GEOLOGY AND GROUND-WATER RESOURCES OF COLBERT COUNTY, ALABAMA

By H. B. Harris, G. K. Moore, and L. R. West

GEOLOGICAL SURVEY OF ALABAMA *COUNTY REPORT 10*

GEOLOGICAL SURVEY OF ALABAMA

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State Geologist

DIVISION OF WATER RESOURCES

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COUNTY REPORT 10

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Prepared by the United States Geological Survey
in cooperation with the
Colbert County Board of Revenue, the city of Tuscumbia
and the Geological Survey of Alabama

UNIVERSITY, ALABAMA

1963

The nomenclature in this report follows that of the Geological Survey of Alabama but does not necessarily follow that in use by the U.S. Geological Survey.

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University, Alabama
March 18, 1963

Honorable George C. Wallace
Governor of Alabama
Montgomery, Alabama

Dear Governor Wallace:

I have the honor to transmit the manuscript of a report entitled "Geology and Ground-Water Resources of Colbert County, Alabama," by H. B. Harris, G. K. Moore, and L. R. West, with the request that it be printed as County Report 10 of the Geological Survey of Alabama.

The largest quantities of ground water in Colbert County are obtained from solution openings in the Tuscumbia Limestone and Fort Payne Chert. The water-bearing openings generally occur within 200 feet of the land surface. Pumping-test data indicate that in places along Spring Creek valley south of Tuscumbia yields of 2,000 gallons per minute can be obtained from wells tapping these openings. Ground water in sufficient quantity for domestic use is available in most parts of the county. The water is generally of good chemical quality, but it is hard.

Respectfully,

Philip E. LaMoreaux
State Geologist

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GEOLOGY AND GROUND-WATER RESOURCES OF COLBERT COUNTY, ALABAMA

By H. B. Harris, G. K. Moore, and L. R. West

ABSTRACT

Colbert County is in the northwestern part of Alabama. The western part of the county is in the East Gulf Coastal Plain section of the Coastal Plain physiographic province, and the central and eastern parts of the county are in the Interior Low Plateaus.

The outcropping rocks, from oldest to youngest, consist of the Fort Payne Chert, Tuscumbia Limestone, Ste. Genevieve Limestone, Bethel Sandstone, Gasper Formation, Cypress Sandstone, Golconda Formation, Hartselle Sandstone, and Bangor Limestone, all of Mississippian age; and the Tuscaloosa Group of Late Cretaceous Age. Throughout most of the county the Mississippian formations have been deeply weathered to cherty clay, sand, and gravel, for which the term "regolith" is assigned. Also included in the regolith are alluvial, colluvial, and terrace deposits. Where the structure is known, the rocks dip southwestward at about 25 to 30 feet per mile. Dip reversals indicative of local folding have been noted in a few areas in the western part of the county.

The most productive aquifers in the county are in the Tuscumbia Limestone and Fort Payne Chert, which are composed predominantly of calcium carbonate rocks. The aquifers were formed as the result of solutional enlargement by percolating water of joints and openings along bedding planes. Generally, these openings occur within 200 feet of the land surface.

Pumping tests indicate that yields of several thousand gallons per minute are obtained from these formations in places in Spring Creek valley south of Tuscumbia and probably in other places not tested. Small quantities of ground water adequate for domestic and stock needs can be obtained from most of the other formations in the county.

Except for its hardness, ground water in Colbert County is generally of good chemical quality. Water from the Fort Payne Chert, Tuscumbia Limestone, Tuscaloosa Group, and regolith is moderately hard to hard; water from the Ste. Genevieve Limestone, Gasper Formation, and Bangor Limestone is very hard; and water from the Bethel Sandstone and Hartselle Sandstone is relatively soft.

INTRODUCTION

LOCATION OF AREA

Colbert County, in northwestern Alabama, is bounded on the north by Lauderdale County, on the east by Lawrence County, on the south by Franklin County, and on the west by Mississippi (fig. 1). It has an area of 612 square miles.

PURPOSE AND SCOPE OF INVESTIGATION

A detailed study of the geology and ground-water resources of Colbert County was begun July 1, 1955, by the U.S. Geological Survey in cooperation with the Colbert County Board of Revenue and the Geological Survey of Alabama. In 1957 the city of Tuscumbia entered into the cooperative agreement. The investigation in Colbert County was coordinated with the statewide program of ground-water studies being made cooperatively by the Federal and State Geological Surveys. The purpose of this study was to determine the quantity, quality, and availability of ground water in the county and to relate the occurrence and movement of ground water to the thickness, character, distribution, and structure of each rock formation.

The increasing use of ground water by industry and the continued growth of the population in Tuscumbia, Littleville, and Cherokee have increased the requests for information about the ground-water resources in and near those towns. In addition, drought has aggravated municipal-supply problems in Cherokee.

The investigation was made under the direction of P. E. LaMoreaux, former district geologist in charge of ground-water investigations in Alabama, and W. J. Powell, district geologist.

PREVIOUS INVESTIGATIONS

The first geologic investigations in Colbert County were of a general nature, and were concerned chiefly with evaluating the county's mineral resources. The first published work was by Henry McCalley (1896, p. 147-186), who identified the presence in the county of the Bangor Limestone, Hartselle Sandstone, Tuscumbia Limestone, and Lauderdale or Keokuk Chert and described their physical properties. He described several geologic sections and suggested practical uses for the rocks in some of the formations. Smith (1907) described the geology and climate and, for the first time, provided information about the source, movement, and recovery of ground water. A general report by Adams and others (1926) contains considerable geologic information pertaining to Colbert County. A more detailed evaluation of the ground-water resources of Colbert County was made by Johnston (1933, p. 175-183), who described and evaluated each geologic formation as an aquifer.

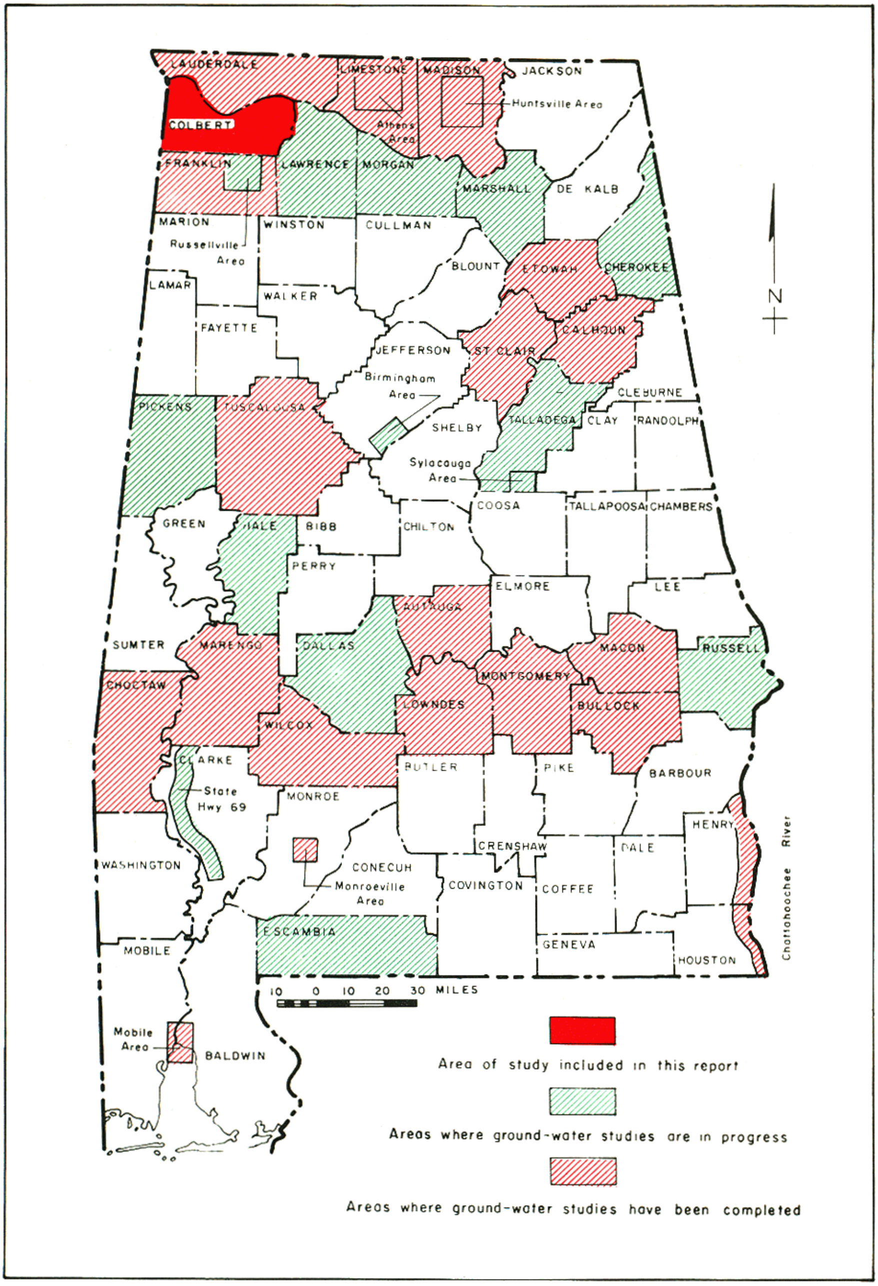

Figure 1.--Area studied and areas of other ground-water studies in Alabama.

METHODS OF INVESTIGATIONS

Significant data concerning wells and springs in Colbert County were collected and evaluated during this investigation. These data, which include depth of wells, information on well or spring construction, yield, drawdown when pumped, depth to water, and use of water were given by Harris and others (1960, table 1). Thirty test wells were drilled under contract to obtain additional geologic and hydrologic data. These wells are cited in table 4, and lithologic and electric logs obtained for each of them are shown in plates 2 and 3. Logs were obtained also for several privately owned wells in the county and these are in the files of the U.S. Geological Survey. Included in table 4 are 23 private wells and springs, which are repeated from Harris and others (1960), because data from them are used for interpretive discussions in this report.

Thirty pumping tests were made in 18 test wells to determine the amount of water available from the limestone aquifers (figs. 12-14 and table 3).

Periodic water-level measurements were made in selected wells from which hydrographs were prepared, relating precipitation, atmospheric pressure, and earthquakes to water-level fluctuations in the aquifers (figs. 5-10, 15, and 16). Water-surface maps were prepared for parts of Colbert County to present information on the movement of ground water (pls. 5 and 6).

Chemical analyses of 56 samples of water from 38 wells and springs were made by the Geological Survey to determine the chemical quality of the water (table 5).

Geologic mapping of the county was started in October 1957 and completed in June 1958. The geology was mapped on 7½-minute quadrangles at a scale of 1:24,000 and then reduced by projection to 1:63,360 (pl. 1).

ACKNOWLEDGMENTS

The residents and officials of Colbert County provided information and made wells available for pumping tests, electric logging, and water sampling for chemical analysis. Acknowledgment is made of the cooperation extended by the Colbert County Board of Revenue and particular thanks are given to Mr. Gresham Hale and Mr. John B. Sockwell, board chairmen. Thanks are given also to the Tuscumbia Utility Board and for the special efforts and

interest of Messrs. Joseph McWilliams, board chairman, Dewey L. Wilson, member, and H. G. Henneger, mayor of Tuscumbia. Mr. L. E. Hamlet, former manager, and Mr. C. Ricks, present manager of the Tuscumbia Utilities Department, provided equipment that aided development of several test wells and their personal interest contributed much to this study. The writers gratefully acknowledge the interest and assistance of Dr. Walter B. Jones, who was State Geologist at the time of this investigation.

PHYSIOGRAPHY

Colbert County is partly in two physiographic provinces of the eastern United States. The western part of the county is in the East Gulf Coastal Plain section of the Coastal Plain physiographic province, and the central and eastern parts are in the Interior Low Plateaus province (fig. 2). In the Coastal Plain province the streams have cut down through the Cretaceous gravels and into the underlying Paleozoic limestones, leaving ridges of moderate relief. Since most of the larger perennial streams, notably Bear Creek, have deepened their channels as a result of uplift, the underlying limestones are well exposed along the streams. That part of the county in the Interior Low Plateaus province is characterized by a slightly tilted limestone plateau, which extends southward for several miles from the Tennessee River, and a second, higher upland, which extends to the southern boundary of the county. The upland, known locally as the mountain, is terminated along its northern edge by an escarpment as much as 200 feet high.

The relief on the limestone plateau results more from rock solution than from surface drainage. Deep valleys do not occur in this area, but vertical drainage and several small streams have formed a gently rolling topography from Tuscumbia westward to the Coastal Plain province boundary. The most prominent topographic features of the limestone plateau are the bowl- and funnel-shaped sinks that have formed from solution of the underlying limestones. Many of the sinks are elliptical, and east and southeast of Sheffield most of them have a northwesterly orientation.

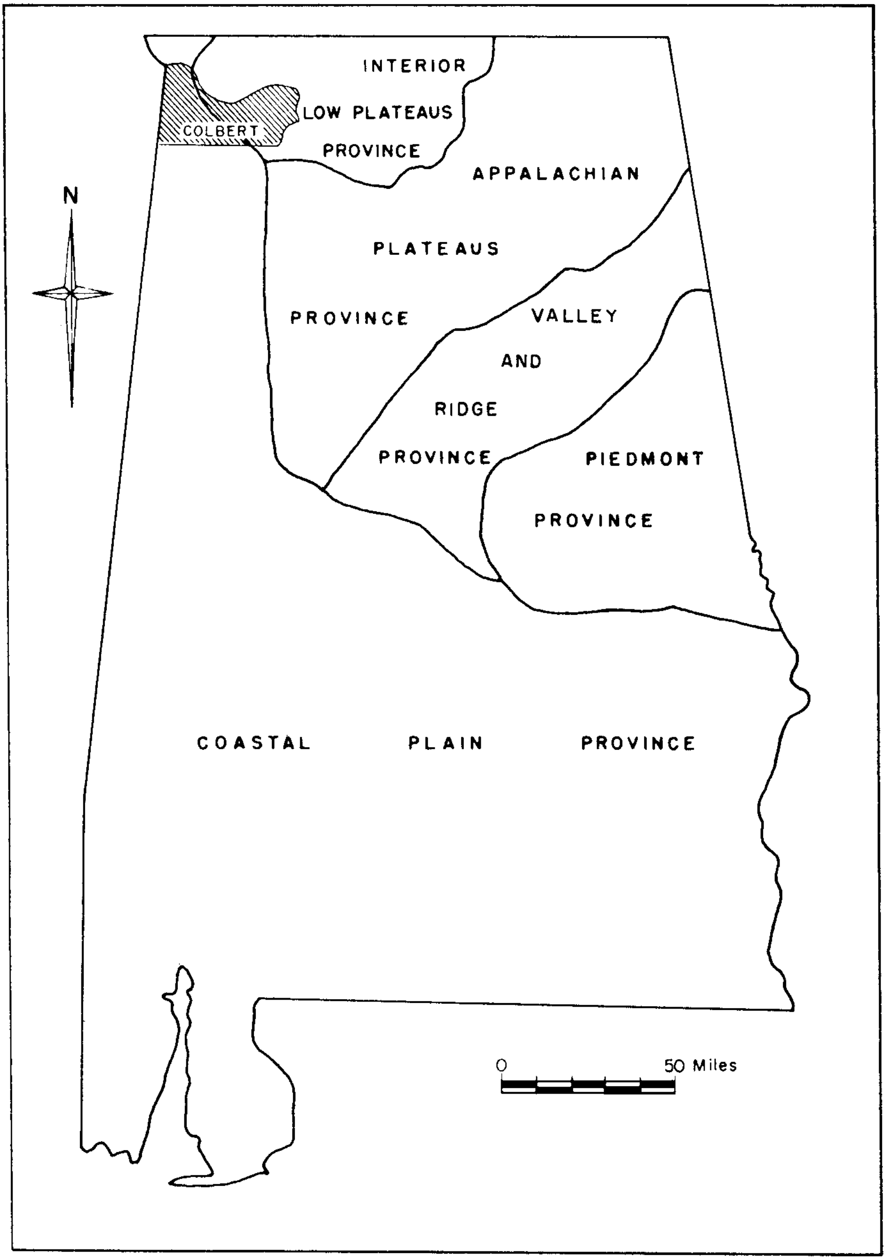

Figure 2.--Physiographic provinces in Alabama.

CLIMATE

Colbert County is in an area of mild humid climate. Temperature records from Muscle Shoals are available for the 69-year period 1890-1959, and precipitation records are available for the 75-year period 1884-1959. The average annual precipitation at Muscle Shoals is 51.67 inches and the average annual temperature is 60°F. Most of the precipitation is in the form of rain, but snow generally occurs about twice a year. The highest average monthly precipitation, 5.71 inches, occurs in March, and the lowest, 2.85 inches, in September. The highest average monthly temperature, 79.6°F, occurs in July, and the lowest, 41.9°F, in January. Freezing temperatures generally do not last more than two days.

WELL-NUMBERING SYSTEM

The well-numbering system used in Colbert County is based on the Federal land classification. Each township is divided into 36 sections that are numbered consecutively, starting with 1 in the northeast corner of the township and ending with 36 in the southeast corner. The townships have been assigned letters in the same order, starting with A in the northeast corner of the county and ending with X in the southeast corner. The wells and springs within a township have been numbered consecutively in the same way that sections are numbered, as for example, L-1, L-2, L-3 (fig. 3). Most of the wells and springs inventoried during the study were cited by Harris and others (1960, table 1 and pl. 1). However, since publication of that report additional test wells have been drilled and these have been assigned the next higher numbers; they are shown on plate 1, along with some of the previously inventoried wells and springs.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

GEOLOGIC STRUCTURE

Colbert County is on the north edge of the Warrior basin and on the south flank of the Nashville dome. The southern and western parts of the county are within the Mississippi Embayment area. The regional dip is southwest at 25 to 30 feet per mile, except where steeper dips and dip reversals indicate local structural features (pl. 1). The most prominent of these is an anticline north of the community of Allsboro. This anticline has an east-west

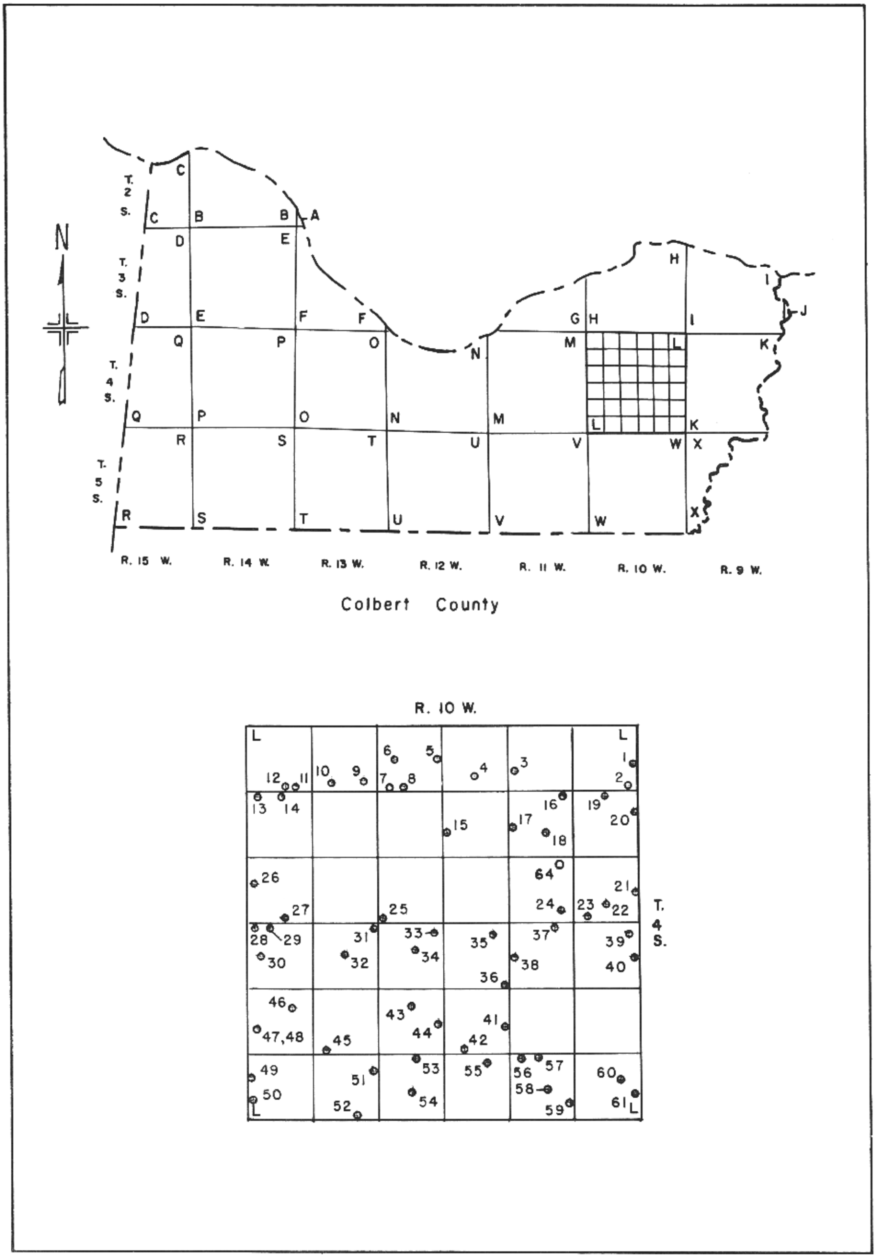

Figure 3.--Well-numbering system used in this report.

trend and was traced for about 2 miles from sec. 11, T. 4 S., R. 15 W., westward to sec. 9, T. 4 S., R. 15 W. The flanks of the anticline dip from 4° to 14°; the steeper dips are toward the north.

Semmes (1929, p. 73-76) indicated the existence of a small dome in the southwestern part of T. 3 S., R. 14 W., called the Chisca dome, and an elongate dome or anticline in the northeastern part of T. 4 S., R. 13 W., called the Mountain Mills dome. Except for a few measured dips on widely scattered outcrops, no additional data were collected during this study that would further delineate these domes.

A basin elongate to the northeast was defined from records of test wells southeast of the Tuscumbia-Sheffield area (fig. 4). Within the 32-square-mile area of closure the basin has a relief of about 80 feet.

SUMMARY OF STRATIGRAPHY

The areal distribution of the various geologic units in Colbert County is shown on plate 1. A generalized geologic section of the units that crop out in Colbert County and, so far as investigated, those that underlie the county is given as table 1. The oldest rocks penetrated by test drilling consist of limestone beds of probable Ordovician age. These rocks are overlain by shaly limestone of Silurian age similar in lithology to the Silurian rocks in Lauderdale County, Ala., and in southern Tennessee. The Silurian rocks are overlain in ascending order by the Chattanooga Shale of Devonian age; the Fort Payne Chert, Tuscumbia Limestone, Ste. Genevieve Limestone, Bethel Sandstone, Gasper Formation, Cypress Sandstone, Golconda Formation, Hartselle Sandstone, and Bangor Limestone, all of Mississippian age; and the Tuscaloosa Group of Late Cretaceous Age.

Throughout most of the county the bedrock formations have been deeply weathered in place to clay, sand, and gravel, for which the term "regolith" is assigned. The regolith of Quarternary age also includes alluvial, colluvial, and terrace deposits.

ORDOVICIAN SYSTEM

ORDOVICIAN ROCKS, UNDIFFERENTIATED

The oldest rocks reached by test drilling in Colbert County are limestone beds of Ordovician age that were penetrated by

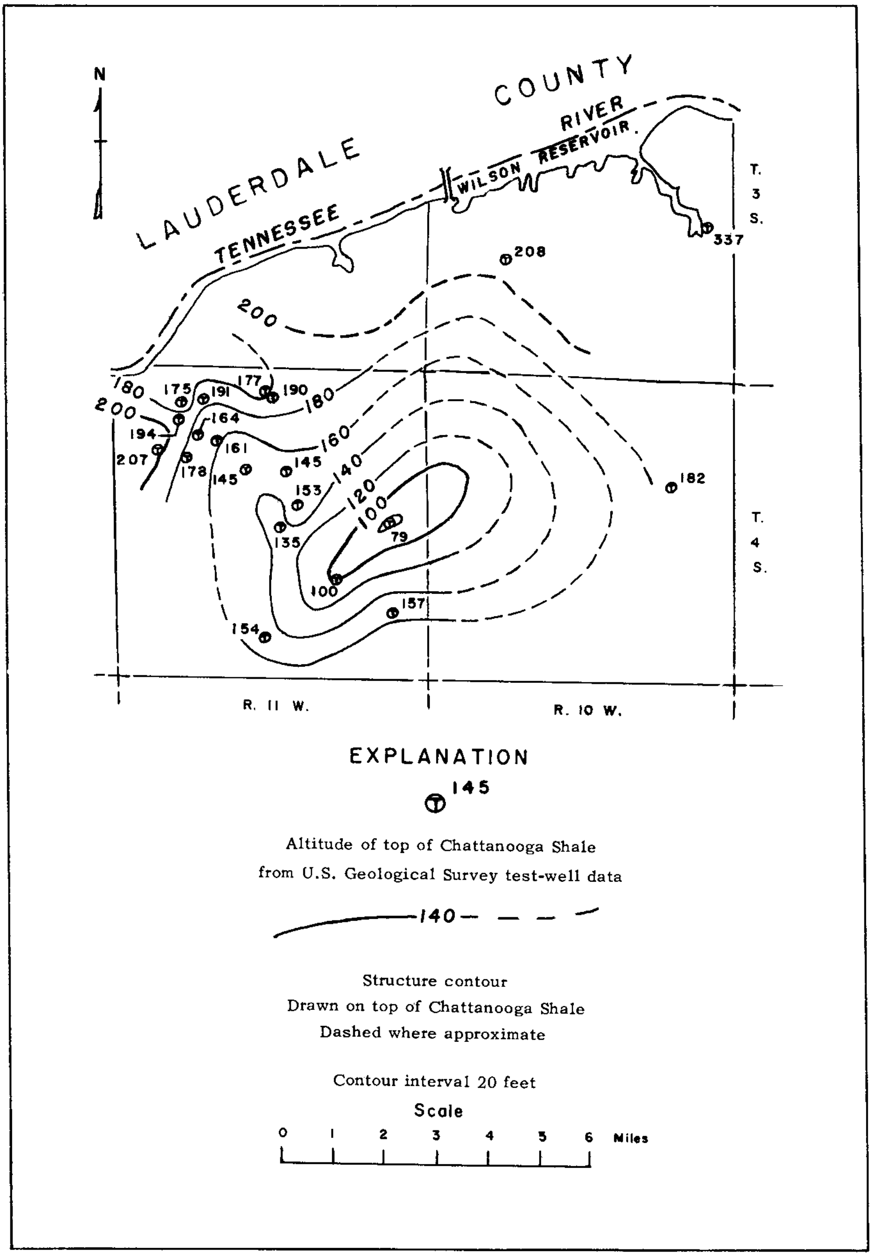

Figure 4.--Configuration of the top of the Chattanooga Shale southeast of the Tuscumbia-Sheffield area.

test well W-67 (pl. 2). As they appear in the drill cuttings these rocks are predominantly dark gray, finely to coarsely crystalline, and range from argillaceous limestone to relatively pure limestone. The complete thickness of the Ordovician rocks is not known, but 386 feet was penetrated in well W-67, and 881 feet was reported to have been penetrated by an oil-test well drilled in the S½SW¼NW¼ sec. 10, T. 4 S., R. 15 W. (Toulmin, 1945, p. 63-64). The Ordovician rocks are not known to be water bearing in Colbert County.

SILURIAN SYSTEM

SILURIAN ROCKS, UNDIFFERENTIATED

Beds of greenish-gray silty limestone underlying the Chattanooga Shale were penetrated by 15 test wells in Colbert County. On the basis of stratigraphic position beneath the Chattanooga Shale, these beds are probably of Silurian age. They are not typical of previously described beds of Silurian age in Alabama but may be equivalent to parts of the Brownsport Formation (Foerste, 1903, p. 566) or the Wayne Formation (Drake, 1914, p. 103), both of which crop out in western Tennessee. Beds similar to these have been described in Lauderdale County (Harris and others, 1962). The thickness of Silurian rocks in Colbert County is not known, but as much as 90 feet was penetrated in well W-67 (pl. 2).

DEVONIAN SYSTEM

CHATTANOOGA SHALE

NAME AND DEFINITION

The Chattanooga Shale was named by Hayes (1891, p. 143) for exposures near Chattanooga, Tenn. As defined by him, the formation consists of an upper gray shale, 3 to 4 feet thick, which in many places is concretionary, and a lower black shale; the maximum thickness is about 35 feet. It is considered to be of Late Devonian or possibly late Middle Devonian Age (Hass, 1956, p. 13-23). In Alabama the name is applied to the black shale and sandstone deposits that occur between the Red Mountain Formation or equivalent beds of Silurian age and the Fort Payne Chert.

Table 1.--*Geologic units in Colbert County, Ala., and their water-bearing properties*

Age	Unit	Maximum known thickness (feet)	Lithology	Water-bearing properties
Quaternary	Regolith	100+	Mainly unstratified clay, includes minor amounts of sand and gravel as lenses and beds.	Yields small quantities of water to dug wells in many areas. Quality poor in places.
Late Cretaceous	Tuscaloosa Group	100+	Mainly stratified gravel; includes clay and sand lenses.	Yields small to moderate quantities of good-quality water to wells and springs. Springs are small but numerous.
	Bangor Limestone	90	Gray oolitic and crystalline limestone and light-gray calcareous shale.	Yields small quantities of hard water from cavities in limestone.
	Hartselle Sandstone	200	Tan hard silty thin-bedded sandstone.	Yields small quantities of good-quality soft water to wells and springs.
	Golconda Formation	70	Upper part, olive-gray calcareous shale; lower part, grayish-brown hard limestone.	Not known to be an aquifer.
	Cypress Sandstone	7	Light-gray fine-grained hard sandstone.	Yields small quantities of water to several springs.

Mississippian	Gasper Formation	160	Grayish-green shale; limestone beds generally at top and bottom of formation.	Yields small quantities of water to wells and spring. Quality poor in many places.
	Bethel Sandstone	40	Tan to gray medium- to thick-bedded fine- to medium-grained sandstone and shale.	Yields small quantities of good-quality water to wells and springs. Springs fairly common at base of formation.
	Ste. Genevieve Limestone	43	Upper part, olive-green fissile shale; lower part, light-gray limestone.	Yields small quantities of very hard water to wells and springs.
	Tuscumbia Limestone	200	Gray medium-bedded hard crystalline limestone and chert.	Yields moderate quantities of water to wells and springs. As much as 500 gpm available in area of outcrop, particularly Spring Creek valley. Hard water.
	Fort Payne Chert	207	White to gray hard crystalline limestone and much chert.	Yields moderate to large quantities of water. Yields exceeding 500 gallons per minute per well available in parts of Spring Creek valley and probably in other places not tested. Water moderately hard.
Devonian	Chattanooga Shale	37	Black fissile shale and minor amounts of fine sandstone.	Not known to be an aquifer.
Silurian	Silurian rocks, undifferentiated	90	Greenish-gray silty limestone.	Not known to be an aquifer.
Ordovician	Ordovician rocks, undifferentiated	386	Dark-gray argillaceous to nearly pure limestone.	Not known to be an aquifer.

DISTRIBUTION

The Chattanooga Shale does not crop out in Colbert County. However, it was penetrated by most of the U.S. Geological Survey test wells and probably underlies the entire county.

LITHOLOGY AND THICKNESS

The Chattanooga Shale, as it appears in well cuttings, consists mainly of black shale and minor amounts of gray hard fine-grained sandstone. The formation ranges in thickness from 5 feet (well E-69 and others) to 37 feet (well W-67), and averages 16 feet (pls. 2 and 3).

PALEONTOLOGY

No fossils have been found in drill cuttings from the Chattanooga Shale.

WATER SUPPLY

Because of its poor permeability and slight thickness, the Chattanooga Shale is not an aquifer.

MISSISSIPPIAN SYSTEM

FORT PAYNE CHERT

NAME AND DEFINITION

The Fort Payne Chert, as originally defined by Smith (1890, p. 155-156) for exposures at Fort Payne, DeKalb County, included the entire sequence of rocks between the Chattanooga Shale and the Hartselle Sandstone. In 1892 (p. 16) he abandoned the name Fort Payne Chert and applied the name Lauderdale Chert to those rocks between the Devonian black shale (Chattanooga) and the St. Louis Limestone (upper Tuscumbia). In 1894 he restricted the term Lauderdale Chert to those beds underlying the Tuscumbia Limestone, and overlying the Devonian black shale (Chattanooga). Burchard and Butts (1910, p. 12-17) reapplied the name Fort Payne Chert to the Lauderdale Chert in conformance with usage in several other States where the formation occurs.

DISTRIBUTION

The Fort Payne Chert underlies all of Colbert County. However, in most parts of the county it is covered by younger rocks. The formation crops out and is well exposed along the southern bluffs of the Tennessee River valley and for short distances upstream along some of the major tributaries to the Tennessee River (pl. 1). Near Sheffield, at the O'Neal Bridge and upriver to the Wilson Dam, the Fort Payne Chert and the overlying Tuscumbia Limestone are well exposed in bluffs 50 to 100 feet high.

LITHOLOGY AND THICKNESS

The Fort Payne Chert in Colbert County consists of gray, light-gray, and white crystalline hard limestone containing large quantities of chert, which occurs as thick beds and as nodules that are disseminated through the limestone. The chert ranges in color from light-gray to black; in places it is mottled with dark-green zones composed of glauconite.

The thickness of the Fort Payne Chert in the subsurface is comparatively uniform; it ranges from 162 feet (wells H-80 and M-145) to 207 feet (well M-158) and averages 186 feet (pls. 2 and 3). The formation is overlain conformably by the Tuscumbia Limestone and is underlain unconformably by the Chattanooga Shale.

PALEONTOLOGY

The Fort Payne Chert contains an abundance of crinoid stem plates that range from 0.25 to 0.5 inch in diameter. Large corals, brachiopods, and bryozoans are present in places.

WATER SUPPLY

The Fort Payne Chert is a good aquifer. Ground water occurs in solution openings along fractures and bedding planes. These openings are best developed in the area of outcrop and in areas where the overlying rocks are less than about 200 feet thick, such as in the Spring Creek valley near Tuscumbia. The Fort Payne Chert yields variable quantities of water; however, the smaller yields are nearly always adequate for domestic requirements. Pumping-test data indicate that yields exceeding 500 gallons per minute per well are obtainable from the Fort Payne Chert and the overlying Tuscumbia Limestone in parts of Spring Creek valley (pl. 1). Ground water in the Fort Payne Chert generally is of good chemical quality. On the basis of field analyses of 100 samples, the average chloride content is 8 ppm (parts per million) and the average hardness is 124 ppm.

TUSCUMBIA LIMESTONE

NAME AND DEFINITION

The Tuscumbia Limestone was named by Smith (1894) for exposures at Tuscumbia, Ala. He defined the Tuscumbia as including all the limestone above the Lauderdale Cherty Limestone (Fort Payne Chert) and beneath the Mountain Limestone (Bangor). Butts (Adams and others, 1926, p. 167) later defined the Tuscumbia as including all rocks between the overlying Ste. Genevieve Limestone and the underlying Fort Payne Chert. He divided the Tuscumbia into an upper unit, the St. Louis Limestone, and a lower unit, the Warsaw Limestone. In this investigation the Tuscumbia Limestone was mapped as a formation without division into units.

DISTRIBUTION

The Tuscumbia Limestone underlies almost all of Colbert County. It crops out over large areas in the northern parts of the county. Exposures are common along the bluffs overlooking the Tennessee River and along the valleys of the larger tributaries (pl. 1).

LITHOLOGY AND THICKNESS

The Tuscumbia is a light-gray to gray medium-bedded hard, dense finely crystalline limestone. It contains considerable quantities of chert as nodules and thick bands. The chert ranges in color from very light gray to black. Near Tuscumbia the formation contains a few very thin lenticular beds of greenish-gray shale.

The maximum thickness of the Tuscumbia is probably about 200 feet, in the southern part of the county. However, in most parts of the county the formation has been deeply weathered to clay, and less than 100 feet of limestone remains.

PALEONTOLOGY

The Tuscumbia Limestone is very fossiliferous. Fragments of crinoid stem plates, bryozoa, corals, and brachiopods are common at many exposures. The following fossils were identified:

Fenestella tenax
F. serrulata
Polypora varsoviensis
Spirifer bifurcatus
S. lateralis
Reticularia salemensis
Zaphrentis (Triplophyllum)
Lithostrotion canadense
L. proliferum

WATER SUPPLY

The Tuscumbia is a productive aquifer throughout most of its area of outcrop (pl. 1). Ground water occurs in solution openings along fractures and bedding planes. Where the formation is deeply covered by younger formations, solution openings are poorly developed and the formation will yield little or no water. Test drilling and pumping-test data indicate that large and extensive openings are developed in Spring Creek valley, where as much as 500 gpm (gallons per minute) per well is obtainable from the Tuscumbia. (See "Pumping Tests" section of report.)

Tuscumbia Spring (M-20), the largest spring in Colbert County and one of the largest in Alabama, discharges from the Tuscumbia Limestone. This spring has a minimum discharge of about 6 mgd (million gallons per day) and a maximum discharge of more than 70 mgd (fig. 11). Eight other springs were cited by Harris and others (1960, table 1) and these ranged in discharge from 2 to 242 gpm. Ground water in the Tuscumbia is generally of good chemical quality although somewhat hard. On the basis of field analyses of 307 samples, the average chloride content is 15 ppm and the average hardness is 192 ppm.

STE. GENEVIEVE LIMESTONE

NAME AND DEFINITION

The Ste. Genevieve Limestone was described first by Shumard (1860, p. 406) from exposures in the bluffs along the Mississippi River a few miles south of Ste. Genevieve, Mo. There the Ste. Genevieve consists of very fossiliferous thin-bedded gray limestone and blue marl and occupies a stratigraphic position between the Aux Vases Sandstone above and the St. Louis Limestone below.

Prior to 1926 the Ste. Genevieve Limestone in Alabama was considered to be part of the Bangor, because the Bangor was originally defined to include all Mississippian rocks above the Fort Payne Chert. Butts (Adams and others, 1926, p. 177) restricted the Ste. Genevieve in the northwestern part of Alabama to the rocks between the Warsaw Limestone (Tuscumbia) below and the Bethel Sandstone above.

Morse (1930, p. 117) included the Ste. Genevieve in the Alsobrook Formation, which he named and defined for exposures in sec. 10, T. 4 S., R. 15 W., Colbert County, near the Alsobrook homestead and the Alsobrook bridge about 3 miles north of Allsboro, Ala. Morse defined the Alsobrook as consisting of a basal limestone member overlain by green shale. The limestone is 1 to 10 feet thick and contains a host of *Productus inflatus* that distinguishes the formation from older beds. The overlying greenish-gray shale is 70 to 80 feet thick and contains a yellowish-brown sandstone of variable thickness just above the middle of the shale. Morse named this sandstone the Cripple Deer Sandstone Member.

Welch (1958) retained the name Alsobrook but reduced its rank to that of a member of his Pride Mountain Formation. Welch defined the Alsobrook Member to include the basal limestone and the overlying shale which is equivalent to the Ste. Genevieve.

The name Ste. Genevieve has been retained in this study and, in Colbert County, is restricted to those rocks between the Tuscumbia Limestone below and the Bethel Sandstone above. There is an unconformity at the top and base of the formation.

DISTRIBUTION

In most places the Ste. Genevieve cannot be mapped separately because of poor exposures, and its outcrop area is shown on plate 1 combined with the overlying Bethel and Gasper formations. Good exposures of the Ste. Genevieve occur in the railroad cut half a mile west of Cherokee and in the N½ sec. 10, T. 4 S., R. 15 W., along the road west of Liberty Church. Another exposure is along the road just east of Pride Cemetery in the NE¼ sec. 1, T. 3 S., R. 14 W.

LITHOLOGY AND THICKNESS

The Ste. Genevieve consists of a basal fossiliferous light-gray limestone overlain by olive-green fissile shale. The shale may show red mottling from the effects of weathering. Near Liberty Church the Ste. Genevieve is 43 feet thick; at Cherokee it is 30 feet; at Barton School it is 25 feet; and at Colbert Heights it is only 2 feet. The basal limestone is the most persistent part of the Ste. Genevieve.

PALEONTOLOGY

The following fossils, found in the basal limestone bed of the Ste. Genevieve, have been reported by Butts (Adams and others, 1926, p. 183):

Rhipidomella dubia
Chonetes sp. ?
Productus inflatus
Spirifer sp.
Spiriferina cf. S. *transversa*

WATER SUPPLY

The Ste. Genevieve is not an important aquifer. The upper shaly section probably impedes the downward movement of ground water, which accounts for the numerous springs along the Bethel-Ste. Genevieve contact in some places. Ground water in the Ste. Genevieve limestone is highly mineralized in places. Considerable quantities of water from well E-55 (Harris and others, 1960, table

1) have been sold commercially in past years because of the reputed medicinal qualities. On the basis of field analyses of 13 samples, the average chloride content of water in the Ste. Genevieve Limestone is 54 ppm and the average hardness is 403 ppm.

BETHEL SANDSTONE

NAME AND DEFINITION

The Bethel Sandstone was first described by Butts (1917, p. 63) and named from exposures at Bethel School in Crittenden County, Ky. Butts (Adams and others, 1926, p. 184) also made the first reference to the Bethel in Alabama when he applied the name to the unfossiliferous sandstone beds overlying the Ste. Genevieve Limestone and underlying the Gasper Formation in Colbert County. Morse (1930, p. 116-117) included the Bethel Sandstone in the upper part of his Alsobrook Formation and described it as a yellowish-brown sandstone about 1 foot thick. He named it the Cripple Deer Sandstone Member. Welch (1958) included the Cripple Deer Sandstone of Morse, the overlying shales, and the Allsboro Sandstone of Morse in the Tanyard Branch Member of his Pride Mountain Formation.

DISTRIBUTION

The distribution of the Bethel is very irregular; it crops out in the lower part of the Hartselle escarpment and caps some of the small outliers near the escarpment. The Bethel forms a cliff in the SE¼ sec. 2, T. 4 S., R. 15 W., along the east bank of Big Bear Creek. East from the intersection of Big Bear Creek and the Tishomingo Pike to Barton (SW¼ sec. 4, T. 5 S., R. 15 W.), the Bethel Sandstone is missing in many places and the Gasper Formation rests directly on the Ste. Genevieve.

LITHOLOGY AND THICKNESS

The Bethel consists of tan to dark-gray medium- to thick-bedded fine- to medium-grained sandstone. In some places it is silty and in others it is calcareous or asphaltic. It may be shaly at either top or bottom and in places it consists of two sandstone beds separated by a few feet of shale. In the Cherokee area, the

Bethel is crossbedded and asphaltic. It is well exposed in the railroad cut half a mile west of Cherokee and in a quarry in the NE¼NW¼ sec. 12, T. 4 S., R. 14 W.

The Bethel has a maximum thickness of about 40 feet along the south bank of McCluskey Creek in the western part of the county; it is about 20 feet thick at Cherokee and in the eastern part of the county. The contact with the underlying Ste. Genevieve is unconformable and easily identified. The Bethel is overlain unconformably by the Gasper Formation.

PALEONTOLOGY

The Bethel is not fossiliferous in Colbert County.

WATER SUPPLY

Because it is shaly, the Bethel is not an important aquifer. On the basis of field analyses of 7 samples, the ground water apparently is of good chemical quality; the average chloride content is 16 ppm and the average hardness is 44 ppm.

GASPER FORMATION

NAME AND DEFINITION

The Gasper Formation was first described by Butts (1917, p. 64-84) from exposures along the Gasper River in Warren County, Ky. He defined the formation as about 100 feet thick and consisting of thick-bedded limestone and oolite containing a sandstone member near the middle. Butts (Adams and others, 1926, p. 185-189) identified and defined the Gasper in Alabama as the rocks underlying the Cypress Sandstone and overlying the Bethel Sandstone.

Morse (1930, p. 117, 118, 145) divided the Gasper into the Southward Pond Formation, Southward Spring Sandstone, and the Southward Bridge Formation. The Southward Bridge included the basal limestone beds of Butts' Golconda Formation and Cypress Sandstone. Welch (1958) divided the Gasper into the following members: Wagnon, Southward Spring Sandstone, and Sandfall.

The term Gasper Formation as defined by Butts is retained in this report.

DISTRIBUTION

The Gasper is exposed at the base of the Hartselle escarpment and crops out over an area of about 100 square miles. On the geologic map (pl. 1) it is shown combined with the Ste. Genevieve Limestone and Bethel Sandstone. Limestone beds form small cliffs along the escarpment and cap small outliers. Exposures of the Gasper occur along a county road in the N½ sec. 20, T. 4 S., R. 11 W., in sec. 16, T. 4 S., R. 13 W., and along U.S. Highway 43 in sec. 2, T. 5 S., R. 11 W.

LITHOLOGY AND THICKNESS

The Gasper Formation consists mainly of shale. In most places thin beds of limestone occur at the top and bottom of the formation. The basal limestone ranges in thickness from 8 to 25 feet in western Colbert County. It is gray, partly oolitic, medium-bedded, and very hard. The shale is gray green, calcareous, and hard. Weathering has caused red mottling on the surface of the exposures. A thin bed of tan hard sandstone occurs in the shale from 25 to 60 feet above the base of the Gasper; it is exposed in the SE¼ sec. 2, T. 4 S., R 14 W., and just north of the county road in the SE¼ sec. 1, T. 4 S., R. 15 W. The upper limestone beds are generally gray or grayish tan, finely to coarsely crystalline, fossiliferous, and oolitic. The total thickness of the Gasper ranges from 115 to 165 feet. The formation unconformably overlies the Bethel and unconformably underlies the Cypress Sandstone, or the Golconda Formation where the Cypress is missing.

The Gasper is exposed 2 miles southwest of Barton and is described as follows:

Section of the Gasper Formation in the SE¼NE¼ sec. 16, T. 4 S., R. 13 W., Colbert County

	Thickness (feet)
Hartselle Sandstone	
Sandstone, tan to reddish-brown, calcareous, fine-grained, thin-bedded and crossbedded, hard	5.0
Cypress Sandstone and Golconda Formation	
Shale, reddish-brown, hard. Contains 1-inch to 1.5-inch oblong shale pebbles. Trace of tan medium-grained hard sandstone	1.5
Gasper Formation	
Limestone, gray, oolitic, massive, partly asphaltic	23.0

Section of the Gasper Formation in the SE¼NE¼ sec. 16, T. 4 S., R. 13 W., Colbert County—Continued

	Thickness (feet)
Gasper Formation--Continued	
Shale, grayish-green, calcareous. Contains *Zaphrentis spinulosum*, fenestellid bryozoans, and fragments of crinoid stem plates and brachiopods	26.0
Limestone, gray, finely crystalline, very hard. Contains beds of coarsely crystalline sandy limestone. Fossil *Orthotetes kaskaskiensis*	12.0
Limestone, reddish-tan, crystalline, hard. Contains some sand and fossil fragments	10.0
Shale, grayish-green, calcareous. Contains fossil fragments	30.0
Limestone, light-gray, finely crystalline, hard. Contains particles of clear calcite	10.0
Limestone, gray, sandy, hard	11.0
Covered interval	5.0
Shale, black, hard	5.0
Limestone, gray, oolitic, massive	2.0
Covered interval	---
Total	140.5

PALEONTOLOGY

The Gasper Formation is fossiliferous; most fossils have been found in the middle, shaly, part of the Gasper. Guide fossils include the following:

Campophyllum gasperense
Agassizocrinus conicus
Pentremites godoni
P. pyriformis
Chonetes chesterenses
Talarocrinus symmetricus

WATER SUPPLY

The Gasper is not a good aquifer in Colbert County, but yields adequate supplies for domestic and stock needs in parts of the county. The water is commonly of poor chemical quality and commonly is described as sulfurous. On the basis of 53 field analyses, the average chloride content is 150 ppm and the average hardness is 384 ppm.

CYPRESS SANDSTONE AND GOLCONDA FORMATION

NAME AND DEFINITION

The Cypress Sandstone is identified in Alabama on the basis of stratigraphic relations similar to those occurring in Kentucky and in the type area in Illinois (Adams and others, 1926, p. 189). The formation crops out in only a few places in Colbert County.

The Golconda Formation was named by Brokaw (1917, p. 19-29) from exposures in parts of Saline, Williamson, Pope, and Johnson Counties in southeast Illinois. The Golconda was described as being 100 to 300 feet thick and consisting of varicolored shale and limestone.

Butts (Adams and others, 1926, p. 191-192) identified the Golconda in Colbert County as consisting of oolitic limestone beds and marl, 25 to 60 feet thick. Morse (1930, p. 118) included the basal limestone beds of the Golconda, the underlying Cypress Sandstone, and part of the Gasper in his southward Bridge Formation. Welch (1958) renamed the Golconda, as defined by Butts, the Green Hill Member of the Pride Mountain Formation. Butts' terminology is used in this report.

DISTRIBUTION

The Cypress Sandstone and Golconda Formation crop out in the lower bluffs of the escarpment in the southeastern and central parts of Colbert County. However, the formations could not be mapped separately from the overlying Hartselle Sandstone because of insufficient exposures, and the three formations were mapped as a unit (pl. 1).

LITHOLOGY AND THICKNESS

The Cypress Sandstone consists of light-gray to greenish-gray massive hard fine-grained sandstone. A thickness of 7 feet has been measured.

The Golconda consists of olive-gray calcareous shale and grayish-brown hard limestone. The limestone commonly occurs at the base of the formation. The shale is more or less evenly bedded and is soft. The limestone is coarsely crystalline, massive, and hard, and locally contains silt. The thickness of the formation ranges from 21 feet, south of Barton, to 70 feet, south of Tuscumbia, and averages about 40 feet.

Exposures of the Cypress and Golconda south of Barton are described as follows:

Section of the Cypress Sandstone and Golconda Formation in sec. 22, T. 4 S., R. 13 W., Colbert County

	Thickness (feet)
Hartselle Sandstone	
Sandstone, white, fine-grained, hard, crossbedded	10.0
Golconda Formation	
Shale, light-gray, soft	11.0
Limestone, grayish-tan, partly oolitic, finely crystalline, hard	10.0
Cypress Sandstone	
Sandstone, light greenish-gray, fine-grained, massive	7.0
Gasper Formation	
Covered interval	93.0
Total	131.0

The Golconda is overlain unconformably by the Hartselle Sandstone and underlain unconformably by the Cypress Sandstone or Gasper Formation. The contact between the Golconda and the overlying Hartselle is generally covered by talus.

PALEONTOLOGY

The following fossils occur in the Golconda:

Archimedes
Diaphragmus elegans
Camarophorea explanata
Pterotocrinus capitalis

WATER SUPPLY

The Golconda is not an aquifer in Colbert County. The Cypress Sandstone, which is missing in most areas, supplies water to Denton Spring (P-29) and William Spring (P-30) (Harris and others, 1960, table 1).

HARTSELLE SANDSTONE

NAME AND DEFINITION

The Hartselle Sandstone was named by Smith (1894) for exposures at Hartselle, Morgan County, Ala., and was included as a unit of the overlying Bangor Limestone. Butts (Adams and others, 1926, p. 192-195) separated the Hartselle from the Bangor as described by Smith and defined it as a distinct unit of areal extent that could be correlated with the Hardinsburg Sandstone of the Mississippi Valley. The Hartselle Sandstone in Alabama lies between the Golconda Formation below and the Bangor Limestone above.

DISTRIBUTION

The Hartselle Sandstone crops out in about 100 square miles in the southeastern and central parts of the county. It caps most of the uplands and forms the upper bluffs of the Hartselle escarpment.

LITHOLOGY AND THICKNESS

The Hartselle Sandstone is composed mainly of tan medium- to coarse-grained hard thin-bedded sandstone. The beds are firmly indurated and range from 1 to 12 inches in thickness; the thinner beds occur near the top of the formation. Scattered thin lenses of soft dark-gray silt occur in the lower 100 feet of the Hartselle. The Hartselle is estimated to be 200 feet thick near the southern edge of the county, from where it thins to about 40 feet along the northern edges of the outcrop.

An exposure of Hartselle Sandstone along U.S. Highway 43 in southern Colbert County is described as follows:

Section of the Hartselle Sandstone in sec. 14, T. 5 S., R. 11 W., Colbert County

	Thickness (feet)
Hartselle Sandstone	
Covered interval to top of hill	10.0
Sandstone, tan, very fine grained, thin- to thick-bedded, hard. Contains thin dark-gray bed of silt near bottom	90.7
Covered interval to base of hill	5.3
Total	106.0

The Hartselle in Colbert County is overlain unconformably by the Bangor Limestone and it overlies unconformably the Golconda Formation.

PALEONTOLOGY

No fossils have been found in the Hartselle. Casts of what appear to be small plant stems occur in an abandoned quarry in the SE¼ sec. 29, T. 4 S., R. 11 W.

WATER SUPPLY

The Hartselle Sandstone yields small quantities of water, 5 gpm,or less, to wells and springs. Larger yields appear improbable because the Hartselle is relatively impermeable; silt particles fill interstitial openings between the sand grains. The water is of good chemical quality. On the basis of 91 analyses, the average chloride content is 15 ppm and the average hardness is 55 ppm.

BANGOR LIMESTONE

NAME AND DEFINITION

The Bangor Limestone was named by Smith (1890, p. 155-157) for exposures at Bangor in Blount County, Ala., and was defined as part of the "Upper or Calcareous member of the Sub-Carboniferous." It included the Bangor as presently defined and the sandstone and shales of the Oxmoor Formation (of former usage). Butts (Adams and others, 1926, p. 195-199) restricted the Bangor to the limestone beds overlying the Hartselle Sandstone and below the Pennington Shale. Although the Pennington Shale is absent in Colbert County, Butts' definition of the Bangor is followed in this report.

DISTRIBUTION

The Bangor Limestone outcrop extends westward from the vicinity of Littleville in southern Colbert County to the western edge of R. 14 W. In the southwestern part of the county, where there is considerable relief, outcrops of Bangor form narrow bands around ridges capped by the Tuscaloosa Group (pl. 1).

LITHOLOGY AND THICKNESS

The Bangor Limestone consists of gray dense limestone and soft calcareous shales. The limestone is partly oolitic and partly finely crystalline and thick-bedded; the shales, which generally occur in the basal section, are light gray or olive gray, calcareous, soft, and fossiliferous. The full thickness of the Bangor is not known; from 30 to 90 feet of the basal section is commonly exposed. A section of the Bangor in Colbert County is described as follows:

Section of the Bangor Limestone in SE¼ sec. 31, T. 5 S., R. 13 W. Colbert County

	Thickness (feet)
Bangor Limestone	
Covered interval to top of hill	44.2
Limestone, light-gray to bluish-gray, coarsely crystalline, dense, thin-bedded	16.0
Shale, light-gray, calcareous, soft, weathers light bluish-gray	15.8
Covered interval	36.1
(Total thickness of Bangor--112.1 feet)	
Hartselle Sandstone	
Sandstone, yellowish-brown, fine-grained, thin-bedded, friable	11.5
Covered interval to base of hill	20.5
Total	144.1

The Bangor Limestone in Colbert County unconformably overlies the Hartselle Sandstone and unconformably underlies the Tuscaloosa Group.

PALEONTOLOGY

The lower shaly part of the Bangor is very fossiliferous. Butts (Adams and others, 1926, p. 197) listed six fossils that are either restricted to the Bangor or highly distinctive of it. They are:

Archimedes
Prismopora serrulata
Pentremites pyramidatus
P. brevis
Spirifer increbescens
Composita subquadrata

WATER SUPPLY

The Bangor Limestone has not been adequately tested to determine how productive it is. A relatively small number of wells obtain water from cavities in the upper limestone part of the formation. Most of these wells are adequate for domestic needs. The average chloride content and hardness, based on field analyses of 21 samples, are 27 ppm and 229 ppm, respectively.

CRETACEOUS SYSTEM - UPPER CRETACEOUS SERIES

TUSCALOOSA GROUP

NAME AND DEFINITION

The Tuscaloosa Group of Late Cretaceous Age was originally described and named the Tuscaloosa Formation by Smith and Johnson (1887, p. 95-116) from numerous exposures in Tuscaloosa County and along the Black Warrior River in Hale County, Ala. Conant and others (1945) raised the Tuscaloosa to the rank of group on the basis of their work in western Alabama and divided it into four formations, the Cottondale, Eoline, Coker, and Gordo. The Tuscaloosa was later redefined by Drennen (1953a) to include only the Coker Formation at the bottom and Gordo Formation at the top. These two formations are very similar lithologically and paleontologically and to attempt to map them separately in Colbert County was considered impractical for the purposes of this study.

DISTRIBUTION

The Tuscaloosa Group crops out in southern and western Colbert County, where it caps ridges, hills, and larger upland areas at altitudes ranging from 500 to 650 feet.

LITHOLOGY AND THICKNESS

The Tuscaloosa Group consists mainly of stratified gravel containing lenses of clay and silty sand. The gravel is composed largely of rounded, somewhat polished chert pebbles. Beds are lenticular but in places are continuous. Thin hardpan layers are common in many places and result from cementation of pebbles into crusts by minerals of the limonite group. The Tuscaloosa Group thickens westward to more than 100 feet along the western edge of the county (pl. 4). It rests unconformably on the Bangor Limestone, the Hartselle Sandstone, and, at a few places in western Colbert County, the Gasper Formation and Tuscumbia Limestone (pl. 1).

PALEONTOLOGY

No fossils were found in the Tuscaloosa Group in Colbert County. The formation is reported to contain a few leaf impressions (Smith and Johnson, 1887, p. 119) and lignitized logs (Adams and others, 1926, p. 233). Drennen (1953b, p. 6) reported borings resembling worm trails.

WATER SUPPLY

The Tuscaloosa Group yields small quantities of water to wells and springs. Larger quantities, in excess of 10 gpm, probably can be developed in areas where the thicker deposits occur. The numerous perennial springs indicate that the ground-water potential of the Tuscaloosa Group is good. The ground water is of good chemical quality; the average chloride content and hardness, based on 27 field analyses, are 8 ppm and 80 ppm.

QUATERNARY SYSTEM

REGOLITH

Most of Colbert County is covered by an unconsolidated mantle of rock debris weathered in place, and alluvial, colluvial, and terrace deposits collectively termed regolith. It consists mainly of unstratified clay that includes varying amounts of chert fragments, but the alluvial and terrace deposits contain sand and gravel lenses and beds. Larger amounts of chert and chert gravel occur in the outcrop areas of the Fort Payne Chert than in the areas of other formation outcrops (pl. 1).

The regolith varies considerably in thickness because of erosion; the thinner deposits usually occur in the stream valleys such as Spring and Bear Creek valleys. It is more than 100 feet thick for several square miles in the northeastern part of the county (pl. 4).

The regolith yields water to a large number of dug or shallow drilled wells in Colbert County, which constitute about 16 percent of the wells inventoried. Most of these wells have been dug or drilled in areas underlain by the Tuscumbia Limestone. Some of the wells in the regolith yield inadequate supplies for domestic needs. The average chloride content and hardness, based on field analyses of 60 samples of water obtained from the regolith, are 32 ppm and 121 ppm.

GROUND WATER

SOURCE AND OCCURRENCE

Ground water is the water that occurs in the earth's zone of saturation. The ultimate source of practically all ground water is precipitation, which in Colbert County occurs mainly as rain but occasionally as snow. Only part of the precipitation seeps into the zone of saturation to become ground water. Most of it runs off into streams or is returned to the atmosphere by evaporation or transpiration.

The zone of saturation is a zone in which all rock openings are filled with ground water. The openings range in size from small interstices in sand and gravel deposits, such as those in the Tuscaloosa Group and the regolith, to cavities and tubes a foot or more in diameter, such as those in the Fort Payne Chert and the Tuscumbia Limestone. The ratio of the volume of openings in a rock to its total volume is called its porosity, which determines the amount of water a rock can hold.

For a well to obtain water it must be drilled into porous rocks within the zone of saturation. Rocks (including both consolidated and unconsolidated deposits) that yield water to wells or springs are called aquifers. The yield of a well depends mainly on the capacity of the aquifer to transmit water. This is expressed as permeability, which is defined quantitatively as "* * * the rate of discharge of water through a unit cross-section area of the rock at right angles to the direction of flow if the hydraulic gradient is unity." (Meinzer, 1923, p. 44).

The permeability of a rock depends on the size and degree of interconnection of the openings in the rock--the larger and more interconnected the openings, the more permeable the rock. The most permeable rocks in Colbert County, and consequently the best aquifers, are the weathered parts of the Fort Payne Chert and the Tuscumbia Limestone.

Ground water in Colbert County occurs under both water-table and artesian conditions. Water-table conditions exist where the zone of saturation is unconfined, exemplified mainly in the Tuscaloosa Group and the regolith. Artesian conditions exist where the ground water in an aquifer is confined by clay, shale, or other relatively impermeable deposits. When tapped by a well, artesian water will rise in the well to a level higher than the aquifer. However, the pressure may not be great enough to cause the well to flow. Ground water in the Fort Payne Chert, Tuscumbia Limestone, and some of the overlying consolidated rock formations occurs under artesian conditions but the pressures are generally not sufficient to produce flowing wells.

RECHARGE

As previously stated, the ultimate source of ground water in Colbert County is precipitation, mainly in the form of rain but including an occasional snowfall. Water that seeps into the earth and contributes to the zone of saturation is termed recharge.

Curtis (1953, p. 36), using data compiled from studies made by the Tennessee Valley Authority in northern Alabama, concluded that at least 11.4 inches of the total annual precipitation of 51 inches is contributed to the ground-water reservoirs. Curtis' work was based on the fact that the average streamflow in the Tennessee Valley was 21.4 inches, whereas the surface runoff was estimated to be only 10 inches. The difference between the two quantities was attributed to discharge from the ground-water reservoirs into the streams. Under natural conditions ground-water reservoirs are in a state of approximate dynamic equilibrium and recharge is equal to discharge (Theis, 1938, p. 891). Ground-water flow into streams represents only a part of total ground-water discharge. Consequently, if the foregoing assumptions are sound, it may be assumed further that ground-water recharge in Colbert County generally exceeds 11.4 inches annually, which is more than 20 percent of the total precipitation. The 11.4 inches of recharge, if distributed evenly throughout the county, would produce an average daily recharge of about half a million gallons per square mile.

Recharge in Colbert County occurs mainly during late fall, winter, and early spring. During this period general rainfall is common. Evaporation and plant requirements are at a minimum because of relatively low temperatures. Thus, during this period a larger proportion of rainfall seeps downward to the zone of saturation than during other times of the year. The amount of water stored in the ground-water reservoirs is temporarily increased and the water table or piezometric surface rises. The recharging effects of precipitation, as recorded in 19 observation wells during the period 1956-59, are shown in figures 5 to 10.

MOVEMENT

Ground water is rarely, if ever, static, but moves slowly through the rock openings from areas of intake or recharge to places of outflow or discharge. The rate of movement depends on the gradient and on the size and arrangement of the rock openings. Ground water moves very slowly through interstitial openings such as in sand and gravel, probably at the rate of tens or hundreds of feet per year; however, it moves many times faster through solution cavities and large fractures.

The directions of ground-water movement in parts of Colbert County are shown on the piezometric maps (pls. 5 and 6). These maps, which show the shape of the water-pressure surface during the periods of high (March) and low (December) water levels, were prepared by plotting and contouring the altitudes of the water levels in the various observation wells obtained over a relatively short period of time. Insofar as possible, only wells were used that tap openings in the Fort Payne Chert and (or) Tuscumbia Limestone, which are the most productive water-bearing formations in Colbert County. In general, the ground water moves from higher to lower altitudes--in directions perpendicular to the contour lines. Thus it may be inferred that movement is down the valleys and toward the reservoirs formed by the Tennessee River.

Available data indicate that the geologic structure influences the movement of ground water in Colbert County. For example, the prominent mound (pls. 5 and 6) in the piezometric surface in T. 3 S., R. 14 W., generally coincides with the location of the "Chisca dome" as shown by Semmes (1929, map 3). The northeast-trending depression (pl. 6) in the piezometric surface south of Muscle Shoals generally coincides with and probably is a reflection of the elongate basin in this area as shown in figure 4. If more structural control were available it probably would show further influence on the movement of ground water in the county.

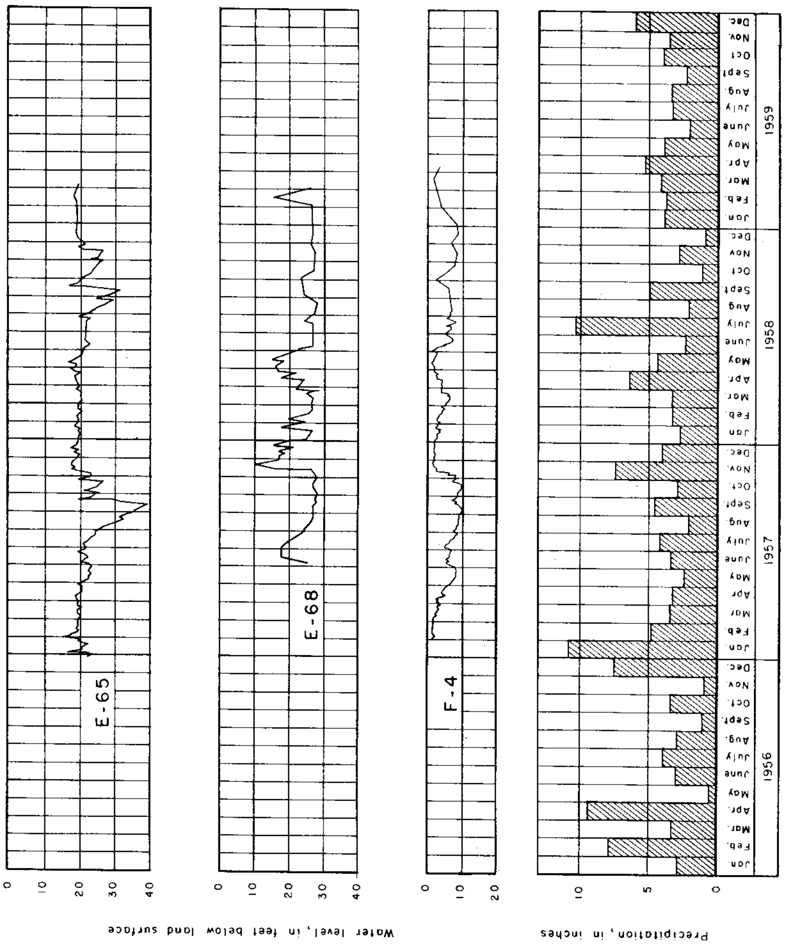

Figure 5.--Hydrographs showing changes in water level in wells E-65, E-68, and F-4 and precipitation at Muscle Shoals, Ala.

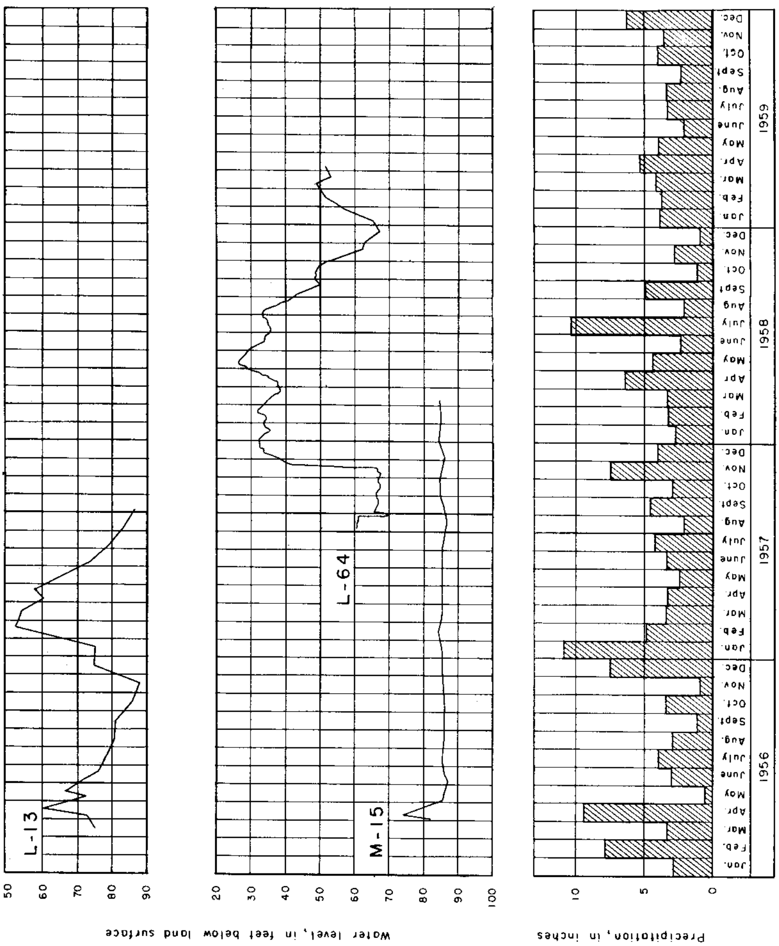

Figure 6.--Hydrographs showing changes in water level in wells L-13, L-64, and M-15 and precipitation at Muscle Shoals.

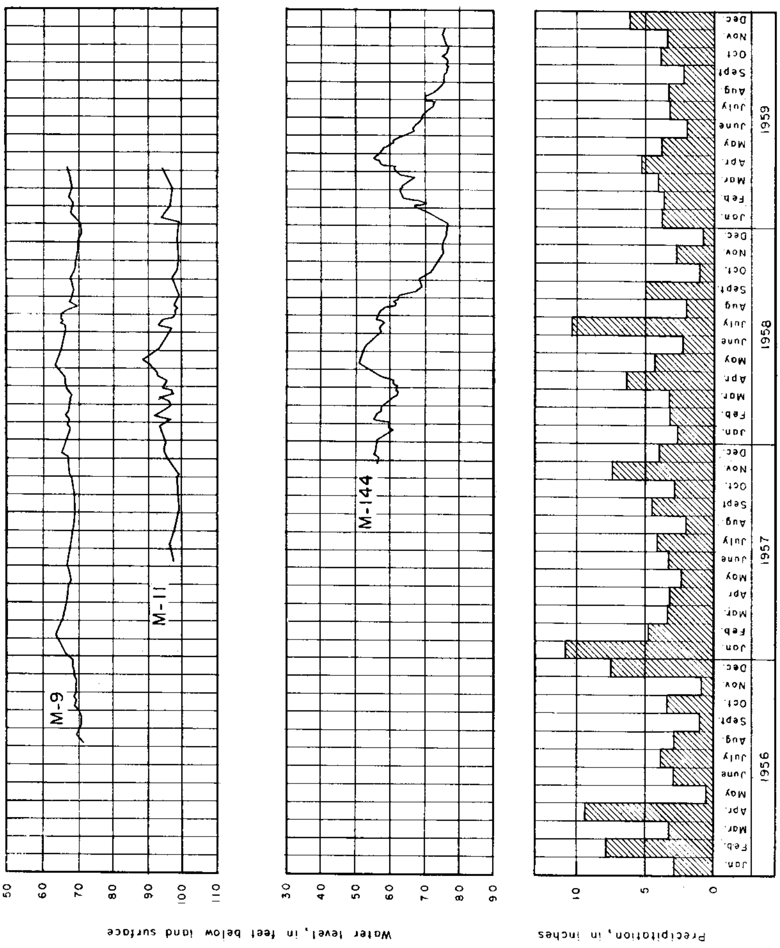

Figure 7.--Hydrographs showing changes in water level in wells M-9, M-11, and M-144 and precipitation at Muscle Shoals.

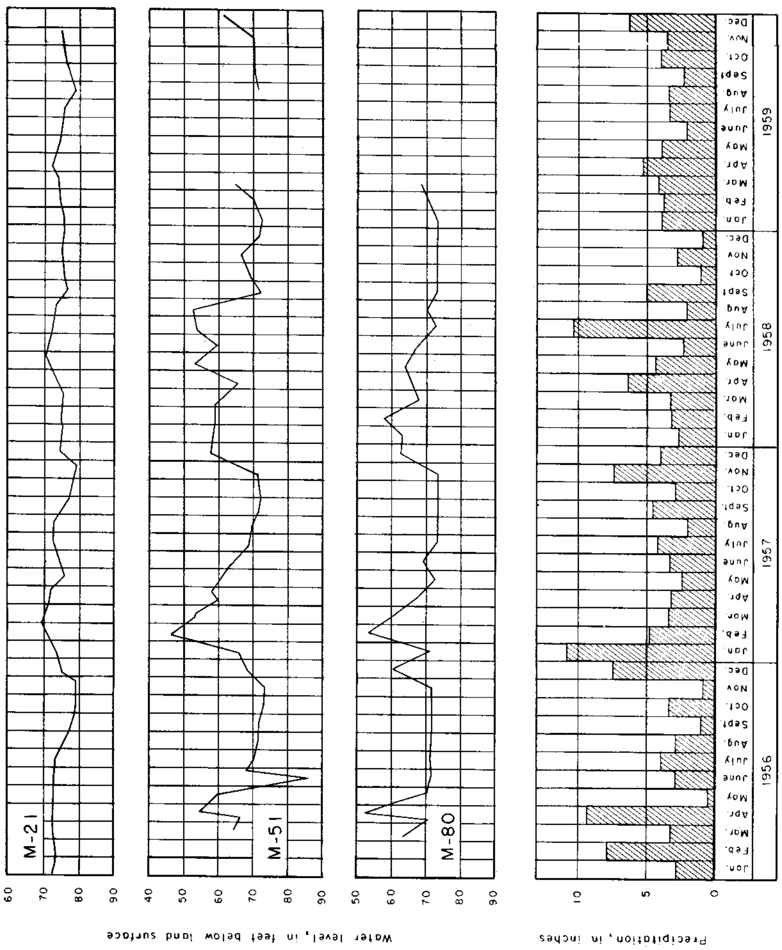

Figure 8.--Hydrographs showing changes in water level in wells M-21, M-51, and M-80 and precipitation at Muscle Shoals.

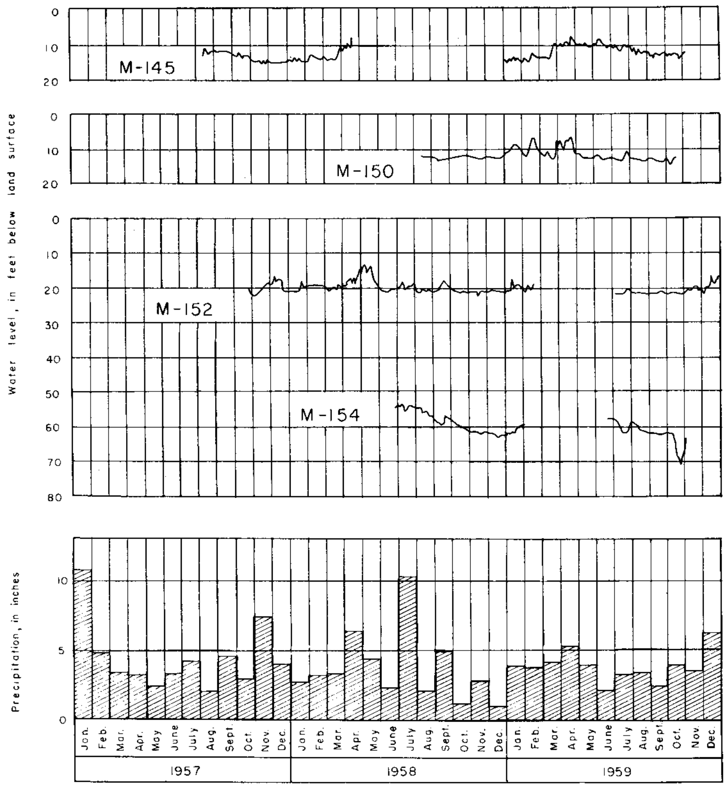

Figure 9.--Hydrographs showing changes in water level in wells M-145, M-150, M-152, and M-154 and precipitation at Muscle Shoals.

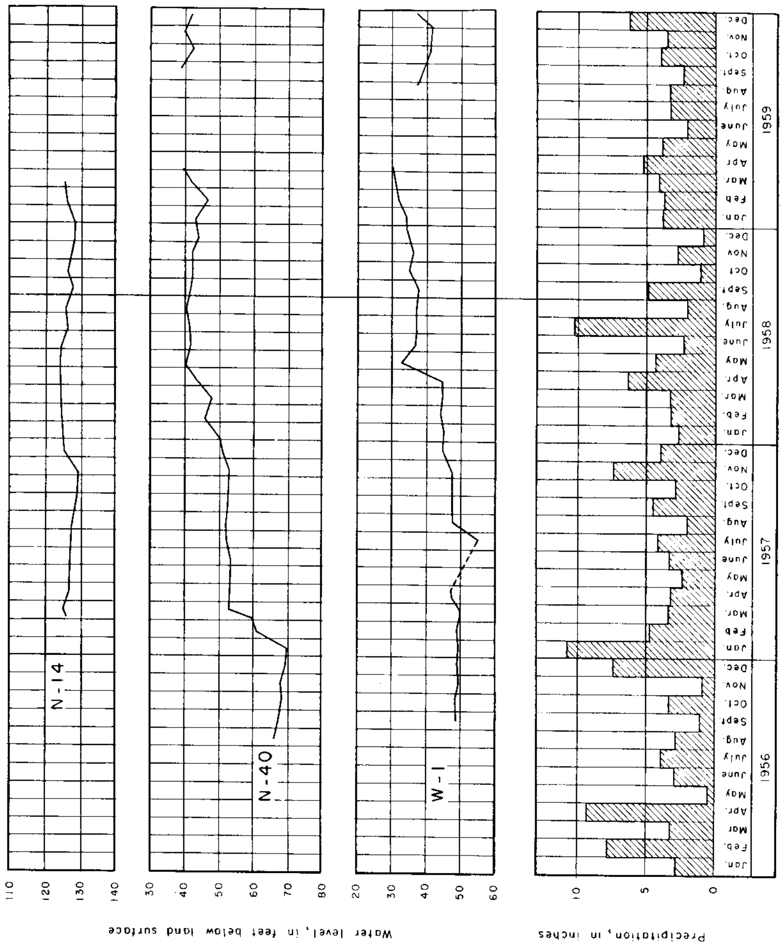

Figure 10.--Hydrographs showing changes in water level in wells N-14, N-40, and W-1 and precipitation at Muscle Shoals.

DISCHARGE

Ground-water discharge consists mainly of evaporation from soil surfaces, transpiration from plant surfaces, discharge from springs, and pumpage from wells. The amount of ground water that is discharged annually by evapotranspiration in Colbert County is unknown but may be large in some parts. Evapotranspiration is greatest during the late spring, summer, and early fall when temperatures are highest and plant growth is greatest. Evapotranspiration apparently is the chief cause of water-level declines during the late spring and summer, as illustrated by some of the hydrographs in figures 5 to 10.

SPRINGS

The discharge from all the known springs in Colbert County was measured (Harris, 1957; Harris and others, 1960, table 1). Most of the measurements were made during the fall of 1955 and represent minimum or near-minimum discharges. The largest spring in Colbert County and one of the largest in Alabama is Tuscumbia Spring (M-20). The minimum known discharge of this spring, which flows from openings in the Tuscumbia Limestone, is about 6 mgd, and the maximum is more than 80 mgd (fig. 11). Other large springs in Colbert County and their minimum discharges are the Baker Bubbling Spring (I-5, fig. 11), 5 mgd; TVA Spring (H-15), 2.1 mgd; Pruitt Spring (I-48), 1.4 mgd; and Parker Spring (F-7, fig. 11), 0.3 mgd.

Most of the larger springs discharge from openings in either the Fort Payne Chert or the Tuscumbia Limestone. A large number of small springs, discharging generally less than 15,000 gpd, issue from sand and gravel beds in the Tuscaloosa Group and from fractures in the Hartselle Sandstone. The total minimum discharge of all known springs in Colbert County is about 13.5 mgd; about 70 percent of this amount is discharged by Tuscumbia Spring (M-20).

WELLS

About 900 wells representing about two-thirds of the wells in Colbert County, have been inventoried (Harris and others, 1960, table 1). Most of the wells supply water for domestic and stock needs, and average withdrawals from these wells probably range from 100 to 200 gpd. In a few parts of the county relatively large quantities of water, possibly several million gallons per day, are

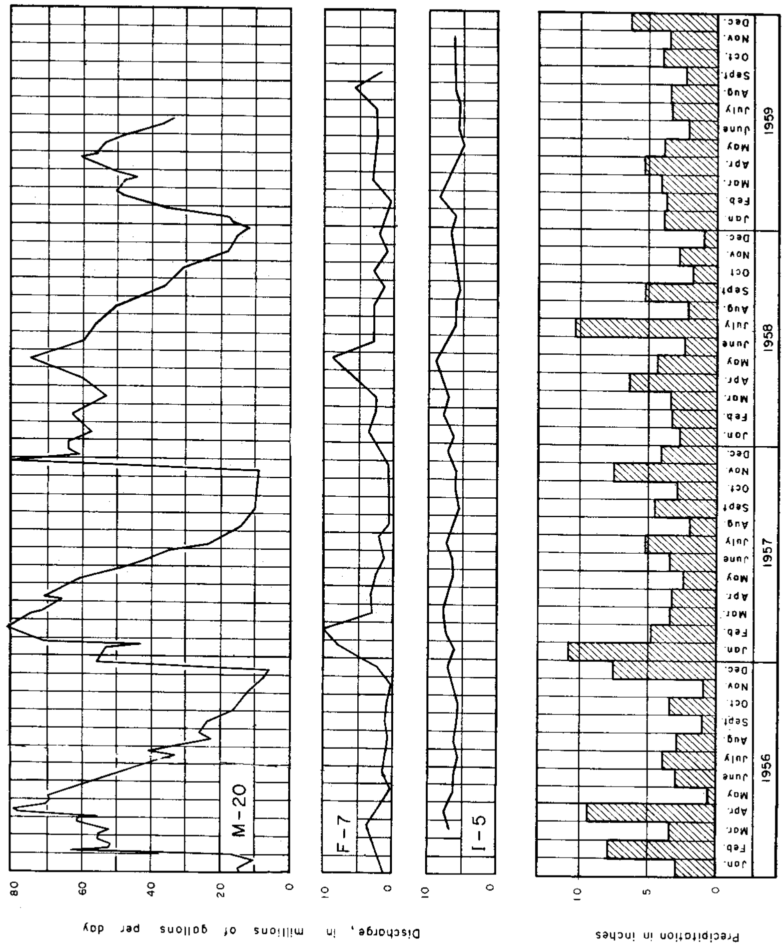

Figure 11.--Hydrographs showing changes in discharge of springs M-20, F-7, and I-5 and precipitation at Muscle Shoals.

withdrawn from wells for industrial and municipal uses. The total ground-water discharge from wells is estimated to be 5 million gpd.

PUMPING TESTS

Pumping tests were made on selected U.S. Geological Survey test wells in Colbert County to evaluate the water-bearing properties of the Fort Payne Chert and the Tuscumbia Limestone. Data obtained from 26 tests on 18 wells are given in table 2.

Both low- and high-capacity tests were made, although not necessarily on each well. The usual procedure was first to test the well at a relatively low capacity with a submergible or jet pump. The pumping rate during these preliminary tests did not exceed 40 gpm, and the duration of pumping was usually only a few hours. If the low-capacity test showed that the well could be pumped at a higher rate, a test at higher capacity and of longer duration was made. Hydrographs showing data from three high-capacity tests constitute figures 12 to 14.

The water-bearing openings in the Fort Payne Chert and Tuscumbia Limestone range from minute cracks and crevices to solution cavities and tubes a foot or more thick as penetrated in drilled wells. Ground-water movement through the large openings may at times be turbulent, especially in the vicinity of a pumped well. Consequently, the Theis method of pumping-test analysis, which assumes laminar flow and aquifer homogeneity and hydrologic isotropism (Theis, 1938), is not applicable to these tests.

In regard to limestone aquifers, it is particularly hazardous to predict well performance at high rates of discharge on the basis of behavior at low rates of discharge. The reasons for discrepancies are not entirely clear, but may be increased entrance loss at higher rates of discharge or dewatering of upper zones in the aquifer, or a combination of both factors. Specific capacity, expressed in gallons per minute per foot of drawdown, commonly is used as an index to the capacity of a well. The specific capacity should be used with caution, however, as there is a decline in specific capacity with higher rates of pumping, the amplitude of the water-level fluctuation may be unknown, and the geometry of the solution system penetrated is unknown.

To obtain a better evaluation of the pumping-test data, some of the wells were tested in steps of increased rates of discharge.

Table 2.—*Data from pumping tests in Colbert County, Ala.*

(Aquifer: Mfp, Fort Payne Chert; Mt, Tuscumbia Limestone)

Well	Aquifer	Total depth (feet)	Cavity depths (feet)	Date of test	Duration of test (hours)	Average pumping rate (gpm)	Water level prior to pumping (feet below land surface)	Water level during pumping (feet below land surface)	Drawdown during test (feet)	Specific capacity (gpm per foot of drawdown)
E-68	Mt	418.5	34- 34.1	Oct. 30, 1957	8.5	12	26.5	27.8	1.3	9
			154-154.2	Jan. 7-8, 1958	24	10	25.6	26.0	.4	25
			182-182.1	Mar. 12, 1958	5.5	40	25.6	47.9	22.3	2
			219-219.1		3	35		34.6	9.0	4
F-4	Mt	296.0	53- 54 65- 65.5	Mar. 16-17, 1957	24	23	8.2	17.9	9.7	2
L-64	Mt Mfp	412.0	80- 80.3 249-249.5 299-299.1 322-322.1 329-329.1	Mar. 24, 1958	5.5	9	35.1	37.6	2.5	4
M-11	Mfp	327.0	84- 85(dry) 142-146.5 172-173 232-233	Sept. 21-22, 1956	24.4	65	99.7	147.0	47.3	4
M-143	Mt	385.0	67- 67.6 110-112 186-186.5	June 8, 1960	24	350	49.0	88.1	39.1	9
M-144	Mt	327.0	105-105.5	Jan. 23, 1958	12 5.5	4 9	60.7	61.2 61.7	.5 1.0	8 9

Table 2.—*Data from pumping tests in Colbert County, Ala.*—Continued

Well	Aquifer	Total depth (feet)	Cavity depths (feet)	Date of test	Duration of test (hours)	Average pumping rate (gpm)	Water level prior to pumping (feet below land surface)	Water level during pumping (feet below land surface)	Drawdown during test (feet)	Specific capacity (gpm per foot of drawdown)
M-145	Mt	279.0	21.5- 23.5	Oct. 10, 1958	2.2	50	12.5	12.7	.2	250
	Mfp		65- 65.5		2.2	100		12.9	.4	250
			96- 97.5		4.5	200		13.8	1.3	150
					15.5	300		15.2	2.7	110
M-147	Mt	280.0	31- 31.6	Sept. 24-25, 1958	4.0	100	9.6	11.9	2.3	44
	Mfp		57- 57.6		8.0	200		14.9	5.3	38
			97- 98		17.0	300		21.1	11.5	26
				Apr. 22, 1959	24.0	250	5.7	14.1	8.4	30
M-149	Mt	335.0	32- 33	Nov. 3, 1958	24.0	33	11.0	27.4	16.4	2
			38- 40							
			43- 46							
			87.5- 89							
M-150	Mt	266.0	18- 19	Aug. 26, 1958	24.0	31	11.9	13.3	1.4	22
	Mfp		32.5- 33							
			100-101							
			132-132.5							
M-151	Mt	353.0	70- 70.1	Oct. 29, 1957	5.5	9	53.3	59.3	6.0	1
M-152	Mt	286.0	40- 41	Dec. 18-19, 1958	5.0	240	21.9	24.7	2.8	86
	Mfp		116-116.1		14.0	287		25.3	3.4	84
				May 4, 1959	2.0	100	[2] 20.0	33.7	13.7	7
M-153	Mfp	317.0	101.5-102	Aug. 19, 1958	11.0	31	6.0	16.2	9.9	3
			227-228							

M-154	Mt Mfp	351.5 200.0	91- 91.3 187-188	Sept. 10, 1958	6.0 9.0 5.0 6.7	99 149 230 320	58.8	65.8 68.4 72.5 77.6	7.0 9.6 13.7 18.8	14 16 17 17
				Dec. 22, 1958	21.0	255	62.4	77.0	14.6	17
				May 13, 1959	24.0	255	53.1	69.8	16.7	15
M-157	Mt Mfp	325.0 200.0	67- 68 183-184	May 5, 1959	7.5 23.5	179 265	15.3	18.4 20.5	3.1 5.2	58 51
				May 19, 1959	24.0	265	18.0	23.6	5.6	47
				Mar. 4-10, 1960	12.0 7.0 23.0 149.5	400 900 1,200 1,600	[3] 12.8	21.1 24.8 35.2 48.0	8.3 12.0 22.4 35.2	48 75 54 45
M-161	Mt Mfp	367.0	115-115.3 197-197.4	June 6, 1960	24.0	300	50.6	83.7	33.1	9
V-119	Mt	234.5	24- 26 28.6- 29.1 43- 45 86- 86.7	Aug. 27, 1958	24.0	31	9.5	15.5	6.0	5
W-67	Mt	860.0	78- 80 86- 86.5	May 28, 1959	3.0	30	26.9	42.1	15.2	2

[1] See fig. 12. [2] See fig. 13. [3] See fig. 14.

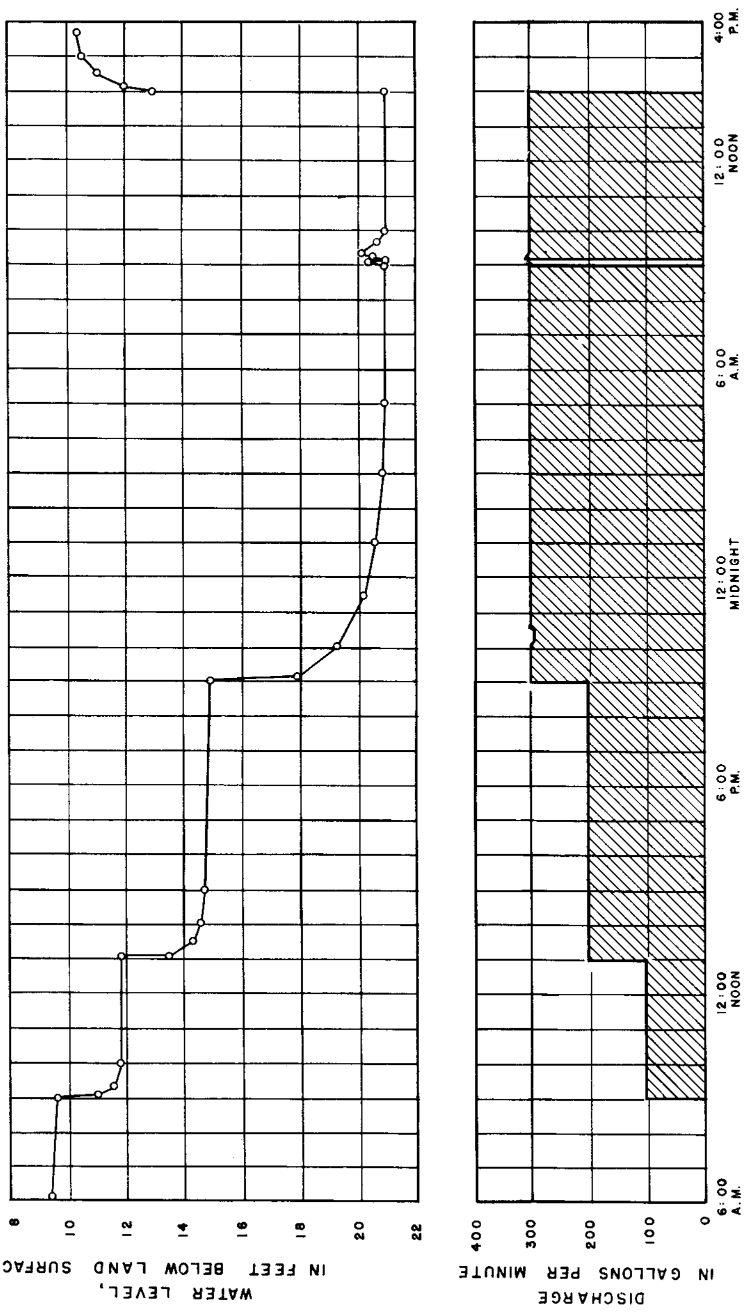

Figure 12.--Hydrograph showing data from pumping test on well M-147.

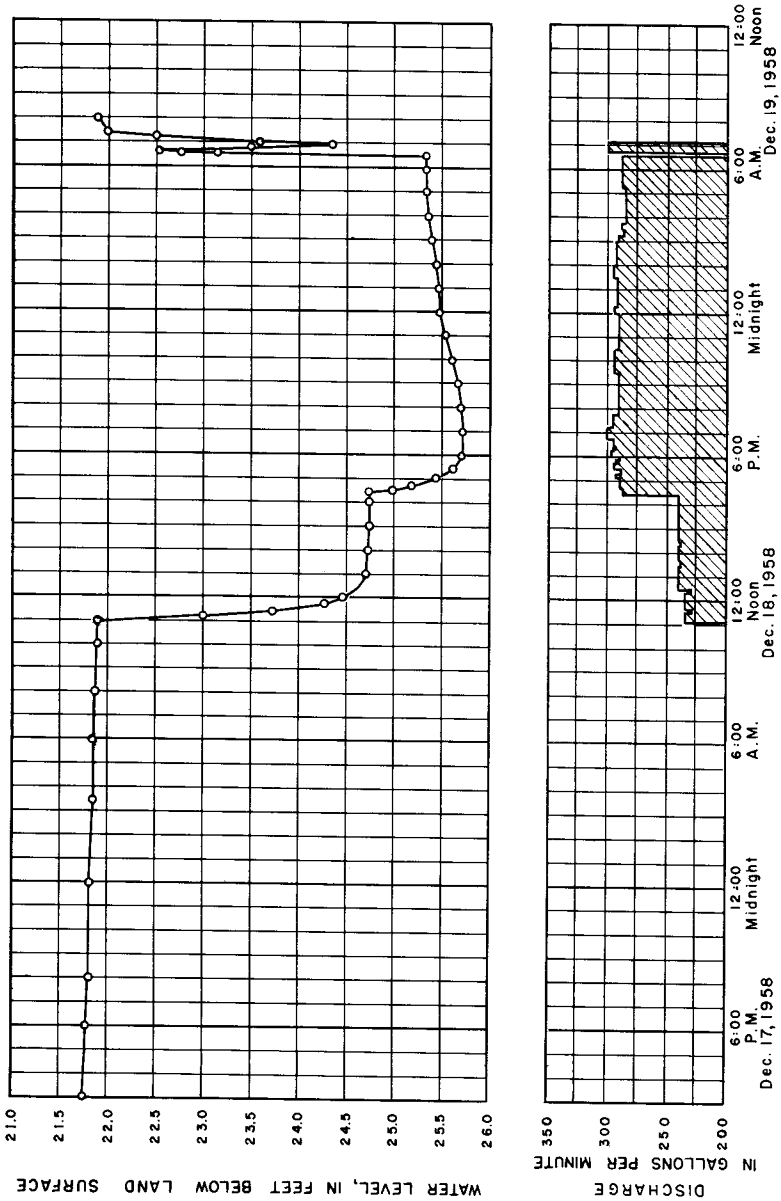

Figure 13.--Hydrograph showing data from pumping test on well M-152.

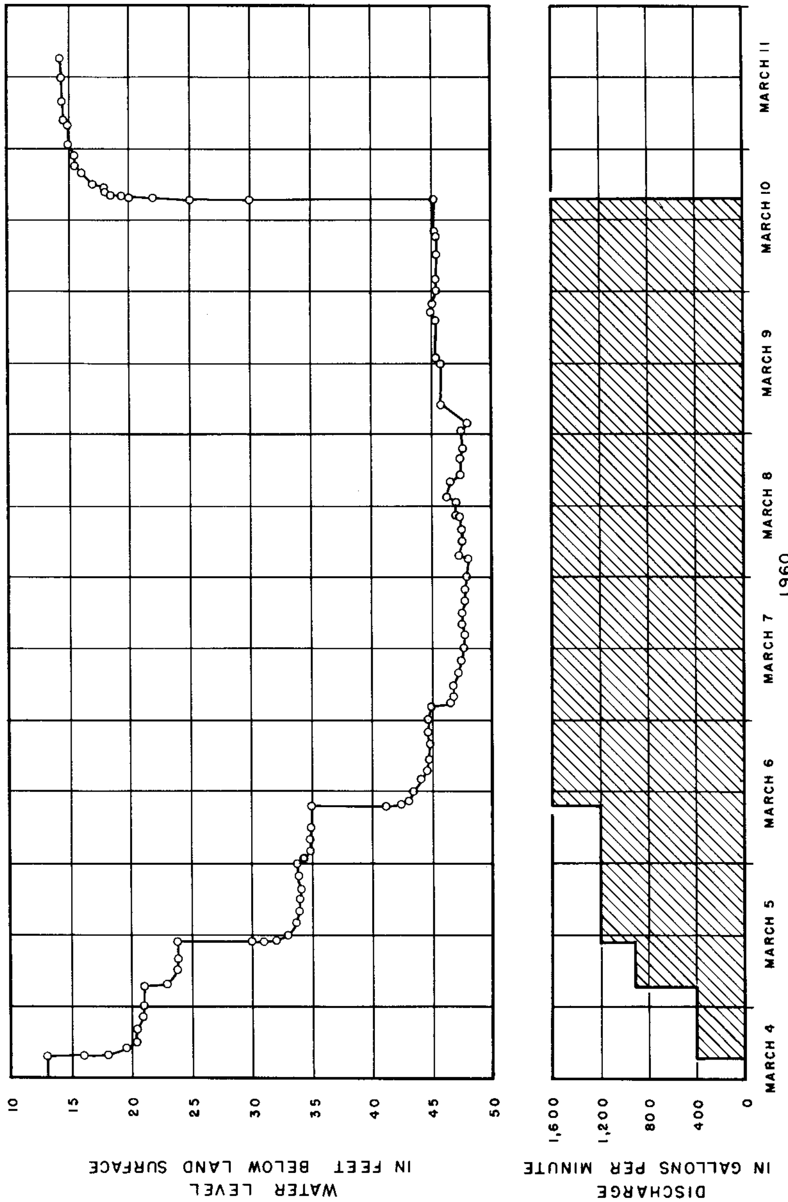

Figure 14.--Hydrograph showing data from pumping test on well M-157.

As shown in table 2, the specific capacities of these wells decreased as the pumping rates were increased.

FLUCTUATIONS OF WATER LEVELS

Water levels in wells fluctuate in response to different forces, which vary considerably in frequency of application and in magnitude. The periods of fluctuation may be seasonal, daily, hourly, or momentary. Fluctuations of water levels are caused by changes in aquifer recharge and discharge, earthquakes, earthtides, loading of the land surface, and variation of atmospheric pressure.

SEASONAL FLUCTUATIONS

The seasonal fluctuations of water levels in Colbert County are caused by variations in recharge and discharge. In the winter and spring, when water levels are high and the rock openings are filled, rainfall results in rising water levels within a relatively short period of time. In the summer and fall, when water levels are low and the rock openings have been drained and soil moisture depleted, precipitation results in a more gradual rise of water levels, or possibly in no rise at all. Seasonal fluctuations of water levels are illustrated in figures 5 to 10.

ATMOSPHERIC PRESSURE

Water levels in wells that tap artesian aquifers commonly respond to changes in atmospheric pressure (fig. 15). An increase in atmospheric pressure results in a decline of the water level in the well, and a decrease in pressure results in a rise. The water-level fluctuations caused by changes in pressure are commonly diurnal. Periods of high pressure and accompanying low water levels and of low pressure and high water levels occur at about 6-hour intervals. Thus there are two "highs" and two "lows" each day.

In general, changes in atmospheric pressure do not affect the water levels in wells that tap water-table aquifers, because the pressure is transmitted uniformly through the material above the water table. However, if the land surface is frozen some fluctuation may occur.

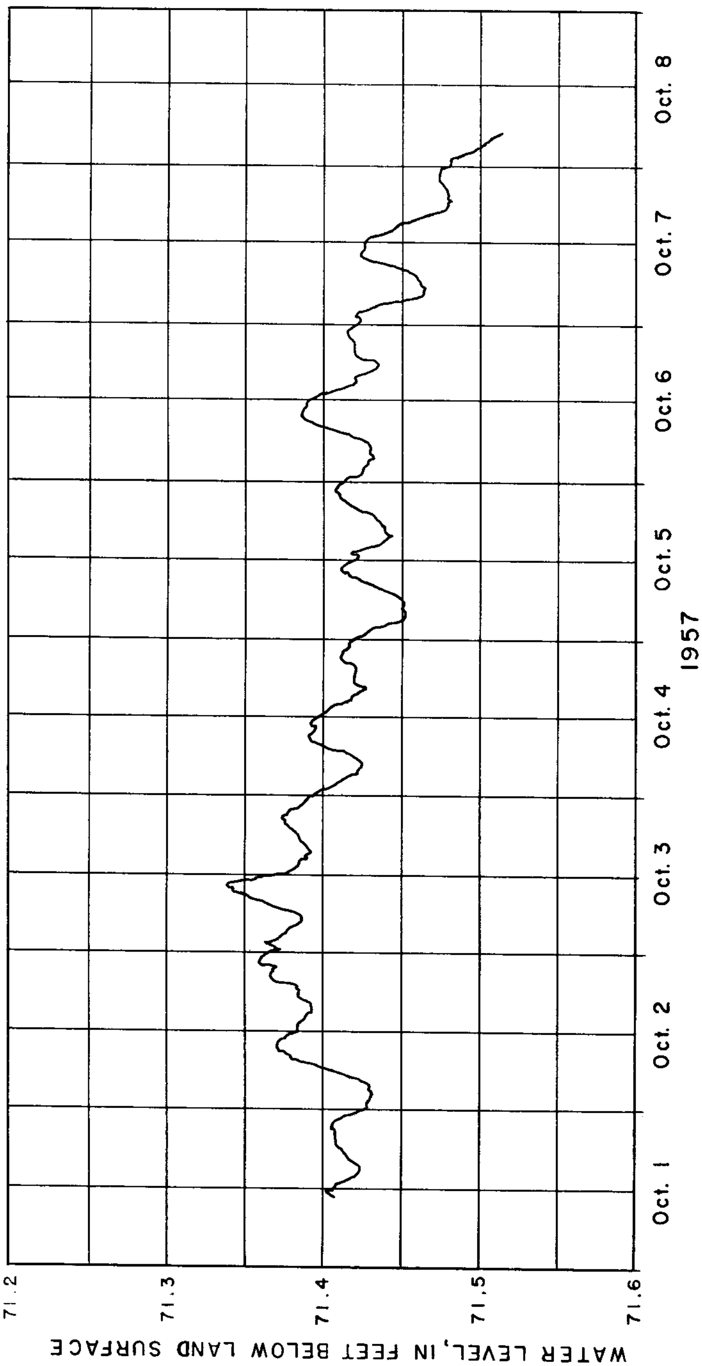

Figure 15.--Hydrograph showing water-level fluctuation in well V-71 caused by changes in atmospheric pressure.

EARTHQUAKES

Fluctuations of water levels caused by earthquakes have been observed in many artesian wells equipped with recording gages. In response to the shock waves produced by the earthquake, the water level in an artesian well first rises, and then oscillates with decreasing amplitude, the magnitude of the rise and fall being approximately equal. A fluctuation of water level in well M-157 is correlated with an earthquake (fig. 16) that occurred in Yellowstone National Park on August 17, 1959, at 11:37 p.m., as reported on the U.S. Coast and Geodetic Survey preliminary determination of epicenters card No. 65-59.

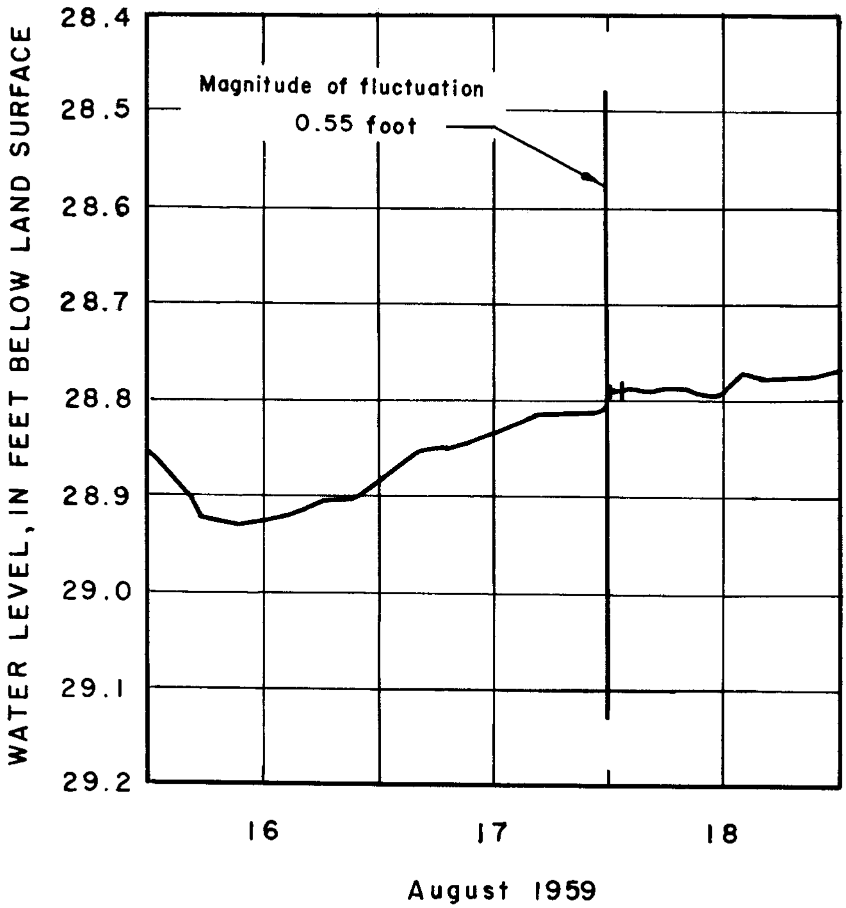

Figure 16.--Hydrograph showing water-level fluctuations in well M-157 caused by earthquake of August 17, 1959.

METHODS OF RECOVERY AND USE OF GROUND WATER

DUG WELLS

Dug wells usually are of large diameter, 3 feet or more, and are excavated with hand tools or with dredging and trenching machinery. About 15 percent of the inventoried wells in Colbert County are dug wells. The wells may be completely or partly curbed, according to the character of the material penetrated. Curbings are made of wood, stone, brick, tile, or concrete. Unless properly curbed and covered, dug wells are subject to pollution and contamination by surface seepage, animals, or falling debris.

Most dug wells in Colbert County are between 10 and 50 feet deep, and the average depth is 32 feet. Most have relatively low yields, although about two-thirds of the wells inventoried were reported adequate for domestic needs. About one-third of the wells were reported to be either inadequate or dry during the dry season of the year. Some of the wells that become dry could be restored to usefulness by being deepened.

DRILLED WELLS

Water for domestic and stock needs in Colbert County is obtained largely from drilled wells. Most of these wells yield less than 10 gpm. However, relatively large quantities, adequate for municipal, irrigational, and industrial needs, are obtained in parts of the county (Harris and others, 1960, table 1). For example, Cherokee obtains its municipal water supply from three drilled wells, which are pumped at rates of 10 to 150 gpm. Muscle Shoals obtains its municipal water supply from four drilled wells, pumped at rates as high as 80 gpm. As much as 500 gpm is pumped from drilled wells for cooling purposes by the Reynolds Alloys, Co., which is probably the largest industrial user of ground water in Colbert County.

Drilled wells in Colbert County are constructed with either cable-tool or rotary drilling rigs. The wells are cased to bedrock with iron, steel, or plastic casing, generally of 6-inch diameter or larger. About 50 percent of the drilled wells are less than 100 feet deep and 85 percent are less than 200 feet deep. Their average depth is 122 feet.

CABLE-TOOL DRILL

The cable-tool, percussion, or churn drill consists mainly of a mast or A-frame, draw-works, cable, drilling tools, bailer, and power unit. A walking beam lifts the cable and drilling tools and allows them to fall so that the bit breaks or crushes the rock, which is removed from the hole with a bailer. The cable-tool drill is used more extensively than the rotary drill in Colbert County because it is better suited for drilling the hard cavernous limestone and chert formations.

ROTARY DRILL

The hydraulic-rotary well-drilling equipment consists of a derrick, cable, and reels for handling tools and casing, a rotary "table" for rotating the drill bit and pipe, and a pump to circulate the drilling mud. The drilling mud is pumped down through the drill pipe and out of the openings in the bit so that the drill cuttings are carried up and out of the hole. The drilling mud serves also to prevent the hole from caving before the casing has been set. The drill cuttings brought up by the drilling mud indicate the nature of the strata penetrated by the bit.

A variation of hydraulic-rotary well-drilling equipment is the air-rotary equipment. This equipment uses a pneumatic bit as well as the rotary bit. Compressed air is used to actuate the pneumatic bit in a percussion motion. The air also serves to remove the cuttings and water from the well.

SPRINGS

Many springs in Colbert County are used as water supplies for domestic and stock needs, and a few are used for municipal and industrial requirements. Perennial springs are particularly numerous in the outcrop of the Tuscaloosa Group in western Colbert County. They are generally found low along hillsides and at many springs it is necessary to install small jet or piston pumps to raise the water to the place of use. Springs are rather common also along the outcrops of the Hartselle Sandstone, the Tuscumbia Limestone, and the Fort Payne Chert.

Tuscumbia Spring (M-20) provides most of the municipal water supply for the city of Tuscumbia. This spring discharges from two openings in the Tuscumbia Limestone and it is supplied by an extensive and well-developed subsurface drainage system, which probably extends for several miles east and southeast of Tuscumbia. The prompt discharge of muddy water after heavy local precipitation and a substantial increase in discharge are the result of quick recharge by surface water through sinkholes near Tuscumbia Spring. Considerable quantities of surface water probably enter the cavity system through a sinkhole less than 1,000 feet east of the spring. Because of these nearby areas of recharge, variations between the minimum and maximum discharge of Tuscumbia Spring is about tenfold. Sustained pumpage at high rates from nearby test wells M-144, M-145, M-147, M-149, M-151, M-152, and M-157, and from high-capacity industrial wells such as M-23 has produced no measurable changes in the discharge from Tuscumbia Spring.

The perennial springs of central and northeastern Colbert County occur in small valleys and most of them discharge small quantities of water from openings in the Fort Payne. Their annual variations of discharge are smaller than those from springs originating in the Tuscumbia. Spring H-15 probably receives some water from Wilson Lake for, unlike that of any other perennial spring in Colbert County, the temperature of its water changes with the season of the year. The spring water is about 10° cooler than the water of the Tennessee River.

ELECTRIC LOGGING

An electric log of a well measures two properties–the electrical resistance of the rocks and the differences of electrical potential between adjacent layers. The electrical resistance of any material is its ability to oppose the flow of electricity and is expressed in ohms. A small electrical potential or differential voltage between adjacent layers of rock also can be measured, and it is expressed in millivolts.

The electrical resistance of a rock is determined by the composition of the rock and the chemical quality, temperature, quantity, and distribution of ground water contained therein. Inasmuch as these factors vary according to rock types, formation boundaries and some rock characteristics can be determined from resistance logs.

The electrical potential of a rock varies positively or negatively with respect to other rocks. The amount of variation depends chiefly upon the chemical quality of the water in the rocks. Beds containing fresh water usually show less difference in potential than do beds containing mineralized water. The resistance and potential curves indicate only relative values; their shapes are more informative than the values recorded.

Electric logs were run in all test wells in Colbert County and were correlated with drillers' logs and sample logs in an effort to determine accurately the formation boundaries and the depths and sizes of cavities penetrated (pls. 2 and 3). Limestone has a high resistance because of its composition and the general absence of primary porosity. The quality of its contained water is fairly consistent from the top to the bottom of the wells and although the water, which is fresh in most places, has a high resistance, it is less than the resistance of the rock. Thus, a permeable zone in the rock is indicated on the electric log by a decrease in resistance and a more positive potential reading.

QUALITY OF WATER

Rainfall contains only small amounts of dissolved substances, but after entering the earth it begins to dissolve minerals from the soil and rocks. The amount and kind of dissolved matter contained in ground water may differ greatly from place to place, according to the amount and type of organic material in the soil, the type of rock through which or over which the water moves, the length of time the water is in contact with them, and the temperature of the water. Common mineral constituents in ground water are the cations—iron, calcium, magnesium, sodium, and potassium, and the anions—bicarbonate, sulfate, chloride, fluoride, and nitrate. Silica usually is present also in natural water.

The chemical quality of water commonly limits its use for domestic, municipal, industrial, or irrigation supplies. U.S. Public Health Service standards for drinking water are in general use throughout the United States. The standards were established in 1914 to control the quality of water supplied to the public by common carriers engaged in interstate traffic. The latest revision of these standards (1962) recommends that supplies should not contain more than 0.3 ppm of iron, 250 ppm of sulfate, 250 ppm of chloride, 0.8 to 1.7 ppm of fluoride according to the annual average of maximum daily air temperature, 45 ppm of nitrate, and 500 ppm of total dissolved solids. Table 3 lists the recommended limits of water quality for various industrial uses as suggested by the New England Water Works Association (1940, p. 263).

The following discussion of the quality of ground water in Colbert County is based on the analyses of 56 samples from 38 wells and springs (table 5) and on the large number of field determinations of chloride content and hardness reported by Harris and others (1960, table 1). Figure 17 is a graphic comparison of the chloride content and hardness of water in the more important aquifers in Colbert County. Of the wells and springs listed in table 5, 1 obtains water from the Tuscaloosa Group, 18 from the Tuscumbia Limestone, 10 from the Fort Payne Chert, 7 from the Tuscumbia Limestone and Fort Payne Chert combined, and 2 from the Gasper Formation.

Iron (Fe) is present in practically all rock and soils. Water having a low pH tends to be corrosive and may dissolve iron in objectionable quantities from piping. Iron in concentrations of more than 0.3 ppm may precipitate on exposure to air, thus forming an insoluble hydrated oxide that produces reddish-brown stains on fixtures and clothing. Water containing excessive iron is unsuitable for laundering and for manufacture of food, paper, ice, and other products. In the water sampled, the iron content did not exceed 0.23 ppm and was generally 0.02 ppm or less (table 5).

Calcium (Ca) and magnesium (Mg) are the main causes of hardness in water and their presence is indicated by the formation of objectionable curds in the presence of soap and by the formation of scale in boilers. Iron, aluminum, and some other substances cause hardness, but they are generally present in quantities so small that they do not have an appreciable effect. The calcium concentration in the water sampled ranged from 1 to 85 ppm and averaged 49 ppm; magnesium ranged from 0 to 71 ppm and averaged 7.5 ppm (table 5). Hard water is most successfully treated with a zeolite softener. Ground water is hard in most parts of Colbert County. Available data indicate that the average hardness ranges from less than 50 ppm in water from the Bethel Sandstone to more than 400 ppm in water from the Ste. Genevieve Limestone (fig. 17). In general water having a hardness of about 60 ppm or less is considered soft; a hardness of 61 to 120 ppm, moderately hard; and a

Table 3.—*Suggested water-quality tolerances for selected industrial uses*[1]

Industry or use	Turbidity	Color	Hardness as $CaCO_3$	Iron (Fe)	Manganese (Mn)	Allowable Limits in ppm			Hydrogen sulfide	Other requirements
						Total solids	Alkalinity as $CaCO_3$	Odor, Taste		
Air conditioning.....	...	...	...	[2] 0.5	0.5	...	...	Low	1	No corrosiveness, no slime formation.
Baking.............	10	10	...	[2] .2	.2	...	...	Low	.2	P[3]
Canning legumes....	10	...	25-75	[2] .2	.2	...	...	Low	1	P
General............	10	...	...	[2] .2	.2	...	...	Low	1	P
Carbonated beverages	2	10	250	.2 [2](.3)	.2	850	50-100	Low	.2	P. No organic color. Oxygen consumed less than 10 ppm.
Cooling............	50	...	50	[2] .5	.5	...	...	...	5	No corrosiveness, no slime formation.
Ice................	5	5	...	[2] .2	.2	...	...	Low	...	P. SiO_2 less than 10 ppm.
Laundering.........	...	...	50	.2	.2	...	...	...	...	
Tanning............	20	10-100	50-135	[2] .2	.2	...	Total 135. Hydroxide, 8.	...	...	
Textiles, general ...	5	20	...	.25	.25	...	...	...	...	
Dyeing.............	5	5-20	...	[2] .25	.25	200	...	...	...	Constant composition. Residual alumina less than 0.5 ppm.
Wool scouring......	...	70	...	[2] 1.0	1.0	...	...	...	...	
Cotton bandage	5	5	...	[2] .2	.2	...	...	Low	...	

[1] After New England Water Works Assoc. Jour., v. 54, p. 271, 1940.
[2] Limit given applies both to iron alone, and to the sum of iron and manganese.
[3] P indicates that potable water, conforming to U.S. Public Health Service standards, is necessary.

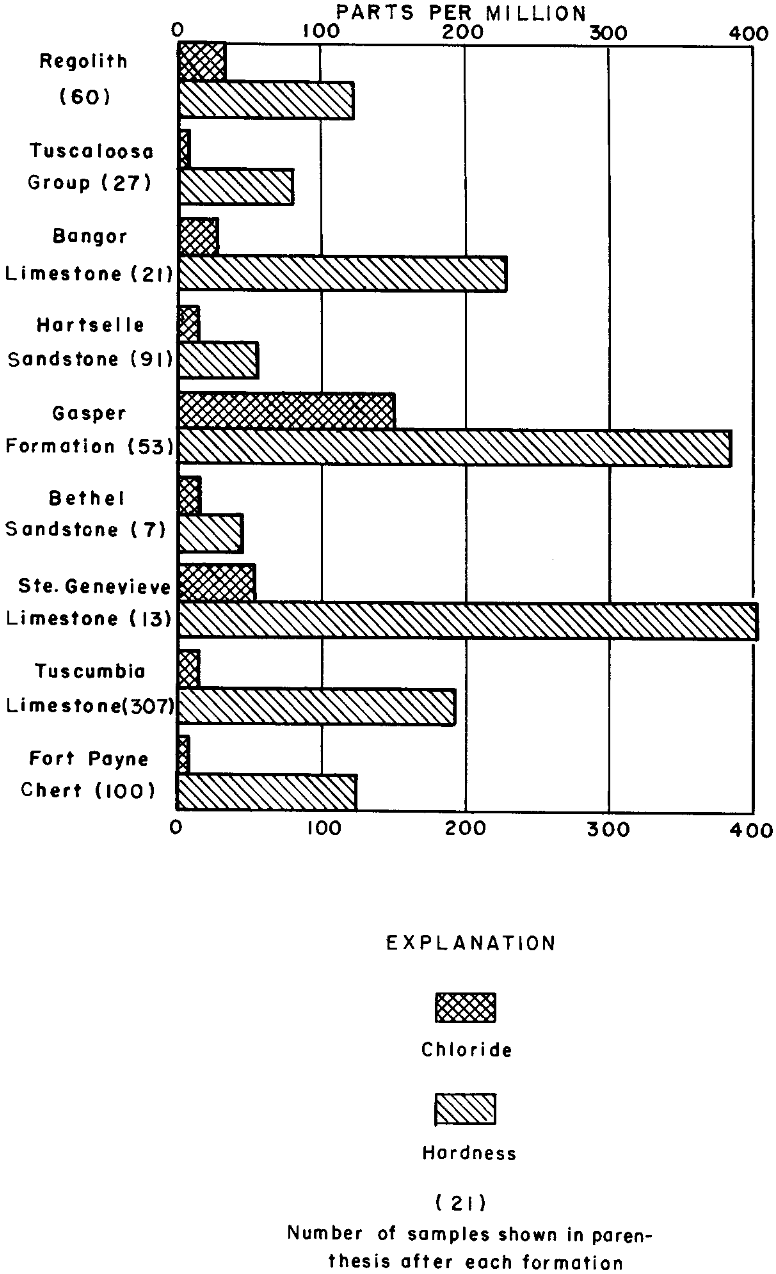

Figure 17.--Graph showing average chloride content and hardness of ground water in Colbert County.

hardness of more than 120 ppm, hard to very hard (Lamar, 1942, p. 25 to 26). A hardness of 200 to 500 ppm is decidedly objectionable and becomes increasingly troublesome as the concentration increases (Hem, 1959, p. 147).

Sodium (Na) and potassium (K) compose only a small part of the dissolved constituents, except in water in the Gasper Formation, where they form a much greater part (table 5). Two samples from well W-2 had a combined sodium and potassium content of 858 ppm and 908 ppm, and a sample from well W-20 had 2,110 ppm. Small to moderate amounts have little or no effect on the suitability of the water for municipal or industrial uses.

Carbonate (CO_3) and bicarbonate (HCO_3) occur in natural water from solution of carbonate rocks from the chemical action of carbonic and organic acids in the water. Both contribute to alkalinity but carbonate is usually present in only small amounts or may be absent. Except for well W-2, none of the ground water sampled contained carbonate. Bicarbonate generally occurs in moderate amounts that would have little or no effect on use of the water. However, samples from wells W-2 and W-20 finished in the Gasper Formation had average bicarbonate contents of 1,555 ppm and 1,295 ppm. Among the 36 other wells and springs bicarbonate ranged from 6 to 424 ppm and averaged 191 ppm.

Sulfate (SO_4) is dissolved from rocks and soils and some forms from oxidation of sulfides. Sulfate may combine with calcium and magnesium to form a hard boiler scale. Sulfate content was negligible in all the samples except those from wells W-2 and W-20, which averaged 142 ppm and 235 ppm (table 5). Many of the wells that obtain water from the Gasper Formation are reported to yield sulfurous water.

Chloride (Cl) is normally present in most natural water. In small to moderate amounts, less than 250 ppm, it has little effect on the suitability of water. Where present in greater concentration it gives the water a salty taste, and in excessive amounts it is injurious to most crops and may cause the water to be corrosive. In most parts of Colbert County, the ground water is low in chloride. However, several wells and springs yield water high in chloride from the Gasper Formation and Ste. Genevieve Limestone (fig. 17; table 5, well W-20, 2,520-2,700 ppm). Locally, high-chloride concentrations occur in shallow aquifers in the regolith, which may indicate pollution (Harris and others, 1960, table 1: V-39, 95 ppm;

V-92, 234 ppm).

Fluoride (F) is dissolved from fluoride-bearing minerals in rocks and occurs in most natural waters in only small amounts. Water that contains more than 1.5 ppm of fluoride is associated with a dental defect known as mottled enamel. Rainwater and Thatcher (1960, p. 163) state, "Available evidence indicates that water containing less than 1.0-0.9 ppm of fluoride seldom causes mottling of children's teeth, and the literature describing the beneficial effect of 0.88-1.5 ppm in drinking water as an aid in the reduction of tooth decay in children is abundant." Samples from wells W-2 and W-20 averaged 5.3 and 6.9 ppm fluoride, which is unusually high. Among the other wells and springs sampled fluoride ranged from 0.0 to 2.8 ppm and averaged 0.4 ppm.

Nitrate (NO_3) in ground water is generally considered the final oxidation product of nitrogenous organic material. High-nitrate concentration along with abnormally high chloride indicates possible pollution. None of the samples contained excessive nitrate.

Hydrogen-ion concentration expressed as the pH, is a measure of the relative acidity or alkalinity of a water. A pH of 7.0 indicates that the water is neutral (hydrogen and hydroxol ions in balance). A pH progressively less than 7.0 denotes increasing acidity, whereas a pH greater than 7.0 denotes increasing alkalinity. The pH of a water indicates its chemical activity toward metal surfaces. As the pH increases, the corrosive activity of the water normally decreases; however, excessively alkaline waters are corrosive to some metals, particularly zinc. Among the samples analyzed the pH ranged from 6.3 to 8.2,which is within the range of pH values of most natural water.

Specific conductance (micromhos at 25°C) is a measure of the ability of water to conduct electricity. It varies with the concentration and degree of ionization of the different minerals in solution and with the temperature. The higher the content of ionizable salts in a water, the greater will be its specific conductance. Conductance furnishes a rough estimate of the dissolved-solids content but it does not indicate relative quantities of specific salts in the solution.

The temperature of ground water in a given locality is generally uniform, varying not more than a few degrees during the year. The average temperature of ground water at depths of a few tens of feet, generally is about the same as, or a little higher than, the mean annual air temperature. It increases with depth, generally at a rate of 1°F for each 50 to 100 feet.

SUMMARY AND CONCLUSIONS

Colbert County is in the northwestern part of Alabama. The western part of the county is in the East Gulf Coastal Plain section of the Coastal Plain physiographic province and is characterized by ridges of moderate relief. The central and eastern parts of the county are in the Interior Low Plateaus and are characterized by a slightly tilted limestone plateau, which extends southward for several miles from the Tennessee River, and a second higher upland, which extends to the southern boundary of the county. An escarpment as much as 200 feet high separates the two uplands.

The oldest rocks penetrated by test drilling consist of limestone beds of probable Ordovician age and they are overlain by shaly limestones of Silurian age and by the Chattanooga Shale of Devonian age. Younger rocks, outcropping in the county, consist of the Fort Payne Chert, Tuscumbia Limestone, Ste. Genevieve Limestone, Bethel Sandstone, Gasper Formation, Cypress Sandstone, Golconda Formation, Hartselle Sandstone, and Bangor Limestone, all of Mississippian age; and the Tuscaloosa Group of Late Cretaceous Age; and unconsolidated alluvial and terrace deposits and weathered rock debris, collectively termed regolith, of Quaternary age. The bedrock dips regionally southwestward at about 25 to 30 feet per mile; local folding has been noted in a few areas in the western part of the county.

The most productive aquifers in the county are in the Tuscumbia Limestone and Fort Payne Chert, which are composed predominantly of calcium carbonate rocks. These aquifers were formed as the result of solutional enlargement by percolating water of joints and openings along bedding planes. Generally, these water-bearing openings are within 200 feet of the land surface. Eighty-five percent of the drilled wells are less than 200 feet deep; their average depth is 122 feet. The most productive wells penetrate the Tuscumbia Limestone and Fort Payne Chert in topographically and structurally low areas, where the formations are not too deeply buried by younger deposits. Such conditions are present in parts of Spring Creek valley in and south of Tuscumbia, where pumping tests have indicated potential yields of as much as 3,000 gpm, and probably in other places not tested. Small quantities of ground water adequate for domestic and stock needs can be obtained from most of the other formations in the county.

Tuscumbia Spring provides most of the municipal water for the city of Tuscumbia. The spring discharges from two openings in the Tuscumbia Limestone and it is supplied by an extensive subsurface drainage system, which probably extends for several miles east and southeast of Tuscumbia. The prompt discharge of muddy water after heavy local precipitation and a substantial increase in discharge are the result of quick recharge by surface water through sinkholes near Tuscumbia Spring. Variations between the minimum and maximum discharge of Tuscumbia Spring range from eightfold to tenfold. Sustained pumpage at high rates from nearby wells has produced no measurable changes in the discharge from Tuscumbia Spring.

Many springs in Colbert County are used as water supplies for domestic, stock, and industrial needs. Perennial springs are particularly numerous in the outcrop of the Tuscaloosa Group, and they are rather common also along the outcrops of the Hartselle Sandstone, Tuscumbia Limestone, and Fort Payne Chert.

Recharge in Colbert County occurs mainly during late fall, winter, and early spring. The average daily recharge to ground-water reservoirs is estimated to be about half a million gallons per square mile. Movement of ground water is generally northward toward the reservoirs formed by the Tennessee River.

Except for its hardness, ground water is generally of good chemical quality. Water from the Ste. Genevieve Limestone, Gasper Formation, and Bangor Limestone is very hard; water from the Fort Payne Chert, Tuscumbia Limestone, Tuscaloosa Group, and regolith is moderately hard to hard; and water from the Bethel Sandstone and Hartselle Sandstone is relatively soft. At some places alkalinity, chloride, fluoride, and sodium may be quality-of-water problems.

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BASIC DATA

Table 4.—*Records of U.S. Geol. Survey test wells and selected private wells and springs in Colbert County, Ala.*

Well or spring no.: Numbers correspond to those in plate 1; asterisk indicates chemical analysis given in table 5.
Type of well: D, drilled; S, spring.
Depth of well and water level: Depths shown in feet are reported; those in feet and tenths are measured.
Altitude: Altitudes determined by aneroid barometer.

Method of lift: F, flows; J, jet; M, manual; T, turbine.
Use: D, domestic supply, Ind, industrial; N, none; P, public supply; S, stock.
Water-bearing formation: Kt, Tuscaloosa Group; Mfp, Fort Payne Chert; Mg, Gasper Formation; Mh, Hartselle Sandstone; Mt, Tuscumbia Limestone.

Well or spring	Owner or location	Driller	Type	Depth of well (feet)	Diameter of well (inches)	Water-bearing formation	Altitude of land surface (feet)	Water level: Above(+) or below land surface (feet)	Water level: Date of measurement	Method of lift	Use of water	Remarks
*E- 4	Cooperage Co.........	....	S	.....	..	Kt	550	.....	....	F	N	Known as Bethune Hollow Spring Estimated flow, 5 gpm on 11-8-55.
*E-10	John Johnson.........	J. Byron Cotton	D	224.8	6	Mt	541	108.6	1-25-56	M	D	Electric log in files of U.S. Geol. Survey.
*E-65	Town of Cherokee.....	R. C. Capley...	D	250	6	Mt	507	22.8	1- 6-56	T	P	Casing: 6-in. to 50 ft none below. Pumped at 10 to 135 gpm. Driller's and electric logs in files of U.S. Geol. Survey. See fig. 5.
*E-68	U.S. Geol. Survey.....	Miller Drilling Co.	D	418.5	6	Mt	490	25.1	5-29-57	...	...	Casing: 6-in. to 21.6 ft.; none below. See pl. 2, fig. 5, and table 2.
*E-69	........do..........	H. W. Peerson Drilling Supply Co.	D	414.0	6	Mt	528	36.3	3- 2-59	...	...	Casing: 6-in. to 21 ft.; none below. See pls. 2 and 5.
*F- 4	........do..........	Hawley Dodson	D	296.0	6	Mt	415	12.0	11-30-56	...	...	Casing: 6-in. to 32 ft.; none below. See pl. 2, fig. 5, and table 2.
*F- 7	....	....	S	.....	..	Mt	420	.....	....	F	D	Known as Parker Spring. See fig. 11.
*H-15	U.S. Government	....	S	.....	..	Mfp	...	.....	....	F	N	Known as TVA Spring. Measured flow, 1,500 gpm on 11-29-55.
*H-19	Town of Muscle Shoals	J. Byron Cotton	D	178	6	Mfp	565	.....	....	J	P	

H-80	U.S. Geol. Survey....	Adams-Massey Co.	D	217.0	6	...	535	15.0	6-14-60	...	...	Casing: 6-in. to 37 ft.; none below. See pls. 2 and 5.
H-81	........do..........	.....do......	D	313.0	6	Mt (?)	540	31.0	...do...	...	...	Casing: 6-in. to 63 ft.; none below. See pls. 2 and 5.
*I- 5	J. G. Baker..........	....	S	.....	..	Mfp	514	.....	....	F	N	Known as Baker Bubbling Spring. See fig. 11.
*I-48	Leonard Pruitt.......	....	S	.....	..	Mfp	515	.....	....	F	D,S	Known as Pruitt Spring. Estimated flow, 1,000 gpm on 9-15-55.
*K-21	City of Leighton.....	H. W. Peerson Drilling Supply Co.	D	.....	..	Mt	587	.....	....	T	P	City well.
L-13	J. W. Hobgood.......	....	D	129.9	6	Mt	536	89.0	10-26-55	M	N	See fig. 6.
*L-64	U.S. Geol. Survey....	Miller Drilling Co.	D	412.0	6	Mt Mfp	562	50.8	6-24-57	...	...	Casing: 6-in. to 18 ft.; none below. See pls. 2 and 5, fig. 6, and table 2.
*M- 3	Town of Muscle Shoals	....	D	165	8	Mfp	510	65.0	8- 6-29	T	P	Reported yield, 40 gpm.
*M- 9	U.S. Geol. Survey....	Hawley Dodson	D	335.0	6	Mt	485	69.2	8-22-56	...	...	Casing: 6-in. to 55.5 ft.; none below. See pls. 2 and 5 and fig. 7.
*M-11	........do..........	.....do......	D	327.0	6	Mfp	528	97.6	6- 3-57	...	...	Casing: 6-in. to 72 ft.; none below. See pls. 2 and 5, fig. 7, and table 2.
M-15	Fred Dobbs, Sr.......	Curtis Spangler	D	173.0	6	Mfp	520	86.1	7-29-55	...	N	Casing: 6-in. to 60 ft.; none below. See fig. 6.
*M-20	City of Tuscumbia....	....	S	.....	..	Mt	427	.....	....	F	P	Known as Tuscumbia Spring. See fig. 11.
*M-21	........do..........	Curtis Spangler	D	238.0	6	Mfp	527	76.6	10-20-55	...	N	Pumped at 60 gpm. See fig. 8.
*M-23	Robbins Tire and Rubber Products, Inc.	J. Byron Cotton	D	91	8	Mt	506	.....	....	T	Ind	Pumped at 600 gpm for 24 hours, 6 days a week.
M-51	J. K. Johnson.......	....	D	103.0	6	Mt	497	73.7	10-18-55	M	D	See fig. 8.
M-80	Ben Findley.........	....	D	171.7	6	Mt	501	73.2	9-14-55	M	N	Do.
*M-123	Town of Colbert Heights.	Earl Crowden.	D	237	8	Mt	477	143	1954	T	P	Casing: 8-in. to 42 ft.; none below. Pumped at 125 gpm for 24 hours in August 1954.
*M-143	U.S. Geol. Survey....	H. W. Peerson Drilling Supply Co.	D	385.0	6	Mt	480	39.2	4-28-60	...	...	Casing: 6-in. to 62 ft.; none below. See pls. 2 and 5 and table 2.

Table 4.—*Records of U.S. Geol. Survey test wells and selected private wells and springs in Colbert County, Ala.*—Continued

Well or spring	Owner or location	Driller	Type	Depth of well (feet)	Diameter of well (inches)	Water-bearing formation	Altitude of land surface (feet)	Water level: Above(+) or below land surface (feet)	Water level: Date of measurement	Method of lift	Use of water	Remarks
*M-144	U.S. Geol. Survey.....	Miller Drilling Co.	D	327.0	6	Mt	492	56.2	11-25-57	...	...	Casing: 6-in. to 40 ft.; none below. See pls. 2 and 5, fig. 7, and table 2.
*M-145	........do..........	Spangler Drilling Co.	D	279.0	6	Mt Mfp	422	10.1	10-10-58	...	...	Casing: 6-in. to 20 ft.; none below. See pls. 2 and 5, fig. 9, and table 2.
*M-146	........do..........	......do......	D	255.0	6	Mt	413	1.6	7-30-58	...	...	Casing: 6-in. to 20 ft.; none below. See pls. 2 and 5.
*M-147	........do..........	......do......	D	280.0	6	Mt Mfp	425	8.6	7-18-58	...	...	Casing: 6-in. to 22 ft.; none below. See pls. 2 and 5, fig. 12, and table 2.
M-148	........do..........	......do......	D	94.0	6	Mt	28	9.2	4- 7-58	...	...	Casing: 6-in. to 43 ft.; none below. Abandoned, redrilled as M-149.
*M-149	........do..........	......do......	D	335.0	6	Mt	428	11.0	11- 3-58	...	...	Casing: 6-in. to 20.5 ft.; none below. See pls. 2 and 5 and table 2.
*M-150	........do..........	......do......	D	266.0	6	Mt Mfp	430	10.0	1-26-58	...	...	Casing: 6-in. to 63.5 ft.; none below. See pls. 2 and 5, fig. 9, and table 2.
*M-151	........do..........	Miller Drilling Co.	D	353.0	6	Mt	504	53.3	11- 5-57	...	...	Casing: 6-in. to 41 ft.; none below. See pls. 3 and 6 and table 2.
*M-152	........do..........	......do......	D	286.0	6	Mt Mfp	437	20.2	10-25-57	...	...	Casing: 6-in. to 14 ft.; none below. See pls. 3 and 6, figs. 9 and 13, and table 2.
*M-153	........do..........	Spangler Drilling Co.	D	317.0	6	Mfp	430	6.4	8-19-58	...	...	Casing: 6-in. to 28 ft.; none below. See pls. 3 and 6 and table 2.

*M-154	........do..........	......do......	D	351.5	6	Mt Mfp	490	54.2	8- 1-58	...	...	Casing: 6-in. to 52 ft.; none below. See pls. 3 and 6, fig. 9, and table 2.
*M-155	........do..........	H. W. Peerson Drilling Supply Co.	D	375.0	6	Mfp	503	63.4	4- 7-60	...	...	Casing: 6-in. to 44 ft.; none below. See pls. 3 and 6.
M-156	........do..........	Spangler Drilling Co.	D	253.0	6	Mt	485	60.2	3-29-59	...	...	Casing: 6-in. to 43 ft.; none below. See pls. 2 and 5.
*M-157	........do..........	H. W. Peerson Drilling Supply Co.	D	325.0	6	Mt Mfp	455	15.3	5- 5-59	...	...	Casing: 6-in. to 40 ft.; none below. Plugged back to 200 ft. See pls. 3 and 6, figs. 14 and 16, and table 2.
M-158	........do..........	......do......	D	515.0	6	Mt	550	109.5	1-22-59	...	...	Casing: 6-in. to 28 ft.; none below. See pls. 3 and 6.
M-159	........do..........	......do......	D	349.0	6	Mt	510	89.3	12-10-59	...	...	Casing: 6-in. to 44.5 ft.; none below. See pls. 3 and 6.
M-160	........do..........	Adams-Massey Co.	D	414.0	6	Mt	485	18.0	4-28-60	...	...	Casing: 6-in. to 26 ft.; none below. See pl. 3.
*M-161	........do..........	Adams-Massey Co.	D	367.0	6	Mt Mfp	490	48.1	5-23-60	...	...	Casing: 6-in. to 102 ft.; none below. See pl. 3 and table 2.
N- 14	Pat Harris...........	Curtis Spangler	D	243.5	6	Mt	549	128.9	11- 2-55	M	D	Electric log in files of U.S. Geol. Survey. See fig. 10.
N- 40	Joe Lonsdale........	Tennessee Valley Authority.	D	377	6	Mg	726	66.7	8- 3-56	...	N	See fig. 10.
V- 71	John Lee...........	....	D	192.2	6	Kt	670	64.6	4-11-56	...	N	Electric log in files of U.S. Geol. Survey. See fig. 15.
V- 94	U.S. Geol. Survey....	Hawley Dodson	D	401.0	6	Mh	630	72.7	11-30-56	...	...	Casing: 6-in. to 25 ft.; none below. See pl. 3.
*V-119	........do..........	Spangler Drilling Co.	D	234.5	6	Mt	458	8.2	3-10-58	...	...	Casing: 6-in. to 15 ft.; none below. See pl. 3 and table 2.
W- 1	R. D. Ford..........	Rhoden Drilling Co.	D	141.5	6	Mt	601	50.1	5-23-56	...	N	See fig. 10.
*W- 2	E. M. Ford..........	Bud Copeland	D	288	6	Mg	593	52	5-23-56	J	D	
*W- 20	Grady L. Pace.......	Charles Richey	D	114.8	6	Mg	547	49.6	6- 4-56	M	D	
*W- 67	U.S. Geol. Survey....	Miller Drilling Co.	D	500.0	6	Mt	501	21.7	1-27-58	...	...	Casing: 6-in. to 29 ft.; none below. See pl. 3 and table 2.

Table 5.—*Chemical analyses of water from wells and springs in Colbert County, Ala.*

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Water-bearing formation: Kt, Tuscaloosa Group; Mfp, Fort Payne Chert; Mg, Gasper Formation; Mt, Tuscumbia Limestone.

Well: Numbers correspond with those in table 4 and on plate 1.

Well	Date of collection	Water-bearing formation	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$: Calcium and magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance in micromhos at 25°C	pH
E- 4	11-22-55	Kt	....	0.01	1.0	.....	0.9	...	6	0	1.0	1.2	0.0	0.1	6	1	14	6.3
E- 10	5- 4-56	Mfp	14	.02	62	18	3.8	...	224	0	3.0	24	.3	4.7	229	45	452	8.0
E- 10	11-20-56	Mfp	....	.00	55	22	8.7[1]		225	0	15	23	2.8	8.1	228	43	454	7.5
E- 65	5- 4-56	Mfp	11	.01	76	2.5	3.8	...	206	0	12	7.0	.2	.0	214	31	411	7.9
E- 65	11-20-56	Mfp	....	.00	85	17	23[1]		238	0	106	18	.5	.0	282	87	593	7.5
E- 68	5-12-58	Mt	....	.00	62	3.8	2.3	...	202	0	4.8	2.0	.0	2.5	170	4	328	7.7
E- 69	3-29-59	Mt	....	.00	41	17	2.0	...	180	0	23	5.0	.4	.1	172	25	332	8.1
F- 4	5-21-58	Mt	....	.00	55	4.6	3.7	...	192	0	4.0	2.0	.0	.2	156	0	302	7.9
F- 7	11-22-55	Mt	....	.00	60	.....	1.4	...	192	0	.8	1.0	.0	3.2	169	12	302	7.4
F- 7	11-23-56	Mt	....	.04	59	2.2	1.4[1]		184	0	2.2	1.5	.1	3.9	156	5	298	7.6
H- 15	11-29-55	Mfp	....	.00	27	.0	10	...	72	0	16	22	.0	.1	89	30	221	7.1
H- 19	5- 4-56	Mfp	12	.02	34	5.1	3.1	...	116	0	.5	1.0	.1	.8	106	11	290	7.4
H- 19	11-23-56	Mfp	....	.00	34	3.2	3.9[1]		119	0	3.5	2.0	.2	2.4	98	0	201	7.2
I- 5	11-22-55	Mfp	....	.01	23	.....	1.1	...	82	0	.5	1.2	.0	1.2	72	5	132	7.2
I- 5	11-23-56	Mfp	....	.00	22	3.2	6.4[1]		92	0	1.5	2.0	.1	.8	68	0	135	7.1
I- 48	11-22-55	Mfp	....	.00	17	.....	1.2	...	68	0	.5	1.2	.1	2.7	62	6	119	7.0
I- 48	11-23-56	Mfp	....	.01	19	3.0	1.8[1]		70	0	1.2	1.5	.1	3.5	60	2	122	7.3
K- 21	6-18-56	Mt	....	.00	48	10	8.0[1]		179	0	21	6.2	.5	.1	161	14	328	7.9
K- 21	11-23-56	Mt	....	.00	54	11	11[1]		210	0	19	6.0	.7	.8	180	8	370	7.5
L- 64	4-21-58	Mt	....	.00	53	7.3	6.8	...	192	0	4.2	6.0	.2	.0	162	4	335	8.0
M- 3	5- 4-56	Mfp Mt	9.8	.01	48	13	12	...	216	0	10	4.0	1.0	.0	173	0	346	8.3

M- 3	11-23-56	Mt	....	.01	46	11	16[1]		205	0	14	7.0	1.1	.0	160	0	351	7.9
M- 9	4-21-58	Mt	....	.01	67	9.0	3.0	...	244	0	4.2	4.2	.0	2.7	204	4	394	7.5
M- 11	9-21-56	Mfp	....	.01	50	3.2	2.8[1]		164	0	5.8	1.5	.3	.4	138	4	265	7.8
M- 11	9-22-56	Mfp	....	.01	69	4.9	3.9[1]		236	0	4.2	1.5	.2	.1	192	0	367	7.5
M- 20	11-22-55	Mt	....	.00	65	.....	3.6	...	204	0	3.0	2.8	.1	4.3	176	9	331	7.5
M- 20	4-10-56	Mt	7.7	.23	43	1.2	1.5	0.7	133	0	3.2	2.2	.1	5.9	112	3	224	7.3
M- 20	11-23-56	Mt	....	.00	65	2.9	3.2[1]		202	0	5.5	4.5	.2	3.6	170	4	337	7.4
M- 21	5-21-58	Mt	....	.00	46	3.9	4.6	...	146	0	16	4.5	.6	4.0	131	12	288	7.7
M- 23	11-30-55	Mt	....	.00	62	.....	5.5	...	201	0	5.5	3.8	.0	3.1	176	11	331	7.4
M-123	5- 4-56	Mt	13	.00	64	13	3.1	...	234	0	13	4.0	.5	.0	213	21	381	8.1
M-123	11-23-56	Mt	....	.00	69	17	8.3[1]		287	0	12	7.0	.9	.0	242	7	463	7.6
M-143	6-10-60	Mt	....	.02	39	14	11	...	200	0	5.6	4.0	.8	.0	155	0	329	8.2
M-144	4-23-58	Mt	....	.00	29	14	44	...	246	0	6.5	14	1.6	.1	130	0	414	7.9
M-145	10-11-58	Mt	....	.01	70	1.8	3.0	...	210	0	5.6	4.5	.1	7.6	182	10	344	7.5
		Mfp																
M-146	9-25-58	Mt	....	.01	58	2.3	3.0	...	181	0	6.4	4.5	.0	2.2	154	6	293	7.7
M-147	9-25-58	Mt	....	.01	82	2.8	7.0	...	249	0	14	9.0	.1	4.5	216	12	411	7.4
		Mfp																
M-147	12-31-58	Mt	....	.00	82	2.8	8.3	...	253	0	13	7.5	.3	1.5	232	24	443	7.5
		Mfp																
M-147	4-23-59	Mt	....	.00	75	3.4	5.8	...	220	0	12	7.0	.2	7.4	201	20	395	7.7
		Mfp																
M-149	11- 4-58	Mt	....	.01	79	2.7	3.2	...	252	0	11	3.5	.1	.1	208	2	372	7.4
M-150	8-27-58	Mt	....	.01	78	1.8	3.3	...	236	0	7.6	5.5	.0	4.9	202	8	376	7.6
		Mfp																
M-151	5-21-58	Mt	....	.00	46	3.9	4.6	...	146	0	16	4.5	.6	4.0	131	12	288	7.7
M-152	12-19-58	Mt	....	.00	64	3.0	8.4	...	172	0	8.0	5.0	.4	2.6	172	0	364	8.1
		Mfp																
M-153	8-20-58	Mfp	....	.01	34	11	9.5	...	164	0	9.2	3.0	.9	.1	130	0	265	7.9
M-154	9-11-58	Mt	....	.01	33	14	29	...	227	0	14	6.5	1.0	.1	140	0	373	7.7
		Mfp																
M-154	12-23-58	Mt	....	.01	50	12	35	...	256	0	11	10	1.4	.0	174	0	437	7.8
		Mfp																
M-154	5-14-59	Mt	....	.01	49	9.1	30	...	244	0	10	6.0	1.5	.5	160	0	410	7.6
		Mfp																
M-155	4- 7-60	Mfp	....	.00	73	3.4	7.6	...	248	0	6.0	.0	.2	.1	196	0	385	8.0
M-157	5- 5-59	Mfp	....	.01	50	.7	1.3	...	156	0	.0	2.0	.0	2.4	128	0	253	7.4
M-161	6- 7-60	Mt	....	.00	53	12	8.5	...	228	0	2.8	8.0	.4	.0	182	0	374	8.1
		Mfp																
V-119	10- -58	Mt	....	.01	38	.7	4.3	...	122	0	1.2	4.5	.0	.2	98	0	198	7.2
W- 2	6-18-56	Mg	....	.00	4.0	9.7	858[1]		1,560	20	120	350	3.6	.6	50	0	3,400	8.4
W- 2	11-23-56	Mg	....	.11	8.4	7.1	908[1]		1,550	0	165	400	7.1	.5	50	0	3,590	7.6
W- 20	6-18-56	Mg	....	.00	44	71	....	...	1,230	0	290	2,700	7.5	15	402	0	9,400	7.6
W- 20	11-17-56	Mg	....	.02	35	46	2,110[1]		1,360	0	180	2,520	6.4	.4	276	0	9,290	8.1
W- 67	4-21-56	Mt	....	.15	26	4.1	282	...	424	0	71	195	1.8	.1	82	0	1,376	8.0

[1] Sodium and potassium combined