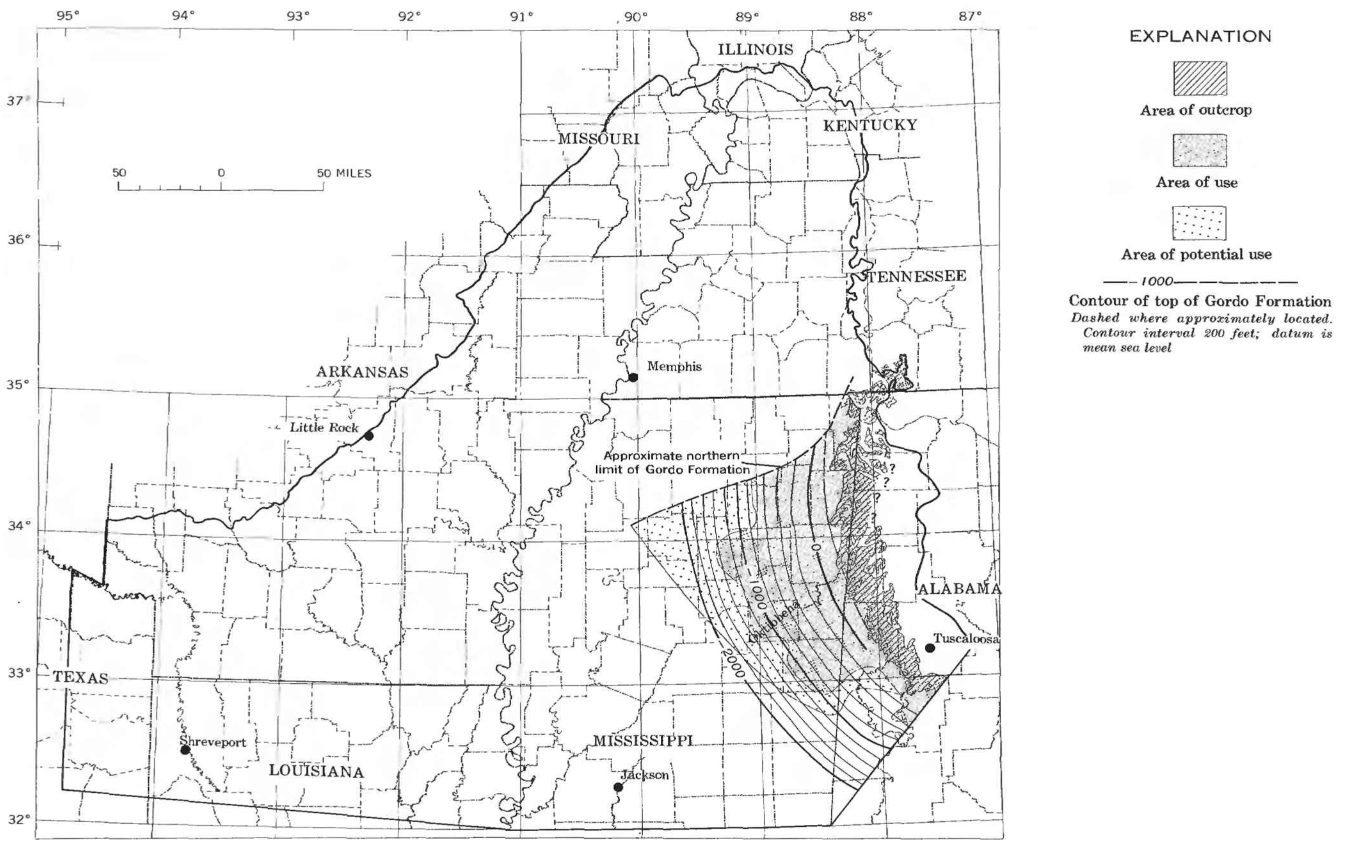

FIGURE 13.—Area of outcrop, configuration of the top, and areas of use and of potential use of the Gordo Formation. Outcrop area modified from Alabama Geol. Survey (1926), Mississippi Geol. Society (1945), and Tennessee Div. Geology (1933).

The regional movement of ground water in the Gordo Formation is toward the southwest (fig. 15). The piezometric surface reflects loss of pressures in lowland areas where numerous wells flow, and the movement of water in the formation is toward these areas. Uncontrolled flowing wells and large withdrawals for public supplies and industrial use have lowered the piezometric surface sufficiently to cause cessation of flows in large areas.

AQUIFER CHARACTERISTICS

Results of an aquifer test using wells in the Gordo Formation in Clay County, Miss., show a coefficient of transmissibility of 160,000 gpd per ft and a coefficient of storage of 0.0001. Results of three pumping tests in Lowndes and Monroe Counties, Miss., indicate coefficients of transmissibility of 33,000, 50,000 and 110,000 gpd per ft. Results of two tests in Hale County, Ala., indicate specific capacities of about 33 and 24 gpm per foot of drawdown. One well reportedly had a drawdown of 18 feet after 5 hours of pumping at a rate of 600 gpm, and the other a reported drawdown of 23 feet after 8 hours of pumping at 545 gpm.

Similar yields are reported for wells tapping the Gordo in Pickens County, Ala. Specific capacities determined and reported for large capacity wells tapping the formation in Mississippi and Alabama average about 30 gpm per foot of drawdown.

Municipal and industrial wells tapping the Gordo commonly yield 500 gpm and, in Mississippi, reportedly yield as much as 1,250 gpm.

QUALITY OF THE WATER

Water from the Gordo Formation is similar in character and amount of dissolved solids to water from the Coker Formation (table 6; pl. 2). Water in zone 1, the outcrop area, is low in dissolved-solids content. Bicarbonate is the principal anion and calcium and sodium are the principal cations. Increases in the dissolved-solids content in the water in the north and central parts of zone 2 are caused by the solution of calcium and iron carbonate; in the south part of the zone the increases are caused by the solution of calcium and magnesium carbonate. The higher concentrations of iron are in zones 1 and 2.

In zone 3 the water changes to a sodium bicarbonate type. In many places the calcium and iron contents of water in zone 3 are less than those of water in zone 2. These decreases are indicative of ion exchange, which

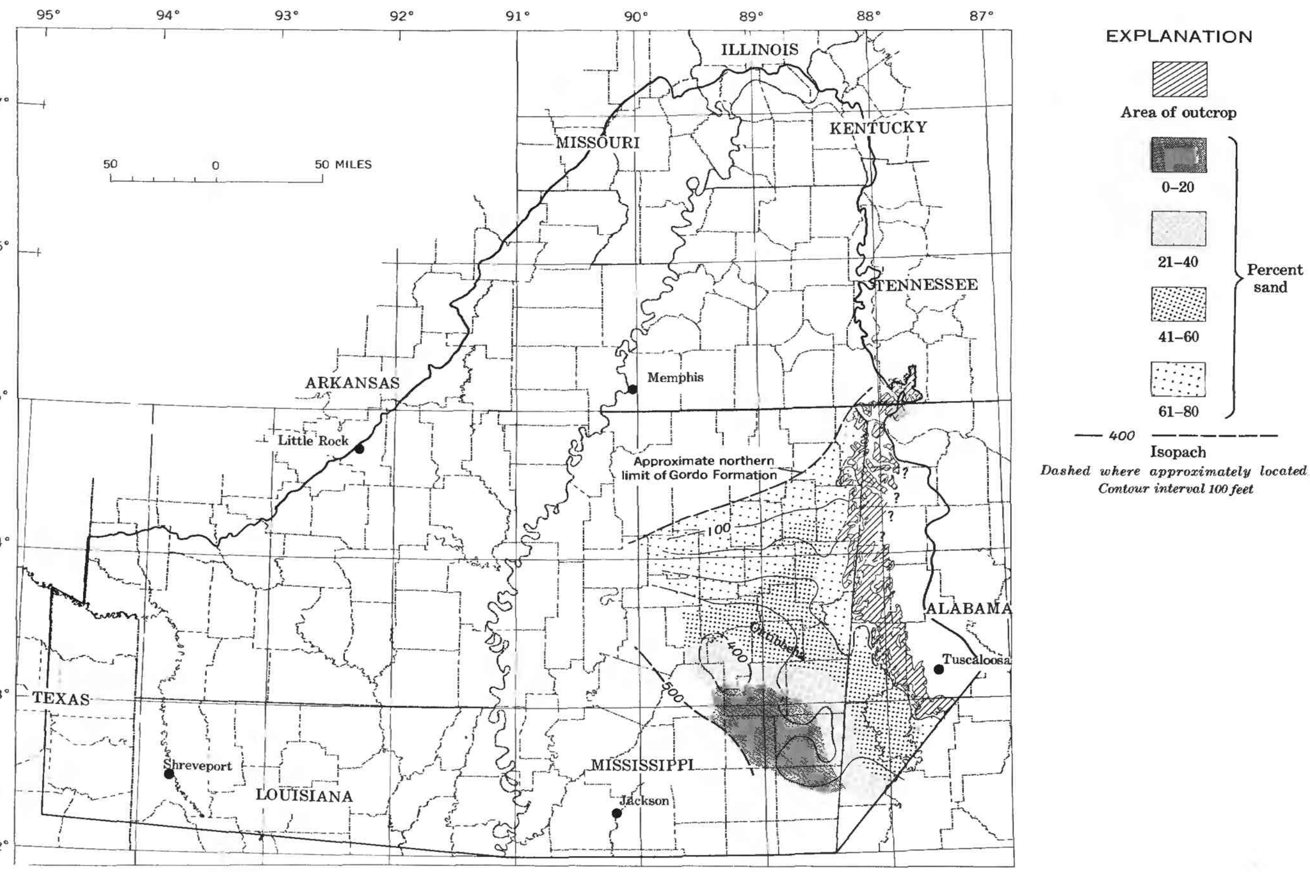

FIGURE 14.—Area of outcrop, thickness, and percentage of sand of the Gordo Formation. Outcrop area modified from Alabama Geol. Survey (1926), Mississippi Geol. Society (1945), and Tennessee Div. Geology (1933).

is, at least partly, responsible for the change in type of water.

The sodium and chloride contents of water downdip from zone 3 increase rapidly over a short distance. In Noxubee County, Miss., the water in the Gordo Formation has a higher dissolved-solids content than water in the massive sand at the base of the Coker Formation. In Calhoun County, Miss., water from the Gordo and Coker Formations is similar in chemical quality (pl. 2). In zone 1 and part of zone 2 water from the Gordo contains an excessive amount of iron. In the remainder of zone 2 and in zone 3, the water is suitable for most uses without treatment. Downdip from zone 3 the water is more highly mineralized than in zones 1, 2, and 3, but it is satisfactory for general use.

Analyses of waters from the Tuscaloosa Formation of Kentucky show that the waters are similar in character and dissolved-solids content to waters from the underlying Paleozoic rocks. The dissolved-solids content of the water ranges from 45 to 385 ppm. The water is a calcium bicarbonate type and increases in the dissolved-solids content are mainly increases in these two constituents.

POTENTIAL USE

The area of potential use of aquifers in the Gordo (fig. 13) is based on electric log determinations. The formation contains potable water in an area of about 12,000 square miles in Alabama and Mississippi, one-third of which is the area of potential use. The Gordo is not tapped in the area of potential use because of the availability of water in overlying aquifers. Large quantities of water are available, but the determinations of the maximum quantity and the quality of the water at a specific location will require test drilling and pumping.

CONCLUSIONS

The Gordo Formation will yield 500 gpm or more in most of the area of use in Alabama and Mississippi. The formation contains potable water in an area of about 12,000 square miles. The present area of use is about 8,000 square miles. Wells tapping the formation yield about 25 mgd.

WOODBINE FORMATION

By R. L. HOSMAN

The Woodbine Formation lies unconformably upon

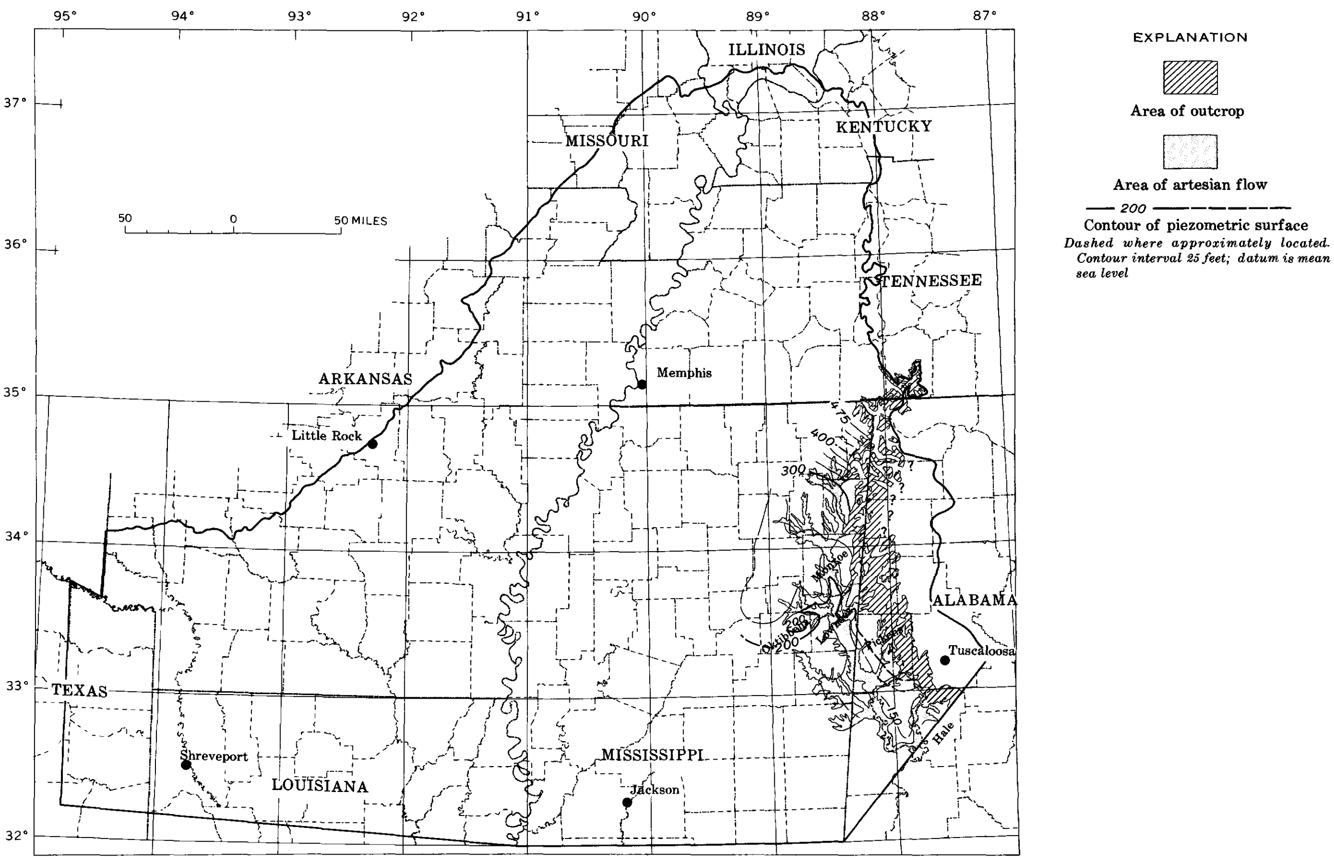

FIGURE 15.—Area of outcrop, piezometric surface of the water, and areas of artesian flow in the Gordo Formation. Outcrop area modified from Alabama Geol. Survey (1926), Mississippi Geol. Society (1945), and Tennessee Div. Geology (1933).

Lower Cretaceous rocks and is overlain by the Tokio Formation. It dips southeastward from the outcrop area in Sevier, Howard, and Pike Counties, Ark. The Woodbine has a maximum subsurface thickness of about 350 feet and contains sand, gravel, clay, and volcanic material. The basal gravel of the Woodbine is as much as 60 feet thick.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Recharge to the Woodbine occurs chiefly in the outcrop area, part of which is covered by Quaternary alluvium. The Woodbine overlaps the truncated Paluxy Sand, and the chemical similarity of water from wells tapping these aquifers near the area of overlap indicates that the units may be hydraulically connected. The Woodbine is tapped only in an area of about 75 square miles in southern Howard County, Ark. (fig. 10), where wells ranging in depth from 400 to nearly 600 feet have been developed in the aquifer as far as 15 miles southeast of the outcrop. Wells in lowland areas are flowing, but yields are low, and the total withdrawal is less than 0.1 mgd.

AQUIFER CHARACTERISTICS

Data relating to the aquifer characteristics are not available. Reported yields of wells range from 1 to 40 gpm.

QUALITY OF THE WATER

The Woodbine Formation contains usable water in and near the outcrop area and as far as 15 miles downdip. The water is generally high in sulfate and bicarbonate contents and low in chloride content (table 7). The hardness of the water is generally less than 20 ppm, and the iron content less than 0.5 ppm. The specific conductance of the samples indicates that the dissolved-solids content of water in this formation generally is in excess of 500 ppm. Because of the high dissolved-solids content, the water is unsuitable for many uses.

POTENTIAL USE

The Woodbine is used as a source of water supply chiefly in southern Howard County, Ark., and it is a potential source of ground water in northwestern Hempstead and south-central Sevier Counties (fig. 10). Counts and others (1955) reported that the basal gravel was cemented in one well in southern Sevier County and did not yield water. This may have been a local condition and does not eliminate the possibility of obtaining water from the Woodbine elsewhere in the area.

TABLE 7.—*Maximum, minimum, and median concentrations of constituents determined in water from the Woodbine Formation*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Iron (Fe)	5.1	0.07	0.18
Bicarbonate plus carbonate (HCO_3+CO_3)	622	20	350
Sulfate (SO_4)	166	7.0	56
Chloride (Cl)	72	4.8	8.8
Nitrate (NO_3)	2.5	.1	1.0
Hardness as $CaCO_3$	86	6	8
Specific conductance (micromhos at 25°C)	987	83	934
pH	9.1	7.0	----------

CONCLUSIONS

The Woodbine supplies water in an area of about 75 square miles in Howard County, Ark., and seems to be a potential source of ground water in an additional area of about 425 square miles. The specific conductance of water from the formation indicates that the dissolved solids are generally in excess of 500 ppm. Reported yields of wells range from 1 to 40 gpm.

EUTAW FORMATION

By J. G. NEWTON and E. H. BOSWELL

The Eutaw Formation is one of the principal sources of ground water in the Coastal Plain of Alabama and Mississippi and is the source of water for a few wells in Tennessee. It is the source of large water supplies in the "Black Belt" of Alabama and Mississippi, a crescent belt 20–40 miles wide underlain by several hundred feet of chalk in the Selma Group. Most flowing artesian wells in Alabama and many in Mississippi tap the Eutaw.

The Eutaw crops out in a northwestward-trending belt that is 10–15 miles wide except in Tennessee. The formation dips southwestward 25–60 feet per mile (fig. 16); the steepest dip is in the southern part of the area.

The Eutaw Formation, in this report, includes all beds between the top of the Gordo Formation and the base of the overlying Selma Group. This usage follows that of Smith and Johnson (1887, p. 86–88). The Eutaw includes the Tombigbee Sand Member at the top and a lower unnamed part. Conant and Monroe

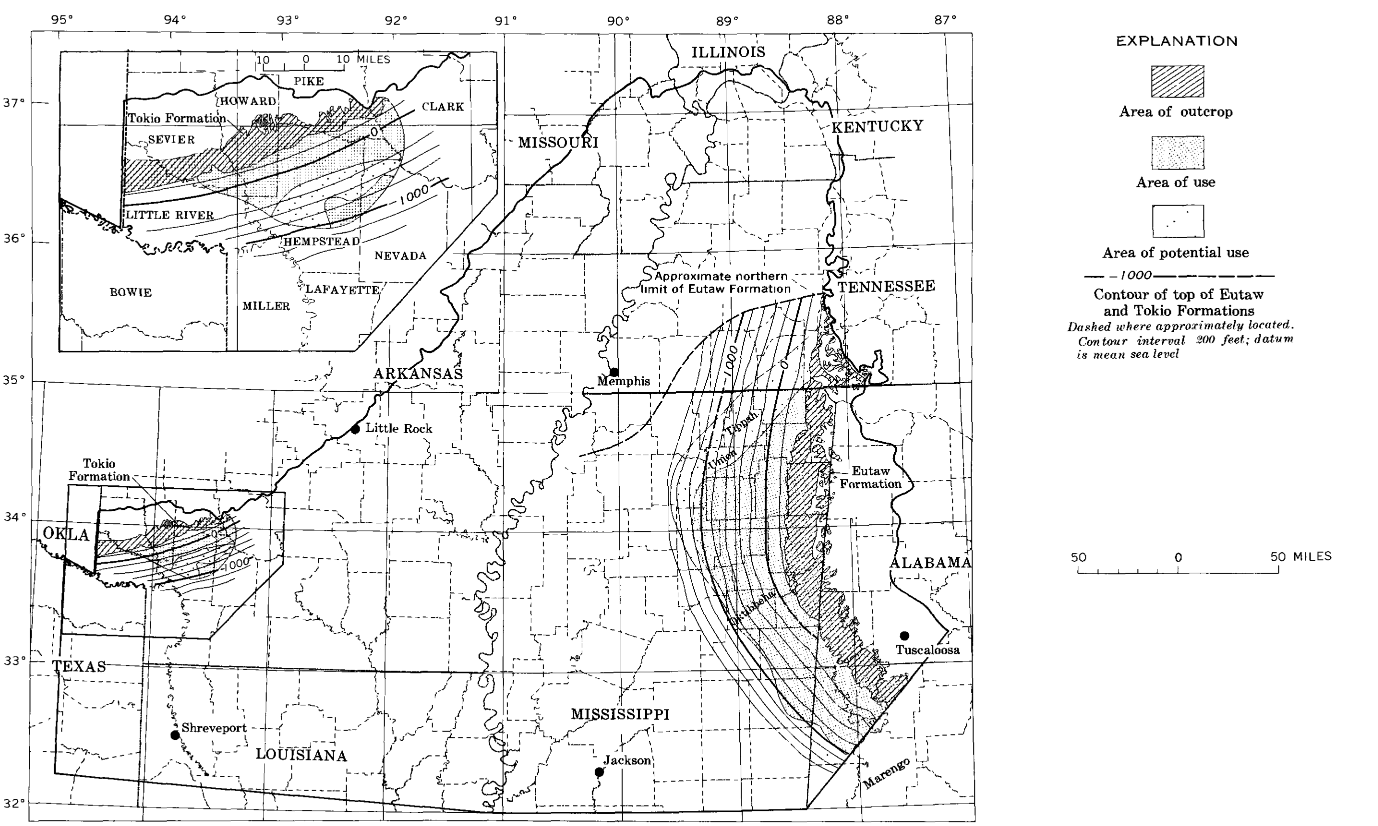

FIGURE 16.—Areas of outcrop, configuration of the top, and areas of use and potential use of the Eutaw and Tokio Formations. Areas of outcrop modified from Alabama Geol. Survey (1926), Arkansas Geol. Survey (1929), Mississippi Geol. Society (1945), and Tennessee Div. Geology (19))).

(1945) reclassified beds between the Selma and Tuscaloosa Groups by defining the McShan Formation as consisting of beds previously included in the lower part of the Eutaw in northwestern Alabama. The classification of Smith and Johnson is followed in this report because the authors could not determine the contact between the Eutaw and McShan Formations at many places in the subsurface and because others have noted that the contact is obscure (Applin and Applin, 1947). In this report, the terms "upper part of the Eutaw Formation" and "lower part of the Eutaw Formation" refer to the aquifers in the upper and lower parts of the formation.

In the eastern part of the area the thickest and most conspicuous sand beds are at the top and at the bottom of the Eutaw. Westward, sand beds occur locally throughout the formation. A basal Cretaceous gravel occuring north of the northern limit of the Gordo Formation is included here as basal Eutaw.

The Eutaw Formation is about 400 feet thick in the subsurface of Alabama and east-central Mississippi and thins northward (fig. 17).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Eutaw Formation receives most of its recharge where its permeable sands crop out (fig. 16).

The area of use of aquifers in the Eutaw is about 11,000 square miles, and generally extends 30–40 miles downdip from the outcrop. Municipal and industrial wells obtain large yields from the formation in Alabama and Mississippi. In Alabama several wells tapping only the basal sand of the lower part of the Eutaw Formation yield more than 500 gpm, and individual wells tapping the fine sands in the upper part of the Eutaw Formation yield 350 gpm or more. In Mississippi yields of wells tapping the lower part of the Eutaw are generally less than 500 gpm, and the maximum reported yield of a well tapping the upper part of the Eutaw is 770 gpm. Yields from wells tapping the formation in lowland areas range from less than 1 gpm to as much as 360 gpm. The amount of water discharging from flowing wells is not known, but is estimated to be from 6 to 9 mgd. Total withdrawal from wells tapping the Eutaw throughout its area of use is about 30 mgd.

The regional movement of ground water in the Eutaw Formation is southwestward down the dip (fig. 18). The piezometric surface reflects the movement of water toward flowing artesian wells in the lowlands along the Tombigbee and Black Warrior Rivers. The water levels have been lowered appreciably in local areas

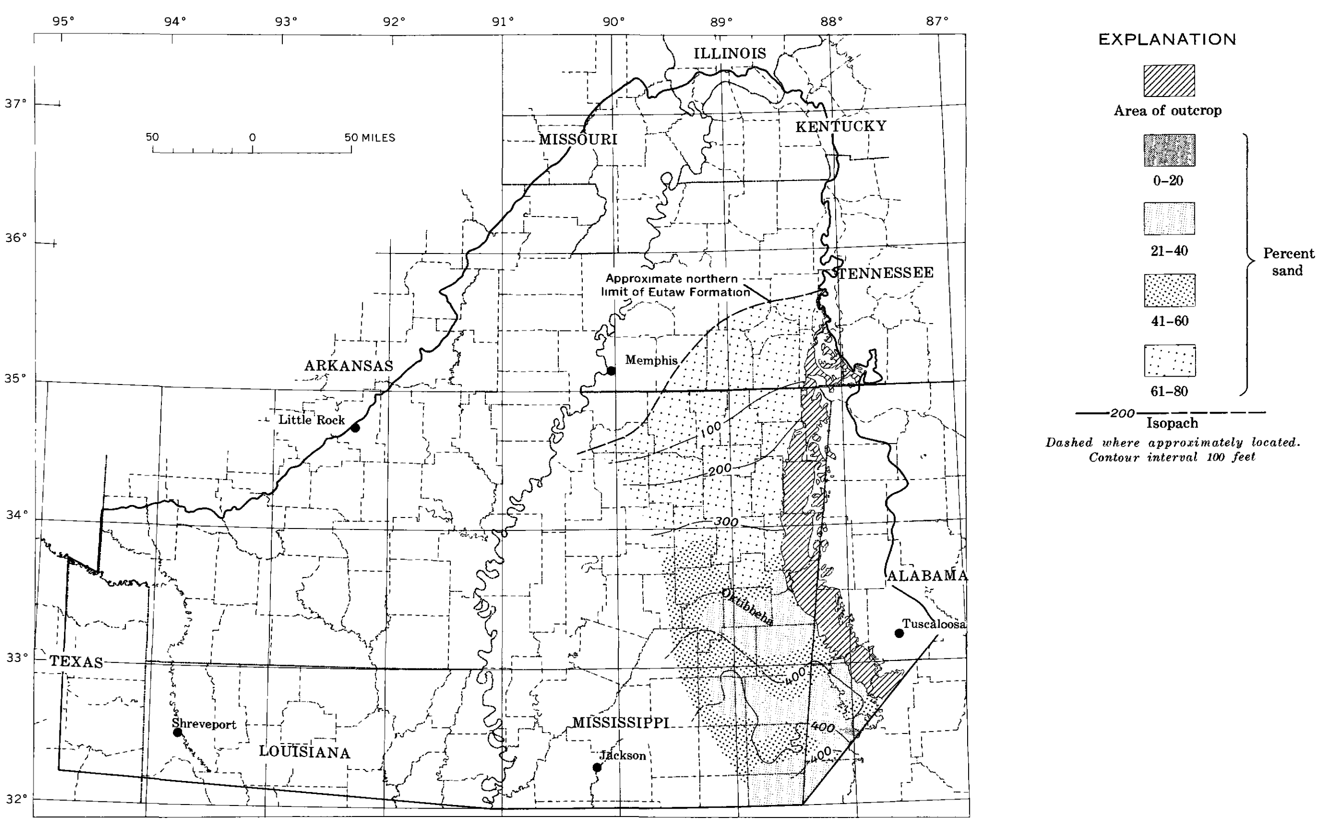

FIGURE 17.—Area of outcrop, thickness, and percentage of sand of the Eutaw Formation. Outcrop area modified from Alabama Geol. Survey (1926), Mississippi Geol. Society (1945), and Tennessee Div. Geology (1933).

where large quantities of water are withdrawn by municipal and industrial wells in Alabama and Mississippi.

AQUIFER CHARACTERISTICS

Results of an aquifer test using wells screened in the lower part of the Eutaw Formation in Monroe County, Miss., show a coefficient of transmissibility of 20,000 gpd per ft and a coefficient of storage of 0.0002. The specific capacity of the pumped well is 4.5 gpm per foot of drawdown. Data from two pumping tests made in Marengo County, Ala., indicate coefficients of transmissibility of 7,700 and 11,400 gpd per ft and specific capacities of 2.9 and 1.9 gpm per foot of drawdown, respectively.

Three aquifer tests were run in wells tapping the upper part of the Eutaw Formation in Marengo County, Ala. The coefficient of transmissibility ranges from 500 to 2,600 gpd per ft and averages 1,500 gpd per ft, and the specific capacity ranges from 0.4 to 1.4 gpm per ft and averages 0.8 gpm per ft. The coefficient of storage for one test is 0.0013. Results of an aquifer test made in Monroe County, Miss., show a coefficient of transmissibility of 13,400 gpd per ft, a coefficient of storage of 0.00016, and a specific capacity of the pumped well of 5.9 gpm per foot of drawdown.

In Mississippi, specific capacities determined and reported for wells tapping various parts of the Eutaw Formation ranged from 3 to 9 gpm per foot of drawdown and averaged about 4 gpm per ft. Properly constructed wells in the formation in most of the area of study in Alabama and Mississippi will yield 300 to 500 gpm.

QUALITY OF THE WATER

Water from the Eutaw Formation is a sodium chloride bicarbonate type except in northeastern Mississippi where it is a calcium bicarbonate type and in Tennessee where it is a sodium bicarbonate type. The type of water in the lower part of the formation is similar (pls. 3, 4) to that in the upper part but the dissolved-solids content of water from the lower part is generally less (tables 8, 9). Dissolved-solids contents in the water from aquifers in the Eutaw Formation are low in the outcrop area and increase as the water moves downdip. The increase is mainly in sodium and bicarbonate where the dissolved-solids content is less than 1,000 ppm; above about 1,000 ppm the increase is primarily in sodium and chloride contents. In parts of Sumter, Greene, and Marengo Counties, Ala., the large concentrations of chloride marking the southern limit of the area of use are associated with the Livingston fault zone. Except for iron and sulfate, maximum concentrations of most constituents generally occur in water in the downdip areas.

TABLE 8.—*Maximum, minimum, and median concentrations of constituents determined in water from the lower part of the Eutaw Formation*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Silica (SiO_2)	20	0.8	
Iron (Fe)	9.9	.00	0.26
Calcium (Ca)	68	.4	10
Magnesium (Mg)	7.9	.0	2.9
Sodium (Na)	1,020	1.5	69
Potassium (K)	28	1.6	4.8
Bicarbonate plus carbonate (HCO_3+CO_3)	540	18	142
Sulfate (SO_4)	34	.0	3.0
Chloride (Cl)	1,320	2.0	62
Fluoride (F)	5.0	.0	.2
Nitrate (NO_3)	7.6	.0	.5
Dissolved solids (residue at 180°C)	2,680	37	248
Hardness as $CaCO_3$	186	1	38
Specific conductance (micromhos at 25°C)	4,880	54	430
pH	8.8	6.1	

TABLE 9.—*Maximum, minimum, and median concentrations of constituents determined in water from the upper part of the Eutaw Formation*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Silica (SiO_2)	35	1.1	10
Iron (Fe)	19	.00	.59
Calcium (Ca)	186	1.0	8.5
Magnesium (Mg)	55	.2	2.7
Sodium (Na)	3,340	2.2	200
Potassium (K)	32	.6	6.9
Bicarbonate plus carbonate (HCO_3+CO_3)	692	6	348
Sulfate (SO_4)	95	.0	4.0
Chloride (Cl)	5,640	1.0	118
Fluoride (F)	7.0	.0	1.0
Nitrate (NO_3)	30	.0	1.1
Dissolved solids (residue at 180°C)	9,620	38	560
Hardness as $CaCO_3$	691	3	32
Specific conductance (micromhos at 25°C)	16,500	33	1,050
pH	8.9	5.0	

POTENTIAL USE

The downdip limit of the area of use of the Eutaw Formation in Alabama and eastern Mississippi marks the occurrence of highly mineralized water in the formation. The area of potential use is limited to about 1,000 square miles in Mississippi and Tennessee (fig. 16). North of the area of potential use, the sands in the Eutaw are thin and irregular and are not considered to be a dependable source of water for wells.

CONCLUSIONS

Wells tapping sands in the upper part of the Eutaw Formation yield as much as 350 gpm in Alabama and 770 gpm in eastern Mississippi. Wells tapping the lower part of the Eutaw Formation in most parts of Alabama and eastern Mississippi yield as much as 500 gpm. The quantity of water withdrawn by wells tapping the formation in the area of use is estimated to be about 30 mgd, of which an estimated 6–9 mgd is discharged from flowing wells. The area of potential use is small; however, the Eutaw is sparsely developed in much of the area of use.

TOKIO FORMATION

By R. L. Hosman

The Tokio Formation overlies the Woodbine Formation and underlies the Brownstown Marl. The formation ranges in thickness from about 50 to more than 300 feet and is composed of poorly sorted crossbedded sands, sandy clay, and gravel. It dips southeastward about 60 feet per mile from its outcrop belt which extends from Clark County, Ark., southwestward into Oklahoma (fig. 16). The outcrop, which is overlain in several places by terrace deposits and Quaternary alluvium, attains a maximum width of about 10 miles in Howard County, Ark.

In southern Sevier County and adjacent parts of Howard and Hempstead Counties, Ark., the Tokio contains three separate aquifers—a basal sand, which becomes a persistent basal gravel to the east, and two upper sands. These three units converge eastward.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Tokio receives its recharge where sands in the formation crop out or where it is overlain by permeable alluvial deposits. It supplies ground water in an area of about 1,000 square miles (fig. 16).

Except in the outcrop, water in the Tokio is under artesian conditions, and most of the wells tapping the formation flow (fig. 18). The Tokio is the largest single source of water to flowing wells in southwestern Arkansas, and most of this flow, about 2 mgd (Counts and others, 1955), is unused. Pumpage from the Tokio is estimated to be about 1 mgd, making a total withdrawal of about 3 mgd. The direction of movement of water is southeastward.

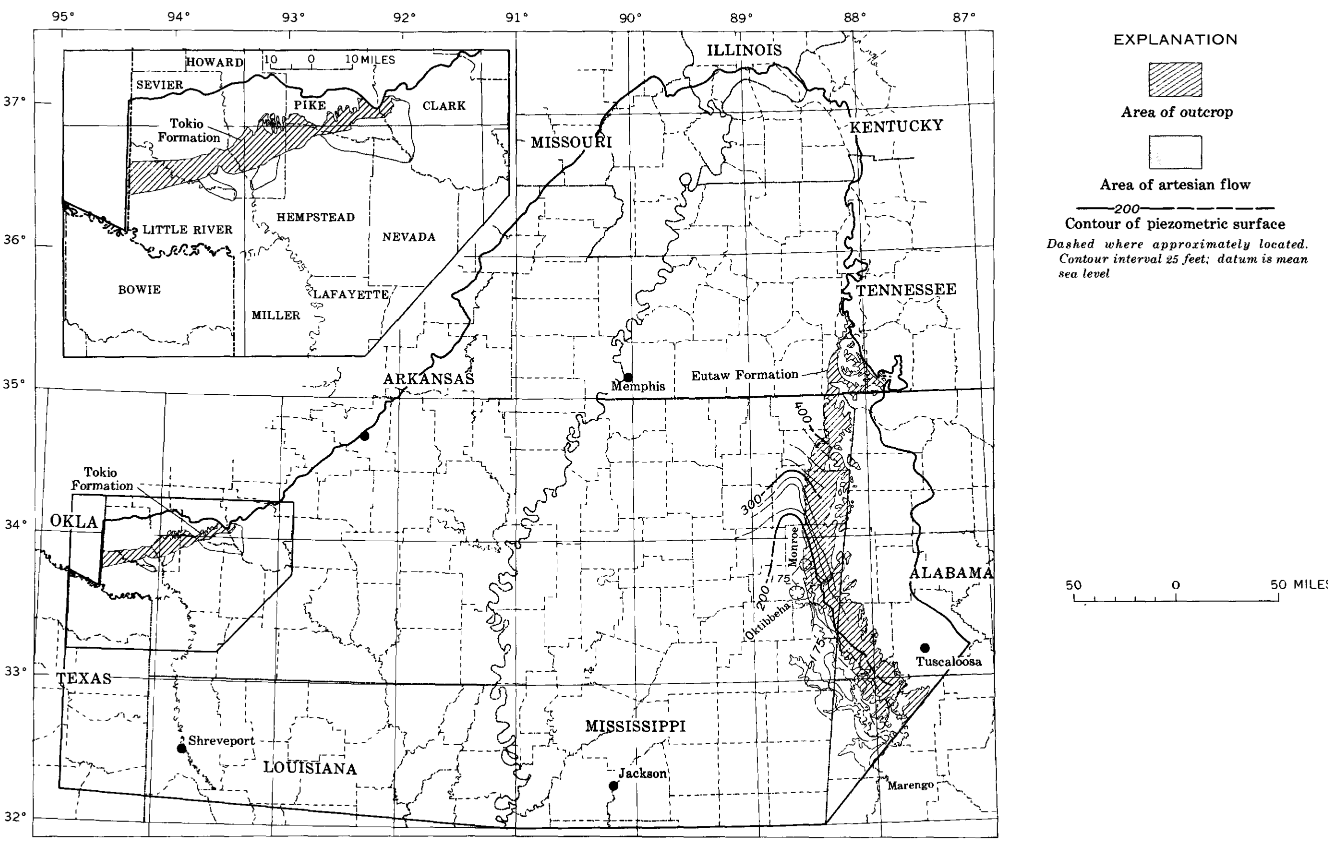

FIGURE 18.—Areas of outcrop, piezometric surface of the water, and areas of artesian flow in the lower part of the Eutaw Formation and in the Tokio Formation. Outcrop areas modified from Alabama Geol. Survey (1926), Arkansas Geol. Survey (1929), Mississippi Geol. Society (1945), and Tennessee Div. Geology (1933).

AQUIFER CHARACTERISTICS

Most wells tapping the Tokio Formation are constructed to obtain small yields; however, some wells yield 100–300 gpm. Most of the flowing wells discharge less than 20 gpm.

Results of an aquifer test in southern Howard County, Ark., show a coefficient of transmissibility of about 1,300 gpd per ft and a coefficient of storage of 0.000044.

Results of a pumping test using a municipal well in Hempstead County, Ark., indicate a coefficient of transmissibility of 4,500 gpd per ft.

QUALITY OF THE WATER

The dissolved-solids content of water from wells in the outcrop area of the Tokio Formation is low, and the increase downdip is gradual (pl. 5). Based on specific conductance values (table 10; fig. 9), the dissolved-solids content ranges from about 25 to more than 2,500 ppm, and the median value is about 235 ppm. The water is a sodium bicarbonate type. The iron content is low, except in north-central Hempstead and southern Howard Counties, Ark.

TABLE 10.—*Maximum, minimum, and median concentrations of constituents determined in water from the Tokio Formation*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Iron (Fe)	54	0.04	0.26
Bicarbonate plus carbonate (HCO_3+CO_3)	784	3	200
Sulfate (SO_4)	397	1.0	24
Chloride (Cl)	1,200	3.5	11
Nitrate (NO_3)	130	.0	.6
Hardness as $CaCO_3$	558	2	16
Specific conductance (micromhos at 25°C)	4,760	41	405
pH	9.0	5.9	----------

Water from the Tokio Formation may require treatment for some uses.

POTENTIAL USE

The area of potential use of aquifers in the Tokio Formation is about 250 square miles (fig. 16). In addition, the area of use, about 1,000 square miles, is undeveloped as most of the wells are concentrated in three small localities. Large quantities of water can be obtained by wells throughout most of the area.

CONCLUSIONS

The Tokio Formation is a largely undeveloped source of ground water in an area of about 1,250 square miles in southwestern Arkansas. Wells having their source in the formation yield as much as 300 gpm. The water is generally of good chemical quality but may require treatment for some uses.

COFFEE SAND

By G. K. MOORE and E. H. BOSWELL

The Coffee Sand overlies the Eutaw Formation in northeastern Mississippi and the adjoining part of Tennessee. North and west the Coffee Sand overlaps the Eutaw Formation and overlies Paleozoic rocks. The Coffee is overlain by the Demopolis Formation in Tennessee and by the upper part of the Demopolis Chalk in Mississippi, and it is equivalent to the Mooreville Chalk and lower part of the Demopolis Chalk of central Mississippi. The southern limit of the formation is marked by a facies change where the Coffee Sand grades into chalks of the Selma Group (the "mud line" of Mellen, 1958, p. 24–26, fig. 13). North and east, the Coffee Sand is overlapped by younger units, and it is absent over igneous intrusives in Tipton and Shelby Counties, Tenn. The formation strikes northward and dips about 35 feet per mile toward the axis of the embayment (fig. 19).

The Coffee Sand is predominately a sand, locally glauconitic and lignitic, that contains varying amounts of clay (fig. 20). The percentage of sand increases to the north. The formation attains a thickness of about 250 feet in southeastern McNairy County, Tenn., and averages about 230 feet thick in Alcorn, Prentiss, Tippah, and northern Union Counties, Miss.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Recharge to the Coffee Sand occurs in an outcrop area of about 800 square miles in western Tennessee and northeastern Mississippi (fig. 19). The formation contains fresh water in an area of about 7,000 square miles, but only about 2,000 square miles are included in the area of use. The water moves downdip toward the west (fig. 21). Data are not available to define the piezometric surface accurately over much of the area.

Municipal pumpage from the Coffee is estimated to be about 1.3 mgd, and industrial pumpage, about 1.2 mgd. Domestic pumpage is generally concentrated in and near the outcrop and is estimated to be 0.4 mgd. Discharge from flowing wells developed in the Coffee Sand is estimated to be 0.2 mgd.

AQUIFER CHARACTERISTICS

The Coffee Sand is capable of yielding small quantities of water everywhere in its area of use and potential use (fig. 19). Moderate amounts of water for municipal and industrial use can be obtained in most of this area.

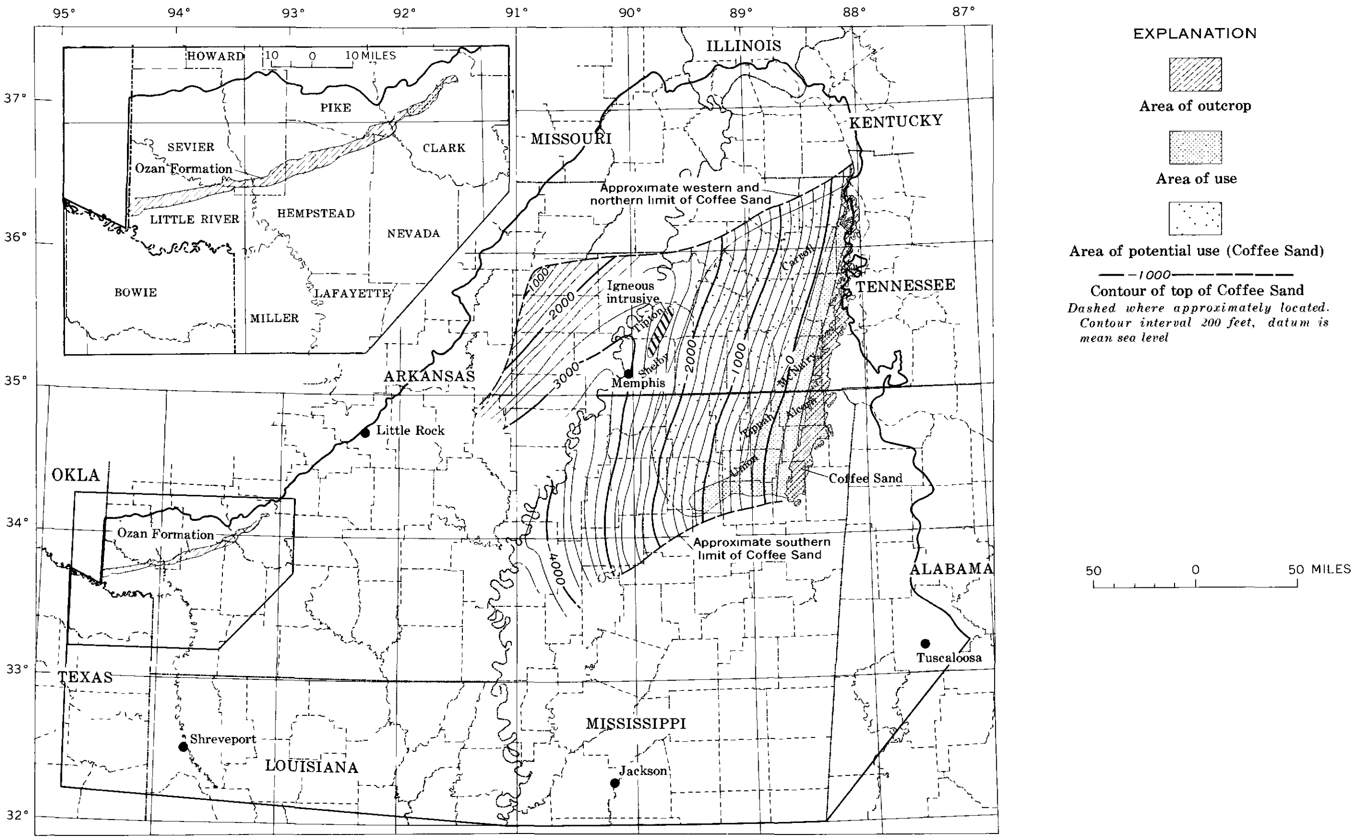

FIGURE 19.—Areas of outcrop, configuration of the top, and areas of use and of potential use of the Coffee Sand and Ozan Formation. Outcrop areas modified from Arkansas Geol. Survey (1929), Mississippi Geol. Society (1945), and Tennessee Div. Geology (1933).

Wells reported to yield as much as 600 gpm have been developed in Carroll and McNairy Counties, Tenn., and yields of more than 500 gpm have been reported for wells in Alcorn, Tippah, and Union Counties, Miss.

Aquifer tests have not been conducted on wells screened in the Coffee Sand, and the hydraulic characteristics of the formation are not known. Reported specific capacities of wells range from 0.5 to 3.5 gpm per foot of drawdown.

QUALITY OF THE WATER

Water in the Coffee Sand is a calcium bicarbonate type near the outcrop and changes to a sodium bicarbonate type as it moves downdip (pl. 6). The dissolved-solids content is low in the northern and eastern part of the area and increases toward the south and west.

The median values (table 11) are indicative of the chemical quality of water in the Coffee Sand in most of the area of use. The maximum concentration of nitrate (19 ppm) was in water from a shallow well, probably polluted by seepage from a surface source. The maximum concentration of fluoride (6.5 ppm) was in water from a 1,600-foot well in Lafayette County, Miss.

Most of the water has a higher sulfate content and a lower chloride content than water from aquifers in the underlying Eutaw Formation. The high chloride content in water from a well in Henderson County, Tenn.,

TABLE 11.—*Maximum, minimum, and median concentrations of constituents determined in water from the Coffee Sand*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Silica (SiO_2)	45	2. 1	10
Iron (Fe)	15	. 04	. 85
Calcium (Ca)	152	1. 3	26
Magnesium (Mg)	24	. 2	5. 3
Sodium (Na)	291	. 7	12
Potassium (K)	8. 5	. 2	3. 0
Bicarbonate plus carbonate (HCO_3+CO_3)	580	4	167
Sulfate (SO_4)	156	. 2	16
Chloride (Cl)	125	1. 2	4. 0
Fluoride (F)	6. 5	. 0	. 2
Nitrate (NO_3)	19	. 0	. 4
Dissolved solids (residue at 180°C)	761	16	200
Hardness as $CaCO_3$	410	4	76
Specific conductance (micromhos at 25°C)	1, 190	17	303
pH	8. 5	5. 4	----------
Color	15	2	----------

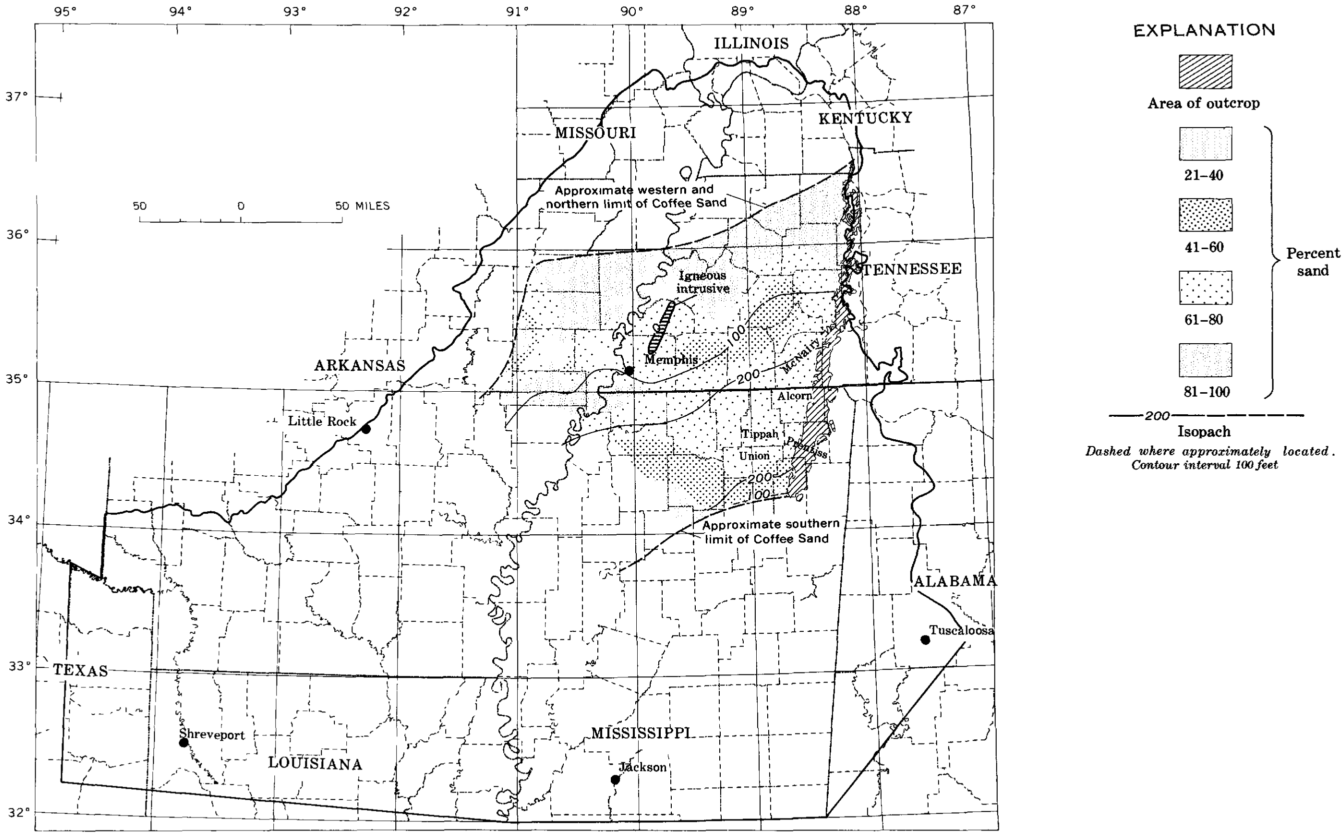

Figure 20.—Area of outcrop, thickness, and percentage of sand of the Coffee Sand. Outcrop area modified from Mississippi Geol. Society (1945), Tennessee Div. Geology (1933), and U.S. Geol. Survey (1932).

may be caused by local recharge from underlying Paleozoic rocks, as the analysis is almost identical with that of water from a Paleozoic source 5½ miles to the east.

Water from the Coffee Sand is suitable for most uses. In some areas treatment for iron removal and softening would be necessary for some uses.

POTENTIAL USE

The Coffee Sand is undeveloped except in and near the outcrop area. Large-capacity wells tap the formation in only a few localities. The western boundary of the area of potential use (fig. 19) is the downdip limit of water containing less than 1,000 ppm dissolved solids. The southern limit of the area of use is where the formation grades into chalks of the Selma Group.

CONCLUSIONS

The Coffee Sand is a major aquifer in the outcrop area and for a short distance westward. In the area of potential use, it is not utilized because of the availability of water in the overlying Ripley Formation at shallower depths. The Coffee contains potable water in an area of about 7,000 square miles.

Withdrawal by pumping or flow from wells tapping the Coffee Sand is estimated to be about 3 mgd.

OZAN FORMATION

By R. L. Hosman

The Ozan Formation, a glauconitic sandy marl, overlies the Brownstown Marl and is overlain by the Annona Chalk. The irregular outcrop, 1–4 miles wide, extends from northeastern Clark County, Ark., southwest into Oklahoma. Much of the outcrop is covered by terrace and alluvial deposits.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Only a few small capacity domestic wells, mostly in Clark County, Ark., withdraw water from the Ozan (fig. 19). Some of the wells in Clark County are flowing.

QUALITY OF THE WATER

Water from the Ozan, even in the outcrop area, generally contains more than 1,000 ppm dissolved solids. As indicated by the specific conductance, the dissolved solids range from about 600 to more than 4,000 ppm (table 12; fig. 9). In general, water from this formation is not suitable for most uses.

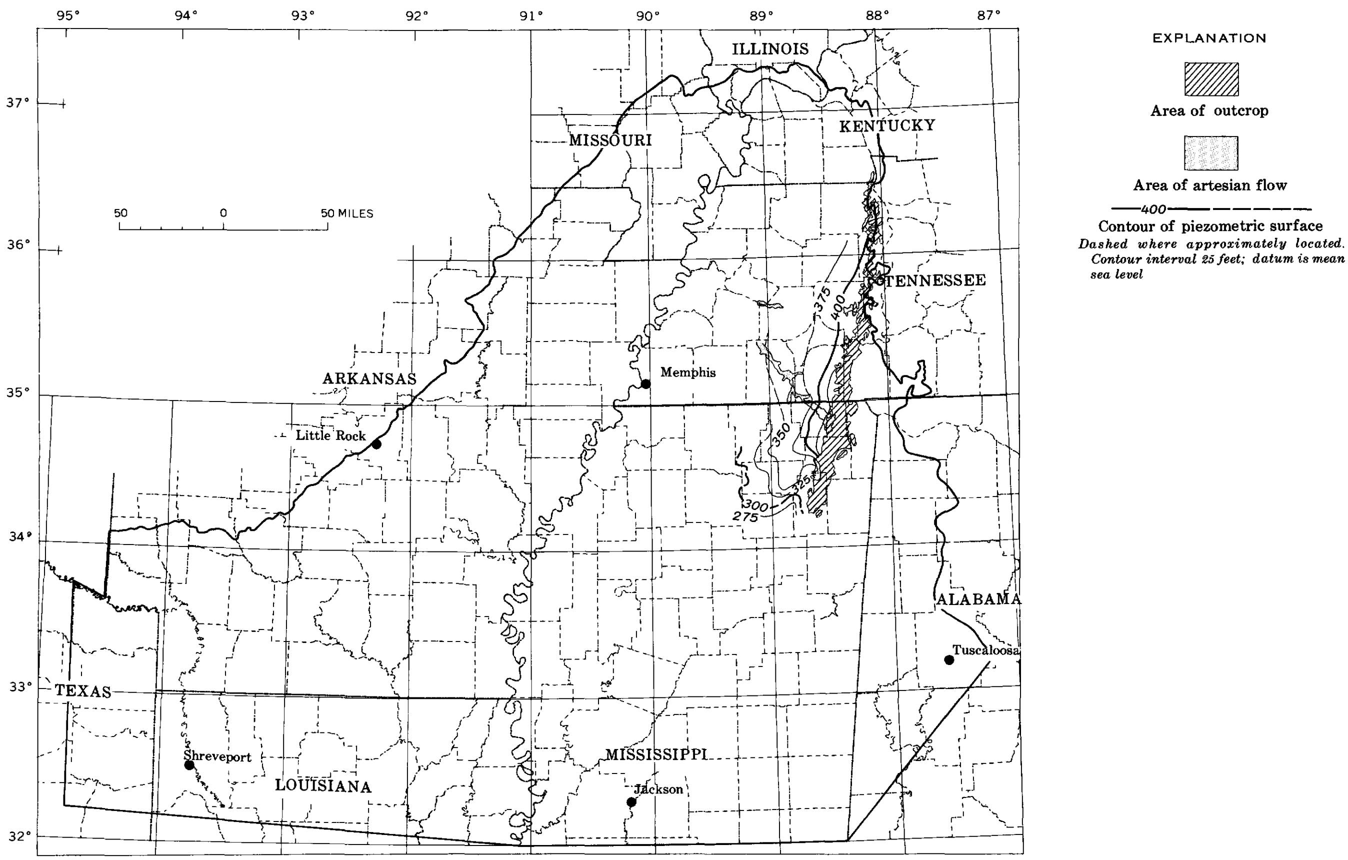

Figure 21.—Area of outcrop, piezometric surface of the water, and areas of artesian flow in the Coffee Sand. Outcrop area modified from Mississippi Geol. Society (1945) and Tennessee Div. Geology (1933).

Table 12.—*Maximum, minimum, and median concentrations of constituents determined in water from the Ozan Formation*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Iron (Fe)	0.76	0.03	0.25
Bicarbonate plus carbonate (HCO_3+CO_3)	607	140	350
Sulfate (SO_4)	517	4.9	245
Chloride (Cl)	2,100	32	792
Nitrate (NO_3)	8.4	.1	1.9
Hardness as $CaCO_3$	396	24	105
Specific conductance (micromhos at 25°C)	7,200	997	3,320
pH	9.3	7.9	----------

AQUIFER CHARACTERISTICS

Data relating to the aquifer characteristics of the Ozan Formation are not available. Most wells screened in the formation are small capacity domestic wells.

POTENTIAL USE

Development of the Ozan has been concentrated in central Clark County, Ark., because in that area no other aquifer is present from which water of a better quality can be obtained. West of Clark County only a few wells have been screened in the Ozan, because water of better quality can be obtained from the underlying Tokio Formation.

CONCLUSIONS

The Ozan Formation is a significant aquifer in central Clark County, Ark., where no other aquifer is present from which water of better quality can be obtained. In general, water from the Ozan is not suitable for most uses.

RIPLEY FORMATION

By L. M. MacCary, G. K. Moore, and E. H. Boswell

The Ripley Formation is undifferentiated in the southern part of the embayment where it is composed mostly of sandy chalk. In northern Mississippi the Ripley includes, in ascending order, the transitional clay, the Coon Creek Tongue, the McNairy Sand Member, and the Chiwapa Member. In Tennessee the Ripley Formation comprises two units, the Coon Creek Tongue and the overlying McNairy Sand Member. Only the McNairy Sand is present in Kentucky, Illinois, and Missouri. In northeastern Arkansas, the Nacatoch Sand has been correlated with sands in the Ripley Formation.

The Ripley Formation is underlain by the Demopolis Chalk in Mississippi, and by the Demopolis Formation and Paleozoic rocks in Tennessee. The McNairy Sand is underlain by Paleozoic rocks and, in a few places, by the Tuscaloosa Formation in Kentucky, by Paleozoic rocks in Illinois, and by Paleozoic rocks or deposits of Selma age in southeastern Missouri.

The Ripley Formation is overlain by the Prairie Bluff Chalk south of Union County, Miss., and by the Owl Creek Formation in northern Mississippi, Tennessee, and Missouri. In western Kentucky and southern Illinois the McNairy Sand is apparently overlain by clays of Tertiary age.

The strike of the Ripley is northward in Mississippi and Tennessee; that of the McNairy Sand is from north to west in Kentucky and from west to southwest in Missouri, and the strike of the Nacatoch Sand is southwestward across Arkansas. The dip is approximately 30 feet per mile toward the axis of the embayment from both the eastern and western margins of the outcrop (fig. 22).

The Ripley Formation thickens toward the axis of the embayment and reaches a maximum thickness of about 575 feet in Shelby County, Tenn. (fig. 23). The percentage of sand in the formation increases northward. The higher percentages occur in northern Tennessee, southern Kentucky, and southeastern Missouri.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Aquifers in the Ripley yield water to wells or are potential sources of water in an area of about 20,000 square miles (fig. 22). The McNairy Sand and the Chiwapa Member are the principal aquifers, and the water levels in the two units are at about the same altitude. An aquifer of limited areal extent in the southern part of the area of use has a lower water level (fig. 24). The area of use is small primarily because of the presence of adequate water supplies at shallower depths in Tertiary and Quaternary aquifers.

Estimated withdrawals from Ripley aquifers are 5 mgd in Mississippi, 10 mgd in Tennessee, 2.5 mgd in Kentucky, 2 mgd in Missouri, 0.5 mgd in Illinois, and 0.3 mgd in Arkansas—a total withdrawal of about 20 mgd.

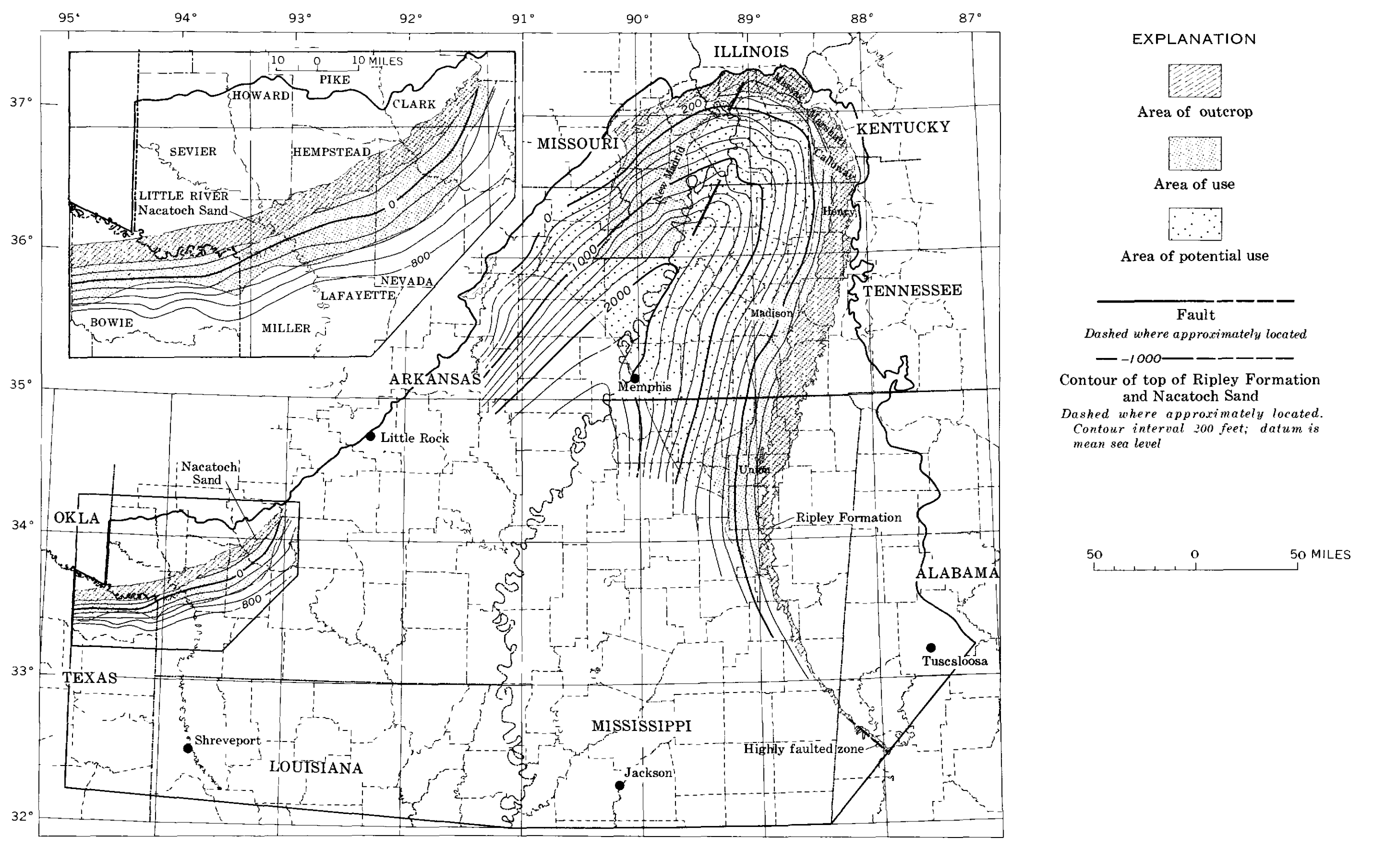

FIGURE 22.—Areas of outcrop, configuration of the top, and areas of use and of potential use of the Ripley Formation and Nacatoch Sand. Outcrop areas modified from Alabama Geol. Survey (1926), Arkansas Geol. Survey (1929), Darton and others (1937), Roberts and Gildersleeve (1945), Mississippi Geol. Society (1945), Missouri Geol. Survey and Water Resources Div. (1961), Tennessee Div. Geology (1933), and U.S. Geol. Survey (1932).

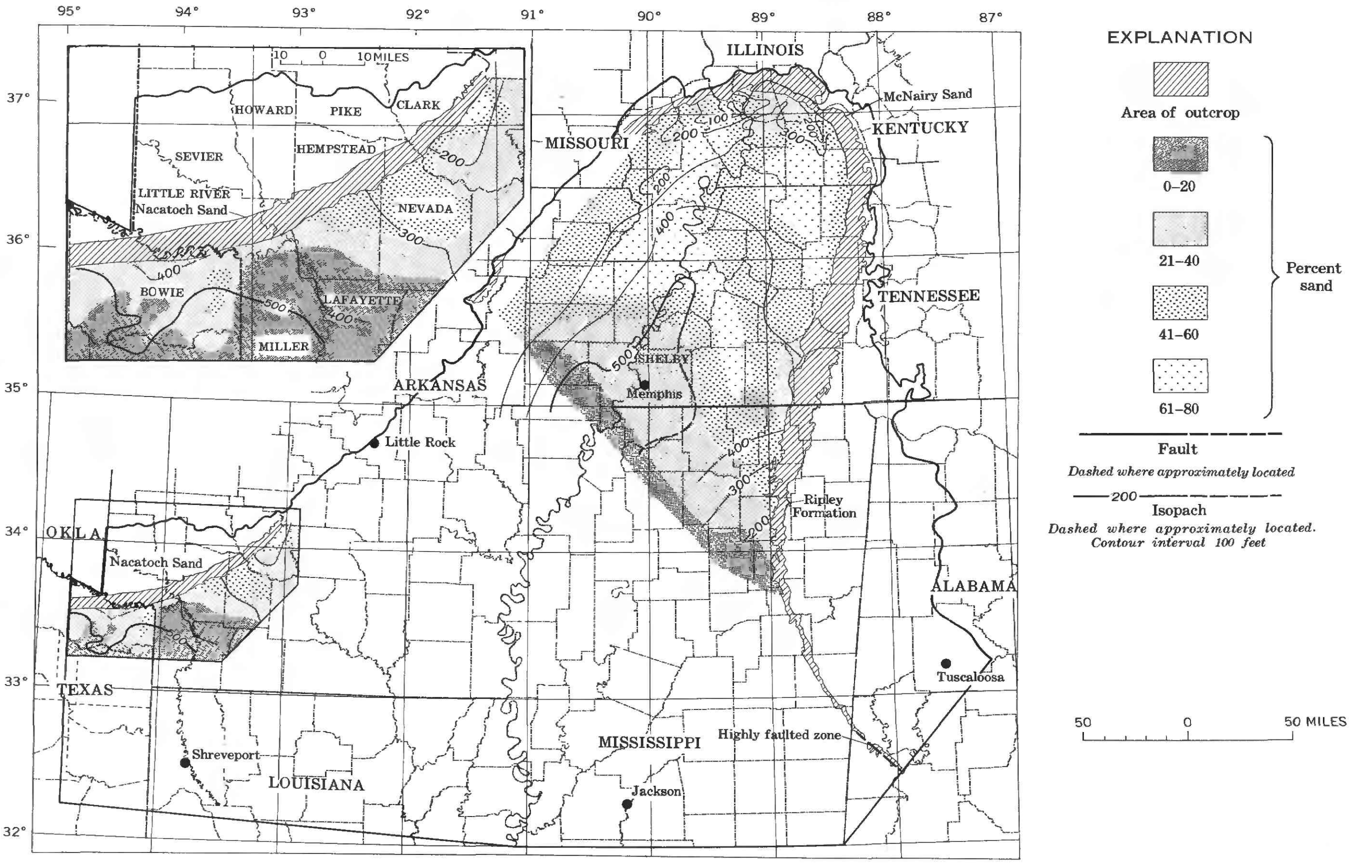

FIGURE 23.—Areas of outcrop, thickness, and percentage of sand of the Ripley Formation and Nacatoch Sand. Outcrop areas modified from Alabama Geol. Survey (1926), Arkansas Geol. Survey (1929), Darton and others (1937), Roberts and Gildersleeve (1945), Mississippi Geol. Society (1945), Missouri Geol. Survey and Water Resources Div. (1961), Tennessee Div. Geology (1933), and U.S. Geol. Survey (1932).

The regional movement of ground water in the Ripley is west and northwest. However, the movement of water in the separate aquifer in the southern part of the area is southwest (fig. 24).

Flowing wells are common in southeastern Missouri, western Tennessee, and north-central Mississippi. The potential area of artesian flow is large (fig. 24).

AQUIFER CHARACTERISTICS

The Ripley Formation is capable of yielding small to moderate amounts of water nearly everywhere in the area of use and area of potential use (fig. 22). Maximum reported yields of wells are 250 gpm in north-central Mississippi, 1,250 gpm in Henry County, Tenn., 1,140 gpm in Calloway County, Ky., 500 gpm in Massac County, Ill., and 720 gpm in New Madrid County, Mo.

Specific capacities of wells tapping the formation in Kentucky range from 1 to 27 gpm per foot. In Missouri the specific capacities range from about 1 to 12 gpm per ft, but most are between 1.5 and 5 gpm per ft. The specific capacity of a well in Madison County, Tenn., is 1.5 gpm per ft, and results of an aquifer test using this well show a coefficient of transmissibility of 25,000 gpd per ft and a coefficient of storage of 0.00076. Results of an aquifer test in Marshall County, Ky., show a coefficient of transmissibility of 32,000 gpd per ft and a coefficient of storage of 0.000096.

QUALITY OF THE WATER

Water from the Ripley Formation is extremely variable in chemical quality and is, at different places, a calcium magnesium bicarbonate type, a sodium chloride type, and a sodium bicarbonate type (pl. 7). The dissolved-solids content (table 13) ranges from 31 to 2,550 ppm; the higher dissolved-solids contents are in water from wells in Missouri and Mississippi. The maximum concentration of nitrate was in water from a shallow well and indicates organic pollution. The higher concentrations of fluoride were in water from the deeper wells.

In Missouri, water from wells in the outcrop area is fairly low in dissolved-solids content, and calcium and bicarbonate are commonly the predominant constituents. Water from many of these shallow wells has a high nitrate content. Normally the water in the for-

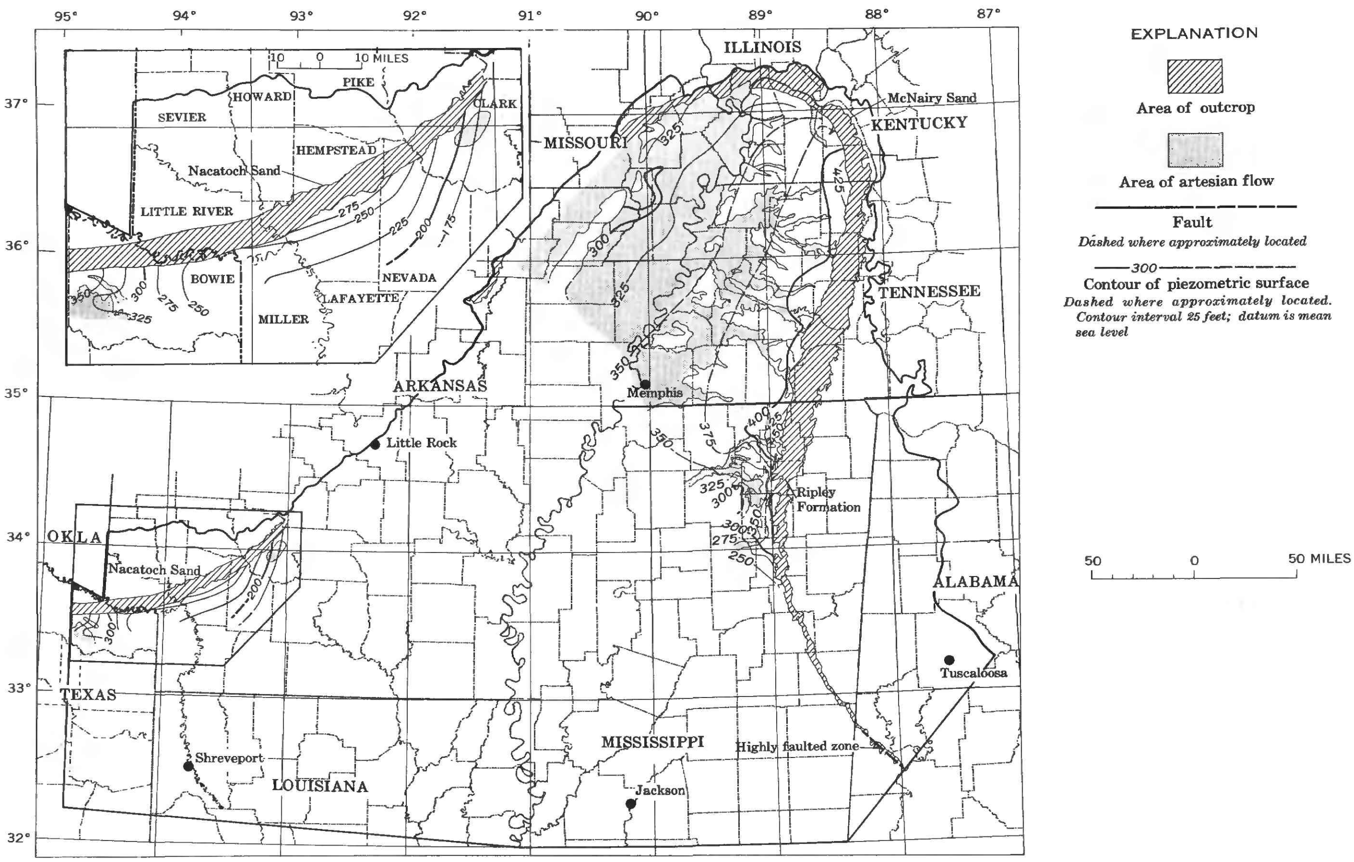

FIGURE 24.—Areas of outcrop, piezometric surface of the water, and areas of artesian flow in the Ripley Formation and Nacatoch Sand. Outcrop areas modified from Alabama Geol. Survey (1926), Arkansas Geol. Survey (1929), Darton and others (1937), Roberts and Gildersleeve (1945), Mississippi Geol. Society (1945), Missouri Geol. Survey and Water Resources Div. (1961), Tennessee Div. Geology (1933), and U.S. Geol. Survey (1932).

mation changes from a calcium bicarbonate type in the outcrop area to a sodium bicarbonate type down the dip. The sodium chloride water in the northern part of the area is probably related to the upward movement of water from underlying Paleozoic rocks. In Dunklin and Pemiscot Counties, Mo., clay and marl of Selma age lie between the McNairy Sand and the Paleozoic rocks, and the water from the McNairy Sand is a sodium bicarbonate type.

In Kentucky and Tennessee, the water from the McNairy Sand generally is low in dissolved solids. The higher dissolved-solids concentrations are in water from wells along the Ohio River in Kentucky, and the concentration decreases southward across Kentucky and most of Tennessee.

In Mississippi, water from the McNairy Sand Member of the Ripley Formation generally is a calcium bicarbonate type, and water from the undifferentiated Ripley Formation generally is a sodium bicarbonate type. The dissolved-solids content of water from these aquifers increases to the south and southwest.

Water from the Ripley Formation is generally of good quality and is suitable for most uses. In many instances, however, some treatment may be necessary to make the waters suitable for industrial uses. The

TABLE 13.—*Maximum, minimum, and median concentrations of constituents determined in water from the Ripley Formation*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Silica (SiO_2)	38	1.8	14
Iron (Fe)	28	.02	.50
Calcium (Ca)	76	1.6	16
Magnesium (Mg)	34	.3	4.6
Sodium (Na)	415	2.1	22
Potassium (K)	12	.2	3.4
Bicarbonate plus carbonate (HCO_3+CO_3)	1,110	.0	95
Sulfate (SO_4)	1,430	.4	12
Chloride (Cl)	475	.0	4.7
Fluoride (F)	4.4	.0	.2
Nitrate (NO_3)	268	.0	.7
Dissolved solids (residue at 180°C)	1,010	31	140
Hardness as $CaCO_3$	952	1	44
Specific conductance (micromhos at 25°C)	2,150	28	168
pH	8.9	4.0	----------

high fluoride content of water in the Ripley in places may make it undesirable for public supplies. The high dissolved-solids and chloride contents in water from the deeper wells in Missouri may make the water unfit for most uses.

POTENTIAL USE

The area of potential use of aquifers in the Ripley Formation is about 12,000 square miles (fig. 22). These units are not tapped in this area primarily because of the availability of ground water in shallower aquifers. Large quantities of water seem to be available, but the maximum quantity and the quality of the water at a given location will have to be determined by test drilling and pumping. At many places in the area of potential use, flowing wells can be obtained (fig. 24).

CONCLUSIONS

The areas of use and of potential use of aquifers in the Ripley Formation cover about 20,000 square miles. Total withdrawal from the Ripley is estimated to be about 20 mgd. Wells capable of yielding as much as 100 gpm can be constructed in the formation nearly everywhere in the area, and yields of more than 1,000 gpm are possible in places.

NACATOCH SAND

By R. L. Hosman and A. T. Long

The Nacatoch Sand in Arkansas is underlain by the Saratoga Chalk and overlain by the Arkadelphia Marl. The Saratoga, Nacatoch, and Arkadelphia in Arkansas are equivalent to the undifferentiated Navarro Group of northeastern Texas.

The Nacatoch Sand in the Mississippi embayment is exposed at the surface in a belt 3–8 miles wide extending from central Clark County, Ark., southwestward to the west edge of Hempstead County (fig. 22). In an area extending across Little River County, Ark., and Bowie County, Tex., it is covered by Quaternary alluvial and terrace deposits. The dip of the Nacatoch increases from about 30 feet per mile toward the southeast in southwestern Arkansas to about 100 feet per mile toward the south in northeastern Texas (fig. 22).

Where it is used as an aquifer, the Nacatoch ranges in thickness from about 150 feet to nearly 600 feet (fig. 23). The lower part of the formation generally consists of marl, clay, and fine glauconitic sand. The upper part is sandy and is the principal aquifer.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Nacatoch receives recharge where it crops out in Hempstead, Nevada, and Clark Counties, Ark. It is also recharged through the alluvium and terrace deposits which overlie parts of the unit in Little River County, Ark., and Bowie County, Tex.

The general direction of movement of ground water in the Nacatoch is southeast (fig. 24). The direction of flow may be governed by the increase in clay content in the downdip direction and by a fault system trending northeastward across southern Bowie County, Tex., and Miller, Lafayette, and Nevada Counties, Ark.

Approximately 400 wells are screened in the Nacatoch in the area of use (fig. 22). Most are domestic and stock wells; a relatively small number are municipal and industrial wells. About 1.2 mgd is withdrawn from the Nacatoch, mostly in southwestern Arkansas, by municipalities and industries. Some of the wells are reported to yield as much as 300 gpm. Flowing wells tap the Nacatoch Sand in southern Bowie County, Tex., and central and southern Clark County, Ark., but the number is diminishing primarily because of declining water levels resulting from unrestricted flow.

AQUIFER CHARACTERISTICS

Two pumping tests have been made in wells tapping the Nacatoch Sand. Analysis of a test in Bowie County, Tex., shows a coefficient of transmissibility of 1,400 gpd per ft; and results of a test in Hempstead County, Ark., show a coefficient of transmissibility of 3,600 gpd per ft.

QUALITY OF THE WATER

The chemical characteristics of water from the Nacatoch Sand are variable (pl. 8). The dissolved-solids content of water in the outcrop normally is low, but 2–20 miles down the dip it is high and the water may not be suitable for most uses. The specific conductance values (table 14 and fig. 9) indicate that the dissolved-solids contents range from about 20 to 6,500 ppm and have a median value of about 450 ppm. Below about 500 ppm dissolved solids, sodium and bicarbonate generally are the principal constituents. Above about 500 ppm, increases in dissolved-solids content are primarily increases in sodium and chloride contents. Median values (table 14) indicate that water is usually soft, and the iron, sulfate, and nitrate contents are low. The high nitrate contents in the water from some wells probably are from organic pollution.

POTENTIAL USE

The Nacatoch Sand is tapped by wells in essentially all of the area where is contains usable water (fig. 22). However, it is capable of supplying water to many more wells.

CONCLUSIONS

Hundreds of wells tapping the Nacatoch are in use, but relatively few yield more than a few gallons per minute. The aquifer is capable of yielding more water than is being withdrawn. The size of the area of artesian flow is diminishing, primarily because of unrestricted flow from wells.

TABLE 14.—*Maximum, minimum, and median concentrations of constituents determined in water from the Nacatoch Sand*

[Data in parts per million except as indicated]

Constituent	Maximum	Minimum	Median
Iron (Fe)	7.8	0.03	0.14
Bicarbonate plus carbonate (HCO_3+CO_3)	622	2	325
Sulfate (SO_4)	120	.2	11
Chloride (Cl)	3,850	3.0	58
Nitrate (NO_3)	110	.0	1.4
Hardness as $CaCO_3$	353	4	29
Specific conductance (micromhos at 25°C)	11,200	38	760
pH	9.0	4.7	----------

In general, water from the outcrop and much of the adjacent area is suitable for most uses. Downdip in the aquifer, the water is not suitable for most uses.

SIGNIFICANCE OF RESULTS

By E. M. CUSHING and E. H. BOSWELL

This report defines and describes the Cretaceous aquifers within the embayment where they contain water having a dissolved-solids content of less than 1,000 ppm. It also includes a brief description of the pre-Cretaceous aquifers. To determine the manner in which these aquifers operate will require a great deal more knowledge of their capicity to store and transmit water. However, certain facts are evident from the present data:

1. The water-bearing units in the Cretaceous System containing fresh water underlie an area of about 45,000 square miles. They supply ground water in an area of about 30,000 square miles and are available for use in an additional 15,000 square miles (fig. 3). In parts of the embayment, two or more aquifers are available for use. Individually, the areas of use and of potential use of the aquifers are, in square miles:

Areas of use and of potential use of the aquifers, in square miles

Aquifer	*Area of use*	*Area of potential use*	*Total*
Lower Cretaceous Series of Alabama and Mississippi	0	4,000	4,000
Trinity Group of Arkansas	750	250	1,000
Coker Formation	2,500	6,500	9,000
Gordo Formation	8,000	4,000	12,000
Woodbine Formation	75	425	500
Eutaw Formation	11,000	1,000	12,000
Tokio Formation	1,000	250	1,250
Coffee Sand	2,000	5,000	7,000
Ozan Formation	30	0	30
Ripley Formation	8,000	12,000	20,000
Nacatoch Formation	1,500	0	1,500

Generally the areas of potential use are large because aquifers in the Tertiary and Quaternary units are available at shallower depths.

2. The Cretaceous aquifers in the eastern and northern parts of the embayment underlie two or more States and are sparsely developed. The total withdrawal and flow from these units is about 90 mgd. Generally, local withdrawal does not exceed 3 mgd.
3. Water from the Cretaceous aquifers is generally of good chemical quality and is suitable for many uses without treatment. For some industrial and municipal uses treatment may be desirable. Iron is the most common troublesome chemical constituent.
4. Flowing wells can be developed in lowland areas because of the high water levels in most Cretaceous aquifers.
5. Most general water-level declines in the Cretaceous aquifers are the result of flow from wells and of increases in pumping; they are not indications of overdevelopment.
6. Most wells tapping Cretaceous aquifers are small capacity domestic wells, but most of the withdrawal is by municipal and industrial wells. Wells yielding as much as 200 gpm probably can be developed from the Cretaceous aquifers throughout the area where they contain fresh water; and in many areas in the eastern and northern part of the embayment, wells yielding as much as 1,000 gpm have been and can be developed. Partly as the result of uncontrolled discharge from flowing wells in some areas of the embayment, the water levels in the aquifers have declined to the extent that wells at higher altitudes have ceased flowing.
7. Where a Cretaceous fresh-water aquifer lies upon permeable Paleozoic rocks, the water from the aquifer in some areas has become highly mineralized. Lowering of the head in the Cretaceous aquifer by pumping or by allowing wells to flow apparently has resulted in the movement of highly mineralized water from the Paleozoic rocks upward into the Cretaceous. Care should be exercised when using an aquifer immediately overlying Paleozoic rocks or overlying units containing highly mineralized water, as development of the aquifer may cause the mineralized water to move into it.
8. Most streams crossing the Cretaceous outcrop receive water from the aquifers during periods of no precipitation and are perennial; thus the aquifers are saturated and are receiving as much recharge as they are capable of receiving under the present hydrologic conditions. Because of the high rain-

fall in the embayment, this condition will continue to exist until large ground-water supplies are developed in areas close to the outcrop of the aquifers and the hydraulic gradient is thereby steepened sufficiently to cause additional water to move down the dip rather than to discharge into the streams.

9. The pre-Cretaceous aquifers are in Paleozoic rocks and are sources of water within the embayment generally where the Cretaceous aquifers are thin. The area of use of pre-Cretaceous aquifers, mostly near the periphery of the embayment, is about 6,500 square miles, and the estimated withdrawal is about 10 mgd. The pre-Cretaceous units probably are potential sources of water over a large area, but the delineation of the area and the study of the individual aquifers in the pre-Cretaceous are beyond the scope of the present embayment study.

APPLICATION OF RESULTS

By E. M. CUSHING and E. H. BOSWELL

On the basis of the data in this report, the water-bearing units that are available as sources of water supply anywhere in the Cretaceous area can be determined, and the following approximations can be made: (1) the range in depth of the well or wells, (2) the water-bearing potential of each unit, (3) the water level, (4) the direction of flow of the water, (5) the yield and specific capacity of the well, and (6) the temperature and quality of the water. In some areas the amount of lowering of the water level due to the pumping of wells in the area (time-distance-drawdown) can be estimated. For example: What are the alternatives in developing a water supply of at least 300 gpm from an artesian aquifer in the southeast corner of Oktibbeha County, Miss.?

From the contour maps showing the configuration of the tops of the aquifers within the embayment (figs. 8, 10, 13, 16, 19, 22), one finds that four aquifers are available—the Lower Cretaceous, Coker, Gordo, and Eutaw (figs. 8, 10, 13, 16). From a topographic map, the land-surface altitude of the southeast corner of Oktibbeha County is about 250 feet above mean sea level.

The shallowest aquifer is the Eutaw Formation. The top (fig. 16) is about 375 feet below sea level or about 625 feet below land surface. The Eutaw is about 350 feet thick (fig. 17), and should be 21–40 percent sand (fig. 17). The total depth required to penetrate all sands in the Eutaw should be about 975 feet. The water level should be about 180 feet above sea level (fig. 18) or about 70 feet below land surface. The direction of movement of the water is southeast (fig. 18). The specific capacity of the well should be about 4 gpm per foot of drawdown, and the yield at least 300 gpm (p. C21. Two sand units are generally present in the Eutaw, so that a well probably could be developed in the upper part of the Eutaw Formation or in the lower part of the Eutaw Formation or in both. The quality of water (pls. 3, 4) should be:

Constituent	*Lower part of Eutaw Formation* Epm	Ppm	*Upper part of Eutaw Formation* Epm	Ppm
Ca	0.2	4	0.5	10
Mg	.1	1	.3	4
Na+K	5.3	120	11.1	260
Fe	--------	Trace	.1	3
HCO_3+CO_3	4.5	275	7.0	425
SO_4	.1	5	.3	14
Cl	.9	32	3.8	135
$F+NO_3$	--------	Trace	--------	---------
Dissolved solids (sum)	--------	About 300	--------	About 640

The temperature of the water in the Eutaw at the point under consideration should be about 69°–74°F (fig. 6). Although an aquifer test has not been made in the Eutaw sands near the selected site, one was made about 40 miles to the north-northeast. Using the values for the coefficients of transmissibility (20,000 gpd per ft) and storage (0.0002) from this test, the time-distance-drawdown relation for a discharge of 300 gpm is shown in figure 25.

The top of the next aquifer, the Gordo Formation (fig. 13), is about 725 feet below sea level or about 975 feet below the land surface. The Gordo is about 375 feet thick (fig. 14) and should be 41–60 percent sand (fig. 14). The total depth required to penetrate all sands in the Gordo should be about 1,350 feet. The water level should be about 190 feet above sea level or about 60 feet below land surface (fig. 14). The direction of movement of the water is southeast (fig. 14). The specific capacity of the well should be about 30 gpm per foot of drawdown, and the yield at least 300 gpm (p. C18). The quality of the water (pl. 2) probably would be:

Constituent	Epm	Ppm
Ca	0.4	8
Mg	.2	2
Na+K	5.1	120
Fe	----------	Trace
HCO_3+CO_3	2.0	120
SO_4	.1	5
Cl	3.7	130
$F+NO_3$	----------	Trace
Dissolved solids (sum)	----------	About 325

The temperature of the water should be 74°–78° F. Analysis of an aquifer test made 15 miles east of the selected site gives a value for the coefficient of transmissibility of about 33,000 gpd per ft. A value for the coefficient of storage could not be computed. However, using the above value for the coefficient of transmissi-

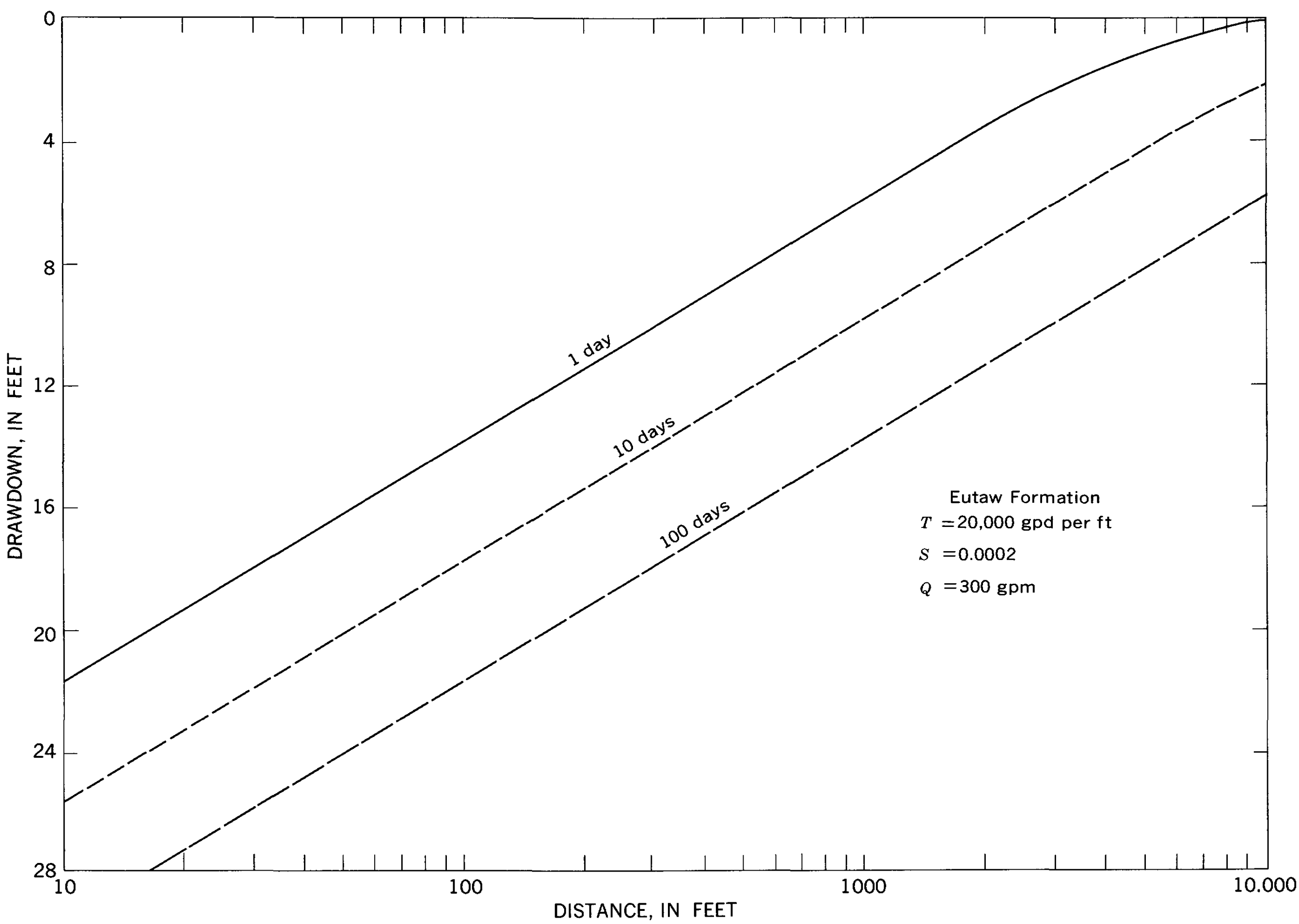

FIGURE 25.—Hypothetical relation between time, distance, and drawdown for a discharge of 300 gpm from the Eutaw Formation in southeastern Oktibbeha County, Miss.

bility and assuming a value for the coefficient of storage of 0.0001, the time-distance-drawdown relation for a discharge of 300 gpm is shown in figure 26.

The top of the Coker Formation (fig. 10) is about 1,100 feet below sea level or about 1,350 feet below land surface. The Coker is about 600 feet thick (fig. 11) and should be 41–60 percent sand (fig. 11). The total depth required to penetrate all sands in the Coker is about 1,950 feet. The water level should be about 210 feet above sea level (fig. 12) or 40 feet below land surface. The direction of movement of the water is south (fig. 12). The specific capacity of the well should be at least 15 gpm per ft, and the yield at least 300 gpm (p. C15). The chemical quality of the water (pl. 2) should be:

Constituent	*Epm*	*Ppm*
Ca	0. 6	12
Mg	. 2	2
Na+K	1. 6	37
Fe	----------	Trace
HCO_3+CO_3	1. 6	100
SO_4	. 05	2
Cl	. 7	25
$F+NO_3$	----------	Trace
Dissolved solids (sum)	----------	About 130

The temperature of the water should be 78°–86° F. Analysis of a pumping test made 15 miles east of the site gives a value for the coefficient of transmissibility of 250,000 gpd per ft and a value for the coefficient of storage of 0.0003. This test was run in the basal sand

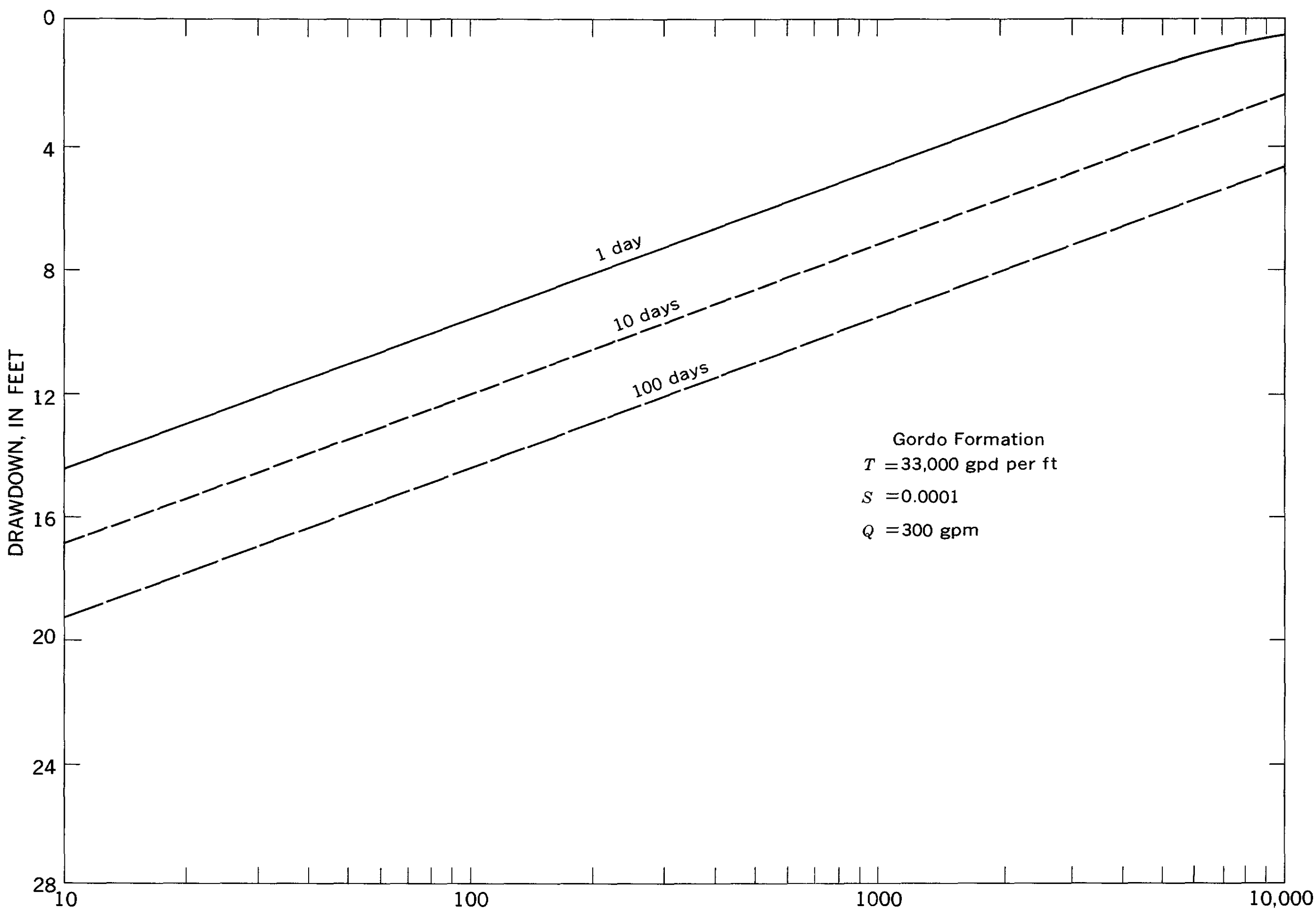

FIGURE 26.—Hypothetical relation between time, distance, and drawdown for a discharge of 300 gpm from the Gordo Formation in southeastern Oktibbeha County, Miss.

of the Coker, the massive sand, and the values are probably high for any other aquifer in the Coker. The time-distance-drawdown relation shown in figure 27 for a discharge of 300 gpm is based on these values.

The deepest aquifer in the southeast corner of Oktibbeha County is in the Lower Cretaceous Series. The top of the unit (fig. 8) is about 1,700 feet below sea level or about 1,950 feet below land surface. As water wells have not been drilled into this unit, information regarding the aquifer is based upon analysis of electric logs in the area.

At least 300 feet of the unit seems to contain fresh water (pl. 1), the quality of which is probably similar to that of the water in the Coker Formation. The specific capacity and the yield of a well probably would be comparable to those of a well in the Coker. The temperature of the water probably is more than 86° F (fig. 6).

The reader should remember that the above determinations are estimates based upon the available information. By drilling and testing a particular site, more exact data can be obtained.

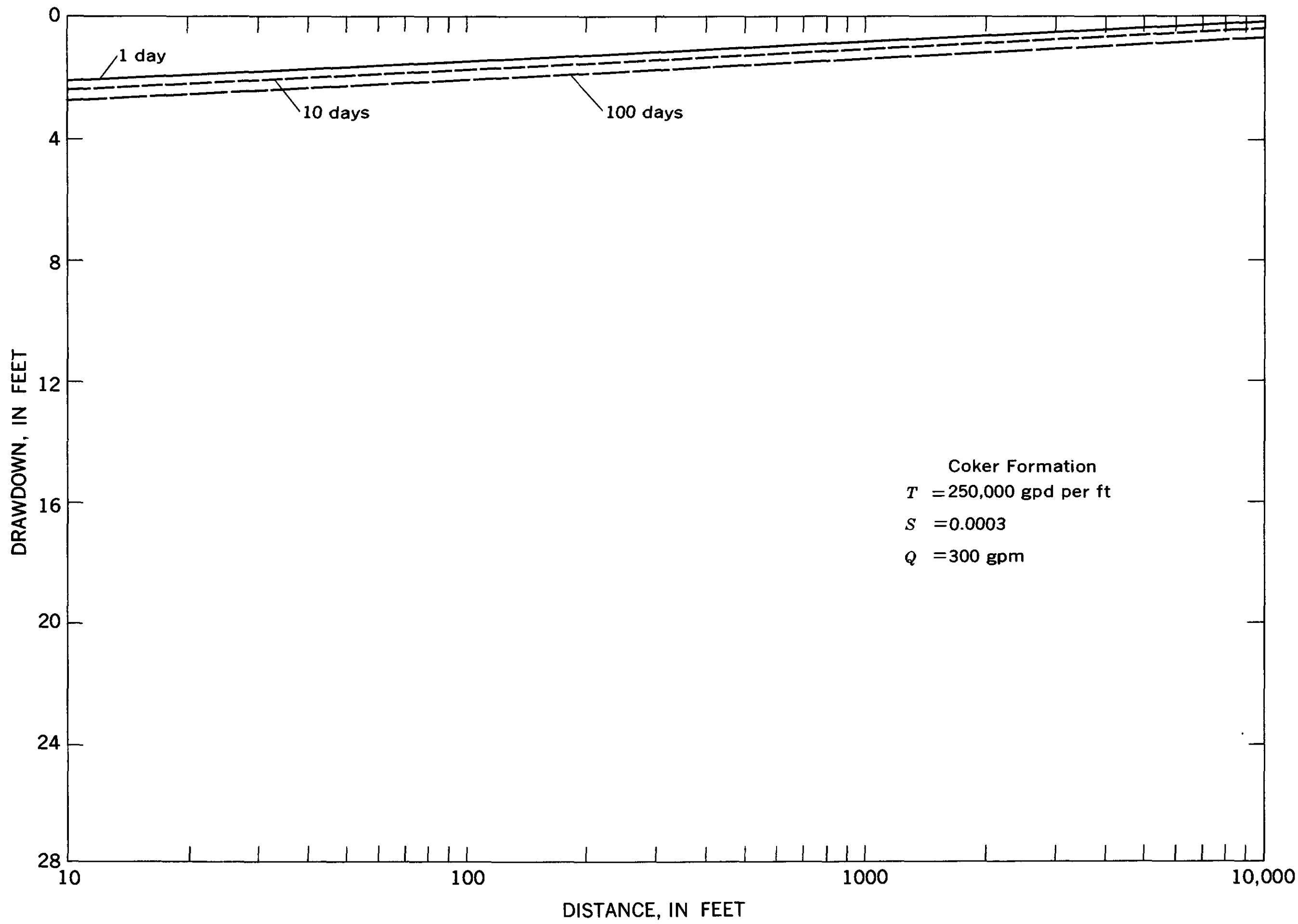

FIGURE 27.—Hypothetical relation between time, distance, and drawdown for a discharge of 300 gpm from the Coker Formation in southeastern Oktibbeha County, Miss.

In many places where the Cretaceous units contain fresh water, more than one aquifer is available. This permits the selection of an aquifer based upon requirements or limitations relating to well yields and interference between wells caused by pumping and to the temperature and quality of the water. At the selected site in Oktibbeha County, Miss., well fields could probably be developed in five separate units, and the interference caused by pumping in one aquifer on the water level in another would be negligible.

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