Geology and Hydrology of the Claiborne Group in Western Tennessee

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1809-F

Prepared in cooperation with the Tennessee Department of Conservation Division of Water Resources

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By GERALD K. MOORE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND HYDROLOGY OF THE CLAIBORNE GROUP IN WESTERN TENNESSEE

By GERALD K. MOORE

ABSTRACT

The area of western Tennessee underlain by the Claiborne Group is about 7,200 square miles and lies on the east flank of the syncline that forms the Mississippi embayment. It includes the Mississippi Alluvial Plain and part of a dissected upland plateau. The Claiborne Group dips to the northwest at 10–25 feet per mile and ranges in altitude from 600 feet above mean sea level in the outcrop area to 900 feet below mean sea level near the embayment axis.

The Claiborne Group is tentatively subdivided into five units including, in ascending order, the Meridian Sand Member of the Tallahatta Formation, the Basic City Shale Member of the Tallahatta Formation, the Sparta Sand, an unnamed clay unit, and an unnamed sand unit. The two major aquifers in the Claiborne Group are the "500-foot" sand and the unnamed sand unit. The top of the "500-foot" sand is correlated with the top of the Sparta Sand; and the base, with the base of the Claiborne Group. The "500-foot" sand ranges in thickness from 200 to 750 feet and consists mainly of very fine to coarse sand or gravel. It also contains layers of white to blue, pink, gray, or brown clay, which constitute only a small percentage of the total thickness. The unnamed sand unit ranges from 0 to 210 feet in thickness and consists mostly of white, gray, or brown fine-grained lignitic sand. An estimated 75 percent of the ground water withdrawn in western Tennessee (west of the northward-flowing segment of the Tennessee River) is taken from the "500-foot" sand and the unnamed sand unit.

The quantities of water available to wells from the "500-foot" sand are currently adequate for all municipal and industrial needs. The permeability of this aquifer is about 570 gallons per day per square foot. An estimated 155 mgd (million gallons per day) is pumped from the "500-foot" sand, about 140 mgd is discharged from the aquifer as the base flow of surface streams, and about 40 mgd is discharged from the report area as underflow. Water from the "500-foot" sand contains objectionable quantities of iron in the western half of the report area. Otherwise the quality of the water is suitable for most needs.

Quantities of water adequate for domestic use and for small municipal systems can be obtained from the unnamed sand unit in most of the report area. The field permeability of this aquifer is probably about 270 gallons per day per square foot. About 8 mgd is discharged into adjacent formations, and about

2 mgd is withdrawn by pumping. Water from the unnamed sand unit contains objectionable quantities of iron in the western half of the report area. Otherwise the water from this aquifer is of good quality.

Ground-water supplies in both the "500-foot" sand and the unnamed sand unit will be adequate for the predicted rate of municipal growth and economic development for many years to come. If the hydraulic gradient in the "500-foot" sand were increased to 19 feet per mile, the average dip of the top of the aquifer, about 578 mgd would be transmitted downdip.

Similarly, the unnamed sand unit would transmit about 34 mgd downdip under a hydraulic gradient of 10 feet per mile. Furthermore, additional amounts of water could be induced into the report area as underflow from adjacent States.

The anticipated effects of additional large scale development are (1) a drop in local and regional water levels in proportion to the increase in pumpage, (2) an increase in the net inflow of ground water from adjacent States, and (3) an increase of recharge to the aquifers at the expense of streamflow.

INTRODUCTION

Owing to its broad distribution and water-bearing characteristics, the Claiborne Group supplies an estimated 75 percent of the ground water withdrawn in western Tennessee (west of the northward flowing segment of the Tennessee River). To provide adequate information regarding the occurrence, availability, quality, and use of ground water from the Claiborne Group, an intensive investigation was undertaken in 1958 by the U.S. Geological Survey in cooperation with the Tennessee Division of Water Resources as part of a study of all the principal aquifers (water-bearing units) in western Tennessee. The order in which each aquifer was to be studied was based primarily on the aquifer's economic importance and on the need for information. Because of its importance the Claiborne Group was selected for early study, and the results of the study are presented in this report.

LOCATION OF AREA

The area of this report coincides with the part of western Tennessee that is underlain by geologic formations of the Claiborne Group (fig. 1). It is bounded on the north by Kentucky, on the south by Mississippi, and on the west by the Mississippi River. The east boundary is formed by the easternmost extent of the Claiborne Group in western Tennessee. As thus defined, the area covers about 7,200 square miles, or 65 percent of western Tennessee.

PURPOSE AND SCOPE

The purpose of this report is: (1) to define the limits of the water-bearing zones in the Claiborne Group, (2) to explain the hydrologic functions of these aquifers, (3) to describe the chemical

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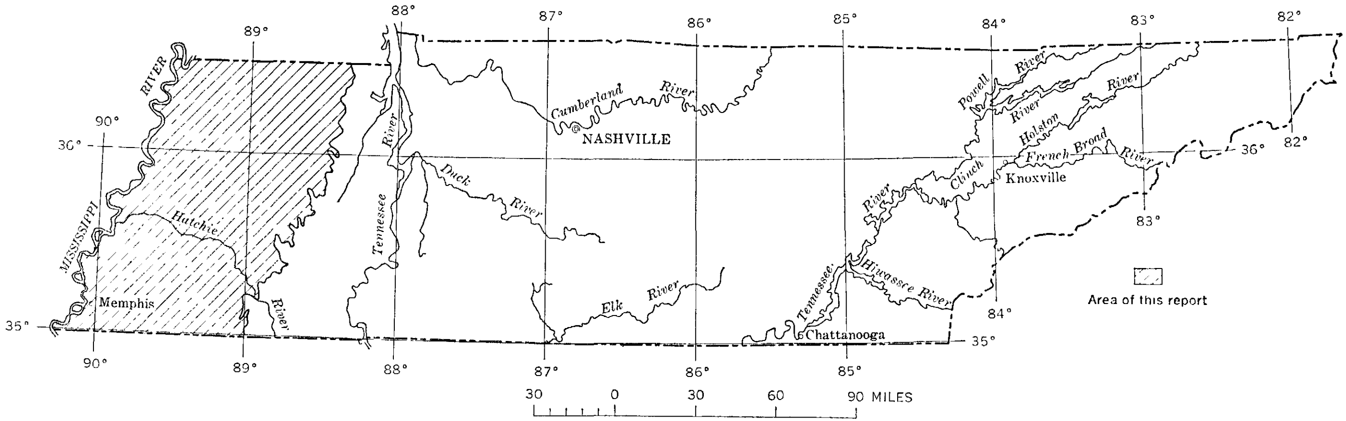

Figure 1.—Location of report area.

quality of the water contained in them, and (4) to determine the effects of past and future development on the overall adequacy of the water supply. Many effects are superimposed on the natural system by surface-water impoundment and ground-water pumping for domestic, municipal, agricultural, and industrial use. Discussed in this report are the effects of pumping on surface runoff, the effects of pumping on water levels, and the amount of water available for future development.

An effective appraisal of the ground-water resources of an aquifer system can be accomplished only through comprehensive studies of the aquifers' physical properties and surroundings. Brief, pertinent descriptions of the geography and geology of the area underlain by the Claiborne Group, therefore, constitute a part of this report.

PREVIOUS INVESTIGATIONS

The first systematic investigation of ground water in Tennessee was made by Glenn (1906). Later, Wells (1933) described in some detail the character and extent of the aquifers underlying western Tennessee. Several recent reports have discussed the geology or occurrence and chemical quality of ground water in part or all of the report area. Lanphere (1955) described the chemical quality of water in the aquifers and discussed the methods of treatment used to render the water suitable for municipal supplies. Stearns and Armstrong (1955) revised the Cretaceous and Tertiary geologic terminology for Tennessee. Schreurs and Marcher (1959) discussed the aquifer characteristics and water use in the Dyersburg quadrangle, a part of the present report area. A fairly comprehensive report on the hydrology of the Memphis area by Criner, Sun, and Nyman (1963) discussed some of the effects of municipal and industrial pumping on the aquifers in Shelby County.

ACKNOWLEDGMENTS

The author is grateful to those who aided in the collection of data for this study. Citizens, city officials, well drillers, and representatives of industries throughout the report area cooperated in supplying information on wells and made wells available for water-level observations, electric and gamma-ray logging, pumping tests, and the collection of water samples for chemical analysis.

In particular, the author wishes to thank the Layne-Central Co. and the Watson Co. of Memphis for supplying data on wells from their files.

Much of the data on the Memphis area was obtained from groundwater studies made in cooperation with the Light, Gas, and Water Division of the city of Memphis.

GEOGRAPHY

SURFACE FEATURES

The area underlain by the Claiborne Group in Tennessee is entirely within the east flank of the upper Mississippi embayment region of the Gulf Coastal Plain (Fenneman, 1938, p. 84) and includes part of the Plateau Slope (Safford, 1869, p. 110) and the Mississippi Alluvial Plain (Fenneman, 1938, p. 83). The land surface forms a broad plateau that slopes southwestward and ends abruptly at the Chickasaw bluffs (Safford, 1869, p. 110), which overlook the flood plain of the Mississippi River. From a high of about 700 feet above sea level along the Tennessee-Mississippi drainage divide east of the report area, the plateau descends toward the Mississippi River to an altitude along the crest of the Chickasaw bluffs of 390 feet in the northwest and 300 feet in the southwest. The plateau is partly dissected and consists of broad stream valleys and rolling uplands. Other common surface features of the plateau are hills produced by erosion.

The Mississippi Alluvial Plain lies at the foot of the Chickasaw bluffs and consists of a low, flat area that is about 10 miles wide in the northwestern part of the report area and gradually narrows toward the southwest corner of the area. It finally disappears where the Mississippi River impinges on the Chickasaw bluffs a short distance north of Memphis.

DRAINAGE

The report area is drained by six major streams, which have low gradients and flow into the Mississippi River. From north to south, these streams are the Obion, Forked Deer, Hatchie, Loosahatchie, and Wolf Rivers and Nonconnah Creek. Except for Nonconnah Creek, all these streams are perennial. The longest stream is the Hatchie River, which is 120 miles long. Although the Obion River flows southwestward, the other five streams flow west-northwestward to within a few miles of the Mississippi River, where their channels swing to the southwest.

The major part of the low flows of these streams is maintained by discharge from the aquifers of the Claiborne Group.

PRECIPITATION

Records of the U.S. Weather Bureau show that the average annual precipitation in western Tennessee is 50.42 inches. This amount provides excess recharge to the aquifers and thus insures the perennial flow of most rivers and creeks. Moreover, about 58 percent of the precipitation falls between November of one year and April of the following year, which is the period of active recharge to the ground-water aquifers. The wettest month is January, having an average rainfall of 5.96 inches; and the driest is October, having an average of 2.85 inches. The annual snowfall is generally 4–6 inches. Droughts lasting 15–30 days are not uncommon in late summer and fall, and heavy downpours of 3–3.5 inches of rain in 24 hours occur on an average of once each year (Hershfield, 1961, chart 43). The average monthly precipitation in western Tennessee is shown in the following table.

Average monthly precipitation, in inches, in western Tennessee

Month	Precipitation	Month	Precipitation
January	5.96	July	4.04
February	4.65	August	3.05
March	5.28	September	3.30
April	4.42	October	2.85
May	4.16	November	4.27
June	3.96	December	4.47

GEOLOGY OF THE CLAIBORNE GROUP

NAME AND DEFINITION

The name Claiborne Group was applied by Conrad (1856, p. 257–258) to beds constituting the "Lower or older Eocene" and underlying the Jackson Group in the vicinity of Vicksburg, Miss. For many years the lower boundary of the Claiborne Group was in dispute. As used in Tennessee and in this report, the Claiborne Group overlies the Wilcox Group, underlies the Jackson(?) Formation, and is middle Eocene in age.

SUBDIVISION

Prior to this investigation, divisions of the Claiborne Group were not determined in Tennessee, and the group was not correlated with formations in adjacent parts of Mississippi and Arkansas. Study of 33 geophysical logs and 25 lithologic logs shows that the Claiborne can be partly subdivided on a tentative basis and that the geologic units can be correlated with equivalent units in adjacent areas (pl. 1). As considered in this report, the Claiborne Group in Tennessee consists of five units, which include, in ascending order, the Meridian Sand Member of the Tallahatta Formation (Brown, 1947, pl. 4), the Basic City Shale Member of the Tallahatta Formation (Brown, 1947, pl. 4), the Sparta Sand, an "unnamed clay unit," and an "unnamed sand unit." The character and stratigraphy of these units, as shown on electrical and gamma-ray logs, are shown on plate 1. The older units thicken toward the south and west and are thickest in southwestern Shelby County near the axis of the Mississippi embayment (pl. 1). The unnamed clay and sand units, however, are thickest in southeastern Lake County, but they decrease in thickness in all directions from this locale. The faults shown on plate 1 were determined from the structure-contour maps (pls. 3, 4).

A comparison of the stratigraphic section used in some previous reports with that used in this report is shown in table 1. The geologic and hydrologic properties of the various formations are summarized in table 2.

The Meridian Sand Member of the Tallahatta Formation is the basal unit in the Claiborne Group of Tennessee. This unit is equivalent to the Meridian Sand Member of the Tallahatta Formation of Mississippi as shown by Brown (1947, pl. 4) and correlates with the Carrizo Sand (Hosman, 1962, p. 389) of Arkansas. Like the Carrizo Sand of Arkansas, the sand facies of the Meridian in Tennessee is distinctively micaceous.

The Basic City Shale Member of the Tallahatta Formation (Brown, 1947, pl. 4) is probably equivalent to the Cane River Formation of Arkansas.

In 1947 Brown (1947, p. 37 and pl. 4) described the Tallahatta Formation as consisting of the Meridian Sand Member and the Basic City Shale Member and as underlying the Kosciusko Sand (of former usage) in the northernmost part of Mississippi. In the present report, the contact between the Basic City Shale Member and the Sparta Sand (pl. 1) is considered to be about 120 feet higher in the section than the equivalent contact between the Tallahatta Formation and the Kosciusko Sand shown by Brown (1947, pl. 4). This revision of Brown's section is based on the author's interpretation of the electric logs of several wells that have been drilled in northern Mississippi since Brown published his findings.

The upper contact of the Sparta Sand in western Tennessee (pl. 1) correlates with the upper contact of the Kosciusko Sand in Mississippi, as shown by Brown (1947, pl. 4). In Tennessee the Sparta Sand underlies two unnamed units.

A clay unit directly overlies the Sparta and is overlain in turn by a unit composed predominantly of sand. These units may be equivalent to the Cook Mountain and Cockfield Formations of Mississippi and Arkansas, but no definite correlation can be made at this time. As the stratigraphy of these unnamed units resembles that of the underlying formations of the Claiborne Group, the unnamed units are considered to be part of the Claiborne Group for the purposes of this report. The unnamed sand unit, for example, is a continuous body of sand in nearly all the report area; whereas sand lenses in the overlying Jackson(?) Formation are thin and discontinuous, even over short distances.

TABLE 1.—*Geologic column for the Eocene of western Tennessee*

<table>
<tr><th colspan="2">Wells (1933)</th><th colspan="2">Stearns and Armstrong (1955)</th><th>Cushing, Boswell, and Hosman (1964)</th><th colspan="3">This report</th></tr>
<tr><td colspan="2" rowspan="3">Jackson formation</td><td rowspan="6">Jackson and Claiborne groups</td><td rowspan="3"></td><td>Jackson(?) Formation</td><td colspan="3">Jackson(?) Formation</td></tr>
<tr><td rowspan="5">Claiborne Group, undifferentiated</td><td colspan="2">Unnamed sand unit</td><td rowspan="5">Claiborne Group</td></tr>
<tr><td colspan="2">Unnamed clay unit</td></tr>
<tr><td rowspan="4">Wilcox group</td><td rowspan="2">Grenada formation [1]
— — — ? — — —</td><td rowspan="3">? “500-foot” sand</td><td>Sparta Sand</td><td rowspan="3">“500-foot” sand</td></tr>
<tr><td>Basic City Shale Member of the Tallahatta Formation</td></tr>
<tr><td>Holly Springs sand</td><td>Meridian Sand Member of the Tallahatta Formation</td></tr>
<tr><td>Ackerman formation [1]</td><td colspan="2">Wilcox group</td><td>Wilcox Group, undifferentiated</td><td colspan="3">Wilcox Group, undifferentiated</td></tr>
</table>

[1] Term no longer used by the U.S. Geol. Survey.

TABLE 2.—*Generalized geologic section of the Eocene formations of western Tennessee and their water-bearing characteristics*

System	Series	Group	Formation	Thickness (feet)	Lithologic character	Water-bearing properties
Tertiary	Eocene	Jackson	Jackson(?) Formation	0–400	Predominantly a gray or greenish-gray clay. A few layers of fine-grained gray sand. Partly lignitic.	Generally impervious. Sand layers yield small quantities of water to a few domestic wells.
		Claiborne	Unnamed sand unit.	0–210	White to gray or brown fine-grained lignitic sand and interbedded clays.	Yields as much as 400 gpm to municipal wells. Downdip the water contains sufficient iron to require aeration for most uses.
			Unnamed clay unit.	25–150	White to red or tan partly lignitic clay.	Does not yield water to wells.
			Sparta Sand (Kosciusko Sand).	100–260	Massive lignitic argillaceous sands and a few interbedded clay layers.	A prolific aquifer—the “500-foot” sand. Yields as much as 2,000 gpm to municipal and industrial wells. Downdip, the water contains sufficient iron to require aeration for most uses.
			Basic City Shale Member of the Tallahatta Formation.	50–295	Beds of white to gray lignitic sand and typically micaceous clay.	
			Meridian Sand Member of the Tallahatta Formation.	85–195	Beds of typically micaceous lignitic sand and a few interbedded clay layers.	
		Wilcox		0–700	Massive beds of gray to tan micaceous clay and sand and a few beds of lignitic clay.	The clay beds do not yield water to wells. Contains a major aquifer—the “1400-foot” sand of the Memphis area.

LOWER PART OF THE CLAIBORNE GROUP ("500-FOOT" SAND)

For some time the term "500-foot sand" (Klaer, 1940, p. 92) has been used to designate the principal aquifer from which Memphis obtained its water supply. The base of this unit was defined and correlated with the base of the Claiborne Group by Stearns and Armstrong (1955, p. 4). The top of the "500-foot" sand has never been defined geologically but has been considered to be the hydrologic top of the aquifer in the Memphis area. For the purposes of this report, the top of the "500-foot" sand is correlated with the top of the Sparta Sand. As such, the "500-foot" sand includes two formations (table 1) but constitutes a single areally extensive aquifer that ranges in thickness from 750 feet in southwestern Shelby County to 200 feet in northeastern Weakley County.

The outcrop area of the "500-foot" sand in western Tennessee is a broad belt extending northeastward across the State (pl. 4). The east boundary of this belt corresponds with the east edge of the report area. The west edge of the belt extends from the northeast corner of Weakley County to the southeast corner of Shelby County and is marked by the intersection of the top of the Sparta Sand with the land surface. The area of outcrop covers about 2,100 square miles. The upper and lower contacts of the "500-foot" sand were projected from the subsurface by means of the structure-contour lines on plates 3 and 4.

Sand composes most of all three units in the "500-foot" sand. Beds of white to blue, pink, gray, or brown clay constitute only a small percentage of the total thickness. In the subsurface, the sand is thick bedded, white to brown or gray, very fine grained to gravelly, and partly argillaceous, micaceous, and lignitic. The sand grains range from clear to white and from well rounded to subangular. Mechanical analyses of samples from the Memphis area indicate that the grain size varies both vertically and laterally but that the sands are generally well sorted. As much as 85–95 percent of the drill samples obtained from 5- to 10-foot intervals in the "500-foot" sand is retained on adjacent sieves (Criner and Armstrong, 1958, p. 8). The thin indurated "rock" layers penetrated in many places by drilling are probably iron-cemented sandstones. The "500-foot" sand lacks marine fossils but contains an abundant flora, which was described by Berry (1916). In 1916, however, the Claiborne Group was thought to be absent in Tennessee, and both Claiborne and Wilcox floras are listed by Berry as being Wilcox in age.

The relations between the various lithologies in the "500-foot" sand as well as the changes in thickness are shown by means of a fence diagram and isopach map (pl. 2). Wells on the fence diagram were projected at right angles into the lines of section. The location of the faults shown was determined on the structure-contour maps (pls. 3, 4). Control points for the isopach map were established by overlaying the structure-contour maps of the top and of the bottom of the "500-foot" sand.

UPPER PART OF THE CLAIBORNE GROUP

The upper part of the Claiborne Group is divided in this report into the unnamed clay and unnamed sand units. The outcrop areas of the unnamed clay and unnamed sand have not been determined, but both units probably crop out in narrow belts west of and adjacent to the outcrop area of the "500-foot" sand. These belts should be broadest near the Tennessee-Kentucky line and should diminish in width progressively southward owing to a gradual decrease in the thickness of both units.

UNNAMED CLAY UNIT

The unnamed clay unit overlies the Sparta Sand (pl. 1) and consists predominantly of white to red or tan partly lignitic clay. In the southern and eastern parts of the report area, the unit is partly silty and sandy. Siderite concretions and kaolin were reported from this interval in one well. The unnamed clay unit averages about 80 feet in thickness, but it ranges in thickness from 110 feet in southeast Lake County to 25 feet in the southernmost part of the report area.

The unnamed clay unit is overlain by the unnamed sand unit. The contact is generally well defined in the subsurface. Where the Jackson(?) Formation and the unnamed sand unit have been eroded, as in the southernmost part of the report area (pl. 1), the unnamed clay unit is overlain by terrace deposits.

UNNAMED SAND UNIT

The unnamed sand unit comprises the youngest beds in the Claiborne Group. It is an aquifer in the area of study because it consists mainly of permeable white to gray or brown fine-grained argillaceous lignitic sand. In Lake County and western Dyer County, the unit is clayey but contains a fairly persistent basal sand. The unnamed sand unit has an average thickness in the report area of 100 feet and a maximum thickness of 210 feet in southeastern Lake County. It is completely overlapped by terrace deposits in the southernmost part of the report area.

In the rest of the area, the unnamed sand is overlain by the Jackson(?) Formation, the lower part of which is predominantly clay.

STRUCTURE

The report area lies on the east flank of the syncline that forms the upper Mississippi embayment. Structurally the embayment is a downwarped, partly downfaulted, trough in Paleozoic rocks. The axis of the embayment has migrated in past geologic time but now approximates the course of the Mississippi River (pls. 3, 4). Subsidence and deposition near the present embayment axis began in Late Cretaceous time but were most active during Eocene time (Stearns and Armstrong, 1955, p. 8). A slight shift in the Mississippi-embayment axis occurred during deposition of the "500-foot" sand; evidence for this shift can be seen by comparing the location of the axis shown on the structure-contour map on the base of the "500-foot" sand (pl. 3) with the location of the axis shown on the structure-contour map on the top of the "500-foot" sand (pl. 4). The approximate depth to either contact at any particular site can be computed by finding the difference between the altitude of the land surface at the site and the altitude of the contact as shown on the maps (pls. 3, 4).

The strike of the "500-foot" sand is northeast except in the northern part of the report area, near the Mississippi-embayment axis. The unit dips to the northwest on the east side of the embayment axis and to the southeast on the west side of the axis. The base of the "500-foot" sand dips approximately 25 feet per mile, whereas the top of the "500-foot" sand dips only 19 feet per mile. The difference in the rates of dip indicates a westward thickening of the unit, which was probably caused by regional subsidence concurrent with deposition.

The top of the unnamed sand unit strikes northeast and dips northwest at approximately 10 feet per mile. The base of this unit ranges in altitude from about 500 feet above to 300 feet below mean sea level. Data were inadequate to construct structure-contour maps of the top and bottom of the unnamed sand unit.

Two faults are indicated within the report area by the structure-contour maps of the top and bottom of the "500-foot" sand (pls. 3, 4). The largest of the two faults trends northwest from the northwest corner of Dyer County across southeastern Lake County and northwestern Obion County and into Kentucky. The average displacement along this fault is 100–150 feet. Some preliminary movement along the fault plane during deposition of the "500-foot" sand seems to be indicated by the relatively thick section of the unit on the east side of the fault (pl. 2). At some time after deposition, however, further movement along the fault tilted the eastern block to the south and produced the structure indicated on the contour

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maps. The New Madrid earthquake of 1811–12, which created Reelfoot Lake in Lake County (Fuller, 1912, p. 75), may have been caused by recent movement along this fault. The second major fault in the report area trends west-northwest from west-central Crockett County to north-central Lauderdale County. The average displacement is 60 feet.

The structure in southern Shelby County (pls. 3, 4) suggests the possible presence of minor faults in this area. No faults are shown on the maps, however, as their existence is uncertain.

SUMMARY OF GEOLOGIC HISTORY

The presence of lignite and varicolored clays in the Claiborne Group indicates continental or brackish-water deposition. Although the Wilcox clays underlying the Claiborne Group are also nonmarine, the Claiborne overlaps these sediments in the outcrop area. Hence, the contact may represent a major stratigraphic unconformity (Stearns, 1957, p. 1092). Minor oscillations of sea level (and the resulting stream grading) probably accounted for the four major lithologic breaks that have been used to subdivide the Claiborne Group. Differential subsidence of the embayment area during deposition probably accounts for variations in formation thickness. Because the lithology of the Claiborne Group changes to that of a shallow-water marine facies in De Soto and northern Tunica Counties, Miss., the shoreline during Claiborne time was probably approximately along the present Tennessee-Mississippi line. This position of the shoreline is partly confirmed by the presence of heavy minerals (commonly indicative of seashores) in the Sparta Sand and Basic City Shale Member in Shelby County.

At some time after deposition of the Jackson(?) Formation and before deposition of the terrace deposits, the Jackson(?) Formation and the unnamed sand unit were removed by erosion in the southernmost part of the report area (pl. 1).

GROUND-WATER RESOURCES OF THE CLAIBORNE GROUP

SOURCE OF GROUND WATER

Ground water is the water beneath the land surface that issues, or may be pumped, from wells or springs. The primary source of ground water is precipitation. Nearly all the water that falls as precipitation runs off as streamflow, evaporates from wetted surfaces, is transpired by plants, or is held in the soil by molecular forces, which counteract the downward force of gravity. Nonetheless, some of the water that falls as precipitation seeps through the soil zone until it reaches the water table and then enters the zone of saturation, a zone beneath the land surface in which all openings are filled with water.

OCCURRENCE AND MOVEMENT OF GROUND WATER

Ground water occurs in the zone of saturation under water-table (unconfined) conditions and under artesian (confined) conditions. Water-table conditions exist where the upper surface of an aquifer is exposed to atmospheric pressure. The water level in a well that taps a water-table aquifer coincides with the upper surface of the zone of saturation. Artesian conditions exist where water in an aquifer is confined under pressure greater than atmospheric pressure between relatively impermeable beds. The pressure in an artesian aquifer causes the water level in a well that taps the aquifer to rise above the base of the upper confining bed.

In the outcrop area of the Claiborne Group, ground water occurs partly under water-table conditions and partly under artesian conditions owing to the presence of impermeable beds or other fine-grained material below, within, and above the aquifers. Elsewhere in the report area, artesian conditions exist in the Claiborne aquifers.

Ground water in the Claiborne Group moves slowly (probably not more than a few feet per day) from areas of recharge to areas of discharge. The rate of movement is controlled by the permeability and hydraulic gradient of the aquifer through which the water moves. In a water-table aquifer the hydraulic gradient is determined by the slope of the water table, but in an artesian aquifer the gradient is determined by the slope of the "piezometric surface," a term used to denote the surface to which the water from a given aquifer will rise under its full head.

The water table or piezometric surface of an aquifer slopes downward from areas of ground-water recharge or inflow to areas of ground-water discharge or outflow. Irregularities in the shape and slope of the surface, however, result from influences such as topography, lithology and structure of the aquifer, areas and rates of ground-water withdrawal, and areas of surface-water impoundment. The contour lines for the piezometric surface of the "500-foot" sand and the unnamed sand unit (pls. 5, 6) were constructed from water-level measurements made on January 27–29, 1960. As the direction of ground-water movement is from areas of high hydraulic head to areas of low head, movement is generally at right angles to the contour lines of the piezometric surface. The water moves relatively slowly where the surface slopes gently and faster where the slope is steeper, if the permeability of the aquifers is constant or nearly constant.

As shown by plates 5 and 6, ground water in the "500-foot" sand and the unnamed sand unit generally flows west-northwestward or northwestward until it approaches the axis of the Mississippi embayment. Along the embayment axis, water flows south-southwestward or southwestward and leaves the report area as underflow.

In the outcrop area of the "500-foot" sand, the water-level contour lines curve to the east or southeast and approximately parallel the major streams. In these areas, ground water is discharging into the surface streams.

The depression of the piezometric surface of the "500-foot" sand in Shelby County (pl. 5) is caused by pumping, which is centered in the northwest corner of Memphis. The area influenced by this pumping is delineated by the dotted line (pl. 5) just north of Shelby and Fayette Counties. Ground water south of this line is susceptible to capture by pumping in the Memphis area.

The configuration of the piezometric surface of the unnamed sand unit, as shown by the contour lines on plate 6, indicates that part of the ground water in this aquifer is discharged in northern Shelby County.

On the basis of the contour of the piezometric surface, the areas where flowing wells could be completed in the "500-foot" sand and the unnamed sand unit are considered to be where shown in plates 5 and 6, respectively. These areas are confined in general to the flood plains of streams and to the Mississippi Alluvial Plain. At present, very few flowing wells are completed in the Claiborne aquifers because (1) most of the areas of potential flow are subject to periodic flooding by streams and (2) shallower aquifers yield water suitable for domestic, stock, and irrigation use.

SIGNIFICANT WATER-LEVEL FLUCTUATIONS

Neither the water table nor the piezometric surfaces of the artesian aquifers in the report area are stationary; they fluctuate in response to many different factors such as precipitation, pumping of wells, changes in barometric pressure, earth tides, earthquakes, and loading of the land surface. These factors vary in magnitude and time and produce an irregular and sometimes complicated record of water levels. The only fluctuations that are considered in this report, however, are those due to precipitation and pumping because these factors have the largest and longest lasting effects upon water levels.

In areas not affected by pumping, water levels in the Claiborne aquifers generally fluctuate less than 2 feet between yearly highs and lows. These changes are caused mainly by variations in the amount of precipitation. The seasonal fluctuations in a few wells in and near the outcrop belt of the Claiborne Group and near surface streams, however, have a considerably greater amplitude.

Hydrographs (water-level records) of selected wells tapping the aquifers in the Claiborne Group are shown in figures 2 and 3. The location of these wells is shown in figure 4. The hydrograph for well Fa:W-2 (fig. 3) shows that water levels generally declined from 1951–57, rose slightly in 1958, declined slightly from 1959–61, and rose again in the early part of 1962. These fluctuations are probably a direct result of above or below average precipitation during the 6-month period of recharge ending in April of each

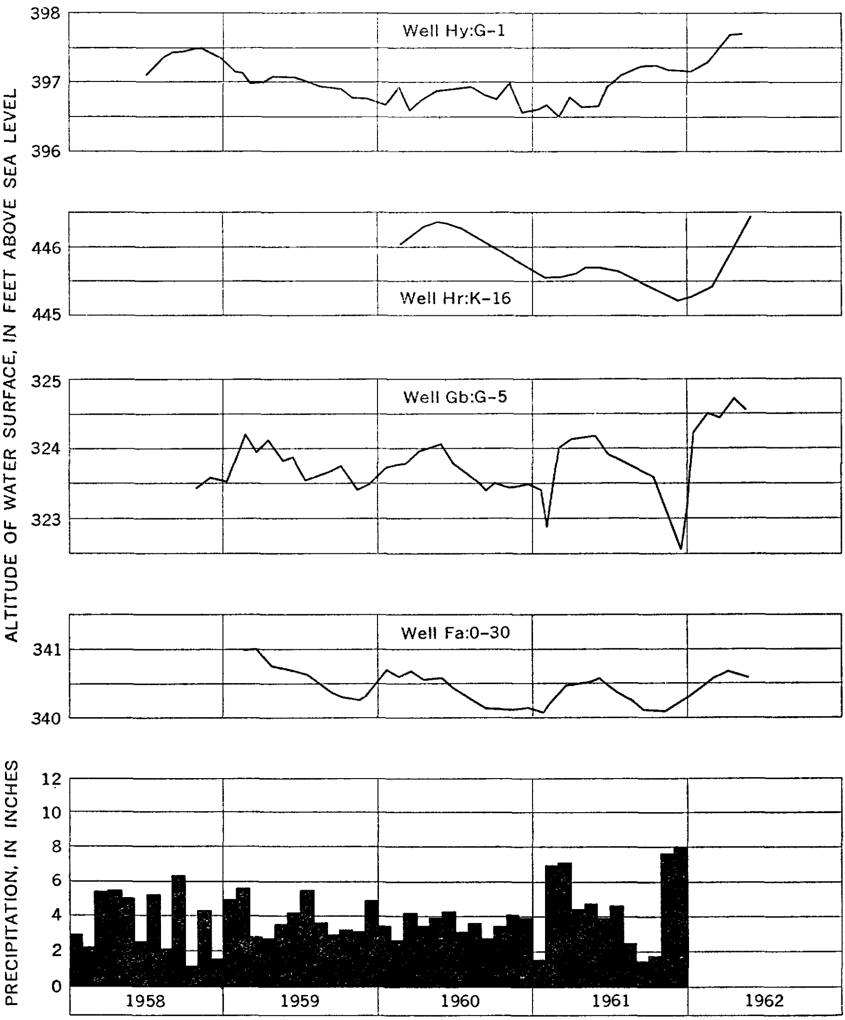

FIGURE 2.—Relationship between water levels in wells completed in the "500-foot" sand and average precipitation in western Tennessee.

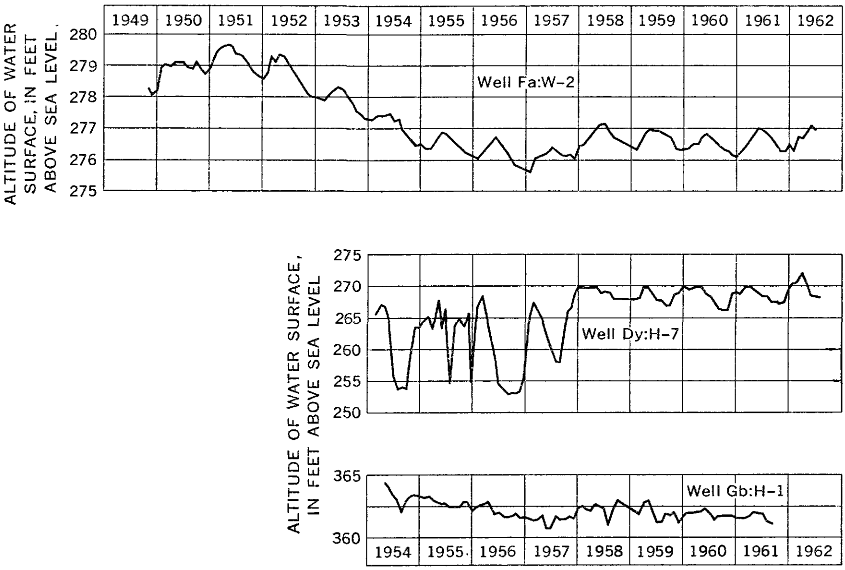

FIGURE 3.—Fluctuation of water levels in wells completed in the "500-foot" sand.

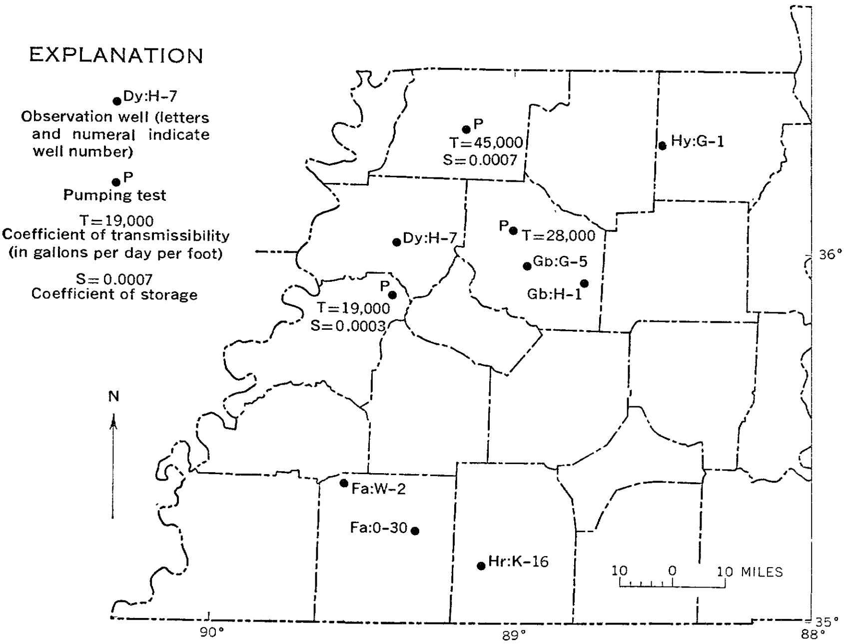

FIGURE 4.—Selected observation wells, pumping-test sites, and coefficients of transmissibility and storage in the unnamed sand unit.

year. Several years of above average precipitation during the seasonal recharge period might raise water levels to near the 1951 levels.

All four wells indicated in figure 2 and well Fa: W–2, in figure 3, are completed in the "500-foot" sand. The total seasonal fluctuation of water levels in these wells ranges from 0.5 to 2.2 feet. Wells Hr: K–16, Fa: O–30, and Hy: G–1 tap the sand in its outcrop area, whereas wells Fa: W–2 and Gb: G–5 tap the sand in the subsurface, farther downdip.

Wells Dy: H–7 and Gb: H–1 (fig. 3) are completed in the "500-foot" sand near centers of municipal-pumping areas at Dyersburg and Milan, respectively. The effect of pumping on water levels in nearby wells depends on several factors, including the amount of pumpage, the permeability and storage characteristics of the aquifer, and the distance of the observation well from the center of pumping. The seasonal fluctuations of water level caused by precipitation are partly obscured in the hydrographs for wells Dy: H–7 and Gb: H–1 (fig. 3) by larger fluctuations caused by variations in the rate of pumping. In the period 1954–57, daily pumpage at Dyersburg ranged between 1.5 and 7 mgd (million gallons per day), and the maximum seasonal fluctuation in water level in well Dy: H–7 during this period was 14.5 feet. In the interval 1958–61, daily pumpage ranged between 1 and 2.5 mgd, and the maximum seasonal fluctuation was 4.6 feet.

AQUIFER LIMITS

"500-FOOT" SAND

The "500-foot" sand is present over about 7,200 square miles in western Tennessee and averages about 450 feet in thickness. The volume of this aquifer is about 600 cubic miles. If the average porosity is 25 percent of its volume, the "500-foot" sand contains 150 cubic miles, or 170 trillion gallons, of water in storage.

The altitudes of the bottom and top of the "500-foot" sand are shown on plates 3 and 4, respectively. The approximate depth to either contact can be calculated from these maps by finding the difference between the contact altitude and the land-surface altitude at any desired point.

Clay layers locally separate the "500-foot" sand into several aquifers. Layers 20 feet thick or more are generally extensive enough laterally to effect an initial hydrologic separation over the area occupied by the average well field. The clay in the basal part of the Basic City Shale Member of the Tallahatta Formation is found throughout the western part of the report area, but few of the other clays have more than local distribution.

UNNAMED SAND UNIT

In western Tennessee the unnamed sand unit is distributed over about 6,500 square miles and averages about 100 feet thick. If the porosity is 25 percent of its volume, the aquifer contains 31 cubic miles, or 34 trillion gallons, of water in storage.

In Lake and western Dyer Counties the unnamed sand unit probably yields only enough water for domestic supplies, but elsewhere it is generally sufficiently thick to yield enough water for small municipal and industrial supplies. The aquifer occurs at a depth of 350 feet or less nearly everywhere that it is present in the subsurface.

At Union City, layers of clay separate the unnamed sand into two aquifers. Elsewhere the effect of interbedded clays upon the hydrology of the unit is unknown.

AQUIFER HYDRAULICS

HYDRAULIC PRINCIPLES

Under natural conditions, the water level in a well corresponds to the water table or piezometric surface of the aquifer. When the well is pumped, the water level in the well drops, a hydraulic gradient toward the well is produced, and a depression is created in the water table or piezometric surface. This depression is nearly in the form of an inverted cone having its apex at the well. The greater the rate of pumping from the well, the greater is the depth of the cone of depression. As pumping continues, the water level in the well continues to decline and the depth of the cone of depression increases, but at a continually decreasing rate, until the cone captures or diverts enough water to balance the discharge from the well. When this balance occurs, the water level in the pumping well ceases to decline and equilibrium conditions exist. If equilibrium conditions are not reached after several days or weeks of pumping, the water level in the well generally reaches a state of virtual equilibrium, wherein additional decline in the water level is insignificant except over long periods of time.

The quantity of water that the Claiborne aquifers will yield to wells over a long period of time depends principally upon the dimensions, permeability, and storage capacity of the aquifers. The dimensions of the aquifers have been determined by geologic studies. The last two properties constitute the hydraulic function of the aquifers and are determinable by aquifer tests. Once determined, the values of these hydraulic properties can be used to predict the effects of pumping and the theoretical yield of wells.

The permeability of an aquifer determines its capacity to transmit water. This function is generally expressed as the coefficient of transmissibility, which is defined as the number of gallons of water per day (gpd) that flows through a strip of the aquifer 1 foot wide, measured at right angles to the direction of flow, under a hydraulic gradient of 1 foot per foot. It is expressed in dimensions of gallons per day per foot (gpd per ft). The field coefficient of permeability is defined as the flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at the prevailing temperature in the aquifer; it is expressed in dimensions of gallons per day per square foot (gpd per sq ft). Hence, the field coefficient of permeability can be calculated for a given aquifer by dividing the coefficient of transmissibility of the aquifer by the saturated thickness of the aquifer.

The storage capacity of an aquifer is computed and expressed as the coefficient of storage. This unit is the volume of water that the aquifer releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. It has no dimensions, because it is a ratio. The coefficient of storage is commonly 0.1–0.3 for a water-table aquifer, compared with 0.001 or less for an artesian aquifer; the difference is due to the fact that water-table and artesian aquifers differ in the relative amounts of water released or taken into storage with changes in water level. For example, as the water table is depressed near a pumping well, a relatively large quantity of water is drained from the water-bearing material through which the water table falls. In an artesian aquifer, however, the interstices remain filled, and only a small amount of water is released from storage as the hydrostatic pressure declines; this apparent accretion of water from storage is mainly a result of elastic compaction of the aquifer and the confining beds. The practical effect of the difference between the storage capacities of water table and artesian aquifers is that pumping at a given rate from an artesian aquifer lowers the water level faster than does pumping at the same rate from an equivalent aquifer under water-table conditions.

When aquifer tests are made to determine the hydraulic properties of aquifers, the rate of withdrawal of water from the pumped well is controlled and measured carefully, and the effects of pumping on the water level are measured in one or more observation wells that are screened in the same aquifer. The coefficients of transmissibility and storage can then by computed by analyzing the pumping-test data in the manner described by Wenzel (1942), Brown (1953), or Walton (1962).

"500-FOOT" SAND

During the hydrologic investigation of the "500-foot" sand, 11 aquifer tests lasting from less than 1 hour to as much as 16 hours were conducted at towns outside the Memphis area. The coefficients

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of transmissibility and storage were obtained from semilog plots of drawdown or of recovery of water levels in the manner described by Brown (1953, p. 858).

The results of the aquifer tests were evaluated by comparing them with the results from much longer tests in the Memphis area, where pumping tests that lasted 2–17 days were made at five well fields. In addition, 10 other tests lasting 2–48 hours were made in the Memphis area. The coefficients of transmissibility computed from all the Memphis-area tests ranged from 50,000 to 400,000 gpd per ft, although most values were between 150,000 and 320,000 gpd per ft. For the same group of tests the coefficients of storage ranged from 0.0001 to 0.003. In comparison, the coefficients of transmissibility determined from the short pumping tests that were made outside the Memphis area ranged from 20,000 to 220,000 gpd per ft, and the coefficients of storage ranged from 0.0001 to 0.0006. The results of the short pumping tests are very consistent with those obtained from much longer tests in Memphis, considering that the "500-foot" sand is thickest in the Memphis area.

All wells tested were partially penetrating and most were screened near the top of the "500-foot" sand aquifer. Nearly all the values of transmissibility and storage, therefore, indicate the hydraulic character of only the upper part of the aquifer. The coefficient of transmissibility of 400,000 gpd per ft is probably representative, however, of the entire thickness (700 ft) of the "500-foot" sand in the Memphis area. The field coefficient of permeability is therefore 570 gpd per sq ft. Lines of theoretically equal transmissibility in the "500-foot" sand throughout the report area (pl. 7) are based on this value and on the known range in aquifer thickness. Plate 7 also shows the range in transmissibility as computed from pumping tests that were made in the wells that partly penetrate the "500-foot" aquifer. Wells constructed similarly to those used for the pumping tests and located in an area in which the aquifer has the same transmissibility would probably yield about the same amount of water.

Both apparent and potential coefficients of transmissibility are highest in Shelby County, where the aquifer is thickest, and decrease in value to the northeast (pl. 7). Transmissibilities of at least 50,000 gpd per ft are indicated for the "500-foot" sand nearly everywhere in the report area.

Transmissibility values can be used to estimate the relative yield of a well in terms of its specific capacity, which is defined as the number of gallons per minute a well will yield for each foot of drawdown of the water level. The specific capacity of a well depends primarily on the hydraulic characteristics of the aquifer, the period of pumping, and the construction and degree of development

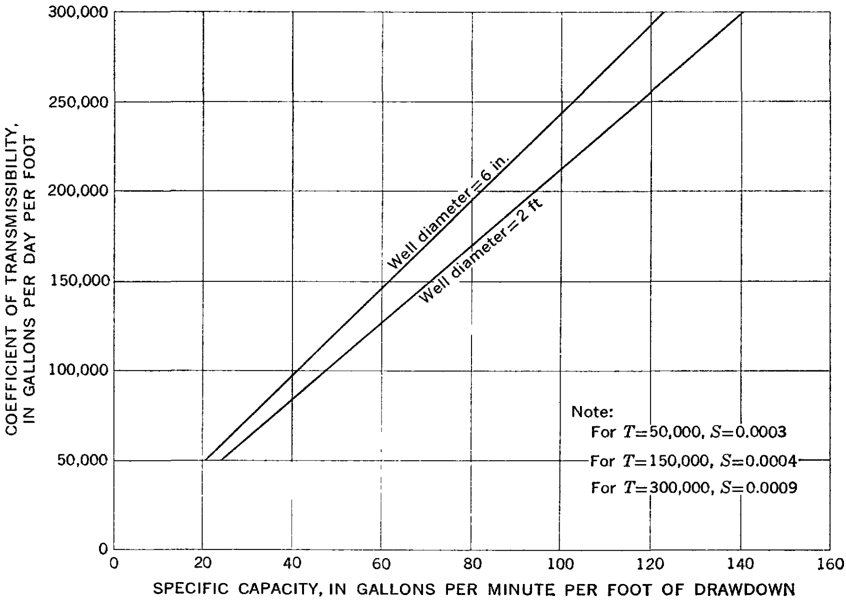


FIGURE 5.—Relationship of specific capacity of wells after 1 day of pumping to the transmissibility of the "500-foot" sand.

of the well. The maximum specific capacities that can be obtained for the range of transmissibilities in the "500-foot" sand are shown in figure 5. Wells having diameters between 6 inches and 2 feet would have theoretical specific capacities that plot between the two curves. In practice, the specific capacity of most wells ranges from 60 to 80 percent of the values indicated in figure 5, because the well only partly penetrates the aquifer and because of well and screen loss. The coefficients of storage used in computing the curves in figure 5 are average values.

Another significant use of the coefficients of transmissibility and storage is the determination of the effects of pumping at specified rates of discharge upon water levels at various times and at various distances from the pumped wells (the amount of interference). Drawdowns of water level were computed and plotted to show theoretical time and distance-drawdown relationships. The theoretical drawdown that would result at given times and distances in an aquifer having the range in coefficients of transmissibility and storage determined for the "500-foot" sand is shown in figure 6. As the water-level drawdown in the aquifer is directly related to the discharge, pumping rates of 1000, 1500, or 2,000 gpm (gallons per minute) would result in drawdown of two, three, and four times, respectively, those shown in figure 6 at the same time and distance and for the same values of transmissibility and storage. The coeffi-

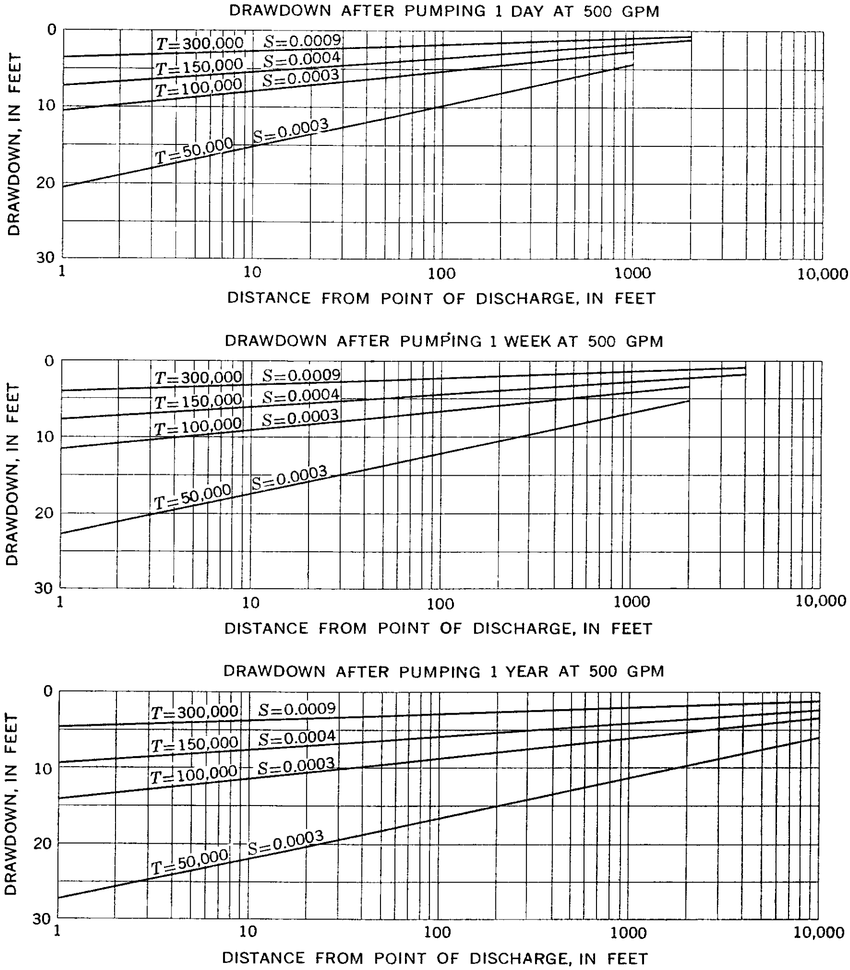


FIGURE 6.—Theoretical drawdowns at given times and distances in an ideal aquifer having the range in transmissibility and storage determined for the "500-foot" sand.

cients of storage used in computing the curves in figure 6 are average values.

UNNAMED SAND UNIT

Three aquifer tests were made using wells screened in the unnamed sand unit to determine the hydraulic characteristics of this aquifer. The location of the wells and the calculated coefficients of transmissibility and storage are shown in figure 4. The maximum transmissibility was determined to be 45,000 gpd per ft at Troy. Whether this value represents the transmissibility for the entire 170-foot thickness of the aquifer at Troy or indicates local anomalous conditions is not known. The unnamed sand unit is finer grained than the "500-foot" sand, however, and the foregoing value is reasonable for the entire thickness. If so, the average field coefficient of permeability for the unnamed sand aquifer is about 265 gpd per sq ft. In general, the results of pumping tests in the unnamed sand suggest higher transmissibilities in the northern and eastern parts of the area underlain by this unit.

The maximum specific capacities that can be determined for the known range in transmissibilities in the unnamed sand aquifer are shown in figure 7. In practice, most wells have specific capacities 20–40 percent less than these values, the difference depending on the design and the degree of development of individual wells.

The theoretical drawdown that would result at given times and distances for the range in coefficients of transmissibility and storage determined for the unnamed sand unit is shown in figure 8. Other conditions remaining the same, pumping rates of 200, 300, or 400 gpm would result in drawdowns of water levels two, three, and four times those shown in figure 8.

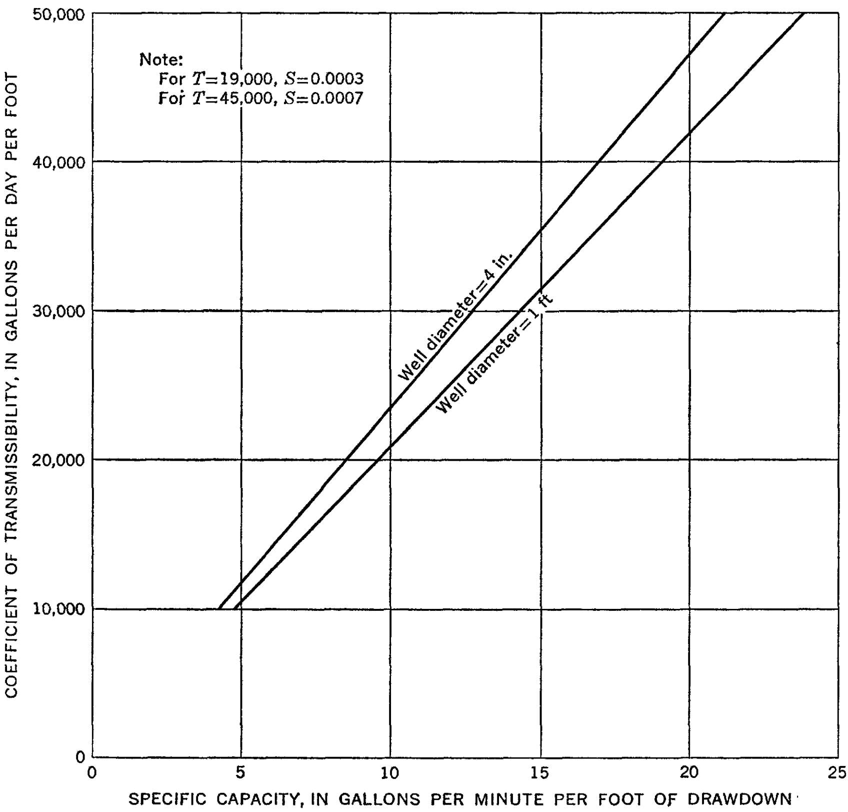
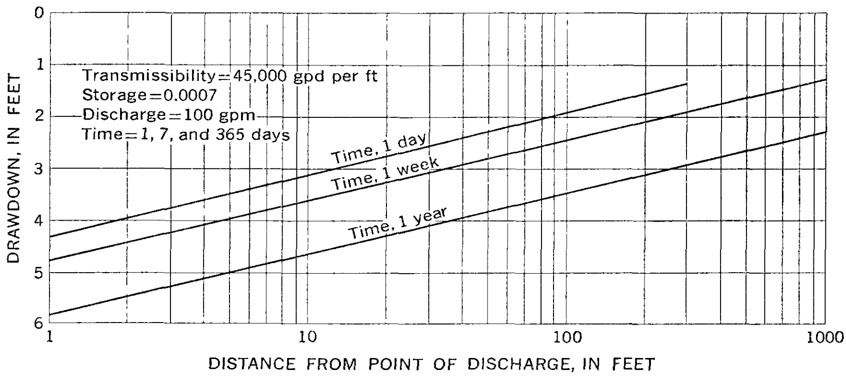


FIGURE 7.—Relationship of specific capacity of wells after 1 day of pumping to the transmissibility of the unnamed sand unit.



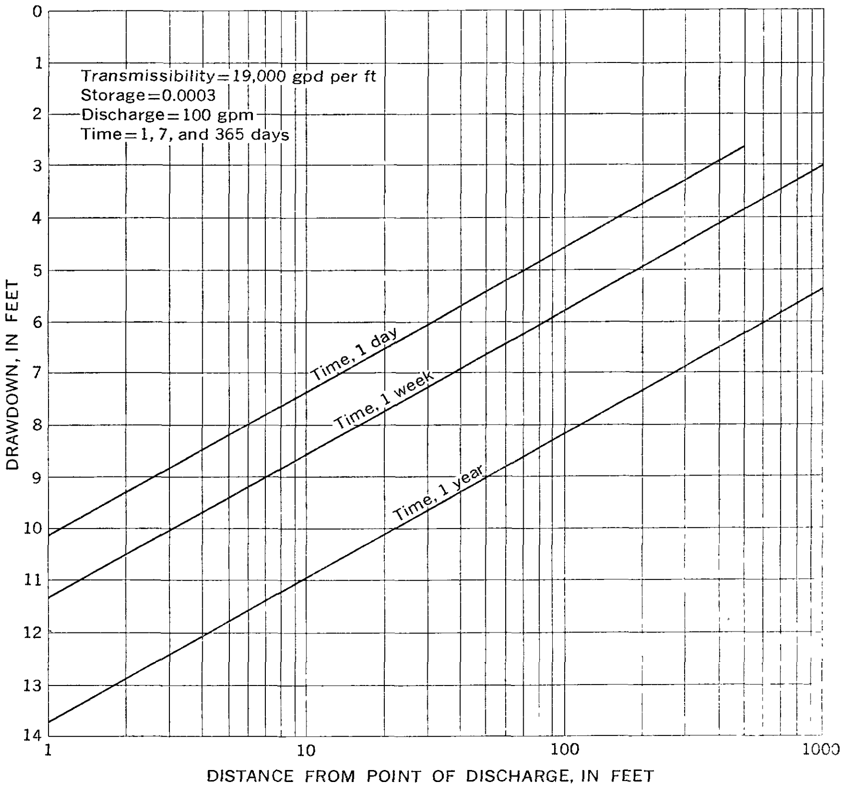


FIGURE 8.—Theoretical drawdown at given times and distances in an ideal aquifer having the range in transmissibility and storage determined for the unnamed sand unit.

OPERATION OF THE AQUIFER SYSTEMS

RECHARGE AND DISCHARGE

On an annual basis, recharge balances discharge plus or minus any change in storage. The aquifers in western Tennessee, however, receive an excess of potential recharge from precipitation. Because depletion of storage is very small, the amount of recharge to the aquifers of the Claiborne Group can be calculated approximately by totaling the amounts of water annually pumped or discharged from the aquifers. Most recharge to the Claiborne Group occurs by infiltration of precipitation in the outcrop areas of the aquifers. Some additional recharge is also received by seepage from adjacent formations and by underflow from adjacent States. The various amounts of recharge and discharge to and from the aquifers are summarized in table 3.

TABLE 3.—*Water budgets, in million gallons per day, in 1960 for the aquifers of th Claiborne Group*

[Amounts that are discharged to the streams are neglected]

"500-foot" sand	
Recharge:	
Recharge from precipitation on the outcrop area in Tennessee	133
Underflow from the north	3
Underflow from the south	25
Underflow from the west	20
Accretion from adjacent formations	10
Total average recharge	191
Discharge:	
Estimated pumpage	155
Underflow along the Mississippi-embayment axis	37
Total average discharge	192
Depletion of storage	1
Unnamed sand unit	
Recharge:	
Recharge from precipitation on the outcrop area in Tennessee	8
Underflow from the north	1
Accretion from adjacent formations	1
Total average recharge	10
Discharge:	
Estimated pumpage	2
Discharge to adjacent formations	8
Total average discharge	10

Practically all recharge from precipitation to the Claiborne Group occurs from November 1st of one year through April 30th of the following year. In the intervening months, May–October, evapotranspiration exceeds rainfall, and nearly all rain that seeps into the ground is absorbed by the soil. Little, if any, reaches the water table.

In the 750 square miles of the outcrop belt of the "500-foot" sand that is influenced by pumping in Shelby County, the average recharge from precipitation in 1960 was 80 mgd. In the remaining 1,350 square miles of the outcrop belt of the "500-foot" sand, the average recharge from precipitation was about 53 mgd in 1960. Thus, the total recharge to the "500-foot" sand from precipitation averaged 133 mgd in 1960. In the unnamed sand unit the average withdrawal and discharge of 8 mgd of water in 1960 was replaced by recharge from precipitation on the outcrop area.

A considerable amount of water in the aquifers of the Claiborne Group in Tennessee enters the State as underflow from the north, south, and west. Under natural conditions, about 3 mgd flowed into the State from Kentucky through the "500-foot" sand in 1960, and about 1 mgd flowed into the State through the unnamed sand unit. An undetermined amount of water flowed toward the Mississippi-embayment axis from Arkansas and Missouri in the northern part of the report area, but most, if not all, of this water left Tennessee as underflow along the axis of the embayment in the southern part of the area. Additional amounts of water were induced into Tennessee from the south and west because of pumping; this movement of water is discussed on page F28 as an effect of pumping.

Some of the water that flows downdip through the "500-foot" sand leaves Tennessee as underflow along the axis of the Mississippi embayment (pl. 5). This volume of water was calculated from the hydraulic gradient (pl. 5) and from the transmissibility (pl. 7) of the "500-foot" sand and was about 37 mgd in 1960. Most of this water was captured by pumping at Memphis, however.

EFFECTS OF PUMPING AND INTERAQUIFER MOVEMENT OF GROUND WATER

Prior to the development of water supplies from the "500-foot" sand, the amount of ground water that entered Shelby County from the east through the "500-foot" sand was estimated by Criner, Sun, and Nyman (1963, p. 50) to have been about 30 mgd. In 1960, under conditions of heavy pumping, the amount of ground water moving eastward into Shelby County through the "500-foot" sand was estimated at 60 mgd (Criner, Sun, and Nyman, 1963, p. 51). The additional water probably resulted chiefly from a reduction in surface runoff. No significant effect upon the flow of the major rivers in the outcrop area of the "500-foot" sand, however, has been observed. Wolf River, for example, has one of the largest base flows per square mile of drainage area of any river in the State. Any reduction in the base flow of the streams east of Shelby County has been obscured by the variations in base flow caused by factors other than the increased flow through the "500-foot" sand.

A factor that also might account for the lack of an observable effect of pumping from the "500-foot" sand on surface runoff is the apparent time lag between peak seasonal pumping and annual low water levels in the outcrop area of the "500-foot" sand. At a distance of 15–30 miles from the center of pumping in Memphis, the time lag between peak pumping and low water level is 1–4 months (Criner, Sun, and Nyman, 1963, p. 40). Consequently, the effect of peak pumping from July through September might not affect water levels in the recharge area of the "500-foot" sand until the interval November–January. The practical result of this time lag would be a reduction in the amount of direct surface runoff in the November–January period rather than a reduction in base flow during the period of peak pumping from July through September.

The major streams in the report area probably do not discharge any water into the Claiborne aquifers except possibly within the area influenced by pumping at Memphis.

Seepage from adjacent geologic formations accounts for a small amount of recharge in the report area. This process is significant in the Memphis area, where the "500-foot" sand is overlain and confined by thin partly silty or sandy clays. Possible sources for this recharge are water in the unnamed sand unit, the alluvial and terrace deposits, and the "1,400-foot" sand of the Wilcox Group. In the report area about 8 mgd moves through the unnamed sand toward the axis of the Mississippi embayment. This water then flows south along the axis and is discharged into the Mississippi River alluvium, terrace deposits, and probably the "500-foot" sand in or just west of Shelby County.

Additional amounts of water are apparently discharged from terrace deposits into the "500-foot" sand in the southern part of Shelby County. Pumping in Shelby County has lowered water levels in the "500-foot" sand below those in the terrace deposits, and a hydraulic gradient between the two aquifers has been established. As a result of this downward seepage, the water table in the terrace deposits has dropped to some extent, and Nonconnah Creek is now dry part of the year, whereas it was formerly a perennial stream.

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Criner, Sun, and Nyman (1963, p. 54) gave the following ground-water budget for the "500-foot" sand in Shelby County:

Inflow	*Million gallons per day*
Across east boundary	60
Across north boundary	20
Across south boundary	25
Across west boundary; leakage from above and other sources	29
Depletion of storage	1
Total	135
Average pumping rate for 1960	135

The information available on water levels west of the Mississippi River is inadequate to determine directly the inflow into Shelby County across the west boundary. Probably no more water is moving across the west boundary than across the north boundary, however. Although hydraulic gradients have been established from the north and west by pumping, the inflow from both directions is moving updip in the "500-foot" sand. If Shelby County receives 20 mgd across the west boundary, then, from the foregoing water budget, 9 mgd is recharged to the aquifer from adjacent geologic formations.

The hydraulic head in the "500-foot" sand is higher than that in the underlying "1,400-foot" sand of the Wilcox Group, except in Shelby County, where the reverse is true. Moreover, the "500-foot" sand partly overlaps the Wilcox Group where they crop out, as discussed on page F12, and occupies the higher position topographically. A net discharge of water into the older unit probably occurs, but the amount of this discharge cannot be estimated at present.

Outside Shelby County, seepage from overlying formations into the Claiborne aquifers is apparently confined to isolated local areas. In some of these areas, pumping lowers the water level in the Claiborne aquifers enough to induce water into them from the overlying formations, such as alluvial deposits. The total amount of water added to the Claiborne aquifers in these areas is probably about 1 mgd for the "500-foot" sand and 1 mgd for the unnamed sand unit.

The total accretion from adjacent formations is probably about 10 mgd for the "500-foot" sand and about 1 mgd for the unnamed sand unit.

Under conditions of heavy pumping in Memphis, 25 mgd has been diverted into Shelby County as underflow through the "500-foot" sand from Mississippi, and probably an additional 20 mgd enters the county as underflow through the "500-foot" sand from Arkansas.

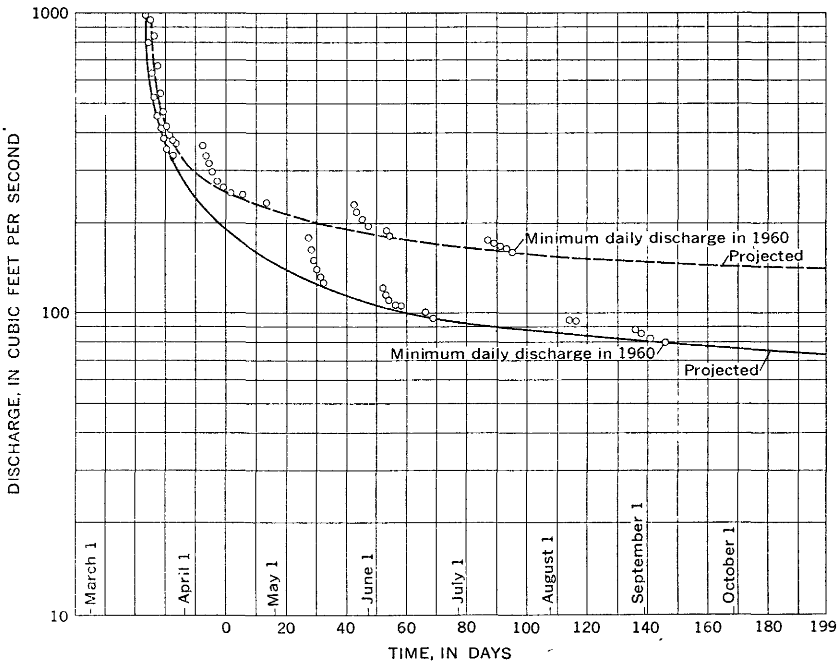
Discharge from the "500-foot" sand that is not balanced by recharge results in a depletion of water in storage and a lowering of water levels. These changes occur chiefly in Shelby County, where the amount of pumpage is continuing to increase year after year. Criner, Sun, and Nyman (1963, p. 54) estimated that an average 1 mgd of the total pumpage in the Memphis area is derived from storage.

GROUND-WATER STORAGE AND BASE FLOW OF STREAMS

A large amount of water is temporarily stored in the Claiborne aquifers during the winter months, and much of this water is then discharged to streams in the outcrop areas during the following seasons. This water constitutes the base flow of the perennial streams in the outcrop area of the Claiborne Group. The aquifers discharge water for two reasons: (1) there is a hydraulic gradient between the uplands and the stream bed and (2) the aquifers are essentially full of water, and additional water cannot be transmitted downdip under existing hydraulic gradients.

The relationships between the changes in ground-water levels, the changes in the depth and discharge of streams, and the variations in precipitation and evapotranspiration are complex. The seasonal trends of these factors can generally be isolated from the shorter term complexities, however. During the period from April through November, as discussed on page F26, practically no water recharges the Claiborne aquifers. Because the aquifers continue to discharge water from April through November, although at a decreasing rate, the amount of water in storage in the aquifers recedes. Therefore, a curve drawn through the lowest points on the stream hydrographs during this period approximately defines the recession of discharge to the streams from the upland areas of outcrop of the aquifers (neglecting bank storage and evapotranspiration). The area under this curve approximately represents the total amount of water discharged from the various aquifers in the basins.

The recession of ground-water discharge for the basins of Wolf River at Rossville and of South Fork Obion River near Greenfield is shown in figure 9. The base-flow data obtained at these stations are probably representative of ground-water discharges from the "500-foot" sand. On the basis of the stream hydrographs and of well hydrographs, the period selected for analysis was April 15–October 31, 1960. Because of a series of rains in the fall, the total discharge of the streams during this season exceeded the ground-water discharge; therefore, parts of both curves are projected.



Wolf River at Rossville (dashed-line curve): location, lat, 35°03′15″, long 89°32′30″; period of plot, March 21–July 19, 1960; drainage area, 503 square miles.

South Fork Obion River near Greenfield (solid-line curve): location, lat 36°07′05″, long 88°48′39″; period of plot, March 19–September 7, 1960; drainage area, 431 square miles.

FIGURE 9.—Recession of ground-water discharge in two basins during April 15–October 31, 1960.

The volumes of ground water discharged from the "500-foot" sand during the 1960 period of recession were calculated from the recession curves in figure 9. The volume of water represented by the area beneath the curves was calculated in five or ten day segments (depending on the slope of the curve) and then totaled.

In the Wolf River basin above Rossville, 21.7 billion gallons of water was discharged from the outcrop area of the "500-foot" sand in 1960. In the South Fork Obion River basin above Greenfield, 12.5 billion gallons was discharged. If the mean of these values represents the average volume of discharge from the "500-foot" sand, about 76 billion gallons of water was discharged to streams crossing the outcrop area during the 1960 period of recession. This volume of discharge is equivalent to a depth of 2.1 inches of water over the 1,350 square miles of the outcrop area. These calculations can be checked by comparing the amount of aquifer discharge with the total seasonal fluctuation of ground-water levels. The following table lists the various declines of water level that would result in the "500-foot" sand for four different porosities if 76 billion gallons of water were discharged from the aquifer:

Porosity (percent)	*Water-level decline (inches)*
20	10.5
25	8.4
30	7
35	6

The actual seasonal fluctuation of water level in the outcrop area of the "500-foot" sand ranged from about 6 to 12 inches in 1960.

WATER QUALITY

The quality of the ground water in the report area is primarily a result of the solvent power of the water. This power is greatly increased by the presence of dissolved carbon dioxide. Some carbon dioxide is dissolved from the air by rainwater, but organic soils generally contain much more of this gas than does the atmosphere. Therefore, as rainwater percolates into and through an organic soil zone, it dissolves additional amounts of carbon dioxide and thus forms a weak acid solution that can dissolve certain minerals in the earth's crust. In general, the farther the water travels and the longer the water remains underground, the more mineral matter it dissolves.

The chemical suitability of water for domestic and municipal use is commonly judged by comparison with standards of the U.S. Public Health Service (1962) for water used on common carriers in interstate commerce. Individuals can become adjusted to drinking water containing larger amounts of chemical constituents than those recommended by the Health Service, but water of inferior quality should be avoided wherever possible. The chemical quality of water in the Claiborne aquifers is within the limits established in the Public Health Service standards for all constituents except iron. The iron content of water in the Claiborne aquifers within the report area ranges from 0 to 16 ppm (parts per million), whereas the recommended limit is 0.3 ppm. Individual chemical analyses of water from most municipal water supplies from the Claiborne aquifers in western Tennessee were reported by Lanphere (1955).

In general, the chemical quality of water from the Claiborne Group at a given locale may be expected to show little or no change with time. For example, analyses of water from selected wells in the report area showed no significant change in quality between 1929 and 1961 (J. H. Hubble, U.S. Geol. Survey, written commun., 1962). Some changes in water quality might occur, however, where significant quantities of water are withdrawn from a new well or well field owing to the induction of water of better or poorer quality into the aquifer.

"500-FOOT" SAND

Wells near the outcrop area of the "500-foot" sand yield water that is generally low in all chemical constituents and somewhat acidic, as evidenced by a relatively low pH (the negative logarithm of hydrogen ion activity). Because of the low pH and probably because of the presence of dissolved oxygen (Moore, 1962, p. 134), water pumped from wells near the outcrop area generally corrodes iron piping.

Downdip in the aquifer, contents of calcium, magnesium, iron, and bicarbonate in the water progressively increase (pl. 8), and acidity correspondingly decreases. The increase in calcium, magnesium, and bicarbonate probably results from the slow solution of available calcium and magnesium minerals as the ground water moves downdip. The solution of these materials reduces the amount of carbonic acid in the water and thereby probably accounts for the downdip decrease in acidity, if no carbon dioxide is added to the system.

The increase in the iron content (pl. 8) of the water downdip in the "500-foot" sand is presumably the result of a shift from an oxidizing environment near the outcrop area to a reducing environment near the axis of the Mississippi embayment (Moore, 1962, p. 134).

Nearly all municipal supplies taken from the "500-foot" sand near the embayment axis must be aerated, and most supplies must also be filtered. These processes precipitate the dissolved iron in the form of an oxide and then remove the iron oxide from suspension. Aeration also liberates excess carbon dioxide and hydrogen sulfide gas, thereby making the water less corrosive and more palatable.

The distribution of iron, hardness, pH, and temperature in water from the "500-foot" sand is shown in figure 10. The range and median values of most chemical constituents are listed in table 4.

UNNAMED SAND UNIT

The data currently available are inadequate to show graphically the downdip changes in chemical quality of water in the unnamed sand unit. There is, however, an apparent downdip increase in mineral constituents and temperature. The range and median values of most chemical constituents in water from the unnamed sand unit are shown in table 4. The temperature of the water in this aquifer ranges from 59°F to 63°F.

Aeration and filtration are used to remove iron from the water for municipal supplies in the northwestern part of the report area. No other treatment is used for the chemical content of the water.

TABLE 4.—*Summary of chemical analyses of water from selected wells developed in the "500-foot" sand and unnamed sand unit in western Tennessee*

[Results in parts per million, except as otherwise indicated. Analyses made by the Quality of Water Branch, U.S. Geol. Survey]

Chemical constituent or property	"500-foot" sand (33 analyses)			Unnamed sand unit (11 analyses)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Silica (SiO_2)	3.3	12	21	11	18	33
Iron (Fe)	.0	.5	14	.1	.7	16
Calcium (Ca)	1.3	5.8	31	3.5	12	31
Magnesium (Mg)	.4	1.9	15	1.2	4.6	14
Sodium (Na)	1.9	5.6	17	2.4	9.6	29
Potassium (K)	.2	.9	7.5	.5	1.2	6.6
Carbonate (CO_3)	0	0	4	0	0	0
Bicarbonate (HCO_3)	8.0	29	170	21	82	190
Sulfate (SO_4)	.0	2.2	9.7	1.1	2.6	17
Chloride (Cl)	.6	3.0	19	1.5	3.4	26
Fluoride (F)	.0	.1	.6	.0	.0	.1
Nitrate (NO_3	.0	.6	10	.0	.4	20
Dissolved solids (residue at 180° C)	19	57	150	33	120	180
Hardness as $CaCO_3$	6.0	22	140	14	49	140
Specific conductance (micromhos at 25° C)	23	84	270	39	170	300
pH	5.6	6.2	8.0	6.0	6.1	7.7

WATER USE

The availability of large quantities of ground water from the Claiborne aquifers has been an important factor in the economic development of the report area. All known municipal, industrial, and domestic water users and most irrigation water users rely on ground water for their source of supply. In 1960 the average pumpage from the "500-foot" sand was about 155 mgd, and the average pumpage from the unnamed sand unit was about 2 mgd.

Detailed surveys of water use have been made in three localities in the report area. Use of pumpage from the "500-foot" sand in Shelby County was found to be 45 percent municipal and 55 percent industrial and other. In the Dyersburg quadrangle (Schreurs and Marcher, 1959, p. 40), use of pumpage was 51 percent municipal, 20 percent industrial, and 28 percent other. A survey of Madison County found pumpage use to be 44 percent municipal, 35 percent industrial, and 21 percent other. On the basis of these results, use of pumpage from the aquifers of the Claiborne Group is estimated to be 46 percent municipal, 44 percent industrial, and 10 percent other.

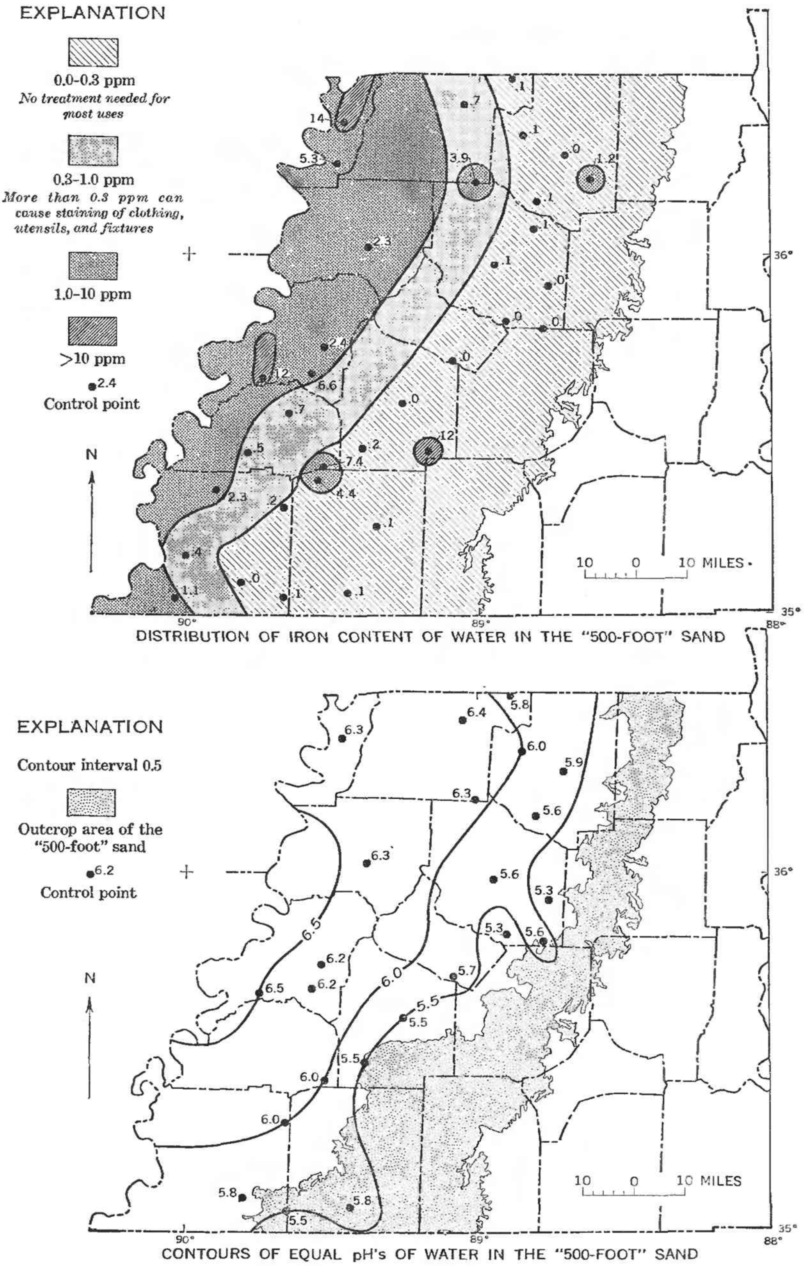
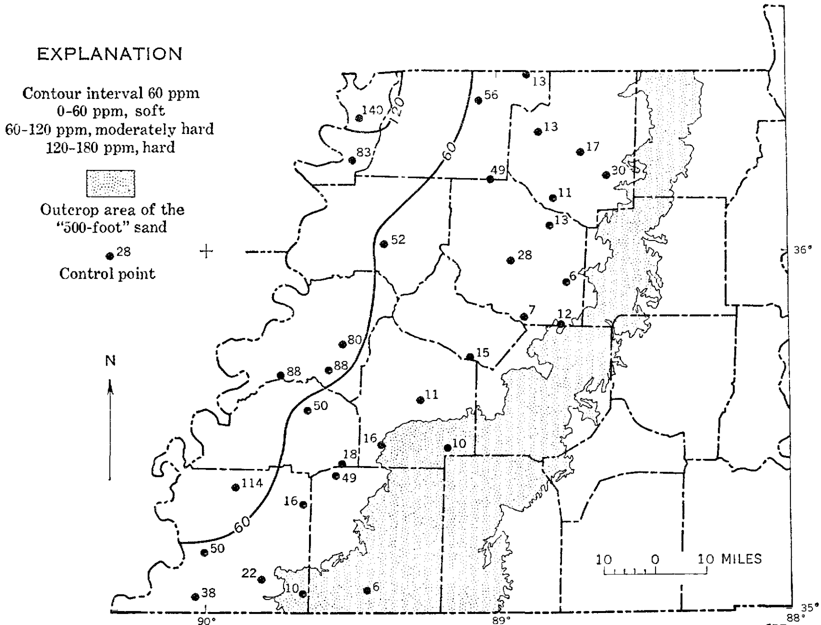
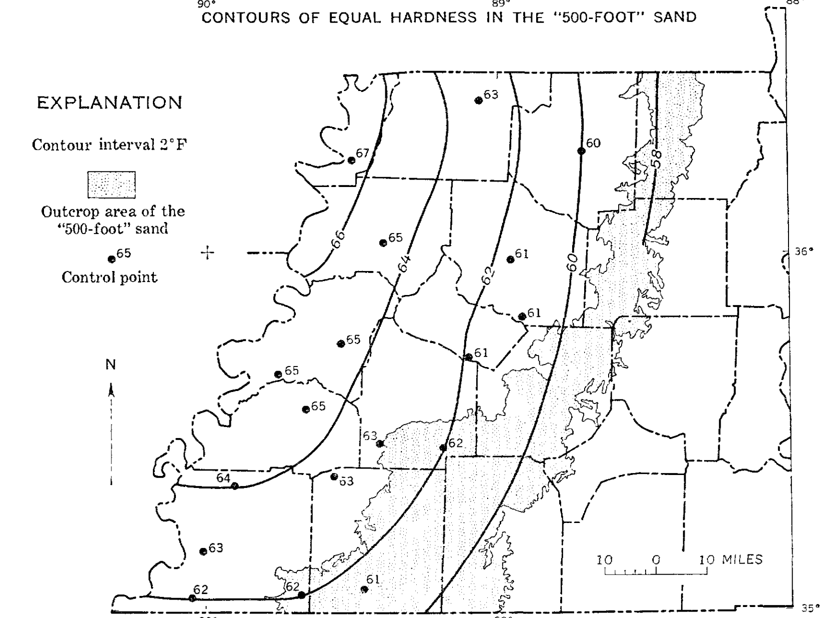


FIGURE 10.—Distribution of iron, hardness, pH, and temperature in water



CONTOURS OF EQUAL HARDNESS IN THE "500-FOOT" SAND



CONTOURS OF EQUAL TEMPERATURES IN THE "500-FOOT" SAND

from the "500-foot" sand. Data collected during the period 1951–61.

The average municipal pumpage from the "500-foot" sand in Shelby County during 1960 was about 61.5 mgd. This total may be broken down by utility district as follows:

Utility district	Average daily pumpage from the "500-foot" sand (thousands of gallons)	Utility district	Average daily pumpage from the "500-foot" sand (thousands of gallons)
Memphis Light, Gas, and Water Division	58,540	Millington	490
Arlington	10	Raleigh	330
Collierville	240	Whitehaven	1,450
Ellendale	[1] 300	Woodstock	[1] 50
Germantown	110	Total	61,520

[1] Estimated.

Outside Shelby County, 29 towns pumped an average of about 9.7 mgd from the "500-foot" sand in 1960. The approximate pumpage at each town is as follows:

Town	Average daily pumpage from the "500-foot" sand (thousands of gallons)	Town	Average daily pumpage from the "500-foot" sand (thousands of gallons)
Bells	75	Maury City	[1] 10
Bradford	80	Medina	100
Brighton	[1] 20	Milan	500
Brownsville	475	Moscow	[1] 15
Cottage Grove	6	Ridgely	175
Covington	400	Ripley	380
Dresden	250	Somerville	180
Dyersburg	1,400	South Fulton	250
Gibson	10	Stanton	60
Gleason	100	Tiptonville	300
Greenfield	150	Trenton	1,000
Henning	15	Union City	1,200
Humboldt	2,000	Whiteville	75
Kenton	100		
Martin	375	Total	9,716
Mason	15		

[1] Estimated.

Towns that use water from the unnamed sand unit pumped an average of about 0.9 mgd in 1960. These towns and the average daily pumpage are listed as follows:

Town	Average daily pumpage from the unnamed sand (thousands of gallons)	Town	Average daily pumpage from the unnamed sand (thousands of gallons)
Alamo	200	Sharon	100
Dyer	220	Troy	60
Gates	[1] 10		
Halls	175	Total	915
Rutherford	150		

[1] Estimated.

The highest monthly pumpage for municipal use generally occurs in July or August; the minimum monthly pumpage is generally in February.

Industrial pumping from the Claiborne aquifers is concentrated in the larger population centers. No complete survey of industrial water use has been made, but pumpage is estimated at an average of 70 mgd.

Withdrawal for domestic and stock use is concentrated in and near the outcrop areas of the Claiborne aquifers. The unnamed sand unit is also used for domestic supplies in the downdip areas, where shallower aquifers are missing or yield water of poor quality.

Irrigation is used on a supplemental basis in western Tennessee. Crops are normally irrigated one time in each growing season. Irrigation wells withdraw water from the Claiborne aquifers in Crockett, Fayette, Gibson, Haywood, Madison, Shelby, and Weakley Counties. The total capacity of all pumps is about 25,000 gpm. About 34 percent of the total capacity can be pumped in Shelby County, and 33 percent can be pumped in Gibson and Weakley Counties (McLemore, 1958, p. 15, 16). The quantity of water withdrawn, however, depends largely on the distribution of areas of deficient rainfall and, therefore, varies considerably from year to year. Average annual withdrawal of ground water for irrigation is about 150 million gallons.

WELL CONSTRUCTION

A well is an engineering device to divert ground water from its natural flow path for use by man. Where relatively small quantities of water are desired, well-design criteria may be of minor importance. It is often the objective, however, to construct a well capable of producing 500–2,000 gpm. In the construction of such high yielding wells, proper methods of well design, construction, and development should be used to insure maximum efficiency.

The two major factors of well construction that determine the yield of a well at a particular site are the amount of penetration of the aquifer by the well and the effective diameter of the well. The amount of penetration of the aquifer is defined as the ratio of the length of a screen in a saturated aquifer to the total thickness of the aquifer, usually expressed as a decimal. If this ratio is one, the penetration is said to be complete; but if the ratio is less than one, the penetration is called partial. The amount of penetration is generally more important than effective diameter in determining well yields. Increasing the penetration of an isotropic artesian aquifer will generally increase the yield of the well. According to Ahrens (1958, fig. 3), an increase in penetration from 0.2 to 0.4 will increase the ultimate yield of a well in an ideal aquifer by as much as 85 percent.

The effective diameter of a well is determined by the amount of development that the well has undergone, the thickness and relative permeability of a gravel pack (if used), the type and amount of perforation in the screen or casing, and the actual diameter of the well. The degree of well development has a considerable influence in determining the effective diameter of a well. Various methods of pumping, surging, and backwashing a newly completed well remove the finer grained materials surrounding the screen and greatly increase the permeability of the aquifer in this zone. Theis, Brown, and Meyer (1954, p. 6) stated that the effect of well development in many instances may be "the same as if a well 10 feet in diameter were placed in an undeveloped aquifer."

The use of a gravel pack—a sand or gravel wall placed between the well screen and the aquifer surrounding the well—can increase the effective diameter of a well by increasing the permeability of the materials outside the well screen in a manner similar to well development. The cost of installing a gravel pack should be balanced, however, against the results that could be obtained by spending the same amount of money on additional well development.

The inside diameter of a well screened in sand or gravel has only a small effect on its productivity relative to other wells in the same locality and in the same aquifer. If a pumping well has a radius of influence of at least 1,000 feet under equilibrium conditions, doubling the diameter of the pumped well would result in a sustained yield increase of less than 10 percent (Ahrens, 1958, p. 28, 30). This relation should be considered in deciding whether or not to construct a well having a diameter substantially larger than required for the installation of the necessary pumping equipment to deliver the desired yield.

WELL INTERFERENCE

In municipal and industrial well fields, interference between closely spaced wells in some places causes excessive drawdown of water levels. In effect, well interference or the decline of water-level in a well caused by pumping nearby wells results in a decrease in the available drawdown and, hence, in the ultimate capacity of the well. Thus, interference is a form of mutual pirating. The problem is chiefly one of economics—namely, whether the cost of pumping water from lower levels is less than the cost of longer pipelines that would be required to transport water from wells spaced farther apart.

A satisfactory method of reducing interference, which has not been extensively used in western Tennessee, is the placing of wells in a given field in groups that include as many wells as there are aquifers and the screening of each well in a different aquifer. In this way, little or no interference would be evident between wells in the same group and, therefore, the length of pipeline that would be needed to collect a given amount of water could be considerably reduced.

The group method would be particularly adaptable in the area underlain by the aquifers in the Claiborne Group; because within these units, clay layers locally separate the water-bearing sands and create virtually separate aquifers. Moreover, the Claiborne is underlain by the Wilcox Group and the Ripley Formation throughout the report area and, in places, is overlain by alluvium and terrace deposits. Each of these units contains one or more aquifers; thus, the number of wells in a given group could be increased.

In the development of wells in the same aquifer, the most favorable arrangement is in a straight line at right angles to the direction of ground-water flow. This arrangement provides the maximum amount of available drawdown in the wells as a group by minimizing interference between wells and, thus, permits the wells to be closer together. As a result, the cost of both pumping and piping the water from a given number of wells is minimized.

AQUIFER POTENTIAL AND FUTURE DEVELOPMENT

The maximum quantity of water that can be pumped from the "500-foot" sand on a sustained basis is limited only by the capacity of the aquifer to store and transmit water. If the hydraulic gradient of the "500-foot" sand were increased to the average dip of the top of aquifer (19 ft per mile), the "500-foot" sand would transmit downdip from the outcrop area about 578 mgd, or the equivalent of 5.8 inches of precipitation per year. Infiltration in the outcrop area could greatly exceed the 5.8 inches that the aquifer would be able to transmit downdip under the assumed gradient of 19 feet per mile, owing to the abundance of rainfall in the outcrop area.

Total pumpage from the "500-foot" sand in Shelby County has not increased at a constant rate through the years. For the period 1958–62, however, the average increase was more than 5 mgd each year (J. H. Criner, U.S. Geol. Survey, oral commun., 1963). If the average increase in pumpage were more than 5 mgd each year from 1960 to 1980, total pumpage at the end of this period would exceed 230 mgd.

Increased future pumping at Memphis will have significant effects upon the system of aquifers in the Claiborne Group. The area of influence of pumping (pl. 5) will increase with the rate of pumping, and recharge will increase in turn; but the absolute expansion of these factors cannot be determined at present. For example, the expansion of the area of influence would not be a straight-line function of the increase in pumping because additional recharge from surface streams, precipitation, and adjacent geologic formations would result from increased hydraulic gradients. The problem of estimating the future effects of increased pumping in the Memphis area can be simplified, however, by assuming that the percentage of water entering Shelby County as underflow through the "500-foot" sand from all directions will be proportional to that of 1960. As mentioned previously, total pumpage in the Memphis area was 135 mgd in 1960. Fifty-nine percent of the total water pumped entered Shelby County as underflow from the north and west. This amount of water was probably replaced in the "500-foot" sand by infiltration of 2.2 inches of the precipitation that fell on the southern 35 percent of the outcrop belt of the "500-foot" sand in Tennessee. If the percentage of the outcrop belt of the "500-foot" sand that is within the area of influence expands as the area influenced by Memphis pumping expands, table 5 shows approximately the rates of annual infiltration and the resulting average hydraulic gradients as pumpage in Memphis increases to 200 mgd and 300 mgd.

TABLE 5.—*Predicted possible pumping conditions in the Memphis area when pumpage reaches 200 mgd and 300 mgd*

[Transmissibility across the north and west boundaries of Shelby County is 350,000 gpd per ft]

Case	Percent of outcrop area of "500-foot" sand within area of influence of pumping	Rate of annual infiltration required (inches)	Average hydraulic gradient across north and west boundaries of Shelby County (ft per mile)
200 mgd			
A	40	5.0	
B	50	4.0	
C	60	3.3	11
D	70	2.9	
E	80	2.5	
300 mgd			
A	40	7.5	
B	50	6.0	
C	60	5.0	17
D	70	4.3	
E	80	3.7	

The effects of future increases in pumping at Memphis will be (1) a reduction and possible seasonal loss of base flow in streams within the area-of-influence of pumping, (2) a drop in water levels that will be directly proportional to the increase in pumpage and inversely proportional to the distance from the center of pumping and, therefore, a reduction in the amount of water in storage, (3) a capture of some of the water being discharged from the State as underflow and an increase in the inflow of water from adjacent States, (4) an increase in leakage from other aquifers through the confining beds, and (5) a change from artesian to water-table conditions in the eastern part of the county.

Outside Shelby County, municipal pumpage from the "500-foot" sand was probably about 4.8 mgd in 1929 (Wells, 1933), 8.1 mgd in 1951 (Lanphere, 1955), and 9.7 mgd in 1960. On the basis of these three values, municipal pumpage will probably reach 13 mgd by the year 1980 and 16 mgd by the year 2000. If other pumpage increased proportionally, the total pumpage by the year 1980 would be 28 mgd, and by the year 2000, 35 mgd.

Pumpage from the "500-foot" sand outside Shelby County was very small (9.7 mgd) in 1960 compared with the amount of water potentially available. The "500-foot" sand has the capacity to transmit at least 372 mgd from the outcrop area to centers of pumping outside Shelby County. Additional amounts of water might also be induced into the area north of Shelby County as underflow from Kentucky, Arkansas, and Missouri.

If the hydraulic gradient of the unnamed sand unit were increased to the average dip of the top of that unit (about 10 ft per mile), about 34 mgd, or the equivalent of 1.4 inches of precipitation per year, would be transmitted downdip from the outcrop area and would be available for use. This amount is about 17 times the present pumpage.

Municipal pumpage from the unnamed sand unit was about 0.25 mgd in 1929 (Wells, 1933), 0.64 mgd in 1951 (Lanphere, 1955), and 0.92 mgd in 1960. Hence, the average annual increase in municipal pumpage from 1929–60 is assumed to have been about 21,000 gpd. At this rate of increase, municipal pumpage would be about 1.1 mgd by the year 1980 and 1.5 mgd by the year 2000. If other pumpage increased proportionally, total pumpage by the year 1980 would be 2.3 mgd, and by the year 2000 it would be 3.3 mgd. The latter figure of 3.3 mgd is far below the 34 mgd that is probably available from the unnamed sand unit.

Thus, ground-water supplies in both the "500-foot" sand and the unnamed sand unit will be adequate for the predicted rate of municipal growth and economic development for many years to come. Future development should be undertaken with the full knowledge that the net increase in pumpage will be offset by an increase in the inflow of ground water from other States, a decrease in the base flow of streams crossing the outcrop areas of the Claiborne aquifers, or both.

SUMMARY AND CONCLUSIONS

There are two major aquifers in the Claiborne Group: the "500-foot" sand and an unnamed sand unit. The "500-foot" sand is present beneath about 7,200 square miles in western Tennessee and has an average thickness of about 450 feet in the subsurface. The unnamed sand unit underlies about 6,500 square miles and has an average thickness of about 100 feet.

Water in both aquifers of the Claiborne Group is under artesian pressure except in some parts of the outcrop area. Wells developed in the aquifers flow where the piezometric surface is higher in altitude than the land surface. Flowing wells may be developed in the Claiborne aquifers on the flood plains of most major rivers that drain the region underlain by the Claiborne deposits and in part of the Mississippi Alluvial Plain. Elsewhere the water level ranges from just below land surface to as much as 150 feet below land surface.

Wells in the Claiborne aquifers yield moderate to large amounts of water of good chemical quality. The coefficients of transmissibility in the "500-foot" sand, determined from 26 aquifer tests, ranged from 20,000 to 400,000 gpd per ft, and the coefficients of storage ranged from 0.0001 to 0.003. The theoretical specific capacities of most wells in the "500-foot" sand range from 22 gpm per ft of drawdown for a transmissibility of 50,000 gpd per ft and a 6-inch-diameter well to 141 gpm per ft of drawdown for a transmissibility of 300,000 gpd per ft and a 24-inch-diameter well. The coefficients of transmissibility in the unnamed sand unit, determined from three aquifer tests, ranged from 19,000 to 45,000 gpd per ft, and the coefficients of storage were 0.0003 and 0.0007. The theoretical specific capacities of most wells in this aquifer range from 8 gpm per ft of drawdown for a 4-inch well and a transmissibility of 20,000 gpd per ft to 19 gpm per ft of drawdown for a 12-inch well and a transmissibility of 40,000 gpd per ft.

The chemical quality of water in the Claiborne aquifers is well within the limits of Public Health Service standards in all constituents except iron. Iron content in the report area ranges from 0.0 to 16 ppm, whereas the recommended limit is 0.3 ppm. Aeration and filtration are necessary to remove iron from the water that is used for many municipal supplies.

Although new wells are continually being developed in western Tennessee, the ground-water supply from the aquifers in the Claiborne Group will be adequate to supply the needs of the water users within the report area for many years to come. In 1962 the total withdrawal from the Claiborne aquifers was about 157 mgd, whereas these aquifers are probably potentially capable of delivering at least

600 mgd. The anticipated effects of additional large scale development from the Claiborne aquifers are (1) a drop in local and regional water levels in proportion to the increase in pumping, (2) an increase in the net inflow of ground water from adjacent States, and (3) an increase of recharge to the Claiborne aquifers in the areas of outcrop at the expense of surface runoff.

REFERENCES

Ahrens, T. P., 1958, Water well engineering, part 3: Water Well Jour., v. 12, no. 12, p. 18, 19, 28, 30–32.

Armstrong, C. A., 1955, Memorandum on the post-Paleocene subsurface stratigraphy of the Memphis area, Tennessee: U.S. Geol. Survey open-file report.

Berry, E. W., 1916, The lower Eocene floras of southeastern North America: U.S. Geol. Survey Prof. Paper 92.

Brown, G. F., 1947, Geology and artesian water of the alluvial plain in northwestern Mississippi: Mississippi Geol. Survey Bull. 65.

Brown, R. H., 1953, Selected procedures for analyzing aquifer test data: Jour. Am. Water Works Assoc., v. 45, no. 8, p. 844–866.

Criner, J. H., and Armstrong, C. A., 1958, Ground-water supply of the Memphis area: U.S. Geol. Survey Circ. 408.

Criner, J. H., Sun, P-C. P., and Nyman, D. J., 1963, Hydrology of the aquifer systems in the Memphis area, Tennessee: U.S. Geol. Survey open-file report.

Conrad, T. A., 1856, Observations on the Eocene deposits of Jackson, Mississippi, with descriptions of thirty-four new species of shells and corals: Acad. Nat. Sci. Philadelphia Jour., v. 7, p. 257–258.

Cushing, E. M., Boswell, E. H., and Hosman, R. L., 1964, General geology of the Mississippi embayment: U.S. Geol. Survey Prof. Paper 448–B.

Fenneman, N. M., 1938, Physiography of eastern United States: New York and London, McGraw-Hill Book Co.

Fuller, M. L., 1912, The New Madrid earthquake: U.S. Geol. Survey Bull. 494.

Glenn, L. C., 1906, Underground waters of Tennessee and Kentucky west of the Tennessee River: U.S. Geol. Survey Water-Supply Paper 164.

Hershfield, D. M., 1961, Rainfall frequency atlas of the United States: U.S. Weather Bur. Tech. Paper 40.

Hosman, R. L., 1962, Correlation of the Carrizo Sand in Arkansas and adjacent States: Geol. Soc. America Bull., v. 73, no. 3, p. 389–394.

Klaer, F. H., 1940, Water levels and artesian pressure in wells in Memphis: U.S. Geol. Water-Supply Paper 907, p. 92–101.

Lanphere, C. R., 1955, Geologic source and chemical quality of public groundwater supplies in western Tennessee: Tennessee Div. Geology Rept. Inv. 1.

McLemore, C. K., 1958, Irrigation in Tennessee: Tennessee Dept. Conserv. and Commerce, Water Resources Div.

Moore, G. K., 1962, Downdip changes in chemical quality of water in the "500-foot" sand of western Tennessee: U.S. Geol. Survey Prof. Paper 450–C, p. 133–134.

Safford, J. M., 1869, Geology of Tennessee: Nashville, State of Tennessee.

Schreurs, R. L., and Marcher, M. V., 1959, Geology and ground-water resources of the Dyersburg quadrangle, Tennessee: Tennessee Div. of Geology Rept. Inv. 7.

Stearns, R. G., 1957, Cretaceous, Paleocene, and lower Eocene geologic history of the northern Mississippi embayment: Geol. Soc. America Bull., v. 68, no. 9, p. 1077–1100.

Stearns, R. G., and Armstrong, C. A., 1955, Post-Paleozoic stratigraphy of western Tennessee and adjacent portions of the upper Mississippi embayment: Tennessee Div. Geology Rept. Inv. 2.

Theis, C. V., Brown, R. H., and Meyer, R. R., 1954, Estimating transmissibility from specific capacity: U.S. Geol. Survey Ground Water Note 24.

U.S. Public Health Service, 1962, Drinking water standards: Federal Register, Mar. 6, p. 2152–2155.

Wells, F. G., 1933, Ground-water resources of western Tennessee, *with a discussion of the* Chemical Character of the water, by F. G. Wells and M. D. Foster: U.S. Geol. Survey Water-Supply Paper 656.

Walton, W. C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey Rept. Inv. 25.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887.

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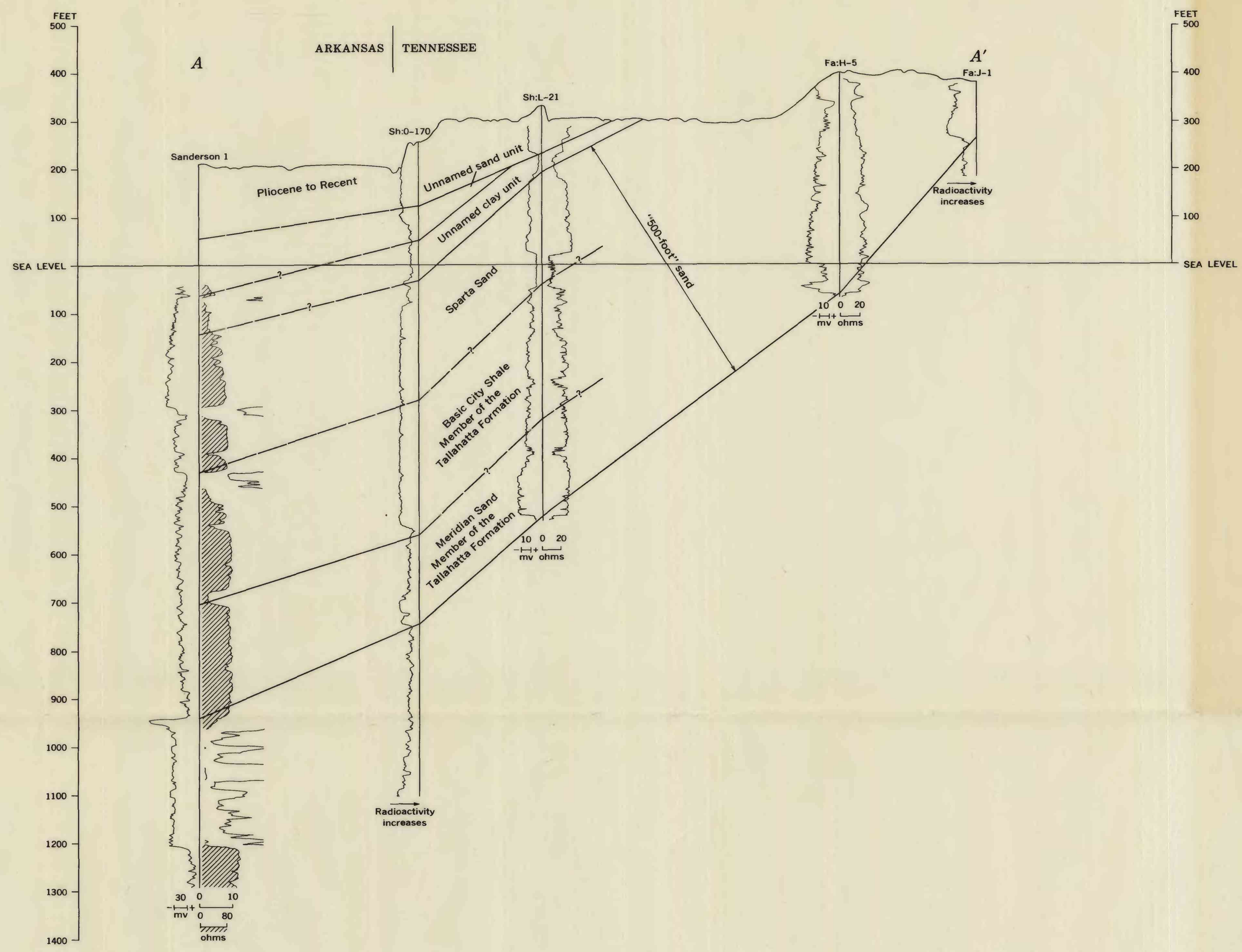
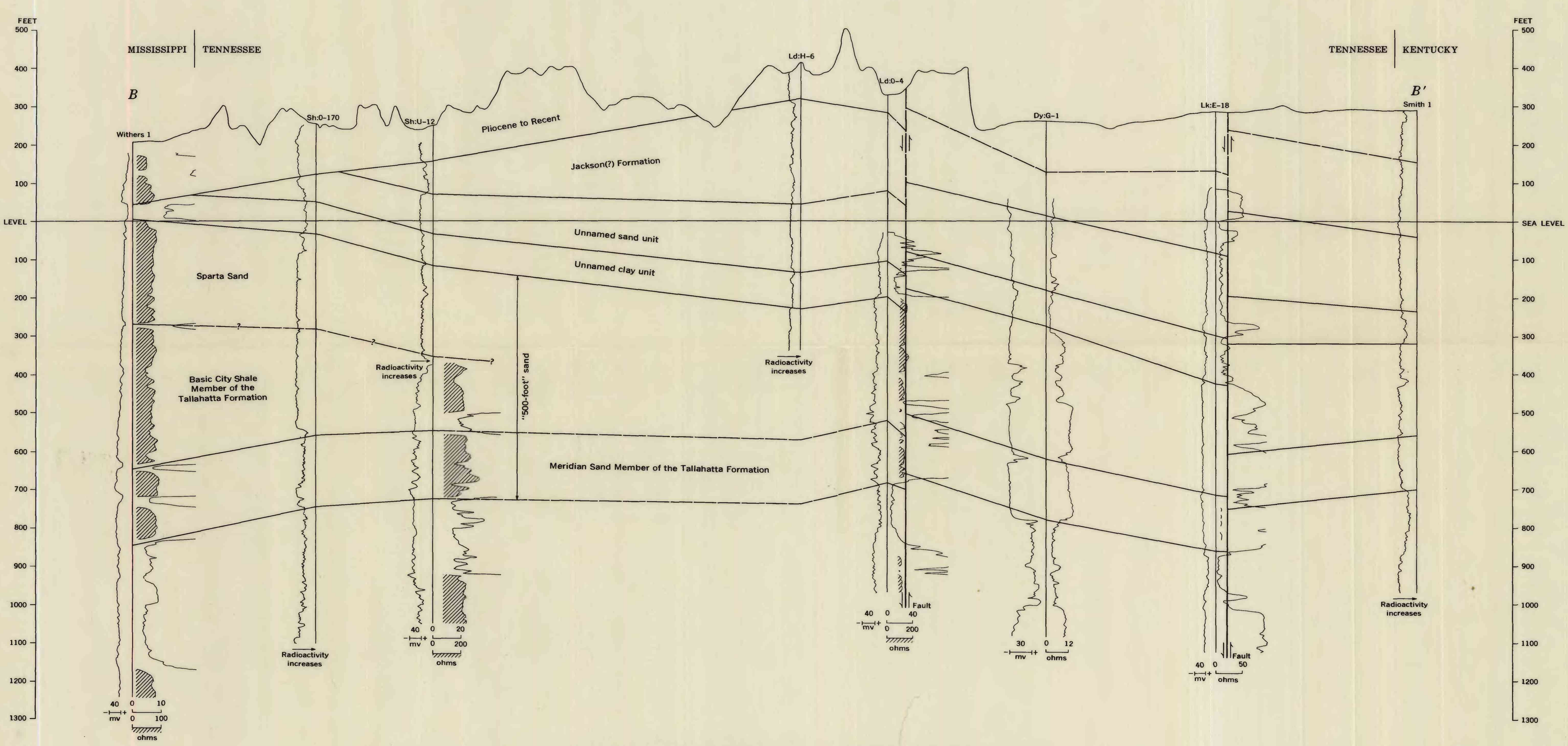
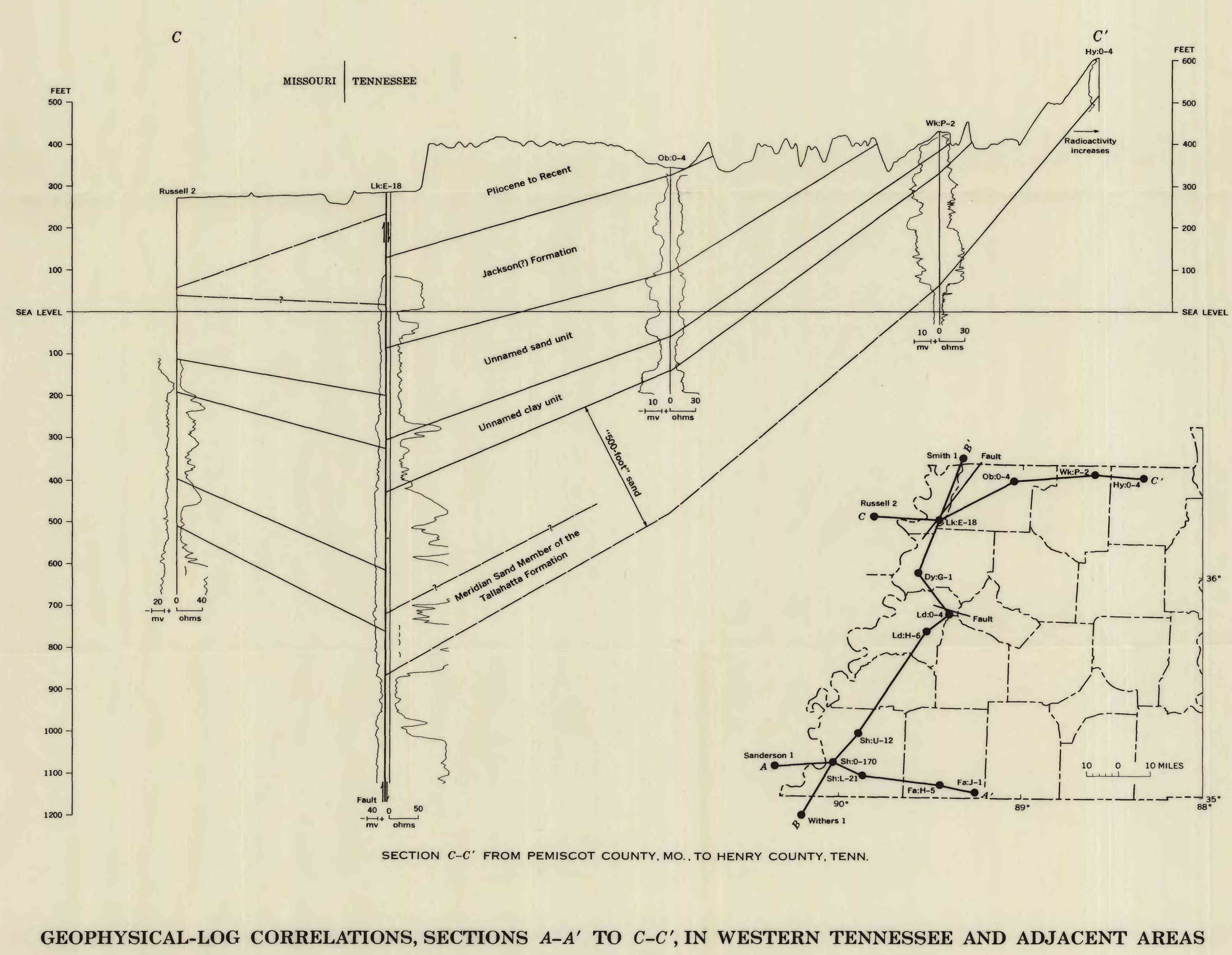


SECTION A–A' FROM CRITTENDEN COUNTY, ARK., TO FAYETTE COUNTY, TENN.



SECTION B–B' FROM DE SOTO COUNTY, MISS., TO FULTON COUNTY, KY.



SECTION C–C' FROM PEMISCOT COUNTY, MO., TO HENRY COUNTY, TENN.

GEOPHYSICAL-LOG CORRELATIONS, SECTIONS A–A' TO C–C', IN WESTERN TENNESSEE AND ADJACENT AREAS

SCALE 1:500 000

10 0 10 20 30 MILES

10 0 10 20 30 KILOMETERS

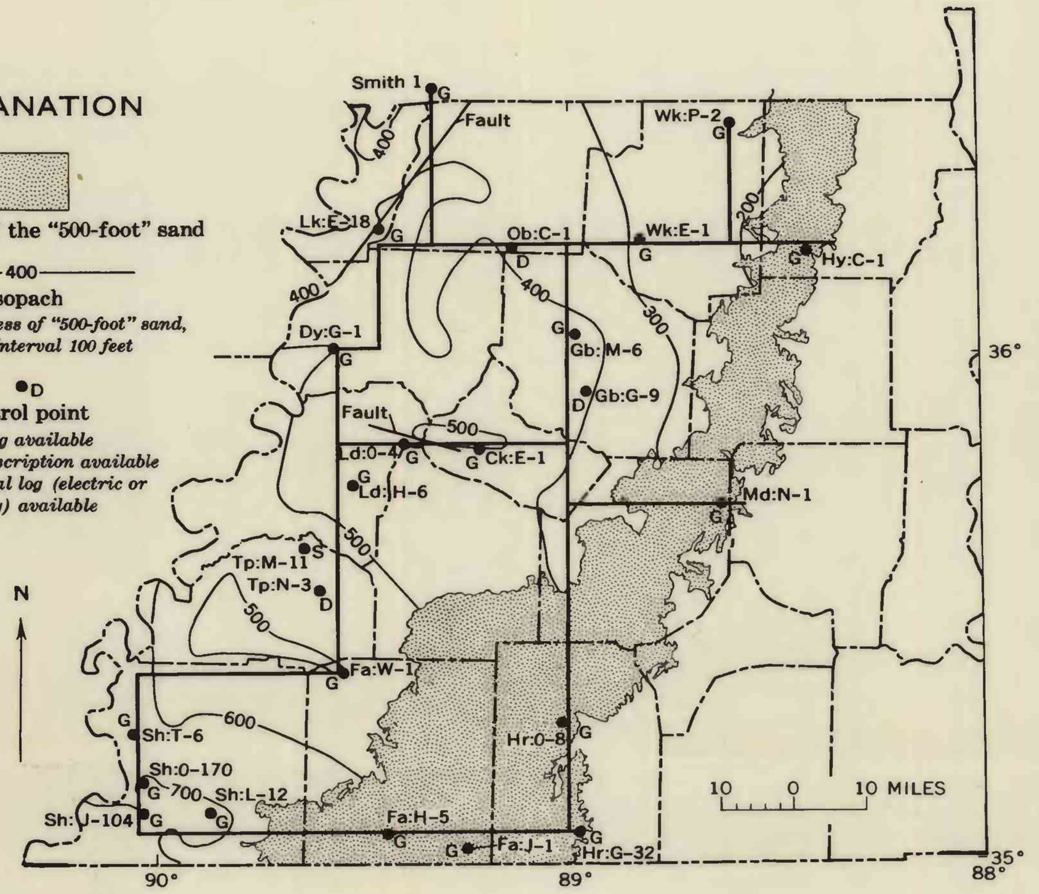
768-379 O - 65 (In pocket)

EXPLANATION

Outcrop area of the "500-foot" sand

——400——
Isopach
Showing thickness of "500-foot" sand, in feet. Interval 100 feet

●D
Control point
D, Drillers log available
S, Sample description available
G, Geophysical log (electric or gamma-ray) available



ISOPACH MAP OF "500-FOOT" SAND SHOWING SECTION LINES OF FENCE DIAGRAM

EXPLANATION

Formations younger than "500-foot" sand

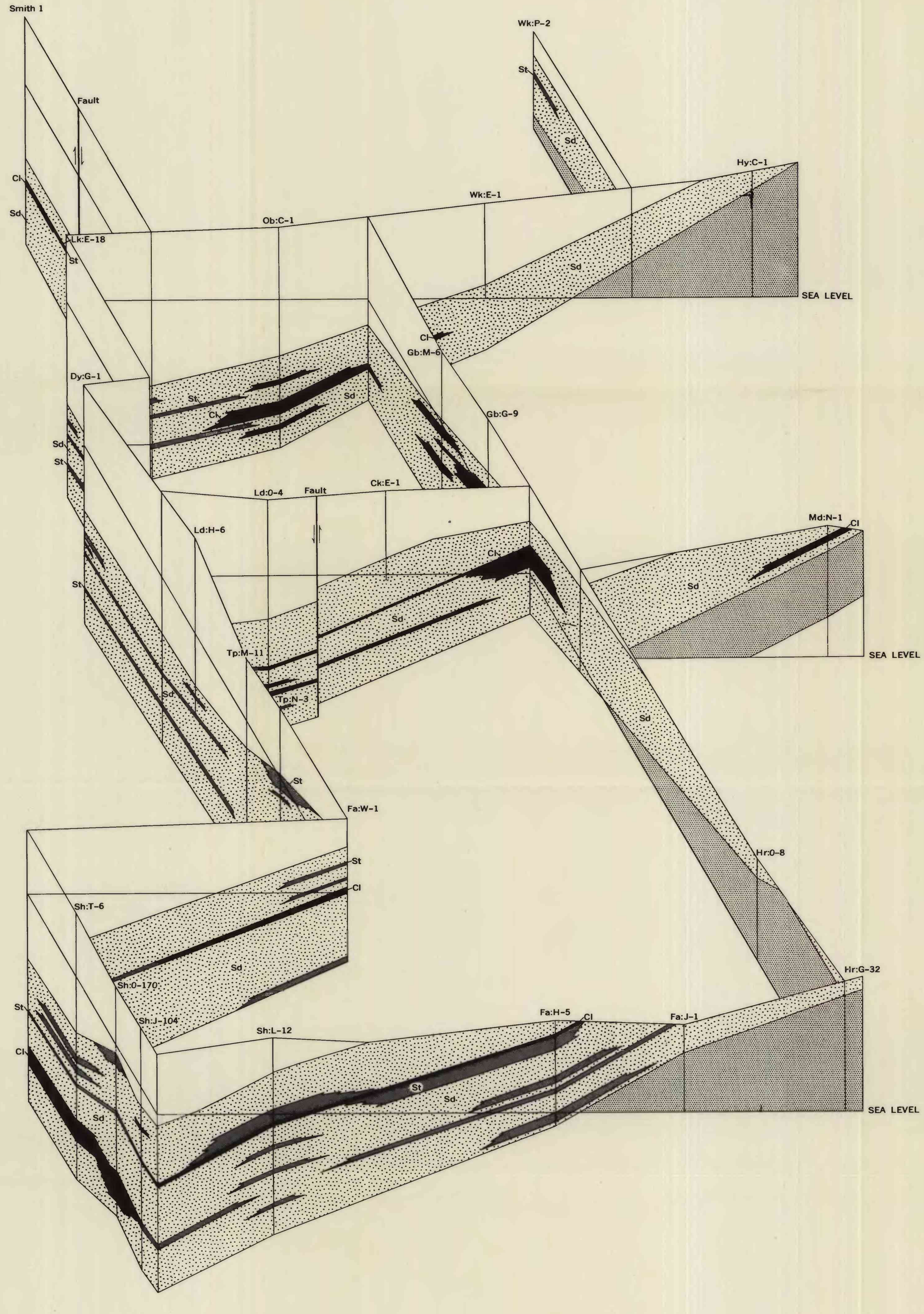
Sd — Sand

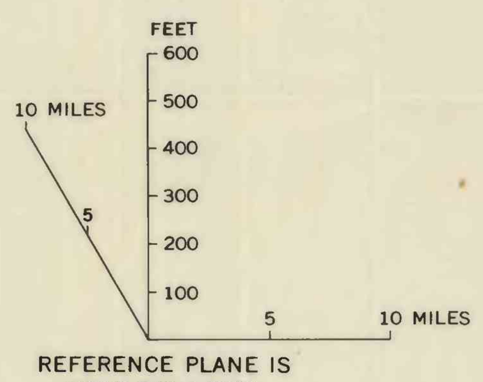
St — Silt

Cl — Clay

Lithologies in the "500-foot" sand

Formations older than "500-foot" sand





FENCE DIAGRAM AND ISOPACH MAP OF THE "500-FOOT" SAND IN WESTERN TENNESSEE

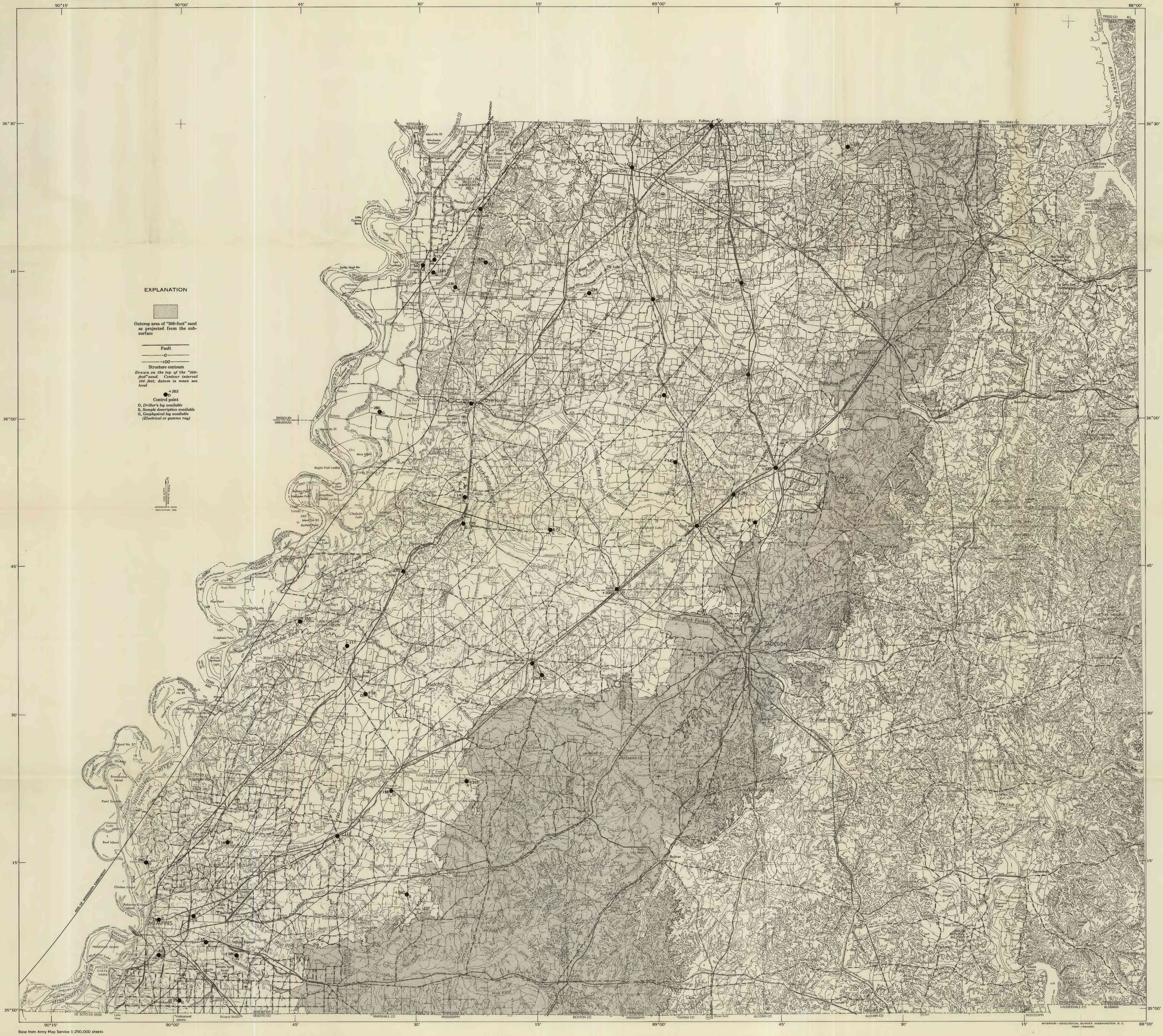
768-379 O - 65 (In pocket)

STRUCTURE-CONTOUR MAP SHOWING CONFIGURATION OF THE BASE OF THE "500-FOOT" SAND IN WESTERN TENNESSEE

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS



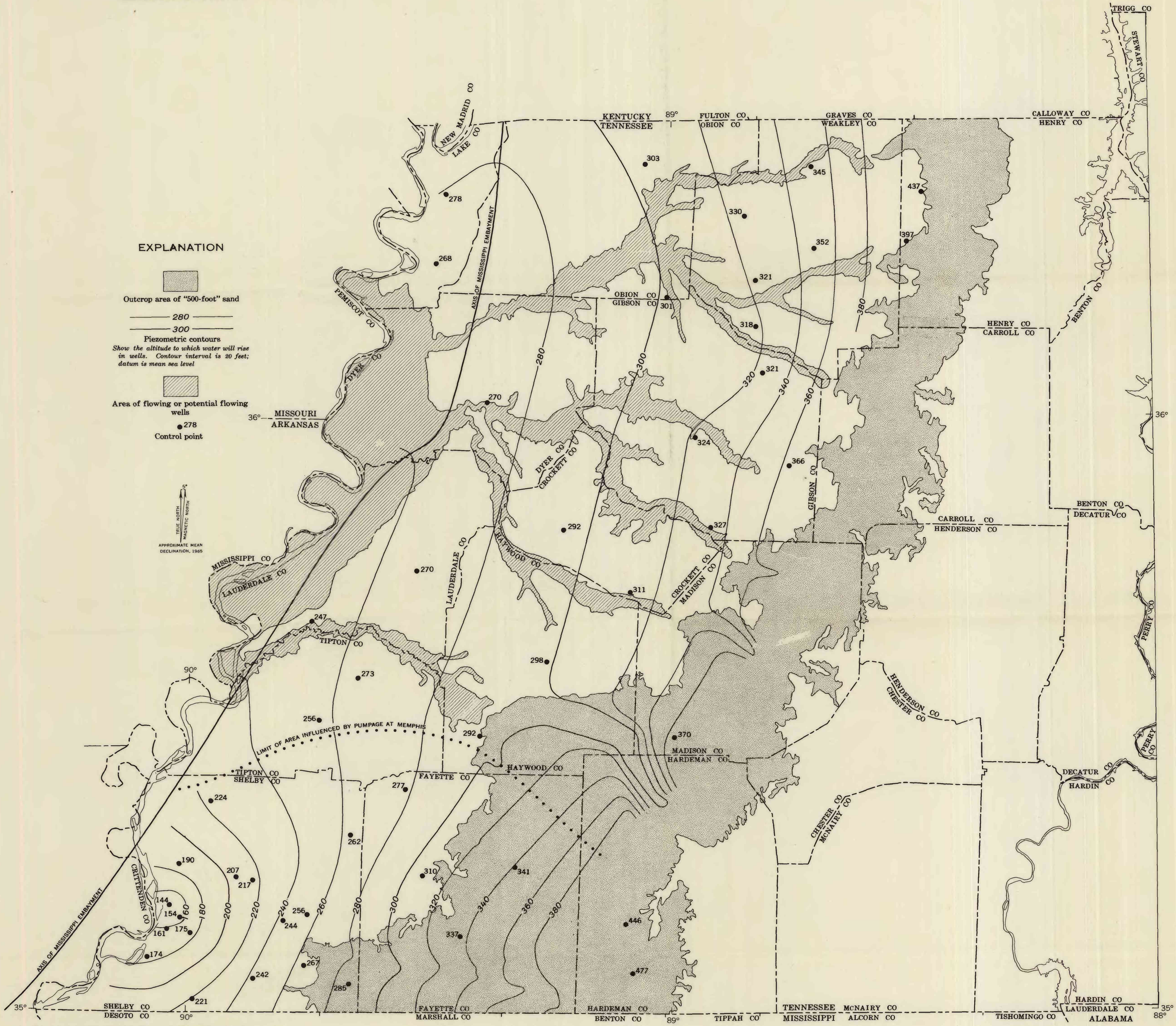
Base from Army Map Service 1:250,000 sheets

STRUCTURE-CONTOUR MAP SHOWING CONFIGURATION OF THE TOP OF THE "500-FOOT" SAND IN WESTERN TENNESSEE

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS



Base adapted from Army Map Service 1:250,000 quadrangles

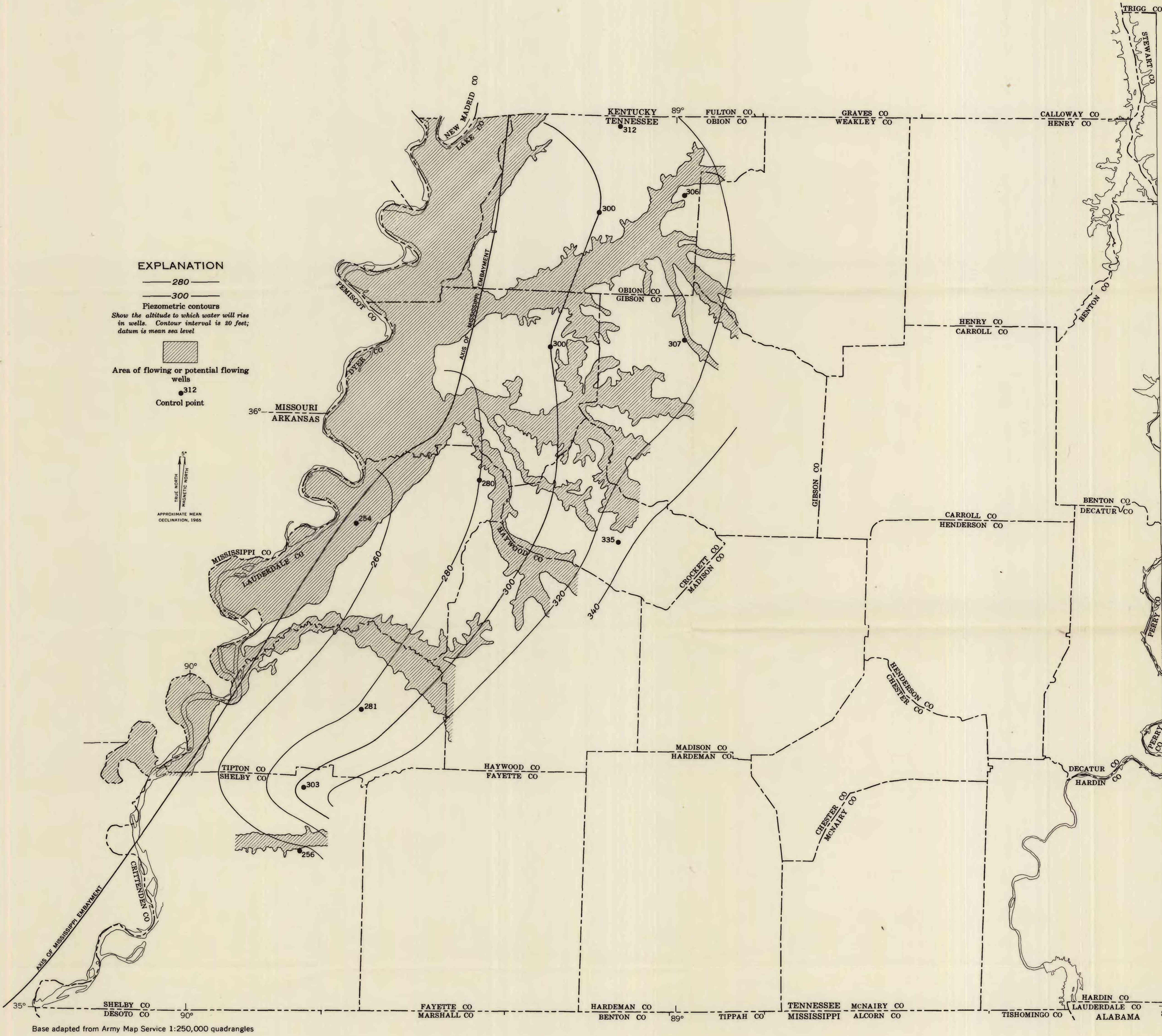
CONTOUR MAP OF THE PIEZOMETRIC SURFACE OF THE "500-FOOT" SAND IN WESTERN TENNESSEE, JANUARY 27-29, 1960

SCALE 1:500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

768-379 O - 65 (In pocket)



Base adapted from Army Map Service 1:250,000 quadrangles

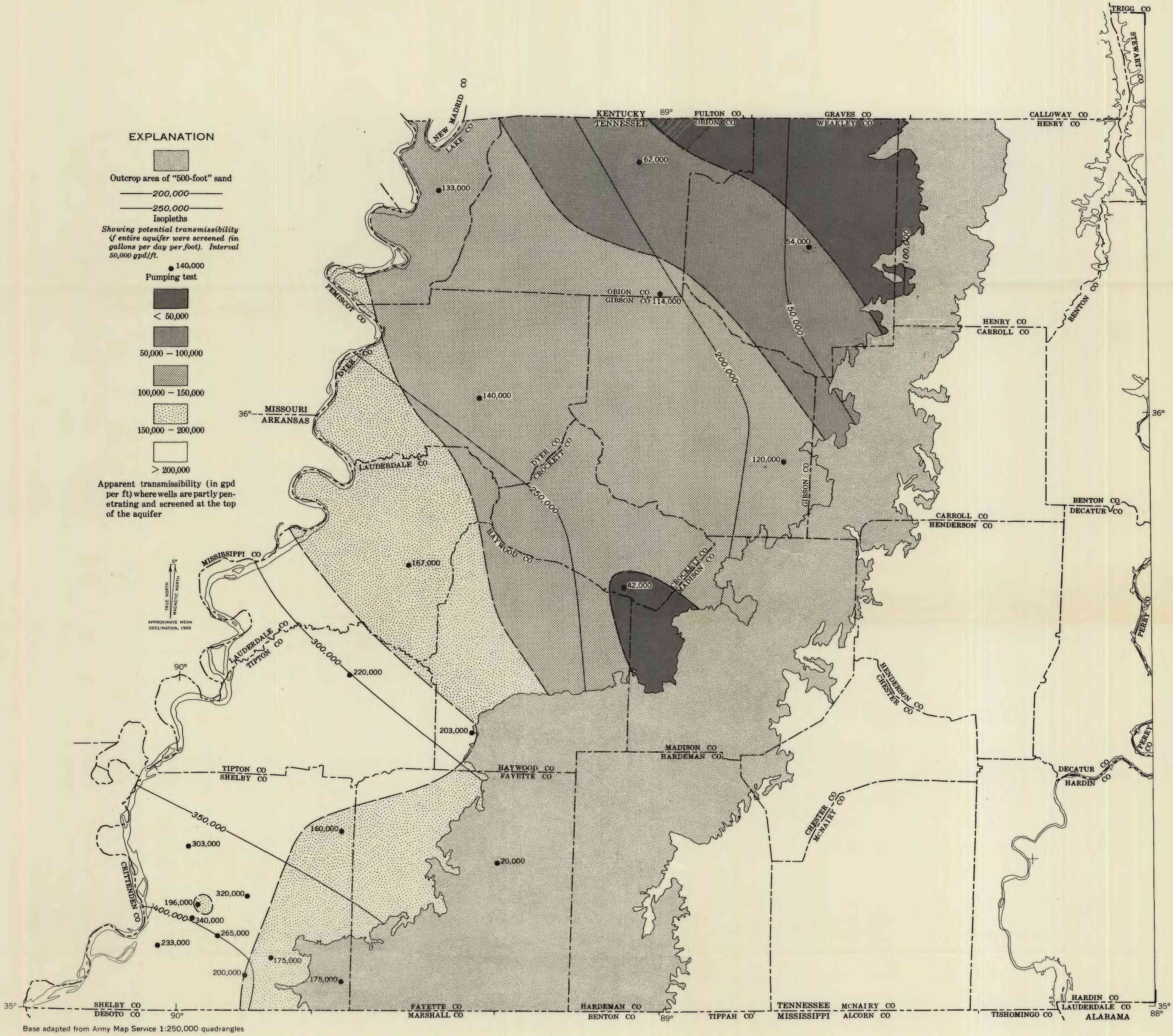
CONTOUR MAP OF THE PIEZOMETRIC SURFACE OF THE UNNAMED SAND UNIT IN WESTERN TENNESSEE, JANUARY 27–29, 1960

SCALE 1:500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

768-379 O - 65 (In pocket)



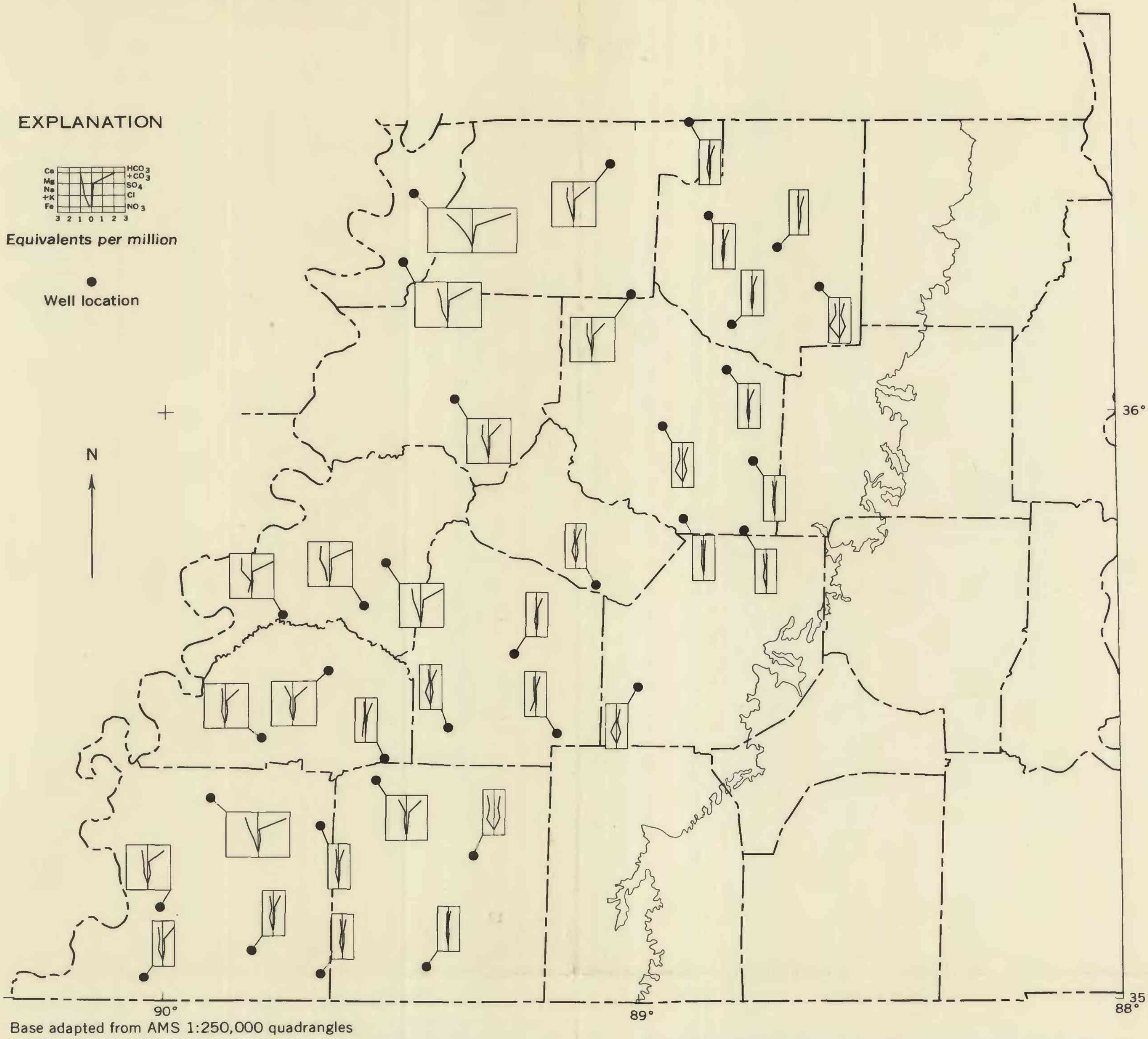
MAP SHOWING APPARENT AND POTENTIAL COEFFICIENTS OF TRANSMISSIBILITY IN THE "500-FOOT" SAND IN WESTERN TENNESSEE

SCALE 1:500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

768-379 O - 65 (In pocket)



MAP SHOWING DOWNDIP CHANGES IN CHEMICAL QUALITY OF WATER IN THE "500-FOOT" SAND IN WESTERN TENNESSEE

10 0 10 20 30 MILES

10 0 10 20 30 KILOMETERS

768-379 O - 65 (In pocket)