GEOHYDROLOGIC UNITS OF THE MISSISSIPPI EMBAYMENT AND TEXAS COASTAL UPLANDS AQUIFER SYSTEMS, SOUTH-CENTRAL UNITED STATES

REGIONAL AQUIFER-SYSTEM ANALYSIS

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Geohydrologic Units of the Mississippi Embayment and Texas Coastal Uplands Aquifer Systems, South-Central United States

By R.L. HOSMAN *and* JONATHAN S. WEISS

REGIONAL AQUIFER-SYSTEM ANALYSIS—GULF COASTAL PLAIN

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities, and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number, and where the volume of interpretive material warrants, separate topical chapters that consider the principal elements of the investigation may be published. The series of RASA interpretive reports begins with Professional Paper 1400 and thereafter will continue in numerical sequence as the interpretive products of subsequent studies become available.

Dallas L. Peck
Director

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[Plates are in separate case]

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METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below:

Multiply inch-pound units	*By*	*To obtain metric units*
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

GEOHYDROLOGIC UNITS OF THE MISSISSIPPI EMBAYMENT AND TEXAS COASTAL UPLANDS AQUIFER SYSTEMS, SOUTH-CENTRAL UNITED STATES

By R.L. Hosman and Jonathan S. Weiss

ABSTRACT

As part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program, the Gulf Coast RASA was initiated to investigate all Tertiary and Quaternary aquifers underlying the Coastal Plain in the south-central United States. Geohydrologic units that make up two of the three regional aquifer systems—Mississippi embayment and Texas coastal uplands—in the area are described in this report. The gulfward boundary of the outcrop of the two aquifer systems is the southernmost outcrop or subcrop of the Vicksburg-Jackson confining unit, and the updip boundary is the contact between Cretaceous and Tertiary deposits, extending northward to the southern tip of Illinois. The uppermost Cretaceous aquifer, the McNairy-Nacatoch aquifer in the northern part of the Mississippi embayment, is also included where it may be hydraulically connected to the younger sediments.

Major regional geohydrologic units generally are coincident with previously defined geologic units. Most of the geohydrologic units consist of alternating sand and clay; however, the entire sequence becomes a clay and carbonate facies gulfward.

The regional geohydrologic units delineated in this study, from youngest to oldest, are (1) Mississippi River Valley alluvial aquifer, (2) Vicksburg-Jackson confining unit, (3) upper Claiborne aquifer, (4) middle Claiborne confining unit, (5) middle Claiborne aquifer, (6) lower Claiborne confining unit, (7) lower Claiborne-upper Wilcox aquifer, (8) middle Wilcox aquifer, (9) lower Wilcox aquifer, (10) Midway confining unit, and (11) McNairy-Nacatoch aquifer. The Mississippi embayment aquifer system contains all of these units and has a maximum thickness of about 5,000 feet. The Texas coastal uplands aquifer system, which is contiguous with the Mississippi embayment aquifer system and extends westward and southwestward from the Sabine uplift, contains all of the foregoing geohydrologic units except the Mississippi River Valley alluvial aquifer, the lower Wilcox aquifer, and the McNairy-Nacatoch aquifer. The Texas coastal uplands aquifer system has a maximum thickness of about 7,000 feet.

INTRODUCTION

The objective of the Gulf Coast Regional Aquifer-System Analysis (RASA) was to study all aquifer systems in Cenozoic deposits underlying the Coastal Plain in the south-central United States. Deposits older than Cenozoic sediments do not contain freshwater-bearing aquifers of regional extent in the study area; therefore, these older deposits are not included in the regional aquifer-system study. The exception is the Upper Cretaceous sediments in the Mississippi embayment, which not only contain freshwater but also hydraulically interconnect to a slight degree with the overlying younger sediments. The Upper Cretaceous sediments in the Mississippi embayment therefore are included in the study. The study area, about 290,000 square miles (mi^2), consists of all or part of Alabama, Arkansas, Florida, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas (fig. 1). Included in the total area is about 60,000 mi^2 of offshore area.

The geohydrologic framework of the aquifer systems was determined using data from about 1,000 borehole geophysical logs (Wilson and Hosman, 1988), which were selected on the basis of spatial distribution of wells (pl. 1) and the degree to which the logs represented regional characteristics. The logs provided most of the geohydrologic data used in the study, including data for determination of the top of the geopressured zone (zone of abnormal hydrostatic pressure). Determination of the top of the geopressured zone was supplemented by consulting a map (Wallace and others, 1981) showing the occurrence of geopressure.

This report focuses on the geohydrologic framework of the Mississippi embayment and Texas coastal uplands aquifer systems, which are two of the three regional aquifer systems studied by the Gulf Coast RASA project. The geohydrologic framework of the coastal lowlands aquifer system, the third regional aquifer system studied, is described in chapter C of this Professional Paper (Weiss, in press).

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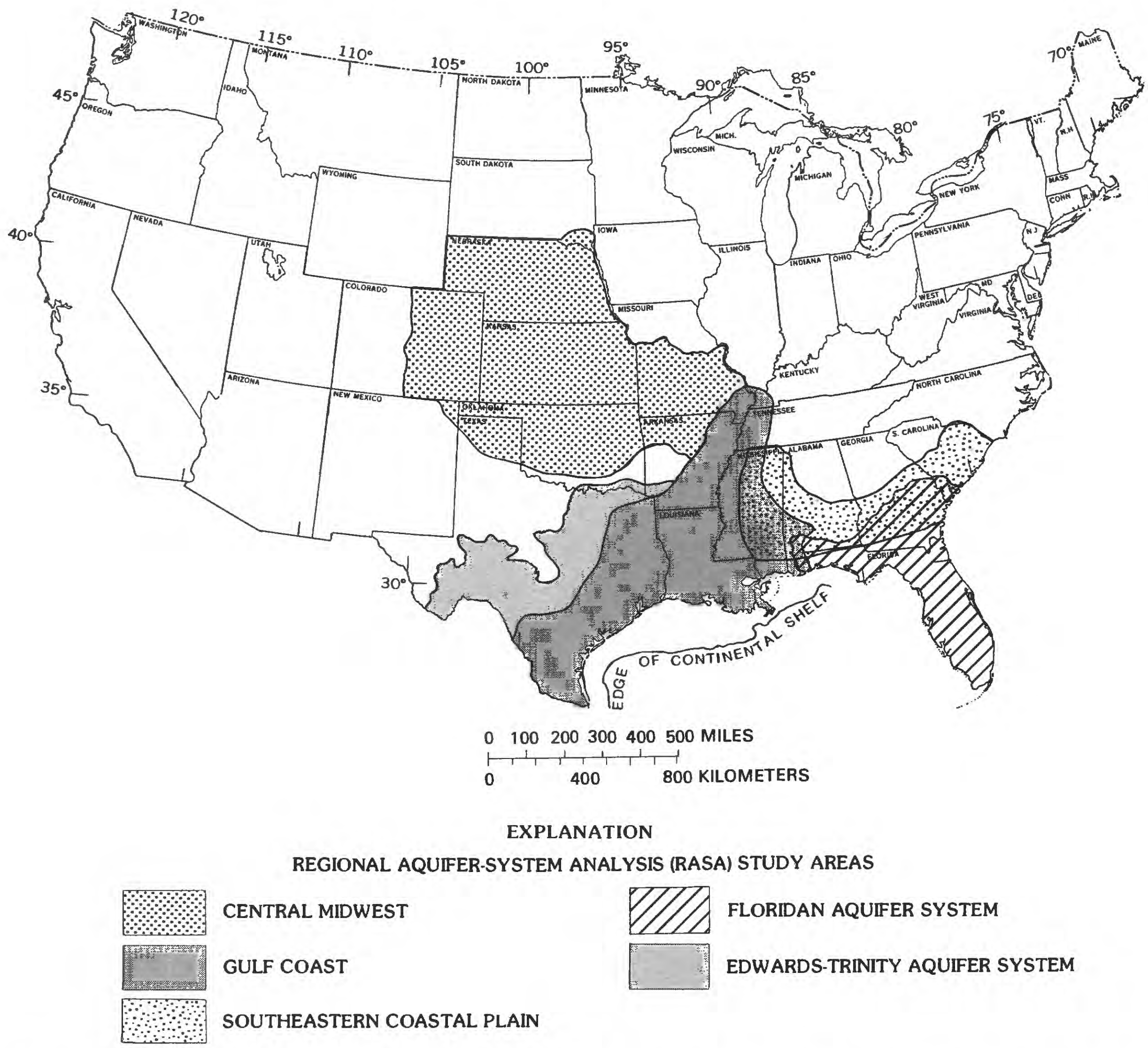

FIGURE 1.—Location of Gulf Coast Regional Aquifer-System Analysis study area and adjacent Regional Aquifer-System Analysis study areas.

The Mississippi embayment and Texas coastal uplands aquifer systems underlie about 188,000 mi^2 in parts of Alabama, Arkansas, Florida, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas from the Rio Grande on the west to the western part of Florida on the east. The gulfward boundary of the two aquifer systems is located where they grade into a clay or calcareous basin facies or are truncated by the top of the geopressured zone. The updip boundary is the contact between Tertiary and Cretaceous deposits except in the northern part of the Mississippi embayment aquifer system, where the McNairy-Nacatoch aquifer is included.

Maps showing various characteristics of the geohydrologic units initially were made using the contouring package of the Surface II graphics system (Sampson, 1978), which performed a linear interpolation of the randomly spaced log data to create maps based on uniformly spaced 5-mile (mi) intervals. Geologic and hydrologic judgment was used to refine the maps, which depict regional trends. Anomalies produced by map generation that could not be judged to be the result of structural or other geologic processes were eliminated.

PREVIOUS INVESTIGATIONS

Because of the size of the study area, the number of previously conducted geohydrologic investigations is quite large. Most of the studies were of multiple- or single-county areas or of smaller areas and are too numerous to cite. A few studies were of larger scope and were of great value in identifying the principal geohydrologic units. A series of U.S. Geological Survey Professional Papers published as chapters of Professional Paper 448 describe the availability of ground and surface water in the Mississippi embayment. Chapter B of Professional Paper 448 (Cushing and others, 1964) describes the general geology of the embayment and provides a basis for identification of geohydrologic units. Chapters D (Hosman and others, 1968) and E (Boswell and others, 1968) of that Professional Paper describe Tertiary and Quaternary aquifers, respectively. Another series of Professional Papers (chapters A-D of Professional Paper 569) by Payne (1968, 1970, 1972, 1975) presents a study of the geohydrology of the Claiborne Group. Baker (1979) describes the geohydrologic framework of the Texas Gulf Coast, which represents a substantial part of the RASA study area.

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The authors thank personnel in the U.S. Geological Survey district offices for providing data used in the study. In addition, numerous suggestions were provided by the Gulf Coast RASA hydrologists in several States involved in the study: Alabama and Florida, J.A. Miller; Arkansas, A.H. Ludwig; Kentucky, R.W. Davis; Louisiana, Angel Martin, Jr.; Mississippi, J.K. Arthur; Missouri, T.O. Mesko; Tennessee, W.S. Parks; and Texas, Sergio Garza.

GEOHYDROLOGIC SETTING

The sediments that make up the geohydrologic units described in this report were deposited in the Gulf Coast geosyncline and the Mississippi embayment during the Paleocene, Eocene, and early Oligocene Epochs of the Tertiary Period and the Pleistocene and Holocene Epochs of the Quaternary Period. (Also included, because of possible hydraulic connection with the younger sediments, is the uppermost water-bearing stratum of Late Cretaceous age in the northern part of the Mississippi embayment.) The cyclical nature of the depositional environments of these strata, alternating continental and marine, controlled the lithologies and, thus, the hydrologic characteristics of the strata. In general, the more sandy continental deposits are permeable and form the aquifers, whereas the more clayey marine deposits are much less permeable and form the confining units.

Deposition throughout the Tertiary Period was affected by major structural features (pl. 2) that largely reflect the configuration and deformation of the Paleozoic basement rocks. Orogenies that began during late Paleozoic time caused the downfaulting and downwarping that formed the Gulf Coast geosyncline and the Mississippi embayment. Most, if not all, of the subsidiary structural features, such as uplifts, synclines, and fault zones, were established at this time and continued to develop throughout the Mesozoic and Cenozoic Eras. Crustal adjustments, as basins received sediments, accentuated positive areas and caused fault zones to remain active. Sedimentation began during the Jurassic Period and continues to the present. Tertiary beds crop out in approximately parallel bands that are progressively younger gulfward in typical offlap sequence. Except where affected by local structure, the beds generally dip and thicken toward the Gulf Coast geosyncline and the axis of the Mississippi embayment trough.

The Midway Group (Paleocene) contains marine clay that forms most of the basal confining unit for both the Mississippi embayment and the Texas coastal uplands aquifer systems in most of the area. To the south, where all stratigraphic units plunge into the Gulf Coast geosyncline, aquifers pinch out in facies changes or are truncated by the geopressured zone. In the northern part of the Mississippi embayment, a water-bearing sand in Upper Cretaceous deposits immediately underlying the Midway Group is being studied to determine whether hydraulic connection with overlying Tertiary aquifers exists.

The Wilcox Group (Paleocene and Eocene), which overlies the Midway Group, contains sand beds of widely varying thickness and texture. Whereas the Wilcox contains massive clean sand beds in places, most of it is composed of interbedded sand, silt, and clay of largely deltaic, lacustrine, and fluvial origin. Lignite is common, and some marine clay of varying extent is present. Locally, the Wilcox Group may contain clay to the extent that the clay section probably could be considered a confining bed. However, from a regional perspective, the sand beds are sufficiently interconnected to constitute an aquifer having reduced horizontal permeability as a result of the clay lenses. Because of the abundance of interbedded clay in most of the Wilcox deposits, vertical permeability is low and in effect confines water in sand beds.

Overlying the Wilcox Group, the Claiborne Group (Eocene) contains a thick sequence of alternating marine and continental deposits. The marine strata are mostly represented by clay, with minor amounts of marl. Sands of varying thickness separate the extensive marine clay beds and themselves contain interbedded clay beds of varying thickness and extent. Together, the areally extensive major sandy sections and intervening clay beds form a series of aquifers and confining units that commonly follow formational boundaries.

Marine clay of the Jackson Group or Formation (Eocene) combines with lithologically similar deposits of the overlying Vicksburg Group or Formation (Oligocene) to form an extensive regional confining bed to water in the uppermost aquifer in the Claiborne Group. This confining unit separates the coastal lowlands aquifer system from the underlying Mississippi embayment and Texas coastal uplands aquifer systems.

Alluvial (Holocene) and terrace (Pleistocene) deposits overlie Tertiary beds in most of the central part of the Mississippi embayment. These relatively young fluvial deposits contain a regional aquifer that is in hydraulic connection with both surface-water bodies and underlying subcrops of Tertiary aquifers. These fluvial deposits are commonly graveliferous at the base, and they generally grade finer upward to sand, silt, and clay.

Major uplifted structures—the Sabine uplift, Monroe uplift, and Jackson dome (pl. 2)—influenced deposition during the Tertiary Period, as did the synclines that flank them. Beds generally thin toward and over the uplifted features and thicken in the depressions. Of lesser effect are gentle uplifted and depressed flexures that trend perpendicular to the coastline; from east to west these are the Sabine arch, Houston embayment, San Marcos arch, and Rio Grande embayment. The Wiggins anticline in southern Mississippi and Alabama approximately parallels the coast.

Faulting is widespread in the area but does not seem to be a major control on the regional movement of ground water. In most cases, fault throws are not large enough to totally offset thicker geohydrologic units. Most of the faults occur in zones, and grabens are common (pl. 2).

The Luling-Mexia-Talco fault zone is a band of faults that generally follows the boundary of the study area in Texas. This series of parallel normal faults and grabens extends into southwestern Arkansas, where it is called the Arkansas fault zone. The Pickens-Gilbertown fault zone, which begins in west-central Mississippi and trends southeastward across Mississippi and southwestern Alabama, appears to be in alignment with the Arkansas fault zone. Many, if not all, of the faults in these systems were active throughout the Tertiary Period.

Other extensive fault zones parallel the coastline and primarily affect Wilcox and younger strata. These are growth faults, some of which appear to be still active. Growth faults form contemporaneously with deposition, which results in thickening of the sediments on the downthrown side. The zone of abnormally high fluid pressures (geopressured zone) is associated with these growth faults (Dickinson, 1953). The abnormally high pressures are imposed by overburden on rapidly buried undercompacted clay and sand. The pressures in the rapidly buried zone thus created are much greater than normal hydrostatic pressure would be for a given depth.

The New Madrid fault zone, a complex of several fault zones within the Reelfoot rift, is a major structural feature in the northern part of the Mississippi embayment. Available data are insufficient to provide more than a rudimentary understanding of the complexity of the fault system and to determine the extent to which the Cretaceous and Tertiary rocks are faulted. Consequently, the effect of faulting on ground-water flow is not known. The New Madrid fault zone produced a major series of earthquakes in 1811–12. The intensity of the earthquakes was the most widespread in recorded history in the conterminous United States (McKeown and Pakiser, 1982); property damage was limited only by the sparsity of population at the time. The zone produces periodic tremors and is considered the most potentially dangerous earthquake-prone area in the conterminous United States (McKeown and Pakiser, 1982).

Salt basins occur across the Coastal Plain in two approximately parallel bands (pl. 2). The northernmost band begins in northeast Texas and extends across northern Louisiana into south-central Mississippi. The other band approximately follows the coastline from southeastern Texas through southern Louisiana. Salt domes in the basins can penetrate most or all Tertiary strata at any given location, but only a relative few are at or near the land surface. The source of the salt in the domes generally is considered to be the deeply buried Louann Salt of Jurassic age. The structural effects caused by dome penetration are localized and are represented chiefly by faulting, which can be complex. Any effects of a salt dome on ground-water flow are likewise localized and are not considered significant to the flow regime in a regional context.

AQUIFER SYSTEMS AND GEOHYDROLOGIC UNITS

For purposes of this study, the aquifers have been grouped into three major systems (Grubb, 1984): (1) the Mississippi embayment aquifer system, (2) the Texas coastal uplands aquifer system, and (3) the coastal lowlands aquifer system (fig. 2). The Mississippi embayment aquifer system, equivalent to the Pearl River aquifer to the east (Miller and Renken, 1988), includes all Paleocene through Oligocene sediments exposed in the Mississippi embayment from the southern tip of Illinois as far southwestward as the Sabine uplift (pl. 2) and as far southeastward as to include the westernmost county of Florida. Also included are the Quaternary alluvium that overlies subcrops of these Tertiary deposits and the uppermost Cretaceous deposits in the northern part of the embayment. The Texas coastal uplands aquifer system also includes Paleocene through Oligocene strata (Vicksburg Formation only) that crop out from the Sabine uplift on the northeast to the Rio Grande on the

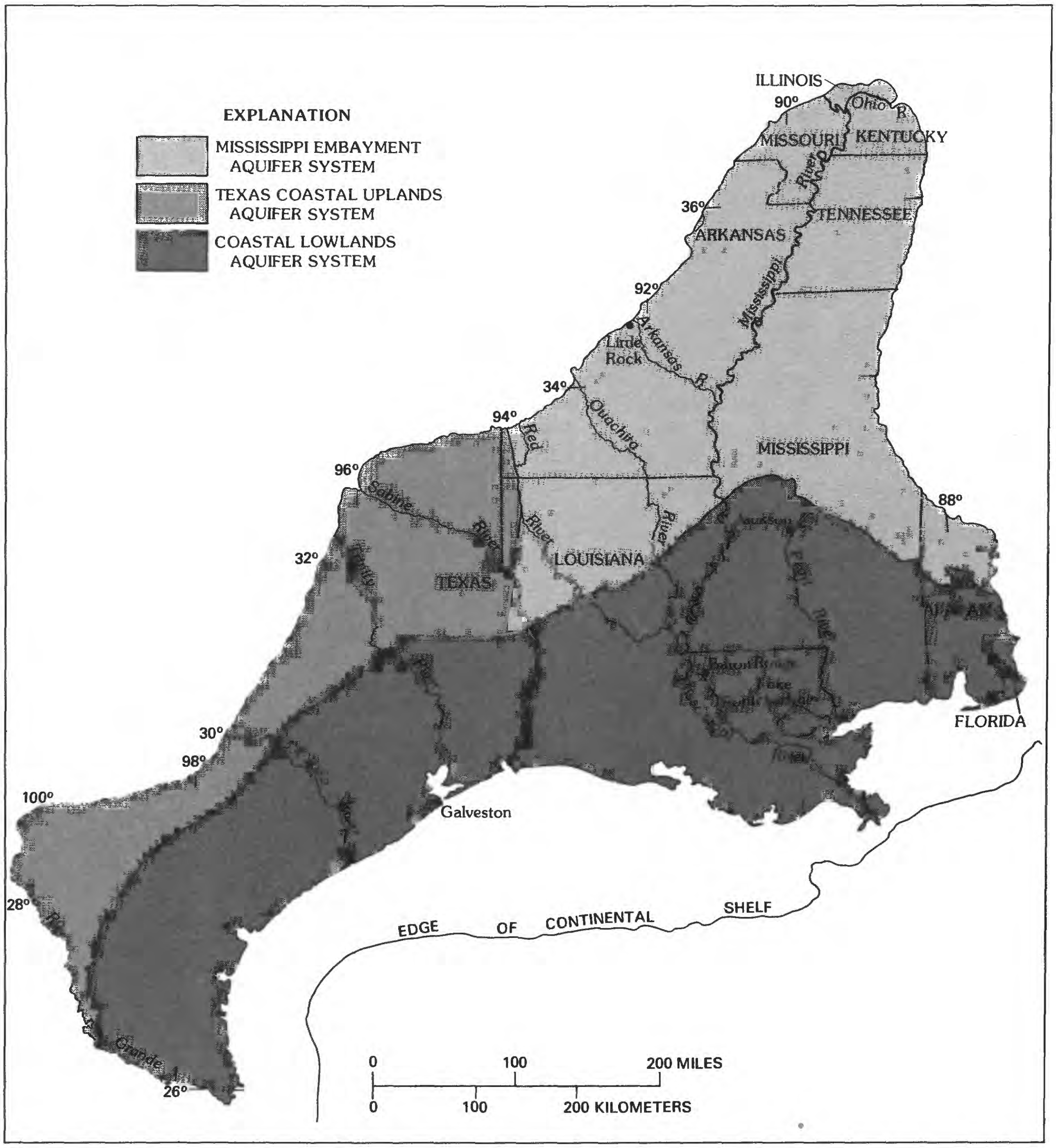

FIGURE 2.—Generalized outcrop of Mississippi embayment, Texas coastal uplands, and coastal lowlands aquifer systems.

southwest. A north-trending centerline across the Sabine uplift and the crest of the Sabine arch extending southward from the uplift constitute a ground-water divide and areally separate the Mississippi embayment and Texas coastal uplands aquifer systems. Because of the ages and similarity of deposition of the sediments within these two aquifer systems, they are combined for description in this report.

Overlying Oligocene through Holocene deposits constituting the coastal lowlands aquifer system are described in a separate report (Weiss, in press). This aquifer system is separated from the Mississippi embayment and

Texas coastal uplands aquifer systems by the intervening Vicksburg-Jackson confining unit, a massive clay. Great thicknesses of interbedded sand and clay beds make up the system, which is subdivided into permeable zones and confining units. Where extensive regional confining units are not present, permeable zones are identified on the basis of hydraulic-head data. The Gulf Coast regional aquifer system underlies the entire Gulf Coast and nearby offshore areas from Texas to westernmost Florida.

To quantitatively describe the ground-water hydrology, the aquifer systems were subdivided into discrete geohydrologic units. Because of the large size of the area and the great thickness of the rocks of interest, the aquifer systems are represented by as few regionally significant geohydrologic units as possible. The occurrences of sand beds and intervening clay bodies were major considerations in determining the subdivision or combination of stratigraphic units into the geohydrologic units. In some areas, a nonhomogeneous stratigraphic unit was subdivided into several geohydrologic units, whereas in other areas, relatively homogeneous stratigraphic units were combined into a single geohydrologic unit.

The designation of a geohydrologic unit as an aquifer or a confining unit was dependent on the predominance of sand or clay. Generally, the permeability of aquifers should be two or more orders of magnitude higher than that of overlying or underlying confining units (Neuman and Witherspoon, 1969). Within this constraint, an aquifer as defined in this report may contain clayey interbeds that at a smaller scale might not be considered part of an aquifer. Similarly, confining layers may contain sandy interbeds. The proportion of atypical material in any given layer may vary considerably.

Previous workers have used various definitions for some of the geohydrologic units in the study area. However, the geohydrologic units described herein do not strictly adhere to previous names. In addition, equivalent geohydrologic units may have different names within the study area, which when combined could result in lengthy, cumbersome names. With the exceptions of the Mississippi River Valley alluvial aquifer and the McNairy-Nacatoch aquifers, the names assigned to the geohydrologic units in this report are rock-stratigraphic terms of group rank. The advantage of this usage is that the assigned names are common to the entire study area and, thus, are generally familiar. Subdivisions within each group were assigned modifiers (lower, middle, and upper). Although these modifiers are not formally recognized by the U.S. Geological Survey as subdivisions for the groups described (and thus are not capitalized), they provide an easy reference to the relative position of each geohydrologic unit. The aquifers may contain several water-bearing zones or may include aquifers recognized by different names in different geographic areas.

Geohydrologic units as defined for use in this study generally are based on stratigraphic units or combinations of stratigraphic units. The correlation chart, table 1, lists the stratigraphic-unit names currently (1986) used by the U.S. Geological Survey (the Upper Cretaceous sediments, named the McNairy-Nacatoch aquifer in the Mississippi embayment, are not listed) and shows general relations between stratigraphic and geohydrologic units. Each stratigraphic unit consists of a predominant lithologic type or a sequence of similar lithologic types, which are chiefly sand and clay. Therefore, sand-clay contacts form most stratigraphic-unit boundaries in the region. As sand-clay contacts are one of the criteria used in delineating aquifers and confining units, stratigraphic-unit and geohydrologic-unit boundaries generally coincide. These boundaries also may deviate from one another where deviations from the typical lithology of the stratigraphic unit exist. Several examples of different relations among stratigraphic-unit and geohydrologic-unit boundaries are shown in plate 3. The outcrops or subcrops of most of the geohydrologic units form approximately parallel bands that follow the inland boundary of the study area (pl. 2) except where affected by structure.

Aquifers defined in this study are not necessarily bounded by confining units. Three aquifers—the lower Claiborne-upper Wilcox, middle Wilcox, and lower Wilcox aquifers—are not separated by confining units but are defined on the basis of markedly different geohydrologic characteristics. The subsurface relations among aquifers and confining units are shown in geohydrologic sections *A-A′* through *H-H′* (pls. 4–7). The wells used in the construction of the geohydrologic sections are listed in table 2.

REGIONAL GEOHYDROLOGIC UNITS

The Mississippi embayment and Texas coastal uplands aquifer systems consist of thick sequences of Cenozoic deposits. In general, the deposits—aquifers and confining layers—thin in an updip direction toward the outcrop and on the flanks of major uplifts. The aquifers terminate downdip as they grade into the clay and calcareous basin facies or are truncated by the top of the geopressured zone. The maximum thickness of the Mississippi embayment aquifer system is about 6,000 feet (ft), and the maximum thickness of the Texas coastal uplands aquifer system (approximately in the Houston embayment) is about 7,000 ft (pl. 8). The aggregate thickness of sand within the aquifer systems generally follows the trends of aquifer-system thickness (pl. 8). The maximum aggregate percentage of sand within both aquifer systems is more than 80 percent. In both aquifer systems, the aggregate percentage of sand decreases gradually and fairly uniformly toward the gulf.

An upper regional confining layer exists at the top of the Eocene section where marine clay of the Jackson Group or Formation (Eocene) and marine clay of the overlying Vicksburg Group or Formation (Oligocene) form the Vicksburg-Jackson confining unit. The Vicksburg-Jackson confining unit separates the Mississippi embayment and Texas coastal uplands aquifer systems from the overlying coastal lowlands aquifer system.

A basal regional confining unit composed of several hundred feet of marine clay in the Midway Group underlies almost all of the study area. This confining unit is assumed to effectively isolate Tertiary aquifers from underlying Upper Cretaceous geohydrologic units in all or almost all of the study area. The possibility of hydraulic connection between Tertiary and Cretaceous aquifers in the northeastern part of the study area where the Midway deposits thin near the outcrop and are underlain by a major Cretaceous aquifer is being investigated during this study. In the southern part of the study area, the downdip limit of sandy facies or the top of the geopressured zone where it occurs above the top of the Midway confining unit is considered to be the base of the regional ground-water flow system.

The regional geohydrologic units defined in this study are (1) Mississippi River Valley alluvial aquifer, (2) Vicksburg-Jackson confining unit, (3) upper Claiborne aquifer, (4) middle Claiborne confining unit, (5) middle Claiborne aquifer, (6) lower Claiborne confining unit, (7) lower Claiborne-upper Wilcox aquifer, (8) middle Wilcox aquifer, (9) lower Wilcox aquifer, (10) Midway confining unit (table 1), and (11) McNairy-Nacatoch aquifer consisting of Upper Cretaceous sediments.

MISSISSIPPI RIVER VALLEY ALLUVIAL AQUIFER

The Mississippi River Valley alluvial aquifer extends from the apex of the Mississippi embayment southward to the Mississippi River Delta at the Gulf of Mexico. In this report, however, the southern limit of the aquifer is considered to be where it crosses the outcrop or subcrop of the Vicksburg-Jackson confining unit (pl. 9). The aquifer, which underlies the alluvial plain of the Mississippi River, has an areal extent of about 32,000 mi^2. The alluvial deposits that make up the aquifer are mostly of Holocene age. Large terraced areas underlain by Pleistocene deposits are included in the aquifer (table 1).

The materials constituting the aquifer range in size from coarse gravel to clay. They commonly grade downward from fine sand, silt, and clay at the top to coarse sand or gravel at the base. The deposits under the terraces tend to be graveliferous.

The Mississippi River Valley alluvial aquifer is capable of sustaining maximum well yields of several thousand gallons per minute because of favorable recharge conditions. Hydraulic gradients in the alluvial aquifer generally are toward the streams. However, high streamflow or sustained pumping can reverse the gradients and induce recharge from the streams to the aquifer, especially near the Mississippi River.

The potential for hydraulic connection between the Mississippi River Valley alluvial aquifer and underlying Tertiary aquifers exists where the alluvial aquifer overlies or is incised into the underlying aquifers. The degree of hydraulic connection depends on the nature of the aquifers in the area of contact and the hydraulic-head differential between them.

VICKSBURG-JACKSON CONFINING UNIT

The Vicksburg-Jackson confining unit (pl. 10) separates the Texas coastal uplands and Mississippi embayment aquifer systems from the coastal lowlands aquifer system and has an areal extent of about 92,000 mi^2. It dips gulfward at dips ranging from about 30 to more than 200 feet per mile (pl. 10). The confining unit is composed primarily of marine clay, marl, and limestone of the Jackson Group (Jackson Formation in Missouri, Kentucky, and Tennessee) and the Vicksburg Group or Formation (table 1). The two stratigraphic units may contain sands that are not significant regionally as aquifers, but the predominant lithology of the confining unit is marine clay. Where the sands are in either the upper or lower part of the Vicksburg-Jackson confining unit, they may be included with immediately overlying or underlying aquifers (pl. 3, well 98). The Vicksburg-Jackson confining unit also may include clays in the overlying younger deposits or in the underlying Claiborne Group (pl. 3, wells 36 and 97).

A geologic time break occurs within the Vicksburg-Jackson confining unit. The lower part of the unit (Jackson) is the uppermost deposit of Eocene age in the area, whereas the upper part (Vicksburg) is of Oligocene age. Although the time break is significant, a change in lithology generally is not evident, and faunal data provide the chief basis for time differentiation.

A gap in the subcrop of the Vicksburg-Jackson confining unit caused by erosion occurs in the vicinity of the northeastern corner of Louisiana (pl. 10), making it the only geohydrologic unit in the Mississippi embayment aquifer system that is not one continuous body. The disconnected segment is approximately coincident with the Desha basin (pl. 2), where the Vicksburg-Jackson confining unit has a maximum thickness of more than 400

TABLE 1.—*Correlation chart of Cenozoic units in the*

[This correlation chart shows geologic names of Cenozoic units in the area of this study as used by the U.S. Geological Survey. Horizontal alignment characteristic of the unit but was dictated by space require-

ERATHEM	SYSTEM	SERIES	TEXAS: SOUTHERN	TEXAS: SOUTHEASTERN and NORTHEASTERN	LOUISIANA	ARKANSAS: SOUTHERN	ARKANSAS: NORTHEASTERN	MISSOURI	ILLINOIS	KENTUCKY
CENOZOIC	QUATERNARY	HOLOCENE PLEISTOCENE	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and loess deposits
CENOZOIC	TERTIARY	PLIOCENE	Golied Sand ?——?—	Goliad Send ?——?—	Citronelle Formation ?——?—					
CENOZOIC	TERTIARY	MIOCENE	Fleming Formation Oakville Sendstone	Fleming Formation	Fleming Fm Blounts Cr Mbr Cestor Cr Mbr Williamson Cr Mbr Dough Hills Mbr Carnahan Beyou Mbr Lena Mbr					
CENOZOIC	TERTIARY	OLIGOCENE	Cetahoula Tuff Frio Cley	Cetehoula Sendstone	Cetahoula Sandstone Vicksburg Formetion	NOT	PRESENT	IN	STUDY	AREA
CENOZOIC	TERTIARY	EOCENE	Jackson Group: Whitsett Fm Manning Cley Wellborn Sandstone Ceddell Fm	Jackson Group: Whitsett Fm Manning Clay Wellborn Sendstone Ceddell Fm	Jackson Group: Yezoo Fm Moodys Brench Marl	Jackson Group: Redfield Fm White Bluff Fm Rison Cley Mbr Pastoria Sand Mbr Ceney Point Merl Mbr	Jackson Group: Undifferentiated	Jackson Formation		Jackson Formation
CENOZOIC	TERTIARY	EOCENE	Claiborne Group: Yegue Fm Leredo Fm El Pico Clay Bigford Fm Carrizo Sand	Claiborne Group: Yegua Fm Cook Mountain Fm Sparta Sand Weches Fm Queen City Send Reklew Fm Carrizo Sand	Claiborne Group: Cockfield Fm Cook Mountain Fm Sparta Sand Cane River Fm Cerrizo Sand	Claiborne Group: Cockfield Fm Cook Mountein Fm Sparta Sand Cane River Fm Carrizo Sand	Claiborne Group: Cockfield Fm Cook Mountein Fm Memphis Send	Claiborne Group: Cockfield(?) Fm Cook Mountain(?) Fm Memphis Sand		Claiborne Group: Cockfield Fm Cook Mountain Fm Sperta Sand Tallehetta Fm
CENOZOIC	TERTIARY	EOCENE PALEOCENE	Wilcox Group: Undifferentiated	Wilcox Group: Undifferentiated	Wilcox Group: Undifferentiated Dolet Hills Fm Naborton Fm	Wilcox Group: Undifferentiated	Wilcox Group: Flour Island Fm Fort Pillow Send Old Breestworks Fm ?——?—	Wilcox Group: Flour Island Fm Fort Pillow Sand Old Breast-works(?) Fm ?——?—	Wilcox Formation No Wilcox deposits identified as being of Paleocene ege	Wilcox Formation No Wilcox deposits identified as being of Paleocene age
CENOZOIC	TERTIARY	PALEOCENE	Midway Group: Wills Point Fm Kincaid Fm	Midway Group: Wills Point Fm Kincaid Fm	Midway Group: Porters Cr Clay Clayton Fm	Midway Group: Porters Cr Clay Clayton Fm	Midway Group: Porters Cr Cley Clayton Fm	Midway Group: Porters Cr Cley Clayton Fm	Midway Group: Porters Cr Cley Cleyton Fm	Midway Group: Porters Cr Clay Clayton Fm

Mississippi embayment and Texas coastal uplands aquifer systems

implies at least general correlation where exact equivalency is not obvious. Vertical space occupied by a unit's name has no relation to any physical ments for listing units and accommodating geologic-age boundaries]

TENNESSEE	MISSISSIPPI		ALABAMA	WESTERN PANHANDLE OF FLORIDA	GEOHYDROLOGIC UNITS
	NORTHERN	CENTRAL AND SOUTHERN			
Alluvium and loess deposits	Alluvium, terrace, and loess deposits	Alluvium, terrace, and loess deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Mississippi River Valley alluvial aquifer
NOT PRESENT IN STUDY AREA		Citronelle Formation Graham Ferry Fm	Citronelle Formation	Citronelle Formetion	Coastal lowlands aquifer system
		Pescagoula Fm Fort Adams Mbr Homochitto Mbr Hettiesburg Fm	Undifferentiated	Pensacola Clay Escambia Sand Mbr	
		Catahoula Sandstone Tatum Limestone Mbr Paynes Hammock Fm Chickasawhay Limestone	Catahoula Sandstone Tatum Limestone Mbr Paynes Hammock Fm Chickasawhay Limestone	Catahoula Sandstone Tetum Limestone Mbr Chickasawhay Limestone	
		Vicksburg Gp: Bucatunna Fm Byram Fm Glendon Fm Marianna Fm and Mint Spring Fm Forest Hill Fm and Red Bluff Fm	Vicksburg Gp: Bucatunna Fm Byrem Fm Glendon Fm Marianna Fm and Mint Spring Fm Red Bluff Fm and Bumpnose Fm	Bucatunna Fm Byram Fm Marianna Fm Bumpnose Fm	Vicksburg-Jackson confining unit
Jackson Formation	Jackson Group: Undifferentiated	Jackson Group: Yazoo Fm Shubuta Mbr Pachuta Marl Mbr Cocoa Sand Mbr North Twistwood Cr Mbr Moodys Branch Marl	Jackson Group: Yazoo Fm Shubuta Mbr Pachuta Marl Mbr Cocoa Sand Mbr North Twistwood Cr Mbr Moodys Branch Marl	Ocala Limestone Moodys Branch Fm	
Claiborne Group: Cockfield Fm Cook Mountain Fm Memphis Sand	Claiborne Group: Cockfield Fm Cook Mountain Fm Sparta Sand Zilpha Clay Winona Sand Tallahatta Fm	Claiborne Group: Cockfield Fm Cook Mountain Fm Gordon Cr Shale Mbr Potterchitto Mbr Archusa Marl Mbr Sparta Sand Zilpha Clay Winona Sand Tallahatta Fm Neshoba Sand Mbr Basic City Shale Mbr Meridian Sand Mbr	Claiborne Group: Gosport Sand Lisbon Fm Tallahatta Fm Meridian Sand Mbr	Claiborne Group: Lisbon Fm Tallahatta Fm	Upper Claiborne aquifer Middle Claiborne confining unit Middle Claiborne aquifer Lower Claiborne confining unit Lower Claiborne-Upper Wilcox aquifer
Wilcox Group: Flour Island Fm Fort Pillow Sand Old Breastworks Fm ?—?	Wilcox Group: Undifferentiated	Wilcox Group: Hatchetigbee Fm Bashi Fm Tuscahoma Fm Nanafalia Fm Fearn Springs Mbr	Wilcox Group: Hatchetigbee Fm Bashi Fm Tuscahoma Sand Bells Landing Marl Mbr Greggs Landing Marl Mbr Nanafalia Fm Grampian Hills Mbr "Middle" mbr Gravel Cr Sand Mbr	Wilcox Group: Hatchetigbee Fm Bashi Fm Undifferentiated	Middle Wilcox aquifer Lower Wilcox aquifer
Midway Group: Porters Cr Clay Clayton Fm	Midway Group: Porters Cr Clay Tippah Sand Lentil Clayton Fm	Midway Group: Naheola Fm Porters Cr Clay Matthews Landing Marl Mbr Clayton Fm	Midway Group: Naheola Fm Coal Bluff Marl Mbr Oak Hill Mbr Porters Cr Clay Matthews Landing Marl Mbr Clayton Fm McBryde Limestone Mbr Pine Barren Mbr	Midway Group: Undifferentiated	Midway confining unit

TABLE 2.—*Wells used in construction of geohydrologic sections*
[Location of wells shown on pl. 1]

Well No.	County or Parish	Owner	Well name
		ARKANSAS	
10	Crittenden	H.L. Hawkins	No. 1, R.G. O'Neal
80		General Crude Oil Co.	No. 1, L.H. Carruth Est.
79	Cross	Ramsey Petroleum Co.	No. 1, Singer
70	Desha	W. Shannon Goodwin	No. 1, S.A. Banks Est.
71		Roy Northen et al.	No. 1, Baxter Land Co.
67	Grant	Connelly, Froderman, & Stratton Drilling Co.	No. 1, Ashcraft
66		Champlin Petr. Co. et al.	No. 3, Core hole
77	Jackson	U.S. Geological Survey	No. 1, Test hole
68	Jefferson	W. Stratton	No. 1, Stratton
69		Gregg Oil Co.	No. 1, H.A. Taylor
13	Lee	U.S. Geological Survey	No. 1, U.S. Geological Survey Test
12		City of Marianna	No. 3, Test hole
52	Little River	Lee and Burnett	No. 1, Troth
53	Miller	Tom Palmer et al.	No. 1, Watts
8	Mississippi	City of Osceola	Water-supply well
7		Dogwood Community Water Assn., Inc.	Water-supply well
15	Phillips	Plymouth Oil Co.	No. 1, J.R. Bush
14		McAlester Fuel Co.	No. A-1, Howe Lumber Co.
9	Poinsett	Town of Tyronza	Test hole
78		Seaboard Oil Co.	No. 1, E.S. Maddox
11	St. Francis	Manning & Martin, Inc.	No. 1, Gregg
		LOUISIANA	
31	Ascension	Republic Natural Gas Co.	No. 2, Natalbany Lumber Co.
63	Beauregard	Getty Oil Co.	No. 1, H.C. Lee et al. 26–1
64		H.L. Hunt	No. 1, Edgewood Land & Logging Co.
54	Caddo	Arkla Oil Co.	No. 3, Mattie Pitts
55		Jones Oil Co.	No. 1, Kuhn
56		Frank J. Hall	No. 1, Wappler
57		Jones-O'Brien, Inc.	No. 1, R.A. Varner
65	Calcasieu	Stanolind Oil and Gas	No. 1, Powell Lumber Co.
58	De Soto	Mallard Drilling Corp.	No. Q1, Olin Unit
30	East Baton Rouge	Shell Oil Co.	No. 1, D.A. Tranchina
101	East Carroll	The California Co.	No. 1, Greeson
28	East Feliciana	Nicklos Oil & Gas Co.	No. 1, Frank Norwood
29		Phillips Petroleum Co.	No. 1, Jones "AA"
97	Grant	Texaco, Inc.	No. 1, Joe Shorter
59	Sabine	Major Oil Co.	No. A-2, Longbell Lumber Co.
87	St. Tammany	B.M. Hester	No. 1, Bogalusa Tung Oil Co., Inc.
86		Union Oil Co. of California	No. 1, State Lease 7183
62	Vernon	Pan American Petroleum Corp.	No. 1, Lutcher-Moore
88	Washington	Davidson et al.	No. 1, Davidson Adams
		MISSISSIPPI	
26	Amite	Gulf Refining Co.	No. A-2, J.A. Rowland et al.
27		Oliver-Stewart	No. 1, C.M. Gallent
16	Bolivar	Central Oil Co.	No. 1, Tuminella
17		Joseph F. Fritz Operating Co. and Gibraltor Oil Corp. et al.	No. 1, Seligman-Polk
98	Covington	Frankfort Oil Co.	No. 1, Graham
102	DeSoto	Union Producing Co.	No. 1, F.T. Withers Est.
91	Forrest	Humble Oil & Refining Co.	No. 1, J.S. Harrison et al.
25	Franklin	Cane Corp. and Donald Caldwell	No. 1, Caldwell-Whittington
74	Grenada	J.R. Lockhart	No. 1, Fite
73		Frederic F. Mellen	Mrs. A.G. Williams
99	Hinds	J.V. Canterberry	No. 1, J.R. Ball
19	Humphreys	Kirby Exploration Co.	No. 1, Varner
18		Roeser and Pendleton	No. 1, State Land

TABLE 2.—*Wells used in construction of geohydrologic sections*—Continued

Well No.	County or Parish	Owner	Well name
		MISSISSIPPI—Continued	
94	Jasper	Kern County Land Co.-Monterey	No. 1, Harvey Gilmore
24	Jefferson	Victor P. Smith and H. Best Oil Co.	No. 1, Groome
23		William Helis	No. 1, Dockery-Carpenter
93	Jones	Union Sulphur Co.	No. 1, Earline Parker
92		Gulf Refining Co.	No. 1, Flynt
96	Kemper	A.E. Manning and R.H. Bordeaux et al.	No. 1, McKelvaine
89	Lamar	Gulf Refining Co.	No. 1, W.J. Howard
90		The Texas Co.	No. 1, J.F. Morrow
95	Lauderdale	C.L. Higgason and L.L. Chapman	No. 1, Malone Thigpen
20	Sharkey	Plymouth Oil Co.	No. 1, U.S.A.
72	Tallahatchie	Gulf Refining Co.	No. 1, T.P. Cason
85	Tippah	Houston Oil & Mineral Co.	No. 1, C.T. Harrell
21	Warren	The Texas Co.	No. 1, A.B. Hinston
22		Union Prod. Co.	No. 1, C.J. Harlen
75	Webster	Pan American Petroleum Corp.	No. 1, Holmes Davis Unit
76		Savannah Water Association	Water well
100	Yazoo	Love Petroleum Co. and A.W. Williams Drilling Co., Inc.	No. 1, Travis Speakes et al.
		MISSOURI	
2	Mississippi	Hercules Oil Co.	No. 1, Big Oak
1		Little Egypt Oil Co.	No. 1, Delaney
4	New Madrid	U.S. Geological Survey	No. 1, New Madrid test well
3		Cordova Union Oil Co.	No. 1, Phillips
6	Pemiscot	City of Steele	No. 2, Water well
5		City of Caruthersville	Water well
		TENNESSEE	
103	Fayette	U.S. Geological Survey and Tennessee Division of Geology	No. T-1-F, Water test
84		Lazaros & Robins	No. 1, Beasley
83		Troxel Manufacturing Co.	No. 5, Test hole
81	Shelby	Col. B.A. Murelle et al.	No. 1, Emily Horton
82		Town of Buckeye	No. 3, Water well
		TEXAS	
48	Brazos	The Texas Co.	No. 1, Orlando
47		Michel T. Halbouty et al.	No. 1, Allen & Clay
42	DeWitt	The Atlantic Refining Co.	No. 1, Eliza J. Smith Unit
43		J.S. Abercrombie	No. 1, T. Williams
37	Duval	Shell Oil Co.	No. 1, L.C. Weatherby "A"
40	Gonzales	Producers Corporation of Nevada	No. 1, J.T. Anderson
41		Tenneco Oil Co.	No. 1, Frank Ullman
49	Grimes	Placid Oil Co.	No. 1, Robert Foster
39	Guadalupe	Allen Burr	No. 1, W.J. Blanks Est.
51	Harris	Pan American Petroleum Corp.	No. 1, Houston Unit
50		Texaco, Inc.	No. 1, M.M. Mergele
38	Jim Wells	Associated Oil & Gas, Gulf States Development Corp., and Investors Syndicate of the Southwest	No. 1, D.H. Lopez
34	La Salle	W.J. Steeger et al.	Joe T. McMillan
35		Sutton Petroleum Co.	No. 1, Buckholt
36	McMullen	Phillips Petroleum Co.	No. 1, Nueces "A"
61	Newton	Boger and Boger	No. 1, Godfrey and Brown
46	Robertson	Dalport Oil Corp., H.M. Robertson, and Jack Frost	No. 1, Stash Okonski
60	Sabine	J.R. and J.P. Goldsmith	No. 1, Southern Pine Lumber
44	Victoria	James R. Dougherty	No. 1, Murphy
45		Gulf Oil Corp.	No. 63, Keeran
33	Zavala	Humble Oil & Refining Co.	No. 1, Marrs McLean
32		Humble Oil & Refining Co.	No. 1, Ike Pryor Est.

ft (pl. 10). This segment is the only part of the Vicksburg-Jackson confining unit that is included in the Mississippi embayment aquifer system, because the eastern two-thirds of the segment is overlain by the Mississippi River Valley alluvial aquifer. Elsewhere, the bottom of the Vicksburg-Jackson confining unit defines the top of the Mississippi embayment and Texas coastal uplands aquifer systems. The outcrop of the main body of the unit forms a wide band that generally parallels the coastline (pl. 10). In two small areas, one in Goliad County in southern Texas and the other near New Orleans, the Vicksburg-Jackson confining unit is about 6,000 to 5,000 ft thick; elsewhere, the confining unit is several hundred to about 1,500 ft thick (pl. 10). In the southern half of Mississippi and the southeastern part of Alabama, the thickness of the confining unit generally is about 100 to 300 ft.

UPPER CLAIBORNE AQUIFER

The upper Claiborne aquifer (pl. 11) underlies the Vicksburg-Jackson confining unit. This aquifer is the uppermost aquifer of Eocene age and underlies about 90,000 mi^2. It is composed mostly of the Yegua Formation in Texas and its equivalent, the Cockfield Formation, elsewhere (table 1). The aquifer consists of interbedded fine sand, silt, and clay with common occurrences of lignite. Thicker sand beds commonly occur in the lower part of the aquifer in parts of the Mississippi embayment. The underlying Cook Mountain Formation and the overlying Jackson Group, which generally are included in confining units, contain sand which may be adjacent to and, therefore, included in the upper Claiborne aquifer (pl. 3, wells 98 and 100).

Sand beds that occur throughout the upper Claiborne aquifer are of limited extent and can be traced for only small distances. The sand beds are the result of fluvial deposition from multiple sources, and the larger unit of which they are part represents the coalescence of these sediments. The degree of hydraulic connection among the sand beds probably is greater in updip areas, where the intervening clay beds are thin, than in downdip areas where the intervening beds are thicker.

In Texas, the outcrop of the upper Claiborne aquifer (pl. 11) approximately parallels the coastline. It is about 30 mi wide in southern Texas and narrows to about 2 to 3 mi over the San Marcos arch and around the southern flank of the Sabine uplift. In northern Louisiana and southern Arkansas, where the overlying Vicksburg-Jackson confining unit is absent, the outcrop or subcrop of the upper Claiborne aquifer is as much as 100 mi wide. Farther north, where the aquifer occupies the central part of the Mississippi embayment, the outcrop or subcrop of the aquifer is 20 to 60 mi wide. The outcrop narrows from about 20 mi to less than 1 mi in southeastern Mississippi and southwestern Alabama. The altitude of the top of the aquifer ranges from more than 500 ft above sea level in the northern part of the Mississippi embayment to more than 8,000 ft below sea level in southeastern Texas and southwestern Louisiana.

The thickest occurrences of the upper Claiborne aquifer are in southeastern and southern Texas (pl. 11). In these areas, elongate thickenings of the aquifer parallel the Gulf Coast. The aquifer is about 1,500 ft thick in an area crossing San Jacinto and Polk Counties. It is thicker farther to the southwest, where it attains a cumulative thickness of about 2,400 ft in northern Duval County. Elsewhere in the Texas Gulf Coast, the thicker zones are 1,200 to 1,400 ft thick. The thicker zones trend across Louisiana in a northeasterly direction into Mississippi; the aquifer is as much as 1,200 ft thick in Louisiana and 600 ft thick in Mississippi. The upper Claiborne aquifer extends northeastward into the Mississippi embayment, where, with a few minor exceptions, it generally is less than 300 ft thick. It is more than 400 ft thick in a very small area in extreme western Tennessee and more than 300 ft thick in the Desha basin in southeastern Arkansas. The upper Claiborne aquifer thins updip toward the outcrop and thins downdip toward the gulf as the sediments that constitute it gradually change to a clay facies.

Although the aggregate percentage of sand is greatest in the Mississippi embayment, the aggregate thickness of sand within the aquifer is greatest in southern Texas (pl. 11). The aquifer is more than 40 percent sand in most of the Mississippi embayment and is more than 80 percent sand in much of that area; the sandiest parts are in the northern part of the embayment, in east-central Arkansas, and in northern Louisiana and southern Arkansas. The aggregate thickness of sand generally ranges from 100 to 300 ft. In some places in the southern part of the study area, from southern Texas to southeastern Alabama, the aquifer is as much as 80 percent sand, but the aggregate percentage of sand probably averages about 50 percent. The area of maximum aggregate sand thickness, 500 to 1,500 ft, parallels the coastline in southern Texas; sand-percentage trends generally follow and parallel thickness trends. In southern Louisiana and Mississippi and southeastern Alabama, where total sand thicknesses mostly are in the 100- to 200-ft range, sand percentages bear no relation to thickness trends.

MIDDLE CLAIBORNE CONFINING UNIT

The confining layer underlying the upper Claiborne aquifer, the middle Claiborne confining unit (pl. 12), primarily is an extensive marine clay. The clay, which is mostly the Cook Mountain Formation (included in the Laredo Formation in part of southern Texas), underlies about 92,000 mi^2 of the area. The confining unit is absent over the Sabine uplift, where the youngest deposits exposed are those of the Wilcox Group, and in part of northeastern Louisiana (parts of East Carroll, West Carroll, Morehouse, and Union Parishes).

Although the middle Claiborne confining unit principally consists of the Cook Mountain Formation, in places it may include clay beds in units adjacent to the Cook Mountain, especially the underlying Sparta Sand (table 1). In some areas the Sparta Sand contains thick clay beds. Where these beds occur in the upper part of the formation, they are included as part of the middle Claiborne confining unit. The confining unit may also contain clay in the lower part of the overlying Cockfield (Yegua) Formation (pl. 3, well 98).

The outcrop of the middle Claiborne confining unit is at its widest—about 30 mi—in southernmost Texas and northwestern Louisiana (pl. 12). The outcrop narrows to less than 1 mi over the San Marcos arch and around the southern flank of the Sabine uplift; it widens to as much as about 10 mi between the two. In southwestern Arkansas the outcrop is about 10 to 20 mi wide. Elsewhere, the outcrop or subcrop is 5 mi wide or less. The altitude of the top of the confining unit ranges from about 500 ft above sea level in southeastern Mississippi to more than 8,000 ft below sea level in southeastern Texas and southwestern Louisiana (pl. 12).

The confining unit is 1,500 to more than 3,400 ft thick near its downdip limit in southern Texas; the thickest part is in Live Oak and Bee Counties (pl. 12). Another area of substantial thickness occurs in southwestern Louisiana, where the unit is more than 2,500 ft thick in parts of Beauregard and Allen Parishes. The thickening is due primarily to downdip facies changes as overlying and underlying sandy units change to a marine clay and calcareous facies. Elsewhere, to the east and northeast, the middle Claiborne confining unit is mostly 100 to 200 ft thick. In these areas, and especially in the updip areas, the confining unit is composed almost exclusively of the Cook Mountain Formation, which thins updip and pinches out in the outcrop. The confining unit is absent in a small area overlying the Monroe uplift; there, the upper Claiborne aquifer is in contact with the underlying middle Claiborne aquifer.

MIDDLE CLAIBORNE AQUIFER

Underlying the middle Claiborne confining unit, the middle Claiborne aquifer (pl. 13) is the most extensively used of the Tertiary aquifers. This aquifer underlies about 136,000 mi^2 and consists primarily of the Sparta Sand, which is present in most of the study area as a continentally derived sand with clay interbeds of varying thickness and extent. Although the Sparta Sand constitutes most of the middle Claiborne aquifer, the aquifer may contain water-bearing strata from adjacent stratigraphic units (table 1). Where sand beds occur in the lower part of the overlying Cook Mountain Formation, for example, they are included in the aquifer, whereas the Cook Mountain generally constitutes a confining bed. The same is true to a greater extent for sand beds underlying the Sparta Sand. (See pl. 3, wells 98 and 36.)

West of the Sabine uplift, the middle Claiborne aquifer contains the Weches Formation and the Queen City Sand, both of which underlie the Sparta Sand (equivalent to the Laredo Formation in part of southern Texas) and are approximately equivalent to the upper two-thirds of the Cane River Formation. In part of southwestern Arkansas, where the corresponding part of the Cane River Formation is sandy, it is included in the middle Claiborne aquifer. Similarly, in Louisiana and Mississippi the middle Claiborne aquifer may extend into stratigraphic units underlying the Sparta Sand.

North of approximately the 35th parallel, the underlying lower Claiborne confining unit undergoes a facies transition. The predominantly marine clay of the confining unit changes to an updip clastic facies of massive sand and becomes part of the middle Claiborne aquifer, which more than doubles the thickness of the middle Claiborne aquifer in a relatively short distance. From this facies change northward, the middle Claiborne aquifer also includes the stratigraphic interval that is occupied by the lower Claiborne confining unit and the lower Claiborne-upper Wilcox aquifer to the south. In this area, the northern part of the Mississippi embayment, the middle Claiborne aquifer is the same as the Memphis aquifer (Hosman and others, 1968), later named the Memphis Sand (Moore and Brown, 1969) in Arkansas, Missouri, and Tennessee. It is composed of thick to massive sands with few or no clay interbeds and supports large withdrawals of ground water.

The outcrop of the middle Claiborne aquifer is widest, as much as about 45 mi, in Texas (pl. 13) northwest and west of the Sabine uplift. To the southwest, it ranges in width from less than 10 to about 30 mi. It narrows to less than 1 mi wide on the southern flank of the Sabine uplift. In southwestern Arkansas, northeast of the Sabine uplift, the width ranges from 10 to 30 mi. The outcrop narrows to about 10 mi approaching the Arkansas River, and then the outcrop or subcrop widens to as much as 30 mi in the northwestern part of the Mississippi embayment. On the eastern side of the embayment, the outcrop ranges from about 15 to 25 mi in width in Kentucky and Tennessee. In northeastern Mississippi, the outcrop or subcrop is as much as 50 mi wide. The outcrop narrows markedly to the southeast, in which direction it generally is about 10 mi wide or less. The aquifer dips toward the axis of the Mississippi embayment and gulfward. The altitude of the top ranges from about 700 ft above sea level in southwestern Texas to more than 10,000 ft below sea level in southern Louisiana (pl. 13).

The thickest occurrence of the middle Claiborne aquifer is in extreme southern Texas, where it is about 2,500 ft thick near the Mexican border (pl. 13). Northeastward, between this area and the Sabine uplift, the thickest part ranges from 600 to about 900 ft thick. The aquifer is present and crops out around the Sabine uplift but is not present on the structure. The aquifer thins to about 300 ft south of the Sabine uplift, then thickens eastward into Louisiana and Mississippi to about 1,000 ft along the Mississippi River where it separates the two States. The middle Claiborne aquifer maintains a maximum thickness of 900 to 1,000 ft northeastward along the axis of the Mississippi embayment as far as the Desha basin. From this area, it gradually thins northeastward toward the head of the embayment, except in a small area in northwestern Mississippi where its thickness exceeds 1,000 ft. It thins updip toward the outcrop that borders the area and also toward the outcrop that surrounds the Sabine uplift. The aquifer also thins and becomes nonexistent downdip toward the gulf and in the southeastern part of the study area as it changes to a calcareous and clay facies.

The middle Claiborne aquifer is sandiest in the Mississippi embayment, especially in the northern part of the embayment (pl. 13). The aquifer contains more than 60 percent sand in much of the embayment and more than 80 percent in most of it. The aggregate thickness of sand is about 800 ft in the vicinity of the juncture of Arkansas, Tennessee, and Mississippi. Elsewhere in the embayment, the aggregate thickness of sand is several hundred feet, thinning toward the outcrop. In some places, sand percentage and sand thickness have the same or similar configurations. These similarities could be significant in planning development of the aquifer in this area.

Sand thicknesses and sand percentages also show relation to each other in Louisiana, southern Mississippi, and southeastern Alabama (pl. 13). Sand percentages vary considerably but probably average at least 50 percent, and aggregate sand thickness generally is 100 to 500 ft. The maximum aggregate sand thickness, about 700 ft, occurs in northeastern Louisiana in Tensas Parish near the Mississippi River. Aggregate sand percentage and thickness are determined for the entire thickness of a geohydrologic unit with no consideration for vertical position. Detailed studies at a smaller scale probably would produce patterns that would indicate depositional trends and histories as well as provide useful information to local development.

The middle Claiborne aquifer is distinctly sandier near the western and especially the southwestern flanks of the Sabine uplift (pl. 13). Sand percentage exceeds 60 percent and sand thickness is as much as 400 ft in these areas. Sand percentage is in excess of 80 percent just southwest of the structure.

In southern Texas, trends showing a relation between total sand thickness and sand percentage parallel the strike of the aquifer, which is northeasterly. The San Marcos arch separates two areas where the thickness and percentage of sand increases. Over the arch, the aggregate sand thickness is about 300 ft, and the percentage of sand mostly is less than 40 percent. To the northeast, the thickness increases to about 500 ft and the sand content to more than 60 percent. Southwest of the San Marcos arch, the total sand thickness increases from about 500 ft to about 1,500 ft in the Rio Grande embayment. In this area the sand content also generally is more than 60 percent. Aggregate sand thickness as well as sand percentage decreases southeastward as the aquifer becomes increasingly calcareous.

LOWER CLAIBORNE CONFINING UNIT

The lower Claiborne confining unit (pl. 14) is a regional confining layer that hydraulically separates the underlying lower Claiborne-upper Wilcox aquifer from the middle Claiborne aquifer above in an area of about 107,000 mi^2.

In much of the downdip area toward the axis of the Mississippi embayment, the Cane River Formation or its equivalents, the Tallahatta Formation (excluding the Meridian Sand Member), Winona Sand, and Zilpha Clay, constitute all or most of the lower Claiborne confining unit (table 1). As these units change to sandier facies updip, they may be included in underlying or overlying aquifers (pl. 3, wells 36, 98, and 100). In Texas, three formations are equivalent to the Cane River Formation. They are, in ascending order, the Reklaw Formation, the Queen City Sand, and the Weches Formation (except in extreme southern Texas, where the Bigford Formation and El Pico Clay represent these units). The Reklaw Formation, which is mostly clay, is virtually the entire lower Claiborne confining unit east of the Sabine uplift.

On the western side of the study area, the lower Claiborne confining unit crops out in a band that is 2 to 10 mi wide (pl. 14); most of the outcrop is less than 5 mi wide. The unit also crops out around the Sabine uplift in a ring that is about 1 to 10 mi wide. The outcrop on the eastern side of the study area is about 5 mi wide or less. It encircles a small area in southwestern Alabama where the underlying geohydrologic unit is exposed at the land surface. The confining unit dips generally gulfward to about 10,000 ft below sea level in south-central Louisiana (pl. 14).

The thickness of the confining unit varies considerably as the sediments undergo facies changes from dense marine clays to more clastic sequences updip. The confining unit is about 600 ft thick in parts of southeastern Arkansas and southwestern Mississippi and about 1,200 ft thick in a small area in southern Texas (pl. 14). The confining unit ceases to exist north of approximately the 35th parallel, where its entire thickness has changed to sand facies.

LOWER CLAIBORNE-UPPER WILCOX AQUIFER

The lower Claiborne-upper Wilcox aquifer (pl. 15) underlies about 110,000 mi^2 and may include all or parts of several stratigraphic units. Most of the aquifer is the Carrizo Sand and its equivalent, the Meridian Sand Member of the Tallahatta Formation (table 1). The Carrizo or Meridian is an extensive sand, commonly massive and unbroken by clay beds, that represents the basal unit of the Claiborne Group. Deposited over an eroded Wilcox surface, the Carrizo or Meridian may be absent over what were topographically high areas. In places, the Wilcox deposits immediately underlying the Carrizo or Meridian are composed of massive sand or a series of thick sand beds separated by relatively thin clay beds. In such areas, the sand in the upper Wilcox is included in the lower Claiborne-upper Wilcox aquifer. In Texas, the lower Claiborne-upper Wilcox aquifer is made up solely of the Carrizo Sand and sand in the upper Wilcox.

The Cane River Formation or its equivalents immediately overlie the Carrizo or Meridian Sand and may contain sand that is included in the lower Claiborne-upper Wilcox aquifer. A marine clay at depth, updip facies generally are represented by a sandy midsection bounded above and below by more or less clayey beds. Where the lower clayey beds are sandy, they and the intervening sand are considered part of the lower Claiborne-upper Wilcox aquifer (pl. 3, wells 98 and 100). Such is the case in southwestern Arkansas, where a sand that probably is equivalent to the Queen City Sand of Texas occurs within the Cane River Formation. This sand and the clay beneath it may be included in the lower Claiborne-upper Wilcox aquifer.

In Mississippi, the Tallahatta Formation, which includes in ascending order the Meridian Sand Member, Basic City Shale Member, and Neshoba Sand Member, overlies the Wilcox Group and is in turn overlain by the Winona Sand. As mentioned previously, the Meridian Sand Member is an important part of the lower Claiborne-upper Wilcox aquifer. Where the lithology of the overlying Basic City, Neshoba, and Winona is predominantly sand, these units also are included in the aquifer.

Most of the outcrop of the lower Claiborne-upper Wilcox aquifer (pl. 15) on the western side of the study area and around the Sabine uplift is about 5 mi wide or less. It is wider, as much as 10 mi wide, in extreme southern Texas and on the western flank of the Sabine uplift. It also is as much as 10 mi wide in part of southwestern Arkansas. On the eastern side of the study area, the outcrop is 10 to 20 mi wide in central Mississippi. It narrows in southwestern Alabama and is less than 2 mi wide in a small area. The aquifer dips toward the axis of the Mississippi embayment and generally gulfward to an altitude of about 8,000 ft below sea level in southwestern Texas (pl. 15).

The lower Claiborne-upper Wilcox aquifer is thickest in extreme southern Texas, where it is 900 to about 1,200 ft thick in an area that crosses several counties (pl. 15). The thickening occurs near the downdip limit of the aquifer. Eastward, in Texas, northern Louisiana, and southern Arkansas, the aquifer generally is 100 to 200 ft thick. The aquifer thickens to about 900 ft in places in western Mississippi but probably averages less than 600 ft. The lower Claiborne-upper Wilcox aquifer is 200 to 600 ft thick in east-central Arkansas and northeastern Mississippi at its northern limit of extent. The aquifer thins toward its outcrop around the Sabine uplift and is absent over that structure. The aquifer also thins updip toward its other outcrops and near its downdip limit, where it changes to a predominantly clay facies.

Beyond the northern limit of its extent, the lower Claiborne-upper Wilcox aquifer becomes part of the middle Claiborne aquifer, because the overlying lower Claiborne confining unit has changed to a sand facies and is part of the middle Claiborne aquifer.

To the south, in the area between the Sabine and Monroe uplifts, the lower Claiborne-upper Wilcox aquifer is thin and difficult to identify in places.

In most of southern Arkansas and northern Louisiana west of the Mississippi River, the lower Claiborne-upper Wilcox aquifer contains more than 80 percent sand (pl. 15). Ranging from about 100 to about 300 ft thick, the aggregate sand thickness is greatest near the northern limit in east-central Arkansas. East of the Mississippi River, the sand content varies considerably, ranging from less than 20 percent to more that 80 percent. The aggregate sand thickness is greater east of the river, being about 500 ft in small areas in Bolivar and Madison Counties, Mississippi. The aquifer is more than 60 percent sand in all of the area of its occurrence west and southwest of the Sabine uplift and is more than 80 percent sand in most of that area. Aggregate sand thickness averages about 200 ft northeast of the San Marcos arch but is as much as about 1,000 ft in the Rio Grande embayment southwest of the arch.

MIDDLE WILCOX AQUIFER

The bulk of Wilcox sediments lying between the lower Claiborne-upper Wilcox aquifer and the lower Wilcox aquifer is called the middle Wilcox aquifer (pl. 16) in this report (table 1). Paleocene and Eocene in age, this aquifer underlies an area of about 166,000 mi^2. Because the middle Wilcox aquifer is composed chiefly of thin interbedded sand, silt, and clay, it has water-bearing characteristics different from those of typical massive-sand aquifers. Because of the fine texture of the sand, horizontal permeability of the aquifer is low. However, it probably is several orders of magnitude greater than the vertical permeability of the interbedded clay. Therefore, although water bearing and able to transmit water laterally, the middle Wilcox aquifer provides considerable vertical resistance to ground-water flow to overlying and underlying aquifers because of its abundant interbedded clay and overall low permeability. In places, sands of the middle Wilcox aquifer grade laterally into sands of both the lower Claiborne-upper Wilcox aquifer and the lower Wilcox aquifer.

In Texas, the outcrop band of the middle Wilcox aquifer (pl. 16) is as much as 25 mi wide and averages about 15 mi wide. This aquifer is the surficial unit over the Sabine uplift. The outcrop or subcrop is narrower in Arkansas and southeastern Missouri, generally less than 10 mi wide. The outcrop is very narrow around the apex of the Mississippi embayment, widening to about 10 mi in western Tennessee. The outcrop widens further, to about 20 mi wide, in Mississippi and southwestern Alabama. The aquifer dips toward the axis of the Mississippi embayment and gulfward to about 12,000 ft below sea level in south-central Louisiana (pl. 16).

Except for shallow dug wells in the outcrop area, the thin discontinuous sand beds of the middle Wilcox aquifer generally are not used as sources of water. Thick sand beds of limited areal extent occur locally; these sand beds can be important local sources of supply, especially where they represent the only viable source of ground water, as commonly is the case where they do occur.

The middle Wilcox aquifer is thickest, about 4,500 to about 5,200 ft, in southern and southeastern Texas (pl. 16). The trend of maximum thickness parallels the coastline, in which direction the aquifer pinches out as it grades to clay and calcareous facies. The area of maximum thickness extends eastward across southern Louisiana and southern Mississippi, where it is 1,500 to about 3,000 ft thick. The aquifer is 200 to 500 ft thick in most of the Mississippi embayment and thins updip toward its outcrop near the perimeter of the study area.

The overall trend is one of increasing sand content from the northeastern to the southwestern and western parts of the study area (pl. 16). The aquifer is sandiest, probably averaging about 60 percent, in Texas. The aquifer also attains its greatest aggregate sand thickness, about 3,000 ft, in southeastern Texas. Elsewhere in the study area, the sand content probably averages less than 50 percent. In the northern Mississippi embayment, the sand percentage generally decreases downdip toward the axis of the embayment, where it is less than 20 percent. The aggregate sand thickness is 100 to 200 ft in most of this area. To the south, in eastern Louisiana, sand percentage increases to more than 60 percent and aggregate sand thickness to more than 1,000 ft. In southern Mississippi the sand percentage generally is less than 40 percent and decreases to less than 20 percent in southeastern Mississippi and southwestern Alabama. The aggregate sand thickness generally is less than 500 ft in this area.

LOWER WILCOX AQUIFER

The lower Wilcox aquifer (pl. 17) underlies the middle Wilcox aquifer in about 104,000 mi^2 of the study area and is the lowermost Tertiary aquifer being studied. This aquifer only occurs in the Mississippi embayment aquifer system. In the northern part of the Mississippi embayment, a massive sand aquifer, the Fort Pillow Sand of Tennessee, Arkansas, and Missouri (Moore and Brown, 1969), occurs in the lower to middle part of the Wilcox deposits. Previously, this sand was informally called the "1400-foot" sand in the Memphis area and the "lower Wilcox aquifer" in the Mississippi embayment (Hosman and others, 1968), a more restricted usage than that used in this report. The aquifer as defined in this report may include Wilcox deposits underlying the previously designated lower Wilcox aquifer (table 1).

Sand beds in the lower part of the Wilcox deposits generally tend to be thicker, more massive, and more continuous than the typically thin interbedded sand characteristic of the main body of the Wilcox. These sand beds may occur as a basal sand, or they may occupy as much as one-third of the Wilcox section. A massive sand at one location may be represented by two or more thick sand beds nearby. The sand beds grade laterally into silt and clay with thin interbedded sand. The nature of the occurrence of these sediments indicates stream deposition, probably by a drainage system similar to that of the Mississippi River. The thick sand beds are hydraulically interconnected laterally and, to a lesser degree, vertically. Collectively, they are considered the lower Wilcox aquifer.

As the lower Wilcox aquifer is a sandy facies of the Wilcox deposits, it interacts hydraulically to varying degrees with the middle Wilcox aquifer, with which it is partly laterally contiguous. Changes in thickness, vertical position, and distribution of the lower Wilcox aquifer reflect facies changes caused by shifting depositional environments within the context of a continental depositional system. Thick or massive sands grade laterally into finer grained counterparts that, although of much lower permeability, are an important part of the aquifer, because the low-permeability sands provide a hydraulic connection between the major sands.

The lower Wilcox aquifer extends southward from the head of the Mississippi embayment into central Louisiana and southern Mississippi and Alabama (pl. 17). The outcrop or subcrop in Arkansas and the northern part of the Mississippi embayment is narrow, generally less than 5 mi wide. The outcrop widens in Mississippi and southwestern Alabama to as much as about 10 mi. The altitude of the top of the aquifer ranges from about 500 ft above sea level in Tennessee to about 10,500 ft below sea level in southeastern Louisiana (pl. 17).

The maximum thickness of the lower Wilcox aquifer, more than 1,200 ft, is in central Mississippi in Simpson County (pl. 17). In the Mississippi embayment, the aquifer generally is less than 400 ft thick and thickens southward in central Louisiana and Mississippi. The aquifer thins updip toward its outcrop and downdip toward its limit where the aquifer becomes indistinguishable from the remainder of the Wilcox deposits.

The sand content of the lower Wilcox aquifer, which is greatest in the northern part of the Mississippi embayment, generally decreases southward and southeastward toward southeastern Mississippi and southwestern Alabama (pl. 17). In most of the northern part of the Mississippi embayment, the sand percentage exceeds 80 percent, and the aggregate sand thickness is as much as 300 to 400 ft. To the south and southeast, the sand content decreases to 20 to 40 percent. The aggregate sand thickness is greatest, more than 600 ft, in Caldwell and La Salle Parishes in east-central Louisiana and in Simpson and Smith Counties in Mississippi, where it is about 700 ft thick.

MIDWAY CONFINING UNIT

The Midway (Paleocene) confining unit (pl. 18) is a thick confining layer that is the base of the flow system for Tertiary aquifers in most of the study area. One possible exception is a relatively small area in the northern part of the Mississippi embayment, where the possibility for movement of water between the underlying McNairy-Nacatoch aquifer (Cretaceous) and overlying Tertiary aquifers exists due to thinning of the Midway. This area includes northeastern Arkansas, southeastern Missouri, the southern tip of Illinois, western Kentucky and Tennessee, and a small part of northeastern Mississippi. The overall extent of the Midway confining unit is about 166,000 mi^2.

The Midway confining unit as referred to in this report is composed almost entirely of deposits of the Midway Group (table 1). The immediately underlying Cretaceous deposits generally contain low-permeability beds also. The Midway consists mostly of dense marine clays, with lesser amounts of calcareous materials in the lower part. The percentage of marl and limestone increases in the southeastern part of the area such that all or almost all of the Midway section is calcareous. Where the underlying McNairy-Nacatoch aquifer (Cretaceous) is included in the study, the Midway confining unit includes upper Cretaceous clay and marl that lie between the top of the McNairy-Nacatoch aquifer and the base of the Midway deposits. The Midway confining unit may contain deposits of the Wilcox Group (pl. 3, wells 102 and 103).

The inland boundary of the study area is the outcrop or subcrop of the Midway confining unit (pl. 18), except where the McNairy-Nacatoch aquifer is included. The Midway confining unit crops out in a band of varying width around the inland boundary of the area except in Missouri and part of Arkansas, where it subcrops beneath the Mississippi River Valley alluvial aquifer, and in a small area in southern Texas, where it is overlapped by Wilcox deposits. The width of the outcrop ranges from less than 1 mi to about 20 mi. The confining unit dips toward the axis of the Mississippi embayment and gulfward to an altitude of about 13,000 ft below sea level in southern Louisiana (pl. 18).

The confining unit generally is 1,000 ft or more thick in the southern part of the study area (pl. 18). Its thickest points are in southern Texas, where it is about 3,200 ft thick, and in East and West Baton Rouge Parishes in Louisiana. The confining unit does not thin noticeably over the Sabine uplift but does thin to less than 400 ft over the Monroe uplift and to less than 200 ft over the Jackson dome. Northeastward, in the Mississippi embayment, the Midway confining unit is less than 1,000 ft thick, except in the Desha basin, where it is about 1,000 ft thick. It thins updip and generally is a few hundred feet thick at the downdip edge of the outcrop.

MCNAIRY-NACATOCH AQUIFER

The McNairy-Nacatoch aquifer (pl. 19) is the lowermost geohydrologic unit included in the Gulf Coast regional aquifer systems and underlies an area of about 28,000 mi^2. An important aquifer in the northeastern part of the study area, it is composed of sand beds in the Nacatoch Sand in Arkansas; the McNairy Sand in Missouri, Illinois, Kentucky, and Tennessee; and the McNairy Sand Member of the Ripley Formation of northern Mississippi.

The Ripley Formation and its aforementioned equivalents underlie the entire study area. In the northern part of the Mississippi embayment, a sand facies within the unit occurs as a single massive sand or as a series of two or more thick sand beds separated by thinner clay and marl interbeds. The sand is clean and fine grained and contains freshwater in much of its area of occurrence. Except in the outcrop, water in the McNairy-Nacatoch aquifer is confined by overlying clay and marl of Late Cretaceous age, which in turn is overlain by thick clay of the Midway Group. This sandy zone within the Ripley Formation and its equivalents has been designated the McNairy-Nacatoch aquifer for purposes of this study. The aquifer extends downdip from its outcrops and subcrops (pl. 19) around the perimeter of the northern Mississippi embayment. Its downdip limit is defined by a line that trends northwesterly across northwestern Mississippi and northeastern Arkansas and marks the extent of the sand facies as well as the boundary of the aquifer. The facies change along this aquifer boundary is somewhat abrupt, as the permeability of the sand is drastically reduced by calcareous cementation. The aquifer dips toward the axis of the Mississippi embayment to about 2,300 ft below sea level where the Mississippi River forms the boundary of the States of Arkansas, Mississippi, and Tennessee (pl. 19).

The thickness of the McNairy-Nacatoch aquifer generally ranges from 100 to 400 ft (pl. 19). It is thickest, more than 450 ft, in northern Lauderdale County, Tennessee. Elsewhere, except for the outcrop and subcrop, it generally is at least 100 ft thick. The aquifer thins near its downdip limit as it approaches the facies change from predominantly sand to clay, marl, and limestone.

As the aquifer is mostly a single massive sand, the sand percentage is 100 percent or nearly so in most of the area of its occurrence (pl. 19). In small areas in western Kentucky and northeastern Arkansas, the sand percentage is somewhat less than 60 percent. The aggregate sand thickness exceeds 400 ft in a small area in western Tennessee but generally is 100 to 200 ft.

SUMMARY

The Mississippi embayment aquifer system is 1,000 ft thick or more in most of its area of occurrence. It thins to extinction at the margins of the study area. It thickens southward toward the Gulf Coast geosyncline and toward the axis of the embayment and is thickest, about 5,000 ft, in southeastern Mississippi. The system then thins gulfward as sand facies disappear. The Texas coastal uplands aquifer system, which is contiguous with the Mississippi embayment aquifer system, is thickest, about 7,000 ft, southwest of the Sabine uplift, approximately in the Houston embayment. The system thins somewhat over the San Marcos arch, then thickens again to about 7,000 ft southwest of the arch.

These two systems are confined above by the Vicksburg-Jackson confining unit of Eocene and Oligocene age and below by the Midway confining unit of Paleocene age. The Vicksburg-Jackson confining unit separates underlying Eocene aquifers from overlying Oligocene and younger aquifers. The Midway confining unit forms the base of the Tertiary aquifer systems. The McNairy-Nacatoch aquifer (Upper Cretaceous) is included in the study in the northern part of the Mississippi embayment, where it is hydraulically connected with overlying Cenozoic aquifers in a limited area.

The Mississippi River Valley alluvial aquifer extends from the apex of the Mississippi embayment to the Gulf of Mexico. In this report, the southern limit of the aquifer is placed at the subcrop of the Vicksburg-Jackson confining unit. It crosses the subcrops of all Tertiary aquifers and confining units in the Mississippi embayment aquifer system. Ground-water circulates between the Mississippi River Valley alluvial aquifer and the underlying Tertiary aquifers; however, the quantity and direction of interaquifer flow depends on local conditions.

The Mississippi embayment and Texas coastal uplands aquifer systems contain massive aquifers that are hydraulically connected to varying degrees. Three aquifers, the lower Claiborne-upper Wilcox aquifer, the middle Wilcox aquifer, and the lower Wilcox aquifer, are not separated by confining layers but are defined on the basis of markedly different geohydrologic characteristics partly due to interbedded clay layers. Both the lower Claiborne-upper Wilcox aquifer and the lower Wilcox aquifer generally consist of or contain massive sands, whereas the intervening middle Wilcox aquifer generally is composed of thin interbedded sand and clay and some thick clay. In some places, the middle Wilcox aquifer grades laterally into the lower Claiborne-upper Wilcox or the lower Wilcox aquifer; in other places, it may be separated vertically from these aquifers by clays. The relation is complex and undoubtedly has a significant effect on the hydraulic connection between the aquifers.

In the central part of the Mississippi embayment, the lower Claiborne-upper Wilcox aquifer merges with the middle Claiborne aquifer where the intervening lower Claiborne confining unit disappears as it changes northward to sand facies. In effect, the middle Claiborne aquifer splits into two discrete aquifers southward from the northernmost extent of the lower Claiborne confining unit. Hydraulic connection between the aquifers decreases southward as the lower Claiborne confining unit becomes thicker and more clayey.

Other aquifers within the Mississippi embayment and Texas coastal uplands aquifer systems are also hydraulically connected to some degree owing to thin, sandy, or locally sandy confining units.

SELECTED REFERENCES

Baker, E.T., Jr., 1979, Stratigraphic and hydrogeologic framework of part of the Coastal Plain of Texas: Texas Department of Water Resources Report 236, 43 p.

Bennett, G.D., 1979, Regional ground-water systems analysis: Water Spectrum, v. 11, no. 4, p. 36–42.

Boswell, E.H., Cushing, E.M., and Hosman, R.L., 1968, Quaternary aquifers in the Mississippi embayment, *with a discussion of* Quality of the water, by H.G. Jeffery: U.S. Geological Survey Professional Paper 448-E, 15 p.

Boswell, E.H., Moore, G.K., MacCary, L.M., and others, 1965, Cretaceous aquifers in the Mississippi embayment, *with discussions of* Quality of the water, by H.G. Jeffery: U.S. Geological Survey Professional Paper 448-C, 37 p.

Cushing, E.M., Boswell, E.H., and Hosman, R.L., 1964, General geology of the Mississippi embayment: U.S. Geological Survey Professional Paper 448-B, 28 p.

Dickinson, George, 1953, Geological aspects of abnormal reservoir pressures in Gulf Coast Louisiana: American Association of Petroleum Geologists Bulletin, v. 37, no. 2, p. 410–432.

Frederiksen, N.O., and others, 1982, Biostratigraphy and paleoecology of lower Paleozoic, Upper Cretaceous, and lower Tertiary rocks in U.S. Geological Survey New Madrid test well, southeastern Missouri: Tulane Studies in Geology and Paleontology, v. 17, no. 2, p. 23–45.

Grubb, H.F., 1984, Planning report for the Gulf Coast Regional Aquifer-System Analysis in the Gulf of Mexico Coastal Plain, United States: U.S. Geological Survey Water-Resources Investigations Report 84–4219, 30 p.

Hosman, R.L., 1988, Geohydrologic framework of the Gulf Coastal Plain: U.S. Geological Survey Hydrologic Investigations Atlas HA-695, scale 1:2,500,000, 2 sheets.

Hosman, R.L., Long, A.T., Lambert, T.W., and others, 1968, Tertiary aquifers in the Mississippi embayment, *with discussions of* Quality of the water, by H.G. Jeffery: U.S. Geological Survey Professional Paper 448-D, 29 p.

McKeown, F.A., and Pakiser, L.C., eds., 1982, Investigations of the New Madrid, Missouri, earthquake region: U.S. Geological Survey Professional Paper 1236, 201 p.

Miller, J.A., and Renken, R.A., 1988, Nomenclature of regional hydrogeologic units of the Southeastern Coastal Plain aquifer system: U.S. Geological Survey Water-Resources Investigations Report 87–4202, 21 p.

Moore, G.K., and Brown, D.L., 1969, Stratigraphy of the Fort Pillow well, Lauderdale County, Tennessee: Tennessee Department of Conservation, Division of Geology Report of Investigations 25, 1 sheet.

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

Neuman, S.P., and Witherspoon, P.A., 1969, Applicability of current theories of flow in leaky aquifers: Water Resources Research, v. 5, no. 4, p. 817–829.

Payne, J.N., 1968, Hydrologic significance of the lithofacies of the Sparta Sand in Arkansas, Louisiana, Mississippi, and Texas: U.S. Geological Survey Professional Paper 569-A, 17 p.

———1970, Geohydrologic significance of lithofacies of the Cockfield Formation of Louisiana and Mississippi and of the Yegua Formation of Texas: U.S. Geological Survey Professional Paper 569-B, 14 p.

———1972, Hydrologic significance of lithofacies of the Cane River Formation or equivalents of Arkansas, Louisiana, Mississippi, and Texas: U.S. Geological Survey Professional Paper 569-C, 17 p.

———1975, Geohydrologic significance of lithofacies of the Carrizo Sand of Arkansas, Louisiana, and Texas and the Meridian Sand of Mississippi: U.S. Geological Survey Professional Paper 569-D, 11 p.

Sampson, R.J., 1978, Surface II graphics system: Kansas Geological Survey Series on Spatial Analysis No. 1, 240 p.

Wallace, R.H., Jr., and others, 1981, Occurrence of geopressure in the northern Gulf of Mexico basin, *in* Fifth conference on geopressured-geothermal energy, United States Gulf Coast: Prepared by the U.S. Geological Survey, map, scale 1:1,000,000.

Weiss, J.S., in press, Geohydrologic units of the coastal lowlands aquifer system, south-central United States: U.S. Geological Survey Professional Paper 1416-C.

Weiss, J.S., and Williamson, A.K., 1985, Subdivision of thick sedimentary units into layers for simulation of ground-water flow: Ground Water, v. 23, no. 6, p. 767–774.

Wilson, T.A., and Hosman, R.L., 1988, Geophysical well-log database for the Gulf Coast aquifer systems, south-central United States: U.S. Geological Survey Open-File Report 87–677, 213 p.

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Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

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