Hydrologic Significance of Lithofacies of the Cane River Formation or Equivalents of Arkansas, Louisiana, Mississippi, and Texas

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By J. N. PAYNE

GEOHYDROLOGY OF THE CLAIBORNE GROUP

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HYDROLOGIC SIGNIFICANCE OF LITHOFACIES OF THE CANE RIVER FORMATION OR EQUIVALENTS OF ARKANSAS, LOUISIANA, MISSISSIPPI, AND TEXAS

By J. N. PAYNE

ABSTRACT

The study of the Cane River Formation or equivalents, the third part of an investigation of the geohydrology of the Claiborne Group, is presented in two parts. The first part discusses the Cane River Formation or equivalents in Arkansas, Louisiana, and Mississippi; the second part, discusses the Reklaw and Queen City Formations of Texas.

The regional dip of the Cane River or equivalents is into the Mississippi embayment and Desha basin or into the gulf coast geosyncline.

The thickness of the Cane River Formation ranges from 70 feet in La Salle Parish, La., to 750 feet in the Desha basin of Arkansas. Several major structural features were active during Cane River time; they cause local variations in thickness.

The Cane River Formation represents the most extensive marine invasion of Claiborne time; consequently, over most of the area it is composed of shale. Sand-percentage maps and maximum sand-unit thickness maps indicate that the formation contains an appreciable amount of sand that was laid down as channel sands or as bar and beach deposits along the margins of the embayment.

The relation of permeability and transmissibility to sand thickness is believed to be similar to the relation found in the Sparta and Cockfield Formations. The coefficient of permeability probably increases with increase in sand thickness.

Recharge of the Cane River is mainly by precipitation in the outcrop area, but a minor amount of recharge takes place by the upward movement of water from the underlying Meridian–upper Wilcox aquifer. Natural discharge from the Cane River Formation is primarily by leakage through the overlying confining beds. Regional flow of water is generally down the dip of the Cane River Formation toward the gulf coast geosyncline and the Mississippi alluvial valley.

In and near the outcrop area, water from the Cane River Formation contains proportionately high concentrations of the cations calcium and magnesium. Farther downdip, sodium is the dominant cation. In Mississippi the dominant anion is bicarbonate. In Arkansas and Louisiana the chloride anion occurs in significant proportions. The distribution of dissolved-solids content of the water reflects the influence of geologic and hydrologic factors.

The regional dip of the Reklaw and Queen City Formations is generally to the southeast into the gulf coast geosyncline.

The depocenter of the Reklaw and Queen City Formations was in the Rio Grande embayment in Webb County, Tex.: there the Reklaw is 850 feet thick, and the Queen City is more than 1,750 feet thick.

Sand-percentage maps and maximum sand-unit thickness maps of the Reklaw Formation and Queen City Sand indicate that in the southwestern part of the area sediments were deposited in a nearshore and alongshore environment. Most of the thick sand bodies of the Reklaw Formation were deposited in early Reklaw time, as bars and beach sands. During the later part of Reklaw time, fewer sand bodies were deposited, for the supply of coarse clastic material was greatly reduced. In Queen City time, sand was deposited mainly in channels in a deltaic environment.

Limited data indicate that the coefficient of permeability increases as the sand thickens.

Recharge of the Reklaw and Queen City takes place by infiltration of precipitation in the outcrop area, by infiltration of water from streams, and by upward movement of water from the Carrizo Sand. In much of the southwestern part of the area, water from the Carrizo Sand has been a major source of recharge to the Reklaw and Queen City Formations.

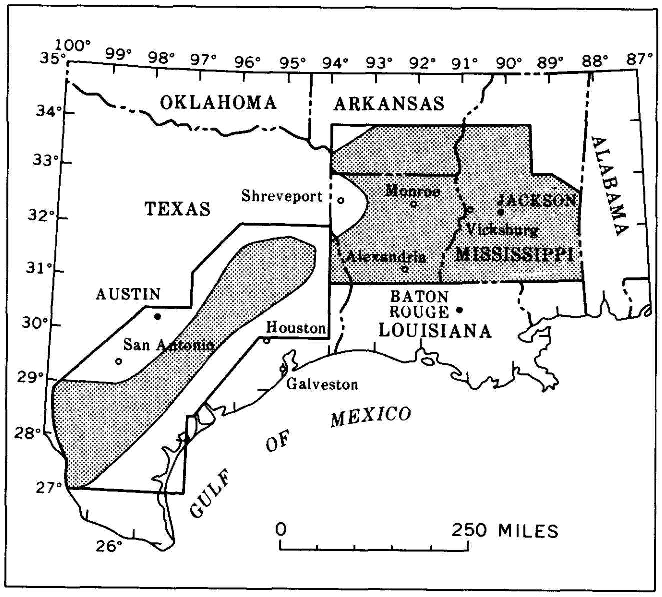
Water from the Reklaw and Queen City in and near the outcrop area and in shallower wells is generally proportionately high in calcium, magnesium, chloride, and sulfate and is very hard. In deeper wells in areas of high sand-percentage concentrations, the water is relatively low in calcium, magnesium, and chloride and is soft.

The distribution of chemical-constituent concentrations, of dissolved-solid content, and of salinity reflect the extent that fresh water has flushed the Reklaw and Queen City and the influence that geologic and hydrologic factors have had on the degree of flushing.

INTRODUCTION

PURPOSE AND SCOPE

The investigation of the significance of the lithofacies of the Cane River Formation or equivalents constitutes the third part of a study of the geohydrology of the Claiborne Group of Eocene age. The report describes and evaluates the relations of stratigraphy, facies development, and depositional controls to the hydraulic characteristics of the Cane River Formation or equivalents in parts of Arkansas, Louisiana, Mississippi, and Texas (fig. 1). Future plans call for a report on the investigation of the Carrizo and Meridian Sands and a



INDEX MAP SHOWING AREA OF THIS REPORT

FIGURE 1.—Location of report area.

summary report on all the aquifers of the Claiborne Group.

To accomplish the objectives of the investigation, data derived from electrical logs of oil, gas, and other test wells, together with data from hydrologic tests, were used to prepare geologic and hydrologic maps and cross sections. The interpretation of the maps and cross sections constitutes the body of this report.

ACKNOWLEDGMENTS

Acknowledgement is made to the Arkansas Geological and Conservation Commission; the Louisiana Geological Survey, Department of Conservation; the Texas Water Development Board; 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 constructive suggestions and criticisms.

APPROACH

The discussion of the geohydrology of the Cane River Formation or equivalents, exclusive of the Meridian Sand Member of the Tallahatta Formation, presents a unique problem of organization imposed partly by natural differences in geologic and hydrologic provinces and partly by artificial differences of the nomenclature used in the various States. In Arkansas and Louisiana the section from the top of the Carrizo Sand to the base of the Sparta Sand is called the Cane River Formation. The equivalent beds in Mississippi are, in ascending order, the Tallahatta Formation, exclusive of the Meridian Sand Member; the Winona Sand; and the Zilpha Clay. In Texas the Cane River equivalent section is composed of the Reklaw Formation, the Queen City Sand, and the Weches Greensand.

On the basis of natural differences, the sandy areas of the Cane River Formation or equivalents can be separated into two provinces: (1) the Arkansas, Louisiana, and Mississippi province, in which the Cane River or equivalent section is generally less than 500 feet thick (pl. 1) and in which the stratigraphic interval is composed of alternating sands and shales from the top of the Carrizo Sand and Meridian Sand Member to about the upper 50–100 feet of the interval (Payne, 1968, pls. 1, 2), and (2) the Texas province, in which the Cane River equivalent section is generally in excess of 800 feet thick and in which the Queen City Sand is generally separated as a distinct unit by shaly intervals 100 feet or more thick both above and below. For the sake of clarity and convenience, the two provinces will be discussed separately in this report.

CANE RIVER FORMATION OF ARKANSAS, LOUISIANA, AND MISSISSIPPI

In this report the Basic City Shale and Neshoba Sand Members of the Tallahatta Formation, the Winona Sand, and Zilpha Clay of Mississippi will be considered as a unit and referred to as the Cane River Formation.

GEOLOGY

The Cane River Formation (Spooner, 1926, p. 235–236) of Arkansas and Louisiana and the formations of the equivalent interval in Mississippi consist predominantly of shales and clays with some interbedded sands, silts, marls, and lignites. The clays and shales are gray to brown and are, in part, glauconitic and fossiliferous. The sands are generally fine, micaceous, locally glauconitic and fossiliferous, and thin bedded. Well-developed sand bodies are found only around the margins of the Mississippi embayment, and are particularly abundant in the northern part of the area of study (pls. 1, 2).

STRUCTURE

The details of the structure on the top of the Cane River Formation are shown by Payne (1968, pl. 3).

In south-central and southwestern Arkansas and in north-central and northwestern Louisiana, the regional dip of the Cane River Formation is to the east and southeast at 25–50 feet per mile into the Mississippi embayment and Desha basin. In north-central and west-central Mississippi the regional dip is to the south-

southwest and west at 25–50 feet per mile into the Mississippi embayment and Desha basin. In south-central Louisiana and in southern Mississippi, the regional dip is to the south and south-southwest into the gulf coast geosyncline at 50–100 feet per mile.

Major positive structural elements that had considerable growth during Cane River time, as reflected by marked thinning of the Cane River Formation over these structural features, are the Sabine arch of western Louisiana and eastern Texas, the Wiggins arch of southern Mississippi, the Monroe uplift in Ouachita and Richland Parishes, La., and the La Salle arch in La Salle and Rapides Parishes, La. (pl. 1). Major negative structural elements that had considerable growth, as indicated by thickening of the Cane River Formation, are the gulf coast geosyncline, the Mississippi embayment, the Desha basin of southeastern Arkansas and northwestern Mississippi, and the Perry basin (Murray, 1961, p. 107) of southern and southeastern Mississippi. Normal faulting such as that found in Sabine Parish, La., (pl. 1) occurred throughout the area.

THICKNESS

The thickness of the Cane River Formation or its equivalents in Arkansas, Louisiana, and Mississippi, where the formation or its equivalents are present in their entirety, ranges from about 70 feet in La Salle Parish, La., to between 650 and 750 feet in Desha County, Ark. (pl. 1). Along the central parts of the Mississippi embayment, Desha basin, and Perry basin the formation is generally 400 to about 600 feet thick. Along the flanks of the Mississippi embayment and over the Wiggins arch area the formation is generally 200–350 feet thick. Pronounced thinning of the formation occurs over the La Salle arch in Avoyelles, La Salle, and Rapides Parishes, La., and over parts of the Monroe uplift in Ouachita and Richland Parishes, La., and Sharkey County, Miss. Minor local variations in thickness occur over some salt domes and oil-field structures.

LITHOLOGIC VARIATIONS AND INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

The Cane River Formation represents the most extensive marine invasion during Claiborne time. In the central part of the embayment, in the Arkansas, Louisiana, and Mississippi part of the report area, the formation is composed of marine clays and shales but includes minor amounts of marls, silts, and marine sand. However, along the margins of the embayment, particularly in Arkansas and west-central and northwestern Mississippi, the formation becomes extremely variable in lithology (pl. 1). (See also Cushing and others, 1964, p. B18; and Hosman and others, 1968, pls. 1, 2, 6.)

Along the margins of the embayment from northern Wayne County, Miss., to Desha and Lincoln Counties, Ark., the pattern of high sand concentration (>40 percent sand), as shown by the increase in sand percentages as well as by the axes of elongation of the thicker sand units, has a generally north to northeast orientation (pls. 1, 2),[1] generally normal to the presumed orientation of the shoreline of the Cane River sea. Other high sand concentrations and massive sand bodies such as those in Columbia County, Ark., have an orientation that is generally parallel to the orientation of the postulated Cane River shoreline. The pattern of sand concentration and of massive sand bodies is believed to represent a combination of channel sands deposited near the seaward extremities of streams that were the predecessors of such streams as the Mississippi, Pearl, Big Black, and Chickasawhay Rivers and offshore and alongshore bars developed off the mouths of the distributaries of these streams. This interpretation is in accord with lithologic descriptions of the sands given in various reports (Brown, 1947, p. 44; Cushing and others, 1964, p. B18–B19; Parks and others, 1963, p. 27–29; Tait and others, 1953, p. 7, 17–23).

Regionally, the sand percentage decreases markedly to the south and southwest, so that in southeastern Arkansas, southwestern Mississippi, and all of Louisiana but the extreme northwestern part, the Cane River Formation contains virtually no sand beds (pls. 1, 2). The sand accumulation extending from Caddo Parish, La., through southern Arkansas to Leflore County, Miss., probably represents the marginal edge of a delta of the ancestral Mississippi River. Northward from the area mapped, the sand content of the Cane River increases, and the sands become more massive and finally merge with the Sparta Sand in northeastern Arkansas to form the Memphis aquifer (Hosman and others, 1968, p. D20, pls. 1, 2).

HYDROLOGY

The Cane River Formation may be considered of importance as an aquifer in the marginal areas of the Mississippi embayment in central and northwestern Mississippi, parts of southern Arkansas, and extreme northwestern Louisiana where sand beds constitute 25–30 percent or more of the formation and where individual sand units are 25 feet or more thick (pls. 1, 2). In these areas the Cane River is an aquifer system composed of poorly connected sand bodies, any one of which may act as an isolated hydrologic unit for short periods of time.

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[1] The method of constructing the sand-percentage maps and maximum sand-unit thickness maps is given in the discussion of the Sparta Sand (Payne, 1968, p. A3–A5).

PERMEABILITY[2] AND TRANSMISSIBILITY[3] IN RELATION TO GEOLOGIC FACTORS

In the Cane River Formation, thicknesses of individual sand units are rather variable, and thicknesses in excess of 75 feet are virtually limited to northwestern Mississippi. Consequently, the range in values of the coefficients of permeability and transmissibility in the Cane River is not nearly so great as the range of these values found in the Sparta Sand and Cockfield Formation (Payne, 1968, p. A5–A6; Payne, 1970). Data on the coefficient of permeability of sands in the Cane River Formation in Arkansas, Louisiana, and Mississippi are virtually nonexistent. It has been assumed from tests of similar sands in Texas and from previous studies of the Sparta and Cockfield Formations that the coefficient of permeability increases with increase in thickness of the sand units (Payne, 1968, p. A6; Payne, 1970). In compiling the map showing the transmissibility of the total sand thickness of the Cane River Formation it has been assumed that the range in values of the coefficient of permeability is from 40 to 50 gpd per sq ft (gallons per day per square foot) for sands 25–50 feet thick to 100 gpd per sq ft for sands 100–125 feet thick (pls. 2, 3).[4] These values are probably realistic for the thinner sand units but are probably quite conservative for the thicker units.

The highest transmissibility values in the Cane River Formation occur in Bolivar, Leflore, and Sunflower Counties, Miss.; there coefficients of transmissibility of 15,000–35,000 gpd per ft can be expected. Transmissibility of the Cane River in Mississippi is generally higher than in Arkansas and northwestern Louisiana. The higher transmissibilities coincide with areas of higher sand concentrations and of thicker individual sand units. (Compare pls. 1, 2, and 3.)

RECHARGE AND DISCHARGE

The Cane River Formation is recharged principally by precipitation in the outcrop area of Arkansas, Louisiana, and Mississippi. A minor amount of recharge probably occurs through the movement of water from the underlying Meridian–upper Wilcox aquifer.

Water is lost from the Cane River Formation by withdrawal from wells and by natural discharge. The largest withdrawals from wells have taken place in the vicinity of Leflore County, Miss.; there long-term withdrawals have resulted in an extensive cone of depression (Brown, 1947, p. 27, pl. 12). Natural discharge from the Cane River takes place primarily by upward leakage through the overlying confining beds. A lesser amount of natural discharge occurs as base flow into streams incised into the Cane River Formation.

REGIONAL FLOW

Water in the Cane River Formation is artesian in most of the area. The regional flow of water in central and northwestern Mississippi is down the regional dip in a westerly and southwesterly direction toward the Mississippi River alluvial valley, except where altered by the cone of depression in Leflore County. In southeastern Mississippi the flow is down the regional dip to the southwest and south toward the gulf coast geosyncline. In southern Arkansas and northwestern Louisiana the flow is down the regional dip to the southeast and south. The directions of regional flow are indicated by the general directions of increasing dissolved-solids content of the waters (pl. 4). An upward component of flow of the water occurs throughout much of the area where the head of the water in the Cane River exceeds that of the water in the overlying Sparta Sand. This upward component becomes more and more dominant as the downdip limits of sand accumulation are approached.

CHEMICAL QUALITY OF WATER AND RELATIONS TO GEOLOGIC AND HYDROLOGIC FACTORS

Data on chemical analyses from the files of the Water Resources Division of the U.S. Geological Survey and from published reports, together with the dissolved-solids content, calculated from electrical logs have been used to prepare a map showing some of the important chemical characteristics of waters in the Cane River Formation (pl. 4). Stiff diagrams of selected chemical analyses have been plotted on the map to show the variation in concentration of the major constituents that make up the dissolved-solids content of the waters.

VARIATIONS IN CHEMICAL QUALITY OF WATER

Water from sands in the Cane River Formation in and near the outcrop area generally shows a relatively high proportion of calcium and magnesium (wells Mr–1, Mr–3, O–1, Aa–1, Cr–1, and Lr–2, pl. 4 and table 1) and, as a consequence, are classed as "hard" waters (>60 mg/l $CaCO_3$). Farther downdip, sodium becomes the dominant cation, and calcium and magnesium are

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[2] 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 (16° C). The "field" coefficient of permeability (now generally referred to as hydraulic conductivity) is the same rate of flow under the prevailing conditions of water temperature (Meinzer and Wenzel, 1942, p. 452).

[3] The coefficient of transmissibility is the field coefficient of permeability multiplied by the thickness in feet of the aquifer (Theis, 1935, p. 520). Bredehoeft (1964, p. D168) has elaborated this definition to account for an aquifer made up of layers of differing permeabilities as—

$$T = \Sigma K_i m_i,$$

where

i = 1, 2, 3, * * * n layers of differing permeability,
T = transmissibility,
K_i = permeability of the i layer, and
m_i = thickness of the i layer.

[4] On the transmissibility map (pl. 3) the interval of 7,500 gpd per foot corresponds approximately to a transmissivity interval of 1,000 square feet per day.

found only in negligible quantities. In Mississippi the dominant anion is bicarbonate even in the area beyond the limits of fresh water (water containing <1,000 mg/l dissolved solids) (pl. 4 and table 1). In Arkansas and northwestern Louisiana the chloride anion makes up a significant proportion of the total anion concentration (pl. 4 and table 1). The exceptionally high chloride concentration in some of the wells in Ouachita County, Ark., may be the result of entrapment of salty water in downfaulted blocks or the result of incomplete flushing because freedom of water movement has been impeded by faulting (wells O–1 and O–6, table 1 and pl. 4; and well O–2, pl. 4). This explanation, however, probably does not apply to wells in the fresh-water area (wells Ds–1, Lf–1, Lf–2, O–3, and O–7, pl. 4 and table 1). These wells are believed to reflect a lesser degree of flushing in the Arkansas and Louisiana part of the area than in the Mississippi part because of the poorer development of maximum sand units and less favorable orientation of these sand bodies with respect to direction of flow. (Compare pls. 2, 3, and 4.) Sulfate occurs in appreciable amounts in only a few wells (Mr–3, Aa–1, Cr–1, and Sc–1, table 1).

DISSOLVED SOLIDS

The relation of dissolved-solids content to the specific conductance of water from the Cane River or equivalents is constant up to concentrations of 10,000 mg/l (fig. 2). A satisfactory method for calculating the dissolved-solids content of water in an aquifer from the long-normal resistivity curve of electrical logs has been described by Turcan (1966, p. 3–13). This method was used to calculate the dissolved solids content of water in the sands of the Cane River Formation.

Turcan's method is based on the equation

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

where

F_f = field formation resistivity factor,

R_o = resistivity read from the long-normal curve corrected to 77°F (25°C), and

R_w = resistivity of the water at 77°F (25°C).

The values obtained were used in preparing a map showing the regional variations in maximum and minimum dissolved-solids content of water in the sands of the Cane River Formation (pl. 4).[5] To avoid logging errors no calculations were made of sands less than 15–20 feet thick.

The effects of geologic and hydrologic factors on water movement and extent of flushing are shown by the distribution pattern of the dissolved-solids content of the waters in the sands of the Cane River Formation. In Mississippi and the eastern part of Arkansas, where the well-developed massive sand units (>50 feet thick) are generally oriented with the long dimension parallel to the direction of regional flow, the contours representing the dissolved-solids content show a pronounced deflection in the downflow or downdip direction. (Compare pls. 2, 3, and 4.) The correlation of lower dissolved-solids content with maximum sand units is less perfect in southwestern Arkansas primarily because the orientation of the massive sand units is roughly normal to the direction of regional flow, and the freedom of water movement and the degree of flushing are impeded by the more shaly areas between the massive sand units.

The area of the Cane River Formation that has sands thicker than 15–20 feet is a relatively narrow band that extends from the outcrop downdip along the margins of the Mississippi embayment; because only small shaly areas connect the sands, virtually the entire area of thicker sands has undergone rather extensive flushing, as indicated by the fact that salinities generally do not greatly exceed 3,000 mg/l. (Compare pls. 3 and 4.)

[5] On the map showing the dissolved-solids content of waters in the sands of the Cane River Formation or equivalents the values 500, 1,000, 3,000, and 10,000 mg/l dissolved solids were chosen on the basis of the standard proposed by the U.S. Public Health Service (1962, p. 7–8) and the salinity classification given by Winslow and Kister (1956, p. 5).

REKLAW FORMATION AND QUEEN CITY SAND OF TEXAS

GEOLOGY

The equivalents of the Cane River Formation in Texas, excluding the Carrizo Sand, are in ascending order—the Reklaw Formation, Queen City Sand, and Weches Greensand. Of these formations, only the Reklaw and Queen City will be considered in this report, as the Weches has no potential as an aquifer.

The Reklaw Formation (Wendlandt and Knebel, 1929, p. 1352) consists of gray, brown, and yellow clays; fine to coarse sands; silts; and minor amounts of lignite. Glauconite is present in varying amounts throughout the formation. Gypsiferous clays occur locally.

The Queen City Sand (Kennedy, 1892, p. 50) is composed of gray fine to medium sand and gray to brown carbonaceous clays or shales and contains minor amounts of lignite, bentonite, and glauconite.

STRUCTURE

In the northern part of the area mapped from Angelina through Grimes Counties, Tex., the regional dip of the top of the Queen City is to the south and southeast at about 100–150 feet per mile into the gulf coast geosyncline (Payne, 1968, pl. 3). From Grimes

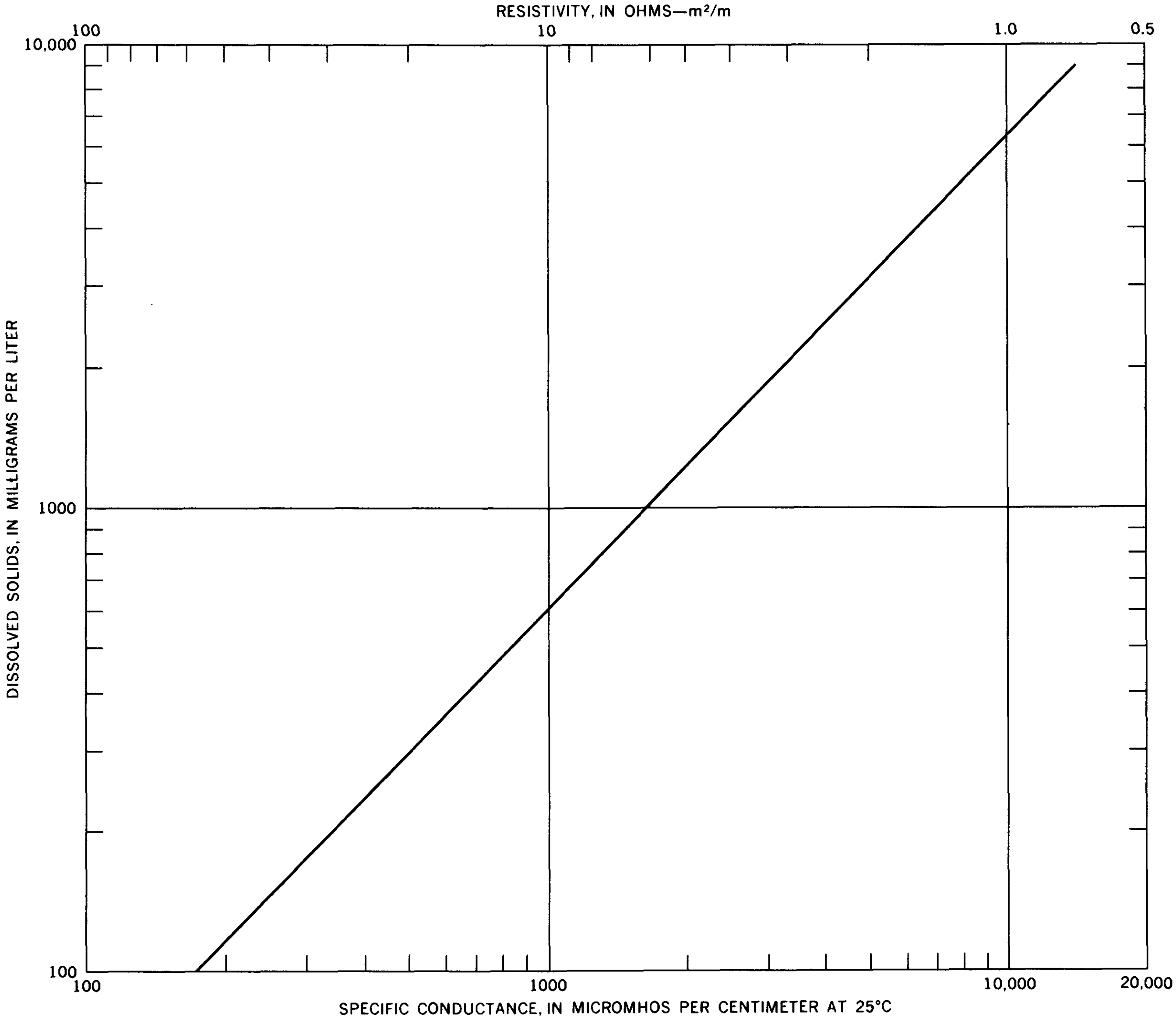


Figure 2.—Relation of specific conductance and resistivity to dissolved-solids content of water from the Cane River Formation or equivalents in Arkansas, Louisiana, Mississippi, and Texas.

County, Tex., southwestward to Webb County, Tex., the regional dip of the top of the Queen City is to the southeast at a rate of about 100–200 feet per mile. The regional dip on the top of the Reklaw Formation in the northern part of the area is to the south and southeast at a rate of about 100–200 feet per mile (pl. 5). From Grimes County, Tex., southwestward to Wilson County, Tex., the regional dip is southeastward at a rate of about 150–300 feet per mile. In Atascosa, Frio, Dimmit, La Salle, McMullen, and northern Webb Counties, Tex., the dip of the top of the Reklaw is to the south east at about 100–200 feet per mile.

That some tectonic activity occurred during Reklaw and Queen City time is indicated by thinning of the Reklaw and Queen City Formations over local structural features such as the one associated with the oil field near Madisonville, Tex. (See pl. 6 and 7.) Normal faulting occurred rather extensively, particularly in the southwestern part of the area.

THICKNESS

The combined thickness of the Cane River equivalents in Texas (Reklaw, Queen City, and Weches Formations) ranges from about 350 feet in Angelina County, Tex., to about 2,700 feet in southern Webb County, Tex.

The maximum thickness of the Reklaw Formation which occurs in the Rio Grande embayment in Webb County, Tex., is 800–850 feet (pl. 6). From this center of deposition, the formation thins rather abruptly to the northwest and north to about 200 feet near the outcrop area in Dimmit, Zavala, and Frio Counties, Tex. Along strike to the northeast from the depocenter in Webb County, the Reklaw thins gradually to a fairly uniform thickness of 300–350 feet in the downdip part of the formation in Grimes through Angelina Counties, Tex. Near the outcrop area northeastward from Bastrop to Nacogdoches and in eastern Angelina and western San Augustine Counties, Tex., the formation is about 150–200 feet thick. (See pl. 6.)

The thickness pattern of the Queen City Sand is quite similar to that of the Reklaw Formation. The depocenter of the Queen City lies in southern Webb and Duval Counties, Tex., where the formation is more than 1,750 feet thick (pl. 7). Northward and northwestward from the depocenter, the formation thins to about 800 feet near the outcrop in Zavala, Frio, and Atascosa Counties, Tex. Along strike from the depocenter northeastward, the Queen City thins rather abruptly to about 750–800 feet in thickness in the downdip reaches of the formation in Karnes and Dewitt Counties and to about 600 feet or less near the outcrop area in Wilson and Gonzales Counties. From Gonzales County northeastward, the formation thins less abruptly to a minimum thickness of 50–100 feet near the "shale out" line in the vicinity of Lufkin, Angelina County, Tex. (See pl. 7.)

LITHOLOGIC VARIATIONS AND INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

The Reklaw Formation is variable in lithologic character. In the northeastern part of the area, the formation is generally 70 percent shale or clay. Southwestward from Brazos County, Tex., the sand content of the formation increases to the extent that in parts of La Salle, Frio, and Atascosa Counties the formation is predominantly sand (pls. 6, 16). The lower 20–200 feet of the formation over much of the area consists chiefly of sand, with lesser amounts of interbedded clays, silts, and lignitic material. The sand is greenish gray, buff, and yellow; partly glauconitic; and fine to coarse. This lower sandy part of the formation, described in various recent reports (Follett, 1966, p. 22; Peckham, 1965, p. A3; Shafer, 1965, p. 13; Shafer, 1966, p. 17; Tarver, 1966, p. 14; Thompson, 1966, p. 21), has been correlated with the Newby Glauconitic Sand Member of Stenzel (1938, p. 65–71). In earlier reports the greater part of the lower 20–200 feet was probably considered part of the underlying Carrizo Sand. The pattern and the distribution of high-sand-concentration areas (>40–50 percent, pl. 8) and of the massive sand units (pl. 8) suggest that the sands accumulated as alongshore and nearshore bars with long dimensions of the sand bodies oriented parallel to the strandline of the Reklaw sea. Some of the massive sand units showing a bifurcating pattern, notably in Frio County, Tex., may represent deltaic deposits laid down along the seaward extremities of streams (pl. 8). During later Reklaw time, deposition of coarse clastic material was greatly reduced over most of the area, deposition of massive sands during this time being limited to the extreme southwestern part of the area from northwestern Atascosa County through Frio, northern and western La Salle and Dimmit Counties, to northwestern Webb County, Tex.

The Queen City Sand is highly variable in lithologic character, grading from 10 to 20 percent sand to more than 70 percent sand within relatively short distances (pl. 7). The highest sand concentration (>60 percent sand) is in the southwestern part of the area in a band extending from Wilson County through Atascosa, Frio, La Salle, McMullen, and Webb Counties, Tex. (pl. 7). Northeast from this area the highest sand concentrations (>40 percent) occur along and near the outcrop (generally within 5–20 miles) in the updip part of the Queen City Sand.

The distribution of the higher sand-concentration areas and the patterns of elongation of the maximum sand units (pl. 9) suggest that the massive sands were deposited in channels and as nearshore and alongshore bars. The intricate interweaving and bifurcating pattern of sand units, many of which are more than 125 feet thick, and the extremely high concentration of sand in Webb County northeastward through Atascosa County, Tex., (pls. 7, 9) probably represent deposition in channels in a delta complex that was formed by ancestors of the Rio Grande and the Nueces River systems. The maximum sand units that are generally less than 75 feet thick and whose direction of elongation parallels the supposed orientation of the strandline of the Queen City sea, those typified by the maximum sand units in Burleson County northeastward through Walker County, Tex. (pl. 9), probably represent nearshore and alongshore bars and beach deposits.

HYDROLOGY

The Reklaw Formation as defined in this report (pl. 16) and the Queen City Sand constitute an aquifer system of potential significance in the southwestern part of the area in Atascosa, Frio, Karnes, La Salle, McMullen, Webb, and Wilson Counties, Tex. In the central and northeastern parts of the area mapped, this aquifer will not support extensive development because the formations contain fewer massive sand units. (Compare pls. 6–9 with pls. 10 and 11.)

PERMEABILITY AND TRANSMISSIBILITY IN RELATION TO GEOLOGIC FACTORS

The few aquifer tests of the Queen City Sand that are available have been made in areas in which the maximum sand units are relatively thin. Tests made in areas in which the maximum sand unit ranges between 25 and 50 feet give an average coefficient of permeability of 50–60 gpd per sq ft. Two tests in Atascosa County made in an area in which the maximum sand-unit thickness is 50–75 feet give an average coefficient of permeability of about 85 gpd per sq ft. From this limited information and the similarities in lithologic character and mode of deposition to the Sparta Sand, the following permeability-thickness relationships were assumed in calculating the coefficient of transmissibility values of the Reklaw Formation and Queen City Sand (pls. 10, 11):

Sand thickness (ft)	*Coefficient of permeability (gpd per sq ft)*
25– 50	50
50– 75	60
75–100	80
>100	200

Rates of discharge of flowing wells in the massive sand area suggest that the coefficient of permeability used for the thicker sands is quite conservative.

The area of highest transmissibility values in the Reklaw and Queen City Formations is found in the southwestern part of the area where thick massive channel and bar sands are extensively developed. Some of the channel sands in the Queen City Sand coincide in geographic position with thick sands in the underlying Reklaw Formation, and in such areas the combined coefficient of transmissibility probably has a value of over 150,000 gpd per foot and may well be in excess of 200,000 gpd per foot (pls. 8–11). There is an abrupt lateral variation in transmissibility coincident with the abrupt lateral variation in sand-unit thicknesses. In the central and northeastern part of the area where the sand concentration is less and where maximum sand units are less thick and less extensive than in the southwestern part, it is doubtful that the combined coefficient of transmissibility values of the Reklaw and Queen City Formations will exceed 30,000 gpd per foot and will generally be 15,000 gpd per foot or less.

RECHARGE AND DISCHARGE

Recharge of the Reklaw Formation and Queen City Sand takes place by infiltration of precipitation in the outcrop area, by movement of water from the underlying Carrizo Sand, and by infiltration of water from streams or lakes incised in the formations. As will be seen in the subsequent discussion on chemical quality of water, movement of water from the Carrizo Sand has probably been an important source of recharge in the massive sand bodies and high-sand-percentage areas of the Reklaw and Queen City Formations in Atascosa, Frio, La Salle, McMullen, Webb, and Wilson Counties, Tex.

Natural discharge from the Reklaw and Queen City Formations is accomplished by leakage through the overlying confining beds. Artificial discharge takes place from flowing and pumped wells.

REGIONAL FLOW

Except for parts of the outcrop area, water in the Reklaw and Queen City Formations is artesian, and the regional flow is generally down the dip of the formations into the gulf coast geosyncline. In Dimmit, La Salle, and Webb Counties, the direction of flow is to the east and east-southeast. From Frio and McMullen Counties northeastward along the strike of the formations to Houston and Trinity Counties (pl. 5), the regional flow is to the southeast. In Houston and Trinity Counties, the direction of regional flow is slightly east of south. There is an upward component of movement of water over an extensive part of the area where the head of the water in the Reklaw and Queen City Formations exceeds the heads in overlying aquifers. This upward component of movement becomes more and more dominant as the sands pinch out downdip and as higher sand concentrations increase the relative vertical permeability updip. (Similar to conditions shown in fig. 4.)

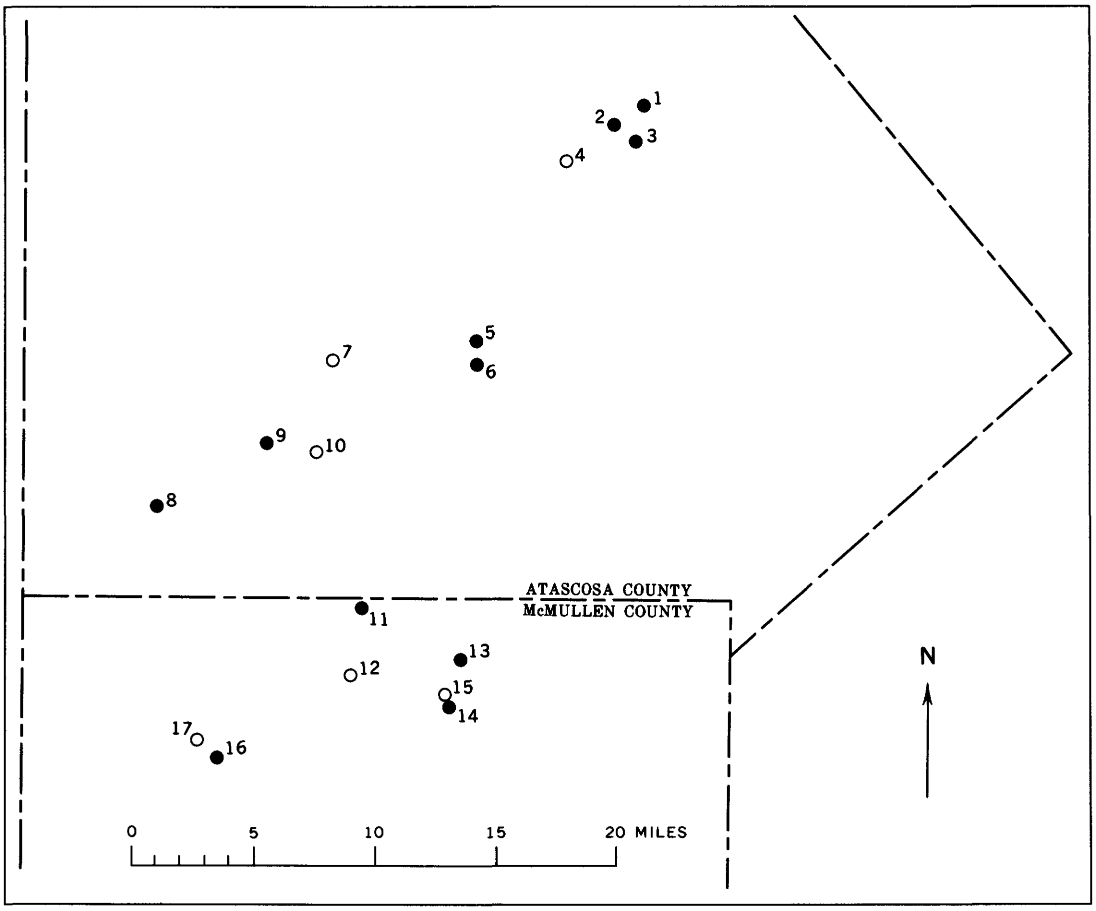
CHEMICAL QUALITY OF WATER AND RELATIONS TO GEOLOGIC AND HYDROLOGIC FACTORS

Data from available chemical analyses of water from the Reklaw Formation and the Queen City Sand, together with calculations of dissolved-solids content based on data from electrical logs, have been used to prepare the maps showing the dissolved-solids content of water in the formations (pls. 13–15) and the geohydrologic sections (pl. 16; fig. 4). Stiff diagrams of representative analyses of water from the formations have been used to construct a section showing the variation in major chemical constituents (pl. 12).

VARIATIONS IN CHEMICAL QUALITY OF WATER

The water from the Reklaw and Queen City Formations is extremely variable in chemical quality (pl. 12 and table 1). In Houston and Leon Counties the water is mainly of the bicarbonate type and is relatively soft. In the remainder of the area in and near the area of outcrop and in the shallower wells, the water is proportionately high in concentrations of calcium, magnesium, chloride, and sulfate and is generally very hard (pl. 12 and table 1). In the deeper wells, particularly in areas of high sand concentration and thick sand units, the water of the Queen City Sand shows a marked reduction in the proportionate amount of calcium, magnesium, chloride, and sulfate content and of hardness. (Note particularly wells A–2 and A–3, M–3 and M–6, and M–5 and M–7, pl. 12; see also table 1.)

Figure 3 shows the dissolved-solids and anion content of water from the Queen City related to the distance of the producing zone above the top of the Carrizo Sand.



Well	Well owner	Depth (ft)	Estimated interval to top of Carrizo Sand (ft)	Constituents, in milligrams per liter			
				Bicarbonate	Sulfate	Chloride	Dissolved solids
1	M. S. Coughran	700	875	836	80	376	------------
2	C. L. Downey	1,000	675	724	140	263	------------
3	R. W. Dorsey	1,159	550	580	80	91	789
4	R. D. Quillian	2,060	------------	280	26	25	------------
5	C. D. Baldree	1,314	1,025	743	152	497	1,710
6	City of Christine	1,717	625	504	83	66	684
7	R. J. Berger	2,300	------------	180	56	28	295
8	Jess McNeal	1,012	1,225	618	220	1,320	------------
9	S. W. Berrey	1,560	675	416	93	73	637
10	Tom Peeler	2,794	------------	280	47	17	357
11	Sam Countiss	2,300	625	744	76	80	972
12	Mrs. Claude Franklin, No. 1	3,998	------------	346	90	64	564
13	Lewis M. Gubbels No. 1	2,000	1,270	1,660	192	658	2,830
14	Lewis M. Gubbels	2,765	510	1,480	128	298	1,990
15	H. M. Roark	3,830	------------	375	103	83	646
16	John Gunn	1,985	1,160	1,520	278	1,800	4,720
17	Jess Willis	3,540	------------	368	95	79	602

NOTE.—Wells in Carrizo Sand shown by open circles. Wells in Queen City Sand shown by solid circles.

FIGURE 3.—Relation of chemical quality of water in the Queen City Sand to distance above top of Carrizo Sand in Atascosa and McMullen Counties, Tex.

TABLE 1.—*Analyses of water from wells in*

[Analyses by U.S. Geological Survey unless otherwise indicated.

Well [1]	State	County or parish	Well owner or designation	Depth of well (ft)	Date of collection	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
									Cane River Formation
Cb-1	Arkansas	Columbia	Sohio Oil Company	376	8-29-50	11	0.12	10	2.8
DS-1	do	Dallas	Town of Sparkman	244	7-26-46	11	.24	6.4	1.2
Lf-1	do	Lafayette	Delmar Crank	350	10- 6-64	13	.07	5.9	1.5
2	do	do	City of Bradley	460	10- 6-64	11	.16	5.7	1.6
Mr-1	do	Miller	Arkansas State Forestry Dept	310	10- 7-64	28	.30	2.5	2.3
2	do	do	R. E. Ransdell	350	10- 6-64	11	.05	1.2	.4
3	do	do	Bright Star School	500	10- 7-64	15	1.5	12	4.5
Nv-1	do	Nevada	Quay Biddle	210	10- 8-64	10	.36	5.7	1.7
O-1	do	Ouachita	W. H. McLeod	450	1-16-59		.26	48	11
3	do	do	City of Chidester	342	8-21-58		3.6	13	3.0
4	do	do	Holiman Dickinson Lumber Co	110	8-21-58		3.1	4.9	5.6
5	do	do	City of Camden	326	4- 8-59		3.0	7.6	2.2
6	do	do	J. D. Robertson	580	4- 8-59		.38	42	11
Bo-1	Louisiana	Bossier	Town of Plain Dealing	335	11-10-59	9.8	.12	7.0	1.4
Cd-1	do	Caddo	C. O. Dupree	210	8- 6-59	12	.52	21	6.0
Aa-1	Mississippi	Attala	W. O. Orman	168	2- 1-57		.08	40	18
Bv-2 [2]	do	Bolivar	Town of Mound Bayou	1,214	2- 4-60	.4	.0	1.2	.0
3	do	do	T. R. Handley	1,516		36	.24	1.0	.20
Cr-1	do	Carroll	Town of Vaiden	210	1- 4-57		2.5	26	8.9
Ck-1	do	Clarke	DeSoto Water Assoc	472	3-29-67	38	.42	2.2	.70
Hm-1 [2]	do	Holmes	Town of Cruger	826	2- 2-61	14.8	.1	.0	.0
2 [4]	do	do	Town of Tchula	1,051		41		2.0	.3
Lr-1	do	Leflore	Minter City Oil Mill	700	1- 3-62	31	.29	.0	.0
2 [5]	do	do	R. L. Kirby	515		17	.4	27	2.9
Sc-1	do	Scott	Town of Sebastopol	270	2-14-67	35	.10	11	2.8
Su-1 [4]	do	Sunflower	J. R. Dockery	960		25	.85	1.2	.4
3 [4]	do	do	W. T. Hull	900		15	.66	1.4	1.2
4	do	do	Mrs. A. J. Word, Sr	1,238	1- 4-62	20	.33	.0	.0
T-1 [4]	do	Tallahatchie	M. P. Sturdivant	650		30	.85	1.1	.6
Ws-1	do	Washington	City of Greenville	1,642	2-19-68	22	.11	.5	.2
2	do	do	G. B. Walker	1,850	12- 4-15	26	2.5	3.2	.60
3	do	do	George Abraham	1,826	2-19-68	21	.94	2.0	.0
5	do	do	Ben Walker	1,792	1- 4-62	17	.16	.0	.0
Y-1 [2]	do	Yazoo	D. F. Berry (Benton Public Supply)	1,772	3- 3-58	2.4	.0	.8	.0
									Reklaw
A-4	Texas	Atascosa	Fergeson	1,040	6-18-32		1.66	48	23
C-2	do	Caldwell	Delhi Community Center	100	6-20-64	25	16	118	57
F-3	do	Frio	Roberts Ranch	208	8-19-52	14		90	17
6	do	do	W. B. Waters, Jr	700	8-13-64	13	1.6	46	14
9	do	do	Thomas and Frazier	115	6-18-32	51	.21	34	8.6
G-4	do	Gonzales	M. G. Derrick	250	4-18-63	16	16	34	7.3
9	do	do	A. E. Linke	172	4-18-63	17	2.3	182	55
12	do	do	S. W. Hendershot, Jr	205	4-17-63	28	2.8	68	7.6
W-7 [6]	do	Wilson	Joe Pavliska	120	3-20-36			111	62
21 [6]	do	do	Stokely Jackson	108	1-24-36			62	26
									Queen
A-1	Texas	Atascosa	S. W. Berrey	1,560	8-18-64	17	0.20	2.8	0.5
3	do	do	C. D. Baldree	1,314	5-25-44	14	.08	4.8	1.4
8	do	do	Dorothy Quillian	274	8-26-64	19	3.5	88	28
B-1	do	Burleson	F. J. Schweda	42	1- 1-51	23		112	69
2	do	do	L. M. Scarmardo	787	6-17-63	14	.07	1.5	.1
4	do	do	W. F. Tonn	23	5-14-64	46	.06	46	3.7
C-1	do	Caldwell	Walter Phillips	110	2- 6-64	49	34	6.0	2.0
3	do	do	William Bowyer	59	2-19-64	45		74	20
F-4	do	Frio	R. W. Brown	110	6-18-32		.26	145	18
5	do	do	W. B. Waters, Jr	300	8-13-64	18	1.2	33	21
8	do	do	Oppenheimer and Lang No. 2	860	5-26-32	20	3.4	90	40
G-1	do	Gonzales	Albert West	700	3-13-63	15		2.2	.4
3	do	do	Patteson Estate	550	3-13-63	12		8.5	3.7
10	do	do	W. O. Phillipus	250	2- 5-63	16		76	44
16	do	do	M. L. Crozier	250	1-24-63	36	14	255	73
H-1	do	Houston	R. E. Smith	160	8-22-63	15	.07	8.0	2.9
3	do	do	Texas Power and Light Co	586	7-18-61	11	.22	.2	.3
8	do	do	O. C. Daniels	250	7-25-61	28	2.4	17	2.4
9	do	do	Mission State Park	43	7-24-61	35	.07	13	5.3
Ls-1	do	La Salle	George Crisp, Sr	1,900	4-26-59	18		11	5.2
2	do	do	Loyd Hurt	252	5-28-63	16	3.0	131	72
3	do	do	Laura E. Cannon	500	10-31-62	19	.58	65	33
5	do	do	Jim Donnell	1,957	5-11-45	37	.63	3.1	.7
L-1	do	Lee	Giddings City Well No. 5	1,196	2-18-44	10	.10	17	5.8
2	do	do	Giddings City Well No. 4	1,354	2-18-44	12	.01	5.1	2.1
4	do	do	Woodrow W. Brewer	486	9-16-53	18	.11	121	37
6	do	do	C. C. Perry	211	8-13-64	14		5.2	1.5
Ln-1 [7]	do	Leon	City of Centerville	365	3-19-51	10	.1	39.8	12.6
2	do	do	J. E. Boykin	40	11-18-59	17	.14	20	1.4
M-1	do	McMullen	J. L. Donnell	2,105	12-27-62	21		3.0	.7
2	do	do	S. J. Martin	3,500	4-24-63	21		1.5	.8
3	do	do	John Gunn	1,985	5-22-63	18	.16	2.5	3.2
W-2 [6]	do	Wilson	J. W. Hierholzer	420	3-30-36			58	41
6 [6]	do	do	S. W. Seale	175	3-23-36				4
11	do	do	O. D. Compton	400	6-16-55	22		138	60

See footnotes at end of table.

the Cane River Formation or equivalents

Constituents in milligrams per liter except as indicated. Tr, trace]

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance at 25°C	Percent sodium	Temperature (°Celsius)	Color (cobalt units)	pH
or equivalents														
106	4.8	273	0	0.7	34	0.1	0.3	304	36	497		20		7.7
313	17	254	0	.2	364	.6	.5	803	21					8.0
135	3.1	275	0	.2	63	.4	1.0	358	20	682			6	7.8
264	3.4	428	34	.0	137	1.0	.2	676	20	1,190		22	7	8.8
1.8	1.3	18	0	3.0	2.6	.0	.0	51	16	49			2	6.6
54	1.4	145	0	.2	3.7	.3	.6	150	4	246		20	6	7.9
35	5.5	98	0	37	5.6	.2	.8	168	48	274			1	7.4
41	2.6	132	0	3.4	1.5	.1	.0	131	21	221			2	7.4
464	13	400	0	1.6	612		1.3	1,440	165	2,490	85	19		8.2
187	6.3	196	0	1.6	205		1.8	612	45	916	90			8.2
3.4	.6	44	0	1.6	4.0		.2	55	35	83	17			7.4
34	3.6	114	0	2.8	8.0		1.2	146	28	210	69	19		7.5
964	13	320	0	6.8	1,410		.3	2,720	150	4,610	93	22		8.0
225	2.2	528	0	1.6	55	1.9		565	23	966	95	21	10	7.9
24	2.9	128	0	9.6	13	.1	1.4	154	77	250	89	22	20	7.5
14	9.8	198	8	23	12	.1	2.7	225	174	393			5	8.5
[3]161.82		32.6		Tr	9	.8		379.29	3				60	8.2
181	3.4	477		1.6	10			473	3					
7.4	6.4	90	0	42	3.8	.0	1.9	197	101	249		18	5	7.0
268	2.7	722	0	.8	3.5	1.1	.0	673	8	1,060		21	12	7.9
[3]74.98		153		3.62	4	.4		190.01	0				20	7.9
226	2.2	599		.2	5.1			573	6					
92	1.0	244	0	.0	3.4	.3	.0	252	0	385		21	30	8.2
[3]52		201		11	4			275	79					
76	3.8	207	0	27	1.9	1.3	.5	261	39	389			10	7.4
185	13	487		1.2	15			486	5			21		
306	3.5	814		1.8	4.6			737	8					
143	1.0	371	0	.6	.8	.9	.0	360	0	575		26	100	7.5
122	2.0	298		2	18			326	5			19		
404	1.5	990	0	.0	44	1.5	1.5	963	2	1,560		29	60	8.0
309	.0	740	12	6.2	13		.0	737	10					
580	1.9	1,420	21	.2	38	1.8	.4	1,360	5	2,150		24	60	8.4
419	2.0	1,100	0	2.0	2.3	1.7	.0	996	0	1,590		27	100	8.2
[3]535.9		1,152		.0	2	4.2		1,233.16	2				20	8.1
Formation														
[3]88		272		73	75		0.5	442	214		47			
[3]131		94		99	448	0.2	1.8	927	529	1,730	35			6.1
[3]42		307		58	50	.6	1.0	424	294	739	24			7.4
156	11	304		92	125	.7	.0	607	172	1,030	65			7.2
53	9.3	149		45	54		.6	330	120		47			
[3]27		90		23	54	.1	.0	218	115	371	34			6.4
[3]107		236		250	325	.4	.5	1,050	680	1,710	26			6.8
[3]32		148		81	46	.2	.0	361	201	533	26			7.0
[3]199		146		545	196			1,186	532					
[3]27		73		123	96			370	263					
City Sand														
[3]245		416		93	73	0.5	0.0	637	9	1,030	98	36		8.2
667	4.6	743		152	497	1.7	2.0	1,652	18	3,070	98			8.2
[3]146		342		171	104	.5	.0	725	334	1,140	49			7.5
[3]69		164	0	334	163		1.5	913	563	1,450	21			8.0
202	1.3	316	0	138	31	.2	.0	545	4	870	99	24	0	7.8
[3]19		132	0	18	28	.2	6.0	232	130	357	24	21		7.0
[3]66		70		88	12	.2	.2	258	23	338	86			6.9
[3]78		66		6.0	261	.3	9.6	526	267	997	39			6.7
[3]128		331		114	228		2.5	800	436		39	32		
[3]271		418		190	153	1.0	.0	893	169	1,140	78	25		7.5
199	21	374		172	258		.0	987	389		51			
[3]169		268		76	54	.2	.0	449	7	751	98	26		7.8
[3]766		320		840	400		.0	2,190	36	3,350	98	26		7.8
[3]104		234		211	130	.1	.0	704	370	1,160	38			7.5
[3]110		152		732	205	.2	.0	1,490	936	1,950	20	22		6.3
[3]74		194		12	14	.2	1.0	223	32	373	83			7.4
[3]140		308		33	12	.4	.8	349	2	566	100	21		7.9
[3]44		121		47	15	.2	.0	219	74	338	56			6.5
[3]13		35		4.6	26	.1	16	130	54	182	35	22		6.0
[3]1,600		950		590	1,520		1.5	4,210	49	6,680	100	33		7.9
[3]499		432		504	588	.0	.2	2,020	623	3,150	64			7.3
[3]280		382		299	212	.5	2.2	1,110	298	1,760	68	26		7.5
933	13	1,530		192	422	4.4	1.0	2,360	10	3,660				8.0
307	15	261		344	127	.4	.2	955	66	1,530		32		8.2
417	9.4	779		155	94	1.9	.8	1,080	21	1,720	96	34		8.5
49	8.8	258		186	111		1.0	694	454	1,090	19	24		7.0
[3]134		306		30	19	.6	.0	355	19	546	94	21		8.0
[3]82.9		185		116.8	32			393	151					8.0
[3]8.9		58		4.0	5.5	.1	15	101	56	147	10			6.5
[3]344		656		98	82	.9	.5	889	10	1,400	99			7.8
[3]981		1,820		168	335		1.5	2,400	7	3,830	100	47		8.0
[3]1,870		1,520		278	1,800		1.5	4,720	19	7,490	100	36		8.0
[3]150		169		259	166			757	316			25		
[3]287		616			94			825	15					
[3]127		239		388	197	.0	.0	1,050	591	1,640	32			7.5

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

Well [1]	State	County or parish	Well owner or designation	Depth of well (ft)	Date of collection	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
									Queen
W-13 [6]	Texas	Wilson	R. C. Teas	1,000	5-18-36			7	2
14 [6]	do	do	T. W. Sutherland	100	8-17-36			23	9
17 [6]	do	do	E. O. Henry	44	6- 9-36			38	4

[1] Numbers for Arkansas, Louisiana, and Mississippi are shown in plate 4, map showing dissolved-solids content of Cane River Formation. Numbers for Texas are shown in plate 14, map showing dissolved-solids content of Queen City Sand. Numbering system does not correspond to State numbering system.
[2] Analyses by Mississippi State Board of Health.
[3] Sodium and potassium calculated as sodium.

As the interval from the producing zone in the Queen City Sand to the top of the Carrizo becomes less, the anions, particularly chloride, and the dissolved-solids content decrease, and the water in the Queen City becomes similar in type to the water in the Carrizo. As suggested by Harris (1965, p. 41), this change strongly indicates that a close hydraulic connection exists between the Carrizo, Reklaw, and Queen City Sands and that there has been a considerable amount of recharge and consequent flushing of the Reklaw and Queen City by flow from the Carrizo Sand. (See also pl. 16 and fig. 4.)

DISSOLVED SOLIDS

The method and limitations of calculation of dissolved solids are discussed in the section on the "Cane River Formation of Arkansas, Louisiana, and Mississippi."

The regional variations in maximum and minimum dissolved-solids content of water in the Reklaw and Queen City Formations are shown in plates 13 and 14.

The variation in dissolved-solids content of water in the Reklaw Formation is closely related to the distribution of maximum sand units and to differences in transmissibility. (See pls. 8, 10, 13.) For example, areas in Frio, La Salle, and Atascosa Counties in which the electrical-log data suggest that the minimum dissolved-solids content of water in the Reklaw is probably less than 500 mg/l coincide with the axes of thickening of maximum sand units and with areas of relatively high transmissibility. (Compare pls. 8 and 10 with pl. 13.) The elongated low minimum dissolved-solids area (<500 mg/l) through La Salle and Atascosa Counties (pl. 13) parallels the strike of the top of the Reklaw Formation (pl. 5). This orientation is normal to the general direction of regional flow and therefore probably represents an area in which there has been more extensive flushing of the Reklaw Formation by upward movement of water from the Carrizo Sand as the result of the higher head of the water in the Carrizo and of the improved interconnection between the two formations (pls. 8, 16; fig. 4) along the axial part of the thick sand units in the Reklaw.

The pattern of dissolved-solids content of water in the Queen City Sand (pl. 14) shows a close relation to geologic and hydrologic factors. The lower dissolved-solids lines may be deflected in the downflow or downdip direction where areas of higher transmissibility, higher sand-percentage concentration, and thicker maximum sand units are oriented parallel to the direction of dip, such as in Grimes and Madison Counties (pl. 14). Where areas of higher transmissibility, higher sand-percentage concentration, and thick maximum sand units are oriented parallel to the strike, as in McMullen and Webb Counties, isolated areas of relatively low dissolved-solids content water may be found whose elongation is normal to the general direction of regional flow. (Compare pls. 5, 7, 9, 11, 14, and 15.)

The pattern of distribution of salinity of water in the Queen City Sand (pl. 15) forms two distinct areas that are reflections of differences in the lithologic framework of the formation. From Gonzales County northeastward, the distribution of salinity is one which would normally be expected. There is an orderly and constant increase in salinity down the dip of the formation in the direction of regional flow. Bands of circumscribed dis-

Cane River Formation or equivalents—Continued

Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance at 25°C	Percent Sodium	Temperature (°Celsius)	Color (cobalt units)	pH
City Sand														
[3]1,645		1,281	---	---	1,620	---	---	4,066	26	---	---	---	---	---
[3]58		73	---	41	84	---	---	251	96	---	---	---	---	---
[3]24		159	---	17	12	---	---	173	113	---	---	---	---	---

[4] Analyses by W. R. Perkins.
[5] Analysis by University of Mississippi.
[6] Analyses by chemists employed by Works Progress Administration under Bureau of Industrial Chemistry, University of Texas.
[7] Analysis by Curtis Laboratories.

solved-solids content (salinity) are formed generally parallel to the regional strike of the formation (pls. 14, 15). This area coincides with the area in which there is a relatively constant decrease in sand-percentage concentration from the outcrop down the dip of the formation and in which there is little development of exceptionally thick or extensive maximum sand units either in the Reklaw or the Queen City (pls. 7–9). In the southwestern part of the area, particularly in Frio, La Salle, McMullen, and Webb Counties, there is no consistency in the pattern of distribution of salinity (pl. 15). At a given location, the water in the Queen City Sand may range from a dissolved-solids content of less than 1,000 mg/l (fresh water) to more than 10,000 mg/l (very saline water), whereas at a location farther downdip, the salinity of the water in the Queen City may range only from 1,000 mg/l to slightly less than 3,000 mg/l (slightly saline water). (See pls. 14–16.) This area of inconsistent distribution of salinity coincides with the area in which the sand-percentage concentrations in both the Reklaw and Queen City Formations have a wide and erratic variation (from <20 percent to >60 percent) and where thick and extensive maximum sand units are developed along well-defined trends (pls. 6–9). The wide local variation in salinity within this area is believed to have been caused by differences in rates of upward movement of fresher water from the underlying Carrizo Sand. The greater the amount of sand and the thicker the individual sand bodies in the Reklaw and Queen City, the greater and more extensive the flushing by fresher water from the Carrizo Sand (pl. 16; fig. 4).

Figure 4 illustrates the relation of (1) differences in head between the Carrizo and Queen City Sands as shown by the potentiometric surfaces, (2) the sand-percentage concentration of the Reklaw and Queen City section, and (3) the degree of flushing that has taken place. The degree of flushing increases with an increase in head difference, an effect which is, however, strongly modified by the sand development.

CONCLUSIONS

1. The mode of deposition is a controlling factor in the hydrology of the Cane River and equivalent formations. The areas in which the Cane River or equivalents are important potential sources of ground water are those areas in which thick sand units of the bar or channel type have been deposited.

2. The most extensive flushing of the Cane River or equivalent formations has taken place in areas of thick and extensive sand units and high sand concentrations.

3. An important source of recharge to the Reklaw and Queen City Formations in much of the southwestern part of the area has been the Carrizo Sand. In general, the closer the producing interval in the Reklaw and Queen City is to the top of the Carrizo, the better the chemical quality of the water.

4. The mapping or plotting of dissolved-solids content and of salinity of the water is an effective means of better understanding the relation between the geology and the hydrology of the formations.

5. The geologic, hydrologic, and chemical maps and illustrations of the Cane River or equivalent formations form a base for quantitative evaluation and description of the water-bearing properties of the formation.

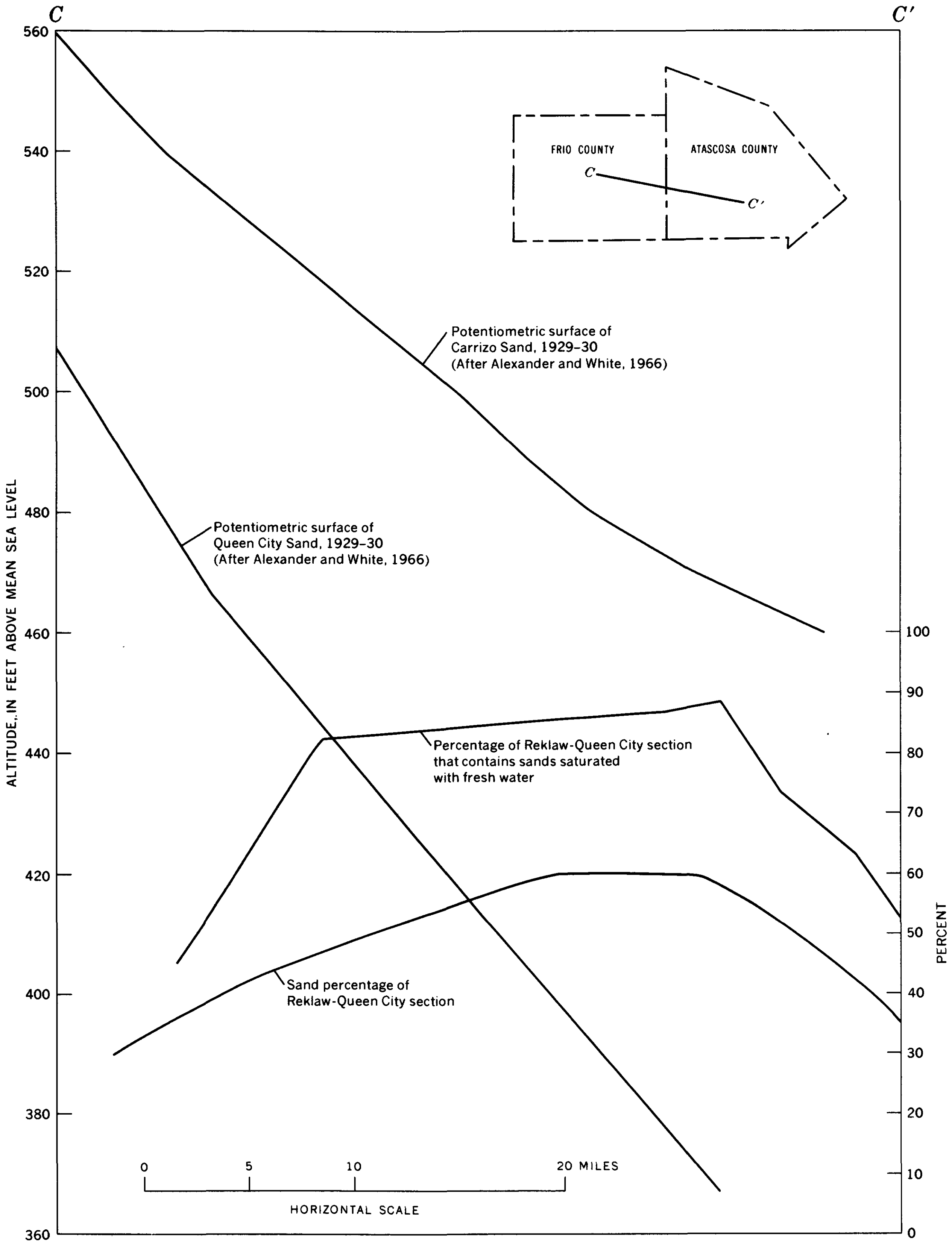


FIGURE 4.—Generalized section *C–C′* through Atascosa and Frio Counties, Tex., showing relation of potentiometric surfaces of Carrizo and Queen City Sands and sand percentage of the Reklaw and Queen City section to the extent of flushing by fresh water of the Queen City Sand.

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