Hydrologic Significance of the Lithofacies of the Sparta Sand in Arkansas Louisiana, Mississippi and Texas

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GEOHYDROLOGY OF THE CLAIBORN GROUP

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HYDROLOGIC SIGNIFICANCE OF THE LITHOFACIES OF THE SPARTA SAND IN ARKANSAS LOUISIANA, MISSISSIPPI, AND TEXAS

By J. N. Payne

ABSTRACT

The study of the geohydrology of the Sparta Sand is the initial phase in the investigation of the geohydrology of the Claiborne Group.

The thicker sections of the Sparta Sand lie along the axes of the Mississippi embayment and Desha basin. The area of maximum thickness, 1,100–1,200 feet, is in Claiborne and Warren Counties, Miss., and Madison Parish, La. Local thickening or thinning over some structures indicates structural movement during Sparta time.

A sand-percentage map prepared from data derived from interpretation of electric logs indicates that the Sparta Sand was deposited as a delta-fluvial plain complex in Arkansas, Louisiana, and Mississippi. This complex shows a text-book example of a well developed channel pattern. The delta–fluvial-plain complex probably resulted from an ancestral Mississippi River system. In most of Texas the sand-percentage map shows a pattern suggestive of offshore or near-shore bar deposition. A map of the maximum sand-unit thickness shows the development during deposition of an interlacing channel pattern in Arkansas, Louisiana, and Mississippi. In the channel areas the maximum thickness of the sand units may be as much as 350 feet; in the interchannel areas the maximum thickness is generally less than 50 feet.

Coefficients of permeability and transmissibility for the Sparta Sand vary widely in localized areas. In the channel-sand area of Arkansas, Louisiana, and Mississippi, data suggest that the coefficient of permeability increases with an increase in maximum sand-unit thickness. These permeability values which depend on sand unit thicknesses, were used to prepare a map showing the transmissibility of the total sand thickness of the Sparta Sand in Arkansas, Louisiana, Mississippi, and eastern Texas. The data on the map show a close relation between channel development and high transmissibility values.

The Sparta Sand is recharged by infiltration of water from precipitation on the outcrop, by leakage from other aquifiers, and by seepage from streams. Natural discharge from the Sparta Sand takes place primarily by leakage through the overlying and underlying confining beds. In Texas, west-central Louisiana, and southeastern Mississippi the direction of flow of ground water is down the regional dip toward the gulf coast geosyncline. In most of Arkansas, Louisiana, and Mississippi the regional flow is toward the Mississippi River alluvial valley. In the channel-sand area of Arkansas, Louisiana, and Mississippi the ground-water flow is governed by changes in transmissibility, which in turn reflects the lithology.

A study of the ground-water chemistry indicates that the areas of higher transmissibility have lower concentrations of dissolved solids than the areas of low transmissibility. On the basis of anion ratios, the waters of the Sparta Sand are grouped into three chemical provinces: the bicarbonate water province, the chloride water province, and the sulfate water province. The dissolved-solids content of waters from the Sparta Sand is closely related to the lithologic framework of the Sparta Sand area. Differences in water chemistry are attributed to regional differences in the rates of ground-water movement. Interpretation of the data suggests that the channel deposits have undergone a higher degree of flushing by fresh water than the interchannel deposits.

INTRODUCTION

PURPOSE AND SCOPE

Abundant electric-log and hydrologic data on the gulf coast area of the United States are available for study and analysis to aid in understanding the relations between hydrologic and geologic factors and delineating the potential for ground-water development. The relations between hydrologic and geologic factors in aquifers can more accurately indicate the ground-water potential if they are studied on a regional basis. Therefore, a study of the formations of the Claiborne Group of Eocene age was begun in early 1961. The initial phase of this study describes and evaluates the relations of stratigraphy, structure, facies development, and depositional controls to the hydraulic characteristics of the Sparta Sand in parts of Arkansas, Louisiana, Mississippi, and Texas (fig. 1). Similar reports will be prepared for the Cockfield and Cane River Formations.

Both electric-log data on oil and gas wells and on test wells and hydrologic data were used to prepare the geologic and hydrologic maps. The electric-log analysis was initiated in areas of dense drilling where extremely close control was available, and was then expanded systematically by running closed traverses of logged sections into less densely drilled areas. Where possible the lithologic interpretation of these sections was veri-

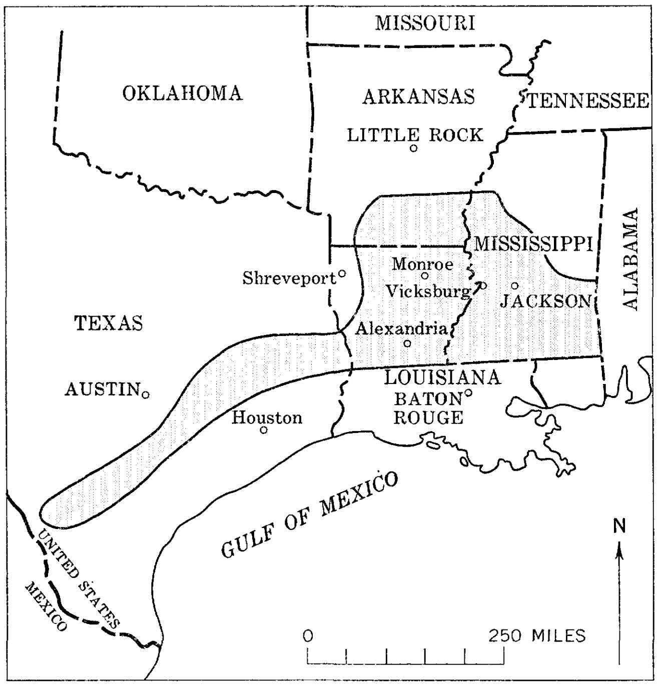

FIGURE 1.—Location of report area.

fied by studies of cuttings or core descriptions along with stratigraphic sections from nearby outcrops. This method reduces the possibilities of making gross errors in correlation and interpretation. The pattern of lithologic variability was mapped from the electric-log interpretations and was used in the preparation of other geologic, hydrologic, and geochemical maps.

The maps accompanying this report are the principal products of the study, and the discussion is merely an elaboration of the data on the maps. Consequently, frequent reference to the maps is necessary for complete understanding.

ACKNOWLEDGMENTS

Acknowledgment is made to the Louisiana Geological Survey, Department of Conservation; the Arkansas Geological Commission; the Texas Water Commission; and the Mississippi Oil and Gas Board for making available their log files. Acknowledgment is also made to the personnel of the district offices of the Water Resources Division of the U.S. Geological Survey in Arkansas, Louisiana, Mississippi, and Texas for supplying hydrologic and geologic information and for making many helpful suggestions and criticisms.

GEOLOGY

The Sparta Sand (Vaughan, 1895, p. 225–226, 1896, p. 25–26; Spooner, 1926, p. 236–237) consists of varying amounts of sand interstratified with silt, clay, and shale, and minor amounts of lignite. The sand is composed almost entirely of rounded to subrounded fine to medium quartz grains and is generally well sorted. There are a few layers of coarse sand and fine gravel (Brown, 1947, table 2, p. 60–64; Jones and Holmes, 1947, table 3, p. 37–38; Hewitt and others, 1949, p. 14). Glauconite, though fairly uncommon, occurs in sands at various stratigraphic positions in the formation, particularly in the upper part (Andersen, 1960; Bornhauser, 1947; Brown, 1947; DeVries and others, 1963; Harvey and others, 1961; Hewitt and others, 1949; Sellards and others, 1932, p. 651; Wendlandt and Knebel, 1929). The shales and clays are typically sandy to silty and gray to dark brown or black depending on the amount of included carbonaceous material.

The correlations of the Sparta Sand as used in this report are shown in the sections through Texas, Louisiana, Mississippi, and Arkansas (pls. 1, 2). As these correlations are based primarily on electrical characteristics, they may not correspond exactly to formational boundaries that might be established by paleontological evidence, but they do define what may be considered as the Sparta hydraulic system and give a consistent interval for the calculation of sand content of the system.

STRUCTURE

The structure of the Sparta Sand is shown by a contour map (pl. 3) of the base of the formation. As this study is concerned primarily with the regional geology and hydrology, faulting has been ignored except where elevation changes are so great and so abrupt that a fault must exist, as in Bienville and Winn Parishes, La., and in Nevada and Ouachita Counties, Ark.

In south-central and southwestern Arkansas and north-central and northwestern Louisiana, the regional dip is to the east and southeast at 25–50 feet per mile toward and into the Mississippi embayment and the Desha basin. In southeastern Arkansas and north-central Mississippi the dip is to the south, southwest, and west at about the same rate into these same structures. In south-central Louisiana and southern Mississippi the influence of the gulf coast geosyncline is dominant, and the regional dip is generally to the south at 50–100 feet per mile. In Angelina, Jasper, Newton, Sabine, San Augustine, and Tyler Counties, Tex., the regional dip is to the south and south-southwest at about 100 feet per mile from the Sabine Arch into the gulf coast geosyncline and the east Texas syncline. From Houston County, Tex., southward to Webb County, Tex., the regional dip is to the southeast at 150–200 feet per mile into the gulf coast geosyncline.

The major structural features that developed considerably during Sparta time are the Mississippi embayment, Desha basin, Sabine arch, and Jackson dome, and, to a lesser extent, the Monroe uplift and the LaSalle arch. These developments are indicated by the thickening or thinning of the Sparta over these structures. The downwarping of the Mississippi embayment during Sparta and post-Sparta time is shown by the marked steepening of the dip on the basinward flanks of Jackson dome and similar structures. Minor structural features are associated with the Tinsley oil field, Yazoo County, Miss., the Madisonville oil field, Madison County, Tex., and other oil fields and a number of salt domes (pls. 3, 4). Faulting such as is shown on pl. 3 occurred throughout the gulf coast area.

THICKNESS

The thickness of the Sparta Sand generally exceeds 800 feet along and near the axes of the Mississippi embayment and the Desha basin in southeastern Arkansas, eastern Louisiana, and western Mississippi (pl. 4). The maximum thickness, 1,100–1,200 feet, occurs in Claiborne and Warren Counties, Miss., and Madison Parish, La. Eastward from the axes of the Mississippi embayment and Desha basin, the Sparta Sand thins rapidly to only 250–300 feet in central and east-central Mississippi and 100–150 feet in southeastern Mississippi. Westward from the axes the thinning is more gradual; the Sparta is 400–600 feet thick in south-central and southwestern Arkansas and central and west-central Louisiana (pl. 4, sheet 1). In eastern Texas the formation generally is 300–500 feet thick, but it thins to 100–200 feet in Fayette and Gonzales Counties and maintains a rather constant thickness of 100–150 feet to the southwestern extremity of the area mapped in Webb County, Tex. (pl. 4, sheet 2).

Local variations in thickness are common and in some places pronounced, as in the Jackson, Miss., area. The more obvious of these variations are associated with localized structural features which were developing during the period of Sparta deposition. Such structures are the Jackson and Tinsley domes of Mississippi, parts of the Monroe uplift in Morehouse and Ouachita Parishes, La., and Sharkey County, Miss., and the Desha basin in Drew and Lincoln Counties, Ark. Variations associated with structural growth are less pronounced over some of the oil-field structures in southern Ouachita, southern Bradley, and northern Union Counties, Ark., and in Madison County, Tex. Additional examples of local variations in thickness can be found by comparing the thickness map of the Sparta Sand with oil and gas maps. Some local variations in thickness of the Sparta result from cut and fill channels at the base of the Sparta that penetrate the upper part of the Cane River Formation, and from differential compaction of shales and clays surrounding massive sand bodies or areas containing a high percentage of sand. Such variations in thickness are generally indiscernible on maps drawn on a regional scale. However, some of the thick elongated areas in Madison, Richland, and Tensas Parishes, La., and Jefferson County, Miss., may result from differential compaction or from downcutting.

LITHOLOGIC VARIATIONS AND INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

The lithology of the Sparta Sand is highly variable both vertically and laterally. Predominantly sandy sections grade into predominantly shaly sections within very short distances (pls. 1, 2, 4). A good method of creating some order from such variability is to prepare a sand-percentage map on which the ratio of the thickness of sand in the formation to the thickness of the formation is expressed as a percentage; that is:

$$\text{Sand percentage} = \frac{\text{total thickness of sand}}{\text{total thickness of formation}} \times 100.$$

The values calculated for each logged section can then be plotted on a map and grouped by appropriate percentage increments. This method was used in the preparation of the sand-percentage map (pl. 4) of the Sparta Sand using increments of <10 percent, 10–30 percent, 30–50 percent, 50–70 percent and >70 percent. As previously mentioned, this work was begun in areas of good control, where the percentage values formed definable patterns that could reasonably be extended into areas of less control.

On the basis of the distribution of sand-concentration patterns, the Sparta can be divided into two areas which seem to have had different depositional environments. One area includes Louisiana, Mississippi, southern Arkansas, and eastern Texas, and the other extends from Grimes to Webb Counties, Tex.

Louisiana, Mississippi, southern Arkansas, and eastern Texas.—The most conspicuous characteristic of the lithologic pattern of the southern Arkansas–Louisiana–Mississippi–eastern Texas area is the well-developed lineation of sand concentrations in a general northerly direction, presumably normal to the orientation of the Sparta shoreline. The pattern of sand distribution in this area was probably created by a system of anastomosing, constantly shifting stream channels and interlacing lakes, marshes and swamps such as would be developed in a large deltaic-fluvial plain. The frontal edge of this large arcuate former delta extends from Wayne County, Miss., southwestward through southeastern Louisiana probably as far as northern Pointe Coupee, St. Landry, and Allen Parishes, and thence west-northwestward into Sabine County, Tex. This delta represents the record of an ancestral Mississippi River system that existed probably in Sparta and possibly in much of Claiborne time. The channel deposits in Houston, Madison, and other counties in east Texas probably represent smaller streams. This interpretation conforms with the ideas of earlier investigators who did surface work in smaller areas (Spooner, 1926; Huner, 1939).

Although the Sparta Sand is predominantly of continental origin in the delta area, brief local invasions of the sea repeatedly covered low-lying areas of the land mass, particularly during later Sparta time. These invasions are indicated by the fossiliferous and glauconitic sand and shale beds in the Sparta (Andersen, 1960, p. 87–88; Chawner, 1936, p. 72; DeVries and others, 1963; p. 14; Harvey and others, 1961, tables 7, 8, and 9; Hewitt and others, 1949, p. 11–14; Huner, 1939, p. 83; Jones and Holmes, 1947, p. 14; Maher and Jones, 1945, p. 40–41; Spooner, 1926, p. 236; Wang, 1952, p. 56–58).

Regionally, the numerous long meandering areas that contain at least 50 percent sand represent "flow-ways," which remained areas of channel development throughout most of Sparta time. (Compare pls. 4 and 6.) Such an area extends from Drew County, Ark., through western Ashley County, Ark., western Morehouse Parish, La., and southward into western Franklin Parish, La. These areas were the sites of channel formation at different times during the deposition of the Sparta and are similar to the channel-development areas along the present courses of the Ouachita and Mississippi Rivers and other streams (Fisk, 1944, pl. 2). The associated areas that contain less than 50 percent sand probably represent interchannel swamp, marsh, and lake areas where the finer detritus and vegetal material accumulated. Large water supplies can be developed in the areas that contain at least 50 percent sand.

In areas of sparse drilling, future development of closer control should show a greater degree of lateral variability than is shown by present maps. However, the general pattern of channel deposition will probably remain, and any revisions will be significant only in specific and detailed local studies.

Regionally, the sand content of the Sparta generally decreases from southern Arkansas, northern Louisiana, and northern and central Mississippi southward toward the margins of the delta (pl. 4). This decrease is probably accompanied by an increase in the occurrence of marine interbeds as the area of marine environment is approached (Bornhauser, 1950, p. 1892).

Central and southern Texas gulf coast.—The channel pattern that is so conspicuous in Arkansas, Louisiana, and Mississippi and less conspicuous in eastern Texas is not apparent in the area from Grimes County to Webb County, Tex. In this area the long axes of the sand-concentration patterns and the sand bodies are parallel to, rather than normal to, the postulated Sparta strand line. Another point of contrast between the two areas is the distance from the outcrop area to the limits of continuous sand deposition, sometimes called the "shale-out" line. If measured normal to the regional dip in Louisiana, the distance generally ranges from 50 to 200 miles; in the area from Grimes County to McMullen County, Tex., the distance generally ranges from 14 to 50 miles. This difference is accounted for not only by differences in degree of regional dip and thickness of the Sparta but also by more extensive sand deposition in the delta area.

The thickness characteristics of the Sparta Sand also differ in the two areas. From Grimes County southwestward the thickness is uniform, but in Arkansas, Louisiana, and Mississippi it is extremely variable. An interpretation of the orientation of the sand bodies parallel to the strand line, the constant thickness of the Sparta interval, and the distance from the outcrop to the "shale-out" line all suggest that the subsurface Sparta sands in the central and southern gulf coast region of Texas are predominantly near-shore bar and beach deposits rather than fluviatile deposits as in outcrop areas in Louisiana (Spooner, 1926, p. 236–237; Huner, 1939, p. 76–82). This interpretation is supported by Sparta–Stone City relations in Leon County, Tex. (Stenzel and others, 1957, p. 20), where the nonfossiliferous continental beds of the Sparta interfinger with, and grade upward into, the fossiliferous marine beds of the Stone City of Stenzel (1938). This suggests that the strand line was near. The interpretation is further supported by Sellards, Adkins, and Plummer's (1932, p. 654) description of the Sparta Sand.

MAXIMUM SAND-UNIT THICKNESS

A study of electric logs indicated that a map of the thickness of the thickest vertically continuous sand body—for convenience, designated the maximum sand-unit thickness (pl. 5)—of the Sparta Sand would aid in better understanding the mode of deposition, more accurately locating channel paths, and understanding some of the variations in hydraulic characteristics. In general, the maximum sand-unit thickness map (pl. 6) is similar to the sand-percentage map; thick sand bodies usually occur in areas in which the total percentage of sand is high. However, there are several exceptions where individual units more than 100 feet thick extend into areas where sand percentage values are low (30–40 percent). In some areas the sand concentration may be 50 percent or more and the maximum sand-unit thickness may be only 30–50 feet. The maximum sand-unit thickness is a major factor in the evaluation of the potential ground-water supply. (See discussion on permeability and transmissibility.)

Louisiana, Mississippi, southern Arkansas, and eastern Texas.—The axes of thickening of the maximum sand units in Arkansas, Louisiana, Mississippi, and eastern Texas (pl. 6, sheet 1) have been plotted to aid in reading the map. These axes also emphasize the interlacing channels that are similar to the meander patterns of present-day streams in areas of heavy alluviation (Fisk, 1944, pl. 2). Within the channel areas the maximum sand units range from 100 to 350 feet in thickness, but in the interchannel areas they generally range from 10 to 50 feet. Maximum sand units 100 feet or more thick may coalesce or diverge, and as entities they are generally of limited aeral extent, but the effect of overlap gives almost continuous interconnection for fluid flow (pl. 5). These thick sand bodies can be traced for several miles parallel to the channel axes (section D–D′), but normal to this direction they are of limited aeral extent (section C–C′). They may occur at any stratigraphic position in the Sparta, but most are in the lower two-thirds of the section.

Central and southern Texas gulf coast.—From Grimes County, Tex., southwestward, the axes of thickening of maximum sand units are not long (pl. 6, sheet 2) and are normal to the regional dip. The limited extent and the orientation of the maximum sand units are not conducive to extensive downdip migration of fresh water.

HYDROLOGY

The Sparta Sand is one of the major sources of ground water in southern Arkansas, northern and north-central Louisiana, western and central Mississippi, and eastern Texas as far west as Burleson County. Large quantities of soft water of low dissolved-solids content (pls. 7, 9; table 1) are available from the Sparta throughout much of this area. However, from Burleson County southwestward in Texas the Sparta Sand is of minor importance as an aquifer because it contains fresh water only in a small area, yields are low, and the water is hard and has a high concentration of dissolved solids (pl. 9; table 1).

When considering the Sparta Sand as an aquifer, one must realize that the aquifer system is made up of several imperfectly connected sand bodies, any one of which may act locally, and for short periods of time, as a separate hydraulic unit. Over longer periods of time and larger areas, these units act as an integral part of the unified Sparta hydraulic system and ultimately form an element of the regional hydrologic system of the gulf coast.

PERMEABILITY [1] AND TRANSMISSIBILITY [2] IN RELATION TO GEOLOGIC FACTORS

Because of the variable lithologic framework of the Sparta, permeability values differ greatly within small areas. For example, the field coefficient of permeability determined from pumping tests in northeastern Ouachita and southwestern Morehouse Parishes ranges from 130 to 890 gpd per sq ft (gallons per day per square foot) in a distance of about 6 miles. In a number of places the permeability of the same sand bed may vary as much as 200–300 gpd per sq ft within 1 mile.

Notable local variations in transmissibility occur in the Jackson area, Hinds County, Miss., in eastern Winn Parish, La., and in southwestern Ashley County and northwestern Desha County, Ark., where the differences in transmissibility of the total sand thickness of the Sparta Sand are as much as 200,000 gpd per ft (pl. 7).

The relations of permeability and porosity to such factors as grain size, grain shape, arrangement, sorting, and packing were summarized by Meinzer (1923, p. 2–28, 63) and Pettijohn (1957, p. 81–89). Permeability and transmissibility are directly related to the lithologic variations of the Sparta Sand and, thus, are indirectly related to its mode of deposition. The direct relations are major factors in the consideration of the hydraulic characteristics of the formation.

In the channel area of Arkansas, Louisiana, and Mississippi, high coefficients of permeability do not necessarily occur in areas in which the percentage of sand is high. These high coefficients of permeability are usually in areas where the maximum sand-unit thickness is greater than 100 feet. Therefore, the maximum sand-unit thickness may be related to the coefficient of permeability of the sand. Coefficients of permeability determined from pumping tests and specific-capacity tests of wells were compared with the thickness of the sand section in which the well was screened. Sufficient data are lacking to reach any firm conclusions, but the comparison strongly indicates that the coefficient of permeability varies directly with the sand thickness. Such a relation is reasonable for sands deposited in channels because the thicker sand units would lie along the lines of persistent flow where velocities would be higher than in the marginal areas. Therefore, the sand in the thicker units would be cleaner, generally better sorted, and

[1] The coefficient of permeability is defined as the rate of flow of water, in gallons per day, through a cross-sectional area of the aquifer 1 foot square under a hydraulic gradient of 100 percent, or 1 foot per foot, at a temperature of 60°F (Meinzer and Wenzel, 1942, p. 452).

[2] Transmissibility of an aquifer is expressed (Bredehoeft, 1964, p. D168) as:

$$T=\Sigma K_i M_i$$

where

$i=1, 2, 3 \ldots n$ layers of differing permeability,
T=transmissibility,
K_i=permeability of the i layer,
M_i=thickness of the i layer.

somewhat coarser than that in the thinner units along the margins of the channel. The correlation between permeability and maximum sand-unit thickness is sufficiently good to warrant the use of different average permeabilities for sand bodies of different thicknesses in calculating transmissibility, rather than an overall average of the coefficients of permeability. Fifty-foot categories of sand-unit thickness were selected; the average coefficient of permeability for each category is as follows:

Sand thickness (ft)	*Average coefficient of permeability (gpd per sq ft)*
≦50	[1] 225–250
51–100	[1] 325–350
101–150	[1] 450–500
≧151	600

[1] The higher values were used in parts of Arkansas and Mississippi where available data indicate a generally higher coefficient of permeability than in Louisiana.

These coefficients of permeability were then used to calculate the transmissibility of the total sand thickness of the Sparta sands. The thickness of sand within each of the 50-foot categories was multiplied by the appropriate average coefficient of permeability, and the products were added to obtain the transmissibility of the total sand thickness at each location. The results were then used to prepare a map showing the transmissibility of the Sparta Sand in the channel sand area of Arkansas, Louisiana, and Mississippi (pl. 7).

The use of the different average coefficients of permeability for different thicknesses of sands seems to give a more realistic coefficient of transmissibility than the use of an overall average value. A simple example will illustrate the differences that may occur in using the two approaches. Assume that we have a total sand thickness of 300 feet, composed of 2 sand units 150 feet thick near well A and 10 sand units 30 feet thick near well B. using the variable permeability values we get a transmissibility value of 135,000 gpd per ft. ($150 \times 450 \times 2$) near well A and a transmissibility of 67,500 gpd per ft. ($30 \times 225 \times 10$) near well B. If an overall average is used, the same transmissibility value is obtained for both wells A and B. The latter approach not ony disagrees with the results from pumping tests but also with certain chemical data. (See section on quality of water.)

The close relation between channel sand thickness and higher transmissibility values is illustrated by comparing plates 6 and 7. Certain minor deviations of maximum transmissibility and maximum sand-unit thickness occur because of inherent properties of the maximum sand-unit thickness map. Only the value for the thickest sand unit in any given section is shown on the maximum sand-unit thickness map (pl. 6). This value may be satisfactory for calculating transmissibility where only one massive sand unit occurs, but frequently several massive sand units of equal or nearly equal thickness are present in the section (pl. 5). This obviously causes differences in the transmissibility and maximum sand-unit thickness maps (pls. 6 and 7).

The foregoing discussion of the relation between sand-unit thickness and the coefficients of permeability and transmissibility in stream-channel deposits does not apply to offshore bars, beach bars, and dune sands, where the agents and mechanics of deposition are different. Southwest from Burleson County, Tex., much of the Sparta Sand appears to be of the offshore bar or beach-bar type, but sufficient hydrologic data are lacking for the determination of the relation of the thickness of the beds of sand to coefficients of permeabiilty and transmissibility.

RECHARGE AND DISCHARGE

The Sparta Sand is recharged by direct infiltration in the outcrop area and by leakage from alluvium and from other aquifers with higher heads.

The rainfall is high in Louisiana, Mississippi, and southern Arkansas, and the contribution of water to the Sparta aquifer by direct seepage from streams is therefore negligible because most of the streams serve as drains for ground-water discharge. In Texas, where rainfall is relatively low, the infiltration of water from streams may be appreciable.

Discharge from the Sparta Sand occurs by withdrawal from wells and by natural discharge. The effects of large withdrawals from wells are evident in the Hodge-Jonesboro area, Louisiana, in Jackson, Miss., in El Dorado, Ark., and near Monroe, La. (pl. 8). Natural discharge takes place primarily by leakage from the Sparta Sand through the overlying and underlying confining beds.

REGIONAL FLOW

In a formation having the geologic framework of the Sparta Sand, alternating sand and shale bodies that have an appreciable regional dip, the bulk of the ground water available even in the outcrop area, is confined above and below by relatively impermeable beds.

The flow of water in an artesian aquifer occurs because of the difference in head. In Texas, along the south flank of the Sabine uplift in Louisiana, and in southeastern Mississippi, the direction of flow is generally down the regional dip toward the gulf coast geosyncline. In most of Arkansas, Louisiana, and Mississippi, the major focus of discharge is the Mississippi River alluvial valley. The regional direction of flow is inferred from the water-level contours (pl. 8), the general increase in dissolved-solids content, and the limits of fresh water downdip in the aquifer (pls. 8, 9, 10; fig. 2).

The relation of recharge, discharge, and regional flow to the geology and to the piezometric surfaces is shown in figure 2, which is a generalized section from Bienville Parish, La., to Jasper County, Miss.

In the area shown in figure 2, water from precipitation that falls on the upland areas of the Cockfield and Sparta enters these formations either directly or by downward percolation through surficial material. Within short distances after entering these formations, the water is in an artesian system, as it is confined above and below either by the interbedded shales of the Cockfield and Sparta Formations themselves or by the clays and shales of the associated Cane River and Cook Mountain Formations and Vicksburg and Jackson groups. In the recharge area the piezometric surface in the Cockfield is higher than the piezometric surface in the Sparta. The Cockfield Formation, however, is more accessible to the regional discharge area in the valley; consequently, the piezometric surface in the Cockfield is more steeply inclined than that in the Sparta. Near the discharge area the relative positions of the two piezometric surfaces are reversed. Furthermore, the recharge areas of the Cockfield and Sparta Formations in Mississippi are considerably higher than those in Louisiana; thus, the piezometric surface is generally higher on the east side of the alluvial valley than on the west. Another major factor affecting the regional movement of water in the Cockfield and Sparta Formations is the westward offset of the alluvial valley relative to the structural axis of the Mississippi embayment. Because of this offset and the effects of the Monroe uplift, the depth to the Cockfield and Sparta aquifers in the area of discharge in eastern Louisiana is much less than that in western Mississippi.

With these factors in mind, a reasonable interpretation of the flow pattern in the systems can be made. (See directional arrows in figure 2.) Normally, water moves downdip in the formations, but where the elevation of the water levels in the Cockfield is different from that in the Sparta, the water moves vertically and causes a generalized regional flow pattern as shown in figure 2. The regional flow pattern is similar to that diagrammed and discussed by Le Grand (1964, fig. 4, p. 185). The areas of recharge for the Sparta are between the base of the formation in the outcrop areas and the points of intersection of the Sparta and Cockfield piezometric surfaces on both sides of the Mississippi alluvial valley. (See fig. 2.) The principal area of natural discharge is between the two points of intersection.

Together, the flow components produce a markedly asymmetrical flow pattern that contrasts with the symmetrical structural pattern of the Mississippi embayment. The zone of flushing extends to a much greater depth on the east flank of the embayment than on the west flank. (See pl. 8, fig. 2, and section on quality of water.) The saline-water core, 10,000 ppm (parts per million) dissolved solids, perches on the western limb of the Mississippi embayment. Thus, an updip compo-

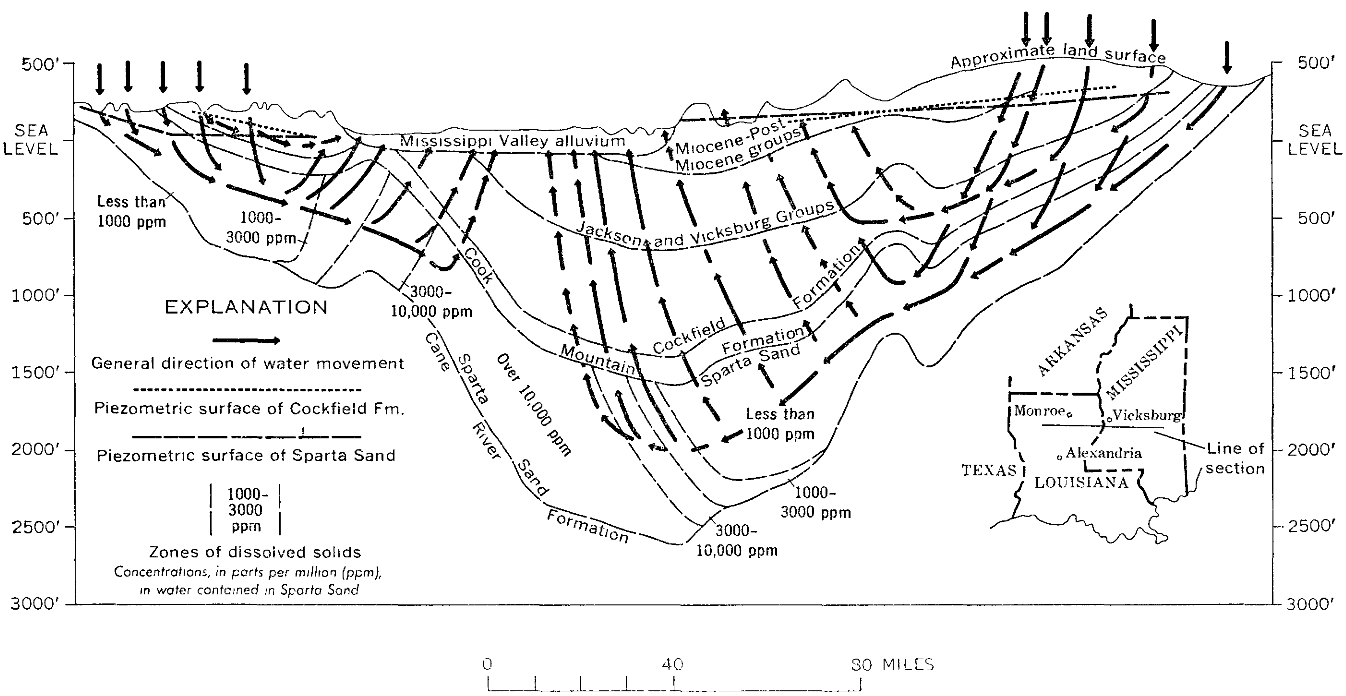

FIGURE 2.—Relation of regional geology and hydrology.

nent of movement exists on the east side of the saline-water core. (See fig. 2.)

This hydraulic system has probably existed since post-Oligocene or pre-Pleistocene time. Repeated fluctuations in sea level accompanied by periods of stream degradation and aggradation and consequent changes in water levels have probably occurred since Sparta time. However, the timespan since the inception of the system is so long that these fluctuations of relatively short duration have left no recognizable marks on the regional pattern. Local effects of pumping on this regional flow pattern have been negligible.

In the channel-sand area of Arkansas, Louisiana, and Mississippi, the rate of flow varies with the lithology. In the high-shale-content areas, the sands form a disconnected or imperfectly connected system where the flow is retarded by an intervening series of shale or silt beds of low permeability. Where the section is predominantly sand, particularly in the channels where massive overlapping sands occur (pl. 5), the slight to moderate reduction in the premeability of the intervening beds does not affect the rate of water movement as much as in the areas where the sand bodies are completely enclosed by shales. Another major factor affecting the regional flow is the orientation of the channel sands with respect to the direction of regional flow. For example, in Claiborne, Union, Morehouse, and Ouachita Parishes, La., channels are oriented in two dominant directions. One trends east-northeast and virtually parallels the direction of regional flow. The other trends north and is nearly normal to the direction of regional flow. (Compare pls. 4, 6, 7, and 8.) In the east-northeast-trending channels the water moves from the recharge area to the discharge area with little restriction by shale or silt barriers, but in the north-trending channels the flow of the water is impeded by the rather extensive shaly areas that lie across the direction of regional water movement. The differences in rate of movement have had, over the period of time involved, a pronounced influence on the degree of flushing, as can be seen by comparing the map of dissolved-solids content (pl. 9) with the map showing the maximum sand-unit thickness and transmissibility (pls. 6, 7). The dissolved-solids content in the channels parallel to flow is appreciably lower than that in the channels normal to flow. In both channel areas the dissolved-solids content is lower than in the adjacent shaly interchannel areas. Similar examples of different degrees of flushing occur throughout the area, particularly in Hinds and Warren Counties, Miss., Union County, Ark., and Houston and Walker Counties, Tex.

The regional flow in the bar-sand area of Texas (pls. 4, 6) is down the dip of the Sparta Sand and is normal to the orientation of the sand beds; therefore, the flow is retarded by the shaly beds. In addition, there is no focal line of discharge similar to the Mississippi alluvial valley. Discharge occurs by slow upward leakage through a thick section of Cook Mountain clays and shales and, in places, a shaly Cockfield section. The results of a study of water levels in Wilson County, Tex. (Anders, 1957, table 6), indicate that the piezometric surface in the Sparta a short distance downdip from the outcrop is higher than that in the overlying Cook Mountain and Cockfield, which indicates that upward leakage from the Sparta starts within very short distances from the outcrop area. Downdip movement is limited by the rapid pinchout of permeable beds of any appreciable thickness (pls. 4, 6). As a result of these factors, downdip flushing of the sands by fresh water has been extremely limited.

Other major factors need further study. Among these are the relations of the lithology of the overlying Cook Mountain and Cockfield Formations to that of the Sparta, the thickness of the Cook Mountain and Cockfield, and the differences in head between the Sparta and the Cockfield. These factors are of particular significance in the area of natural discharge because any factor that increases the discharge will accelerate the movement of water from the recharge area where there is ample supply to counterbalance the loss by discharge. To illustrate the significance of what is implied, let us assume that a predominantly sandy section of the Cook Mountain and Cockfield Formations overlies one of the favorably oriented high-transmissibility channels of the Sparta Sand in the area of discharge into the alluvial valley of the Mississippi River. In such a system an effective conduit would be formed from the area of recharge to the area of discharge. This conduit would allow for an accelerated rate of discharge and a consequent accelerated rate of movement of water, which would result in a more thorough flushing of the Sparta along this flow path than elsewhere in the aquifer.

CHEMICAL QUALITY OF WATER AND RELATIONS TO GEOLOGIC AND HYDROLOGIC FACTORS

The relations of the regional chemical variations of water in the Sparta Sand to geologic and hydrologic factors has been analyzed through the use of available chemical analyses. These data were supplemented by calculations of dissolved-solids content from electric logs to interpret the major regional chemical characteristics of the water.

As a prelude to any discussion of water quality, one must realize that the analyses represent only water from the zone sampled and are not necessarily indicative of the water chemistry in other zones of the Sparta aquifer system. Therefore, in the marginal areas of any particular water province, waters of different types would probably be found in the several sand units that make up the Sparta system. This occurs in the Monroe, La., area, where waters from different sands in the same well have been analyzed (fig. 3).

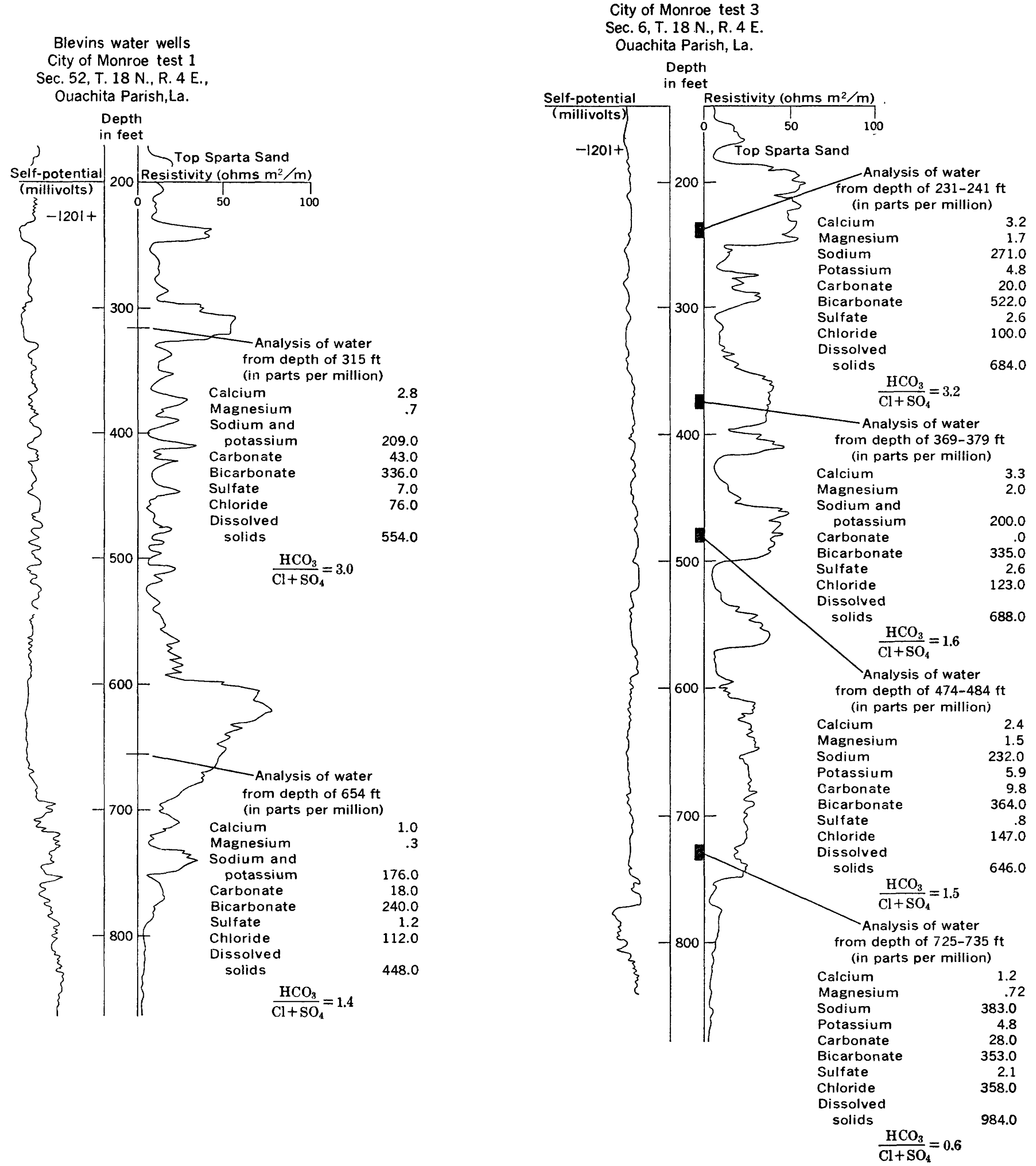

FIGURE 3.—Electric logs of wells and chemical analyses of waters from the Sparta Sand in the Monroe, La., area, showing the variation in major chemical constituents at different stratigraphic positions within the formation.

CHEMICAL PROVINCES

Only the major constituents of the dissolved solids in water from the Sparta (table 1) are considered in this report. Regionally, sodium is the dominant cation. Calcium and magnesium occur in appreciable amounts only in very small areas. The anions, on the other hand, occur in rather well defined provinces. As suggested by Hem (1959, p. 155–156), the following chemical ratios were studied in terms of equivalent parts per million: sulfate : chloride + bicarbonate; bicarbonate : chloride + sulfate; chloride : bicarbonate + sulfate. The resulting values were plotted on a map (pl. 9). Examination of these data showed that the waters of the Sparta can be grouped into three rather well defined chemical provinces—a bicarbonate water province, a chloride water province, and a sulfate water province—on the basis of the relations between the anions.

Bicarbonate water province.—This province is that area where bicarbonate : chloride + sulfate ≧ 1. It covers central and western Louisiana, all but the southeastern part of southern Arkansas, virtually all of Mississippi, and small areas in the updip part of the Sparta in Texas. In the downdip areas, the sands of the Sparta may contain mixed bicarbonate-chloride waters having varying percentages of these anions (fig. 3). Updip from the bacarbonate water–chloride water boundary, toward the recharge area, the bicarbonate anion becomes more and more predominant until it is virtually the only anion present. This is illustrated by a comparison of the analyses for wells LMo–2, LOu–2, LOu–1, LL–1, LL–3, LL–2, MW–1, MW–2, MH–1, and MR–1 (table 1 and pl. 9).

The bicarbonate distribution seems to be a function of rate of water movement and of time. That is, the greater the degree of flushing the greater the proportion of bicarbonate. This relation is indicated by the position of the line where bicarbonate : chloride + sulfate = 1 relative to the limits of fresh water as delineated by the 1,000–ppm minimum-dissolved-solids line on plate 9. The boundary of the bicarbonate water province is, in general, considerably updip from the limit-of-fresh-water line in Louisiana, but in Mississippi the bicarbonate line is generally downdip from, or coincides with, the limit-of-fresh-water line. The relative positions of the bicarbonate and limit-of-fresh-water lines in Louisiana and Mississippi coincide with differences in head in the two States as reflected by the slopes of the piezometric surfaces (pl. 8, fig. 2). The water level in Mississippi is 100–150 feet higher in the recharge area than the water level in a corresponding position in Louisiana. Thus, the steeper hydraulic gradient in Mississippi, aided by the more favorable orientation of many of the high-transmissibility channel areas in relation to the direction of flow, has increased the degree of flushing on the east side of the valley. (See pls. 6, 7, 10.)

Chloride water province.—This province is that area where chloride : bicarbonate + sulfate ≧ 1. In Texas it includes all of the Sparta Sand except for limited areas in, and short distances downdip from, the outcrop (pl. 9). In Louisiana it is generally confined to the downdip area of the Sparta and to the saline-water tongue, which generally coincides with the area overlain by the Mississippi valley alluvium in eastern Louisiana and southeastern Arkansas. The chloride type waters generally represent areas of discharge where the dominant component of flow in the Sparta is upward (pl. 2, fig. 2), and they therefore lie beyond the limits of extensive flushing by fresh water. (See pls. 8, 9, 10.)

Sulfate water province.—Southwestward from Burleson County, Tex., along the Sparta trend to Webb County, sulfate may constitute up to 50 percent or more of the total anion content of the waters (table 1, well TWn–4). The ratio value arbitrarily chosen for definition of this province is 0.25 (sulfate : chloride + bicarbonate ≧ 0.25). The sulfate water province lies along, and slightly downdip from, the outcrop area of the Sparta (pl. 9). It coincides closely with an area in which the formations overlying and underlying the Sparta Sand contain gypsum and gypsiferous clays (Alexander and others, 1964, p. 34–35 and 43–46). The sulfate content can probably be attributed to the solution of gypsum by waters passing through these gypsiferous formations and the soils derived from them. The dispersion of these salts downdip in the Sparta would be relatively slow because the regional downdip rate of flow is very slow.

DISSOLVED SOLIDS

The dissolved-solids content of water is one of the most effective chemical tools that can be used to understand the relations of water movement, variations of chemical quality, and the influence of geologic factors on water movement. The relation of the dissolved-solids content to the specific conductance of water from the Sparta Sand is remarkably constant (fig. 4), even in the higher ranges of concentration (≧ 3,000 ppm). Because of this relation, electric logs can be used to compute dissolved-solids content. The electric logs provide extensive regional control for computing dissolved-solids contents in formational waters.

A satisfactory method of computing the dissolved-solids content of water from the long-normal curve of

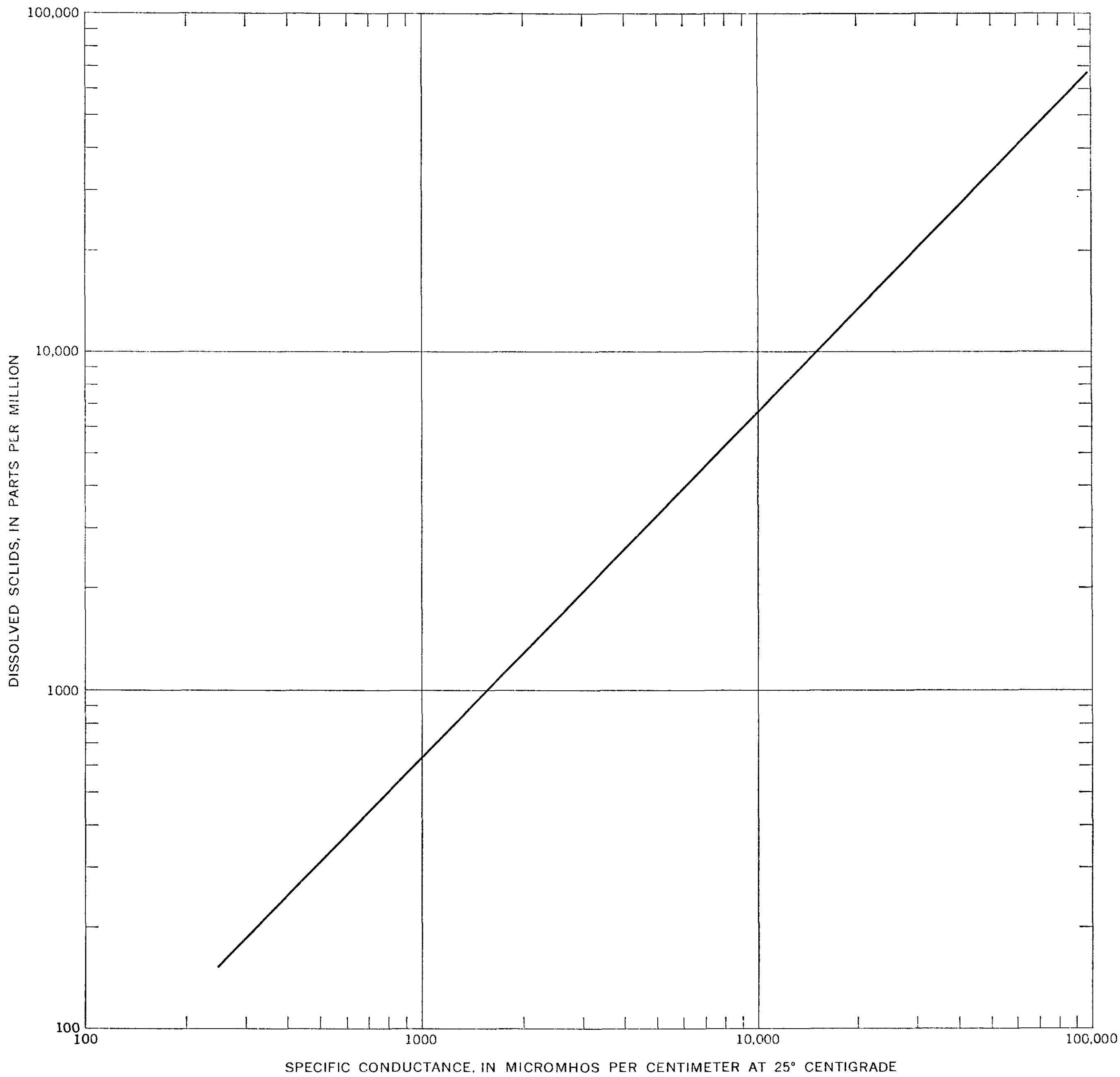

FIGURE 4.—Relation of specific conductance to dissolved-solids content in waters from the Sparta Sand in Arkansas, Louisiana, Mississippi, and Texas.

electric logs was described by Turcan (1960).[3] This method was used to calculate the dissolved-solids content of the water in the Sparta. The values thus obtained, along with data from available chemical analyses, were used to construct the dissolved-solids map (pl. 9).[4] To avoid errors introduced by electrode spacing, calculations were not made for sands less than 15 feet thick. No values are shown for waters containing less than 200 ppm or more than 10,000 ppm dissolved solids.

[3] Turcan's method is based on the equation:

$$F_f=\frac{R_o}{R_w}$$

where

F_f=the field formation resistivity factor,

R_o=the resistivity read from the long-normal curve corrected to 77°F,

R_w=the resistivity of the water at 77°F.

[4] Contour intervals of 500, 1,000, 3,000, and 10,000 ppm are used on the dissolved-solids map. These intervals were chosen on the bases of the standards proposed by the U.S. Health Service (1962, p. 7–8) and the salinity classification given by Winslow (1956, p. 5).

TABLE 1.—*Analyses of water from representative wells in the Sparta Sand*

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

No. on plate 9 [1]	State	County or parish	Well owner or designation	Date of collection	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Percent sodium	Dissolved solids: Residue on evaporation (180°C)	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH
ADs-1	Arkansas	Desha	J. L. McKennon.	11- 7-56	......	0.00	0.3	0.4	54	......	124	6	6.6	5.2	......	0.5	96	136	......	2	0	222	8.4
ADr-1	Arkansas	Drew	Harold Scroggins.	7-28-53	13	.10	.4	.0	68	1.5	170	.0	.9	4.8	0.1	.7	98	174	......	1	0	265	8.0
ADr-2	Arkansas	Drew	J. M. Martin	2-10-54	11	.29	1.9	.4	184	2.0	425	.0	5.4	38.0	.6	2.5	99	464	......	6	0	749	8.0
AUn-1	Arkansas	Union	City of Smackover No. 1.	......	12	.02	1.8	.3	106	1.4	256	.0	.6	20.0	.1	.1	97	275	......	6	0	445	8.2
AUn-2	Arkansas	Union	El Dorado Water Co. No. 10.	......	10	.02	2.2	.6	106	1.5	213	8.9	.8	36.0	.1	.1	92	275	......	8	0	454	8.1
LCw-1	Louisiana	Caldwell	Texas Gas Trans., Riverton, La.	9- 1-64	11	.3	1.2	1.0	566	3.1	1040	.0	.0	258	5.2	.4	99	1400	1360	7	0	2240	7.9
LCL-1	Louisiana	Claiborne	City of Homer No. 1.	7- 6-60	39	2.6	16.0	3.4	12	2.0	86	.0	.8	7.6	.1	.1	32	125	123	54	0	162	6.6
LL-1	Louisiana	Lincoln	Village of Choudrant.	12-15-59	13	.04	.8	.2	85	.6	179	3.0	22	9.0	.4	.8	98	226	225	3	0	357	8.4
LL-2	Louisiana	Lincoln	Lincoln Parish School Board Simmsboro.	3-16-60	7.4	.40	.0	.0	45	2.3	112	.0	1.8	4.8	.1	1.0	97	125	123	0	0	190	7.4
LL-3	Louisiana	Lincoln	City of Ruston T-18.	3-23-55	25	.25	1.4	.3	72	1.0	168	.0	13	8.0	.1	.8	96	210	206	5	0	316	7.8
LMo-1	Louisiana	Morehouse	Chemin-A-Haut State Park.	1-13-61	10	.28	6.8	.7	451	4.7	520	.0	1.4	410	2.4	.1	97	1170	1140	20	0	1970	7.8
LMo-2	Louisiana	Morehouse	Village of Collinston.	1-14-60	13	.03	2.1	.2	492	1.9	473	5.0	.4	476	1.2	.2	99.7	1230	1230	6	0	2160	8.3
LOu-1	Louisiana	Ouachita	City of West Monroe.	4-23-52	14	.01	.5	.5	124	1.6	282	7.0	.7	18	.5	1.5	98	317	313	3	0	530	8.7
LOu-2	Louisiana	Ouachita	La. Dept. of Wildlife and Fisheries.	3-20-56	29	1.0	.7	.9	332	2.1	655	.0	.5	130	1.4	1.0	99	839	823	5	0	1370	8.0
LR-1	Louisiana	Rapides	State of Louisiana Hot Wells.	3-24-57	17	8.9	1200	519	26,700	143	262	.0	3.1	44,200	......	......	92	......	72,900	5130	4910	85,900	7.2
LSa-1	Louisiana	Sabine	A. J. Hodges Industries, Hodges Gardens.	6-25-64	23	.24	1.0	.1	105	2.0	230	.0	22.0	9.8	.4	.0	98	289	279	3	0	418	7.6
LWb-1	Louisiana	Webster	Hooten and Arnold.	11- 3-59	12	.07	4.1	.9	141	1.8	328	.0	.8	36	.3	1.3	95	368	360	14	0	601	7.6
LW-1	Louisiana	Winn	City of Winnfield No. 6.	12-20-44	12	.0	1.0	1.2	140	5.6	298	18.0	7.8	24	.1	.8	95	355	357	8	0	573	8.7
MC-1	Mississippi	Copiah	Town of Hazelhurst.	11- 5-64	20	.07	1.0	.1	195	.9	497	.0	2.4	8.0	.6	.3	99	505	473	3	0	753	7.8
MH-1	Mississippi	Hinds	Presto Mfg. Co.	3- 7-56	7.7	.57	1.3	.2	177	2.7	456	9.0	1.0	3.5	.3	1.1	98	464	......	4	0	706	8.5

MR-1	Mississippi	Rankin	United Gas Pipeline Co.	1-31-58	14	.2	.2	.2	87	2.0	214	3.0	11	2.5	.3	.7	97	204	--	6	0	412	8.3
MW-1	Mississippi	Warren	T. M. Morrisey	8- -39	--	--	--	--	--	--	881	--	3	458	2.8	--	--	--	--	9	0	--	--
MW-2	Mississippi	Warren	Vicksburg Industrial Park, Test No. 1.	12- 7-62	15	.37	.8	.7	294	11	704	5.0	.0	44	1.1	.0	97	762	716	5	0	1,180	8.2
MY-1	Mississippi	Yazoo	W. N. Heidel	6- 3-58	--	.32	1.8	.5	62	6.2	148	.0	12	7	.0	2.5	90	229	--	6	0	257	7.8
TAn-1	Texas	Angelina	Pollock Central School.	3- 7-61	11	.1	3.5	.9	435	3.0	572	.0	336	110	1.1	.0	98	1,190	1,180	12	0	1,880	8.1
TAt-1	Texas	Atascosa	W. B. Strickland No. 3.	3-11-49	10	--	67.0	37.0	931	--	420	.0	1,330	435	--	1.8	--	2,980	3,020	319	--	4,360	--
TB-1	Texas	Brazos	City of Bryan No. 5.	8-23-43	19	.1	1.7	.2	69	--	137	11.0	1.5	16	.0	.0	--	184	186	5	0	280	8.1
TBu-1	Texas	Burleson	Chance Farms	6-11-63	17	--	1.5	.6	449	--	482	.0	352	155	.7	.2	99	--	1,210	6	0	1,880	7.7
TBu-2	Texas	Burleson	Sante Fe Railroad, Summerville.	11- 2-39	--	--	19.0	2.3	635	--	628	7.9	98	570	1.4	.0	--	1,722	1,643	57	0	--	8.7
TG-1	Texas	Gonzales	Hollis Bean	1-16-63	16	--	273	84	262	--	458	.0	458	520	2.7	3.0	36	2,030	1,840	1,030	651	2,910	6.7
TG-2	Texas	Gonzales	Robert Graucke	9-19-62	24	--	20	11	166	--	152	.0	114	150	.2	.0	79	553	--	95	0	977	6.9
TG-3	Texas	Gonzales	S. D. Perkins	10-10-62	17	--	51	17	4,370	--	1,010	.0	21	6,270	--	--	98	--	11,200	197	0	17,400	7.1
TH-1	Texas	Houston	Fred W. Ayers	8-28-63	12	.07	11	3.5	300	3.7	720	.0	0.4	80	.6	.2	93	--	766	42	0	1,220	7.5
TH-2	Texas	Houston	Roy White	8-23-63	9.5	8.9	7.5	3.3	155	--	430	.0	4.4	7.1	.6	.2	91	--	399	32	0	675	7.6
TLS-1	Texas	LaSalle	Cotulla Livestock Company.	5-28-63	17	.25	22	15	297	--	308	.0	214	202	.4	.0	85	--	918	116	0	1,520	7.1
TLS-2	Texas	LaSalle	Albert Martin	10-18-42	20	.26	3	1.2	645	--	823	.0	277	318	.9	.0	99	1,696	1,671	12	--	--	8.8
TLS-3	Texas	LaSalle	A. E. Schletze	5-14-59	18	--	50	24	289	6.7	268	.0	350	197	--	.5	73	1,030	1,070	224	4	1,700	7.6
TL-1	Texas	Lee	Carl Droemer	3-22-52	34	--	248	92	350	--	337	.0	557	640	--	.2	43	2,310	2,090	998	722	3,390	7.4
TL-2	Texas	Lee	Edwin Zgabay	11-12-59	14	--	4.5	1.4	235	--	255	.0	208	72	--	.0	97	659	660	17	0	1,050	7.6
TSA-1	Texas	San Augustine.	Bill Goynes	3- 7-61	21	.10	.0	.0	95	--	188	4.0	23	16	--	.0	100	247	251	0	0	396	8.4
TWn-1	Texas	Wilson	Lilly Grove School.	6-13-36	--	--	66	21	69	--	79	--	70	172	--	--	--	--	437	230	--	--	--
TWn-2	Texas	Wilson	Wm. Kosarek	6- 2-36	--	--	--	30	1,818	--	1,220	--	28	2,170	--	--	--	--	4,656	124	--	--	--
TWn-3	Texas	Wilson	V. Lichnovsky	3-28-36	--	--	69	15	80	--	85	--	145	134	--	--	--	--	485	235	--	--	--
TWn-4	Texas	Wilson	A. R. Becker	3-30-49	15	--	22	34	734	--	400	.0	1,010	290	--	2.2	89	--	2,290	195	--	3,310	--

[1] The first letter designates the State, and the following letter or letters designate the county or parish. The numbering system does not correspond to the State numbering systems.

In much of Texas the Sparta aquifer is composed of one continuous sand unit that is 20 feet or more thick; therefore, only the average dissolved-solids content was mapped, and no minimum or maximum dissolved-solids content contours are shown (pl. 9).

In Arkansas, Louisiana, and Mississippi the Sparta is a multi-unit aquifer in which there are usually several sand units, each 20 feet or more thick, that have different dissolved-solids contents (fig. 3). Therefore, in this area three sets of calculations are used to show the range of variation in dissolved-solids content that might be anticipated in the various sands in the Sparta aquifer. These are (1) the minimum dissolved-solids content, which represents the water having the lowest dissolved-solids content in the entire vertical section; (2) the maximum dissolved-solids content, which represents the water having the highest dissolved-solids content; and (3) the average dissolved-solids content, which is an average value weighted proportionately for the thickness of each unit in the section.[5] That the determinations of dissolved solids from the electric logs are well within the limits of reasonable accuracy is demonstrated by the close agreement between the values computed from the logs and the dissolved-solids content as determined by chemicals analyses.

The calculation of dissolved-solids content from electric logs provides close control for one of the principal chemical characteristics of water. Therefore, the influence of various geologic and hydrologic factors on water chemistry can be more accurately determined. The effects of channel development and regional flow on the dissolved-solids content have been discussed in the section on regional flow, but they should be reemphasized to point out the pronounced deflection of lower dissolved-solids contours along channel paths, particularly those oriented favorably with respect to regional flow. (See pls. 4, 6, 7, 8, 9.) The relations of dissolved-solids-content values to channel and interchannel deposits support the use of variable coefficients of permeability (see discussion of permeability and transmissibility) insofar as the relations reflect the ease or difficulty of flushing.

EXTENT OF FLUSHING OF THE SPARTA SAND

The thickness of sand containing fresh water in the Sparta and its percentage of the total sand thickness of the Sparta is shown on plate 10. In a sense this map summarizes the information shown on several of the other maps, for it shows that the more permeable channels aid the movement of ground water when oriented in the direction of regional flow, and that the shaly areas or areas of low transmissibility impede the flow (pls. 4, 6, 7, 9). The map also emphasizes the more thorough flushing of the formation on the east, or Mississippi, side of the salt-water tongue. This flushing apparently results from the high rates of ground-water movement in this area. (See pl. 8 and fig. 2.) The map also shows the extension of the salt-water tongue through Ashley County, Ark. This extension may at first appear anomalous, but when the orientation of this tongue is compared with the change in direction of flow as indicated by the piezometric surface (pl. 8) in northern Louisiana and southern Arkansas, the extension is seen to be a small part of the system that has maintained the salt-water area along the Mississippi River Valley. (See pls. 2 and 8, and fig. 2.)

CONCLUSIONS

1. The principal geologic factor affecting the hydrology of the Sparta Sand is the mode of deposition. The depositional environment controls the distribution of permeability in the system.

2. One of the major controls of the regional flow pattern is the Mississippi River alluvial valley, as it is the focus of discharge in the area in which the Sparta Sand is the principal aquifer.

3. In the channel sands the sand-unit thickness is apparently related to the permeability. The permeability usually increases with an increase in sand-unit thickness.

4. The rate of water movement is related to the lithology of the formation in the channel-sand areas. The chemical evidence suggests that the rates of ground-water movement are higher along continuous channels than in the interchannel areas.

5. The dissolved-solids content of water is one of the most effective chemical tools that can be used to understand the relations of water movement and variations of chemical quality to geologic factors. It can be reliably determined from electric logs, and it thus provides extensive data on a major chemical characteristic of water.

6. Geologic, hydrologic, and geochemical maps of a region can be of great help in the ultimate quantitative evaluation and description of any aquifer system.

7. Maps showing sand percentage, maximum sand-unit thickness, and estimated transmissibility aid in the search for, and evaluation of, large supplies of ground water.

[5] For example, if the Sparta sand section has three sand units whose thicknesses are 20, 30, and 50 feet and whose respective dissolved-solids contents are 200, 250, and 300 ppm, the weighted average dissolved-solids content

$$=\frac{(20\times200)+(30\times250)+(50\times300)}{100\text{ (sum of thickness)}}=\frac{26{,}500}{100}=265\text{ ppm.}$$

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(Annotated for publications containing specific information on the Sparta Sand)

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Andersen, H. V., 1960, Geology of Sabine Parish: Louisiana Geol. Survey. Geol. Bull. 34, 164 p.

Discusses geology and stratigraphic relations. Describes fossiliferous and glauconitic estuarine and lagoonal beds in upper and lower parts. Includes geologic map and geologic section.

Baker, B. B., Dillard, J. W., Souders, V. L., and Peckham, R. C., 1963, Reconnaissance investigation of the ground-water resources of the Sabine River basin, Texas: Texas Water Comm. Bull. 6307, 57 p.

Describes geology and quality and availability of water. Includes geologic cross sections and map.

Baker, B. B., Peckham, R. C., Dillard, J. W., and Souders, V. L., 1963, Reconnaissance investigation of the ground-water resources of the Neches River basin, Texas: Texas Water Comm. Bull. 6308, 67 p.

Briefly describes geology. Discusses hydrology, including water movement, recharge, discharge, water levels, water-bearing characteristics, chemical quality, utilization, development and availability. Tabulates chemical analyses and pumpage. Includes geologic map, geologic cross section, and isopachous map and indicates altitude and depth of top Sparta aquifer.

Baker, R. C., Hewitt, F. A., and Billingsley, G. A., 1948, Ground-water resources of the El Dorado area, Union County, Arkansas: Arkansas Univ. Bur. Research, Research Ser. 14; Arkansas Univ. Bull., v. 42, no. 12, 39 p.

Describes geology. Discusses history of ground-water development, water levels, pumping tests, quality of water, and safe yield. Includes chemical analyses.

Bedinger, M. S., and Reed, J. E., 1961, Geology and ground-water resources of Desha and Lincoln Counties, Arkansas: Arkansas Geol. and Conserv. Comm. Water Resources Circ. 6, 129 p.

Briefly discusses geology and hydrology, pumping test results, public water supplies, and chemical quality. Tabulates well descriptions, water levels and chemical analyses. Includes geologic sections.

Bornhauser, Max, 1947, Marine sedimentary cycles of Tertiary in Mississippi embayment and central Gulf Coast area: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 4, p. 698–712.

Discusses application of rhythmic (cyclical) deposition to Sparta and other Tertiary formations. Includes isopach map of Cane River–Sparta interval.

———1950, Oil and gas accumulation controlled by sedimentary facies in Eocene Wilcox to Cockfield formations, Louisiana Gulf Coast: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 9, p. 1887–1896.

Recognizes marine phases of Sparta downdip. Indicates stratigraphic relations.

Bredehoeft, J. D., 1964, Variation of permeability in the Tensleep Sandstone in the Big Horn Basin, Wyoming, as interpreted from core analyses and geophysical logs: U.S. Geol. Survey Prof. Paper 501–D, p. D166–D170.

Brown, G. F., 1947, Geology and artesian water of the alluvial plain in northwestern Mississippi: Mississippi Geol. Survey Bull. 65, 424 p.

Discusses geology and hydrology of Kosciusko (Sparta) Sand. Includes geologic sections and maps structure of base. Tabulates screen analyses and laboratory coefficients of permeability, chemical analyses, descriptions of wells and water levels, and sample and drillers' logs.

Callahan, J. A., 1963, Ground-water resources in Yazoo County, Mississippi: Mississippi Board Water Commissioners Bull. 63–5, 42 p.

Describes geology and discusses hydrology. Includes chemical analyses and geologic section.

Chawner, W. D., 1936, Geology of Catahoula and Concordia Parishes: Louisiana Dept. Conserv. Geol. Bull. 9, 232 p.

Describes geology and mentions occurrence of marine fossils.

Cooke, C. W., 1925, Correlation of the Eocene formations in Mississippi and Alabama: U.S. Geol. Survey Prof. Paper 140–E, p. 133–135.

Briefly describes Sparta Sand and shows regional correlations.

Cooke, C. W., Gardner, J. A., and Woodring, W. P., 1943, Correlation of the Cenozoic formations of the Atlantic and Gulf Coastal plain and the Caribbean region: Geol. Soc. America Bull., v. 54, no. 11, p. 1713–1723.

Includes correlation chart showing Sparta.

Cronin, J. G., Follett, C. R., Shafer, G. H., and Rettman, P. L., 1963, Reconnaissance investigation of the ground-water resources of the Brazos River basin, Texas: Texas Water Comm. Bull. 6310, 152 p.

Briefly describes Sparta Sand. Discusses water movement, recharge, discharge, utilization of water, present development of aquifer, water levels, chemical quality, availability of water, potential development of aquifer, and some problems of water from Sparta. Tabulates chemical analyses and pumpage. Includes geologic sections and geologic map.

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, 28 p.

Briefly describes geology. Indicates configuration of top of Sparta.

DeVries, D. A., and others, 1963, Jasper County mineral resources: Mississippi Geol. Econ. and Topog. Survey Bull. 95, 101 p.

Describes Kosciusko (Sparta) Sand. Briefly discusses hydrology. Tabulates descriptions of wells, water levels, and chemical analyses.

Ellisor, A. C., 1929, Correlation of the Claiborne of east Texas with the Claiborne of Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 13, no. 10, p. 1335–1346.

Briefly describes Sparta. Correlates various formations of Claiborne. Indicates thickness variations.

Fisk, H. N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., U.S. Dept. Army, Mississippi River Comm., 78 p.

Harvey, E. J., Callahan, J. A., and Wasson, B. E., 1961. Ground-water resources of Hinds, Madison, and Rankin Counties, Mississippi, Part II, Basic data: Mississippi Board Water Commissioners Bull. 61–2, 146 p.

Describes geology. Tabulates descriptions of wells and water levels, data on municipal supplies, logs of wells, and chemical analyses.

——— 1964, Ground-water resources of Hinds, Madison, and Rankin Counties, Mississippi: Missisippi Board Water Commissioners Bull. 64–1, 38 p.

Describes geology. Discusses water levels and movement, well yields and aquifer characteristics, water quality, and development of water supplies. Tabulates records of municipal water supplies, descriptions of wells, chemical analyses, and results of pumping tests.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Hewitt, F. A., Baker, R. C., and Billingsley, G. A., Ground-water resources of Ashley County, Arkansas: Arkansas Univ. Inst. Sci. Technology, Research Ser. no. 16, 35 p.

Describes geology and possible water supply potential. Includes geologic sections showing fresh water in Sparta.

Huner, J. H., Jr., 1939, Geology of Caldwell and Winn Parishes: Louisiana Dept. Conserv. Geol. Bull. 15, 356 p.

Describes geology in detail, including mode of deposition. Mentions calcareous shales and shell fragments. Includes geologic map and sections.

Jones, P. H., and Holmes, C. N., 1947, Ground-water conditions in the Monroe area, Louisiana: Louisiana Geol. Survey Bull. 24, 47 p.

Describes geology and some hydraulic characteristics. Discusses water resources, hydrology, and quality. Tabulates chemical analyses, mechanical analyses, and results of drill stem tests. Includes geologic sections.

Klein, Howard, Baker, R. C., and Billingsley, G. A., 1950, Ground-water resources of Jefferson County, Arkansas: Arkansas Univ. Inst. Sci. and Technology, Research Ser. 19, 44 p.

Discusses geology and hydrology.

LeGrand, H. E., 1964, Hydrogeologic framework of the Gulf and Atlantic Coastal Plain: Southeastern Geology, v. 5, no. 4, p. 177–194.

Lonsdale, J. T., 1935, Geology and ground-water resources of Atascosa and Frio Counties, Texas: U.S. Geol. Survey Water-Supply Paper 676, 90 p.

Differentiates Sparta and includes it in Cook Mountain and post-Bigford. Includes chemical analyses, and descriptions of wells.

Maher, J. C., and Jones, P. H., 1945, Ground-water and geologic structure of Natchitoches area, Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 1, p. 40–41.

Describes geology and hydrology. Includes geologic sections.

Martin, J. L., Hough, L. W., Raggio, D. L., and Sandberg, A. E., 1954, Geology of Webster Parish: Louisiana Geol. Survey, Geol. Bull. 29, 252 p.

Describes geology. Includes geologic map and sections.

Meinzer, O. E., 1923, The occurrence of ground water in the United States: U.S. Geol. Survey Water-Supply Paper 489, 321 p.

Meinzer, O. E., and Wenzel, L. K., 1942, Movement of ground water and its relation to head, permeability and storage, *in* Physics of the Earth, pt. IX, Hydrology: New York, McGraw-Hill Book Co., p. 444–477.

Moody, C. L., 1931, Tertiary history of region of Sabine Uplift, Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 15, no. 5, p. 531–551.

Discusses stratigraphic relations, the strand line, and geologic history.

Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal province of North America: New York, Harper & Brothers, 692 p.

Discusses regional correlations and relationships. Indicates structure. Contains excellent bibliography.

Onellion, F. E., 1956, Geology and ground-water resources of Drew County, Arkansas: Arkansas Geol. and Conserv. Comm. Water Resources Circ. 4, 43 p.

Describes geology. Discusses aquifer test data, utilization of water, and chemical constituents and quality. Tabulates well descriptions, water levels and chemical analyses. Includes geologic sections.

Onellion, F. E., and Criner, J. H., Jr., 1955, Ground-water resources of Chicot County, Arkansas: Arkansas Geol. and Conserv. Comm. Water Resources Circ. 3, 32 p.

Briefly describes Sparta.

Page, L. V., and May, H. G., 1964, Water resources of Bossier and Caddo Parishes, Louisiana: Louisiana Geol. Survey and Dept. Public Works Water Resources Bull. 5, 105 p.

Briefly describes Sparta. Discusses water-bearing characteristics, quality, and water-supply potential. Tabulates chemical analyses, well descriptions, and water levels.

Page, L. V., and Newcome, Roy, Jr., 1963, Water resources of Sabine Parish, Louisiana: Louisiana Geol. Survey and Dept. Public Works Water Resources Bull. 3, 146 p.

Briefly describes Sparta. Discusses hydrology, water resources and quality. Tabulates descriptions of wells, water levels and chemical analyses.

Parks, W. S., Moore, W. H., McCutcheon, T. E., and Wasson, B. E., 1963, Attala County mineral resources: Mississippi Geol. Economic and Topographic Survey Bull. 99, 192 p.

Describes geology in detail. Includes geologic map and section. Discusses hydrology.

Peckham, R. C., Souders, V. L., Dillard, J. W., and Baker, B. B., 1963, Reconnaissance investigation of the ground-water resources of the Trinity River basin, Texas: Texas Water Comm. Bull. 6309, 110 p.

Describes geology in fair detail. Discusses water movement, recharge, discharge, water levels, water-bearing characteristics, chemical quality, and utilization and availability of water. Tabulates chemical analyses and pumpage data. Shows aerial geology. Includes geologic section.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper Bros., 718 p., 2d ed.

Poole, J. L., 1961, Ground-water resources of East Carroll and West Carroll Parishes, Louisiana: Baton Rouge, Louisiana Dept. Public Works, 174 p.

Discusses classification, cyclical sedimentation, stratigraphy, and water-supply potential. p. 59–61.

Rollo, J. R., 1960, Ground water in Louisiana: Louisiana Geol. Survey and Dept. Public Works Water Resources Bull. 1, 84 p.

Briefly discusses geology and hydrology.

Sellards, E. H., Adkins, W. S., and Plummer, F. B., 1932, The geology of Texas, Volume I. Stratigraphy: Texas Univ. Bull. 3232, 1007 p.

Describes geology in fair detail.

Spooner, W. C., 1926, Interior salt domes of Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 10, no. 3, p. 217–292.

Describes and redefines Sparta Sand and discusses mode of deposition.

Stenzel, H. B., 1938, The geology of Leon County, Texas: Texas Univ. Pub. 3818, 295 p.

Stenzel, H. B., Krause, E. K., and Twining, J. T., 1957, Pelecypoda from the type locality of the Stone City beds (middle Eocene) of Texas: Texas Univ. Pub. 5704, p. 18–35.

Discusses relation of fossiliferous Stone City beds to Sparta Sand.

Sundstrom, R. W., and Follett, C. R., 1950, Ground-water resources of Atascosa County, Texas: U.S. Geol. Survey Water-Supply Paper 1079–C, p. 107–153.

Does not differentiate Sparta, but it is probably included in Cook Mountain aquifers.

Tait, D. B., Baker, R. C., and Billingsley, G. A., 1953, The ground-water resources of Columbia County Arkansas—a reconnaissance: U.S. Geol. Survey Circ. 241, 25 p.

Briefly describes Sparta. Tabulates records of wells, water levels, and chemical analyses.

Turcan, A. N., Jr., 1960, Estimating water quality from electrical logs: U.S. Geol. Survey Prof. Paper 450–C, p. C135–C136.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Dept. Health, Education, and Welfare, Public Health Service Pub. 956, 61 p.

Vaughn, T. W., 1895, The stratigraphy of northwestern Louisiana: Am. Geologist, v. 15, p. 205–229.

Proposes name "Sparta."

———, 1896, A brief contribution to the geology and paleontology of northwestern Louisiana: U.S. Geol. Survey Bull. 142, 65 p.

Describes and names Sparta Sand.

Wang, K. K., 1952, Geology of Ouachita Parish: Louisiana Geol. Survey. Geol. Bull. 28, 126 p.

Describes Sparta in detail.

Welch, R. N., 1942, Geology of Vernon Parish: Louisiana Dept. Conserv. Geol. Survey Bull. 22, 90 p.

Shows Sparta on geologic sections.

Wendlandt, E. A., and Knebel, G. M., 1929, Lower Claiborne of east Texas, with special reference to Mount Sylvan dome and salt movements: Am. Assoc. Petroleum Geologists Bull., v. 13, no. 10, p. 1347–1375.

Describes Sparta Sand and Tyler Greensand in Sparta. Considers Sparta Sand a member of Cook Mountain Formation.

White, W. N., Sayre, A. N., and Heuser, J. F., 1941, Geology and ground-water resources of the Lufkin area, Texas: U.S. Geol. Survey Water-Supply Paper 849–A, p. 1–58.

Briefly describes Sparta. Discusses availability and quality of water. Includes chemical analyses.

Winslow, A. G., 1950, Geology and ground-water resources of Walker County, Texas: Texas Board of Water Engineers Bull. 5002, 48 p.

Briefly describes Sparta. Includes geologic sections.

Winslow, A. G., and Kister, L. R., 1956, Saline-water resources of Texas: U.S. Geol. Survey Water-Supply Paper 1365, 105 p.

Discusses Sparta. Includes saline water classification and chemical analyses.

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