REGIONAL STRATIGRAPHY AND SUBSURFACE GEOLOGY OF CENOZOIC DEPOSITS, GULF COASTAL PLAIN, SOUTH-CENTRAL UNITED STATES

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Regional Stratigraphy and Subsurface Geology of Cenozoic Deposits, Gulf Coastal Plain, South-Central United States

By R.L. HOSMAN

REGIONAL AQUIFER-SYSTEM ANALYSIS–GULF COASTAL PLAIN

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1416–G

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1996

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, *Director*

Library of Congress Cataloging-in-Publication Data

Hosman, R.L.
Regional stratigraphy and subsurface geology of Cenozoic deposits, Gulf Coastal Plain, South-Central United States / by R.L. Hosman.
p. cm. — (Regional aquifer-system analysis—Gulf coastal plain) (U.S. Geological Survey professional paper ; 1416–G)
Includes bibliographical references.
Supt. of Docs. no.: I 19.16: 1416G
1. Geology, Stratigraphic—Cenozoic. 2. Geology—Gulf Coast Region (U.S.). I. Title. II. Series. III. Series: U.S. Geological Survey professional paper ; 1416–G.
QE690.H57 1996
551.7′8′0976—dc20 91–42144
CIP

For sale by U.S. Geological Survey, Information Services
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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.

Gordon P. Eaton
Director

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METRIC CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	*By*	*To obtain*
Foot (ft)	0.3048	meter
mile (mi)	1.6093	kilometer
square mile (mi^2)	2.5900	square kilometer

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.

REGIONAL STRATIGRAPHY AND SUBSURFACE GEOLOGY OF CENOZOIC DEPOSITS, GULF COASTAL PLAIN, SOUTH-CENTRAL UNITED STATES

By R.L. HOSMAN

ABSTRACT

The Gulf Coast Regional Aquifer-System Analysis includes all major aquifer systems in Cenozoic deposits in the Gulf Coastal Plain in Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, Texas, and in small areas in Alabama and Florida (western panhandle area), an area of about 290,000 square miles. The Gulf Coast geosyncline and the Mississippi embayment were the major depocenters for the Tertiary and Quaternary deposits that form the framework for the aquifer systems.

Formation of the Gulf Coast geosyncline and the Mississippi embayment began with downwarping and downfaulting at the end of the Paleozoic Era. Sedimentation caused the geosyncline to continue to subside throughout Mesozoic and Cenozoic time. During the Late Cretaceous, at the close of the Mesozoic Era, the sea advanced northward and eventually inundated the Mississippi embayment. Marine cycles persisted throughout the Paleocene and Eocene Epochs of the Tertiary Period, as the sea alternately advanced and retreated over the Mississippi embayment. The resulting sediments form a series of dense marine clays separated by terrigenous sands. The Gulf Coast geosyncline remained submerged during marine regressions in the embayment. After withdrawal of the last Tertiary sea from the Mississippi embayment at the end of the Eocene Epoch, deposition continued along the Gulf Coastal Plain under a shifting variety of nonmarine, marine, near-marine, and deltaic environments. Deposition resumed in the Mississippi embayment during the Quaternary with glacially related terraces and aggradation of streams. Fluvial deposition continues.

Structural features in the Gulf Coastal Plain and Mississippi embayment significantly affected Cenozoic deposition. The Desha basin, for example, is a pronounced Tertiary synclinal depocenter in southeastern Arkansas. Three large uplifts are approximately aligned along the latitude of the northern boundary of Louisiana. These are, from west to east, the Sabine, Monroe, and Jackson uplifts. A belt of three major fault zones, the Luling-Mexia-Talco, Arkansas, and Pickens-Gilbertown, generally follows the strike of sediments across the Gulf Coastal Plain and more or less forms the northern updip extent of the Gulf Coast geosyncline. An alternating series of gentle synclines and anticlines is oriented perpendicular to the coastline along the Gulf Coast in Texas. Beginning at the southwestern end, these are the Rio Grande embayment, San Marcos arch, Houston embayment, and Sabine arch. The Wiggins anticline is oriented approximately along strike of the sediments in southern Mississippi. Salt domes are numerous in the Gulf Coastal Plain and may penetrate thousands of feet of sediments. Although the degree of salt intrusion can be very great, disruption of adjacent strata is limited to the vicinity of the dome.

The physiography of the Gulf Coastal Plain is a direct result of the nature of the strata at land surface and physical forces that act upon them. Different terrains typify the lithologies that underlie them. Sands and clays each produce characteristic geomorphologic patterns; sands tend to produce ridges, and clays produce topographic lows.

Although Cenozoic deposits are not uniformly differentiated, interstate correlations of major Paleocene and Eocene units are generally established throughout the area. Younger deposits are not as well differentiated. Some stratigraphic designations made at surface exposures cannot be extended into the subsurface, and the scarcity of distinct geologic horizons has hampered differentiation on a regional scale. The complexities of facies development in Oligocene and younger coastal deposits preclude the development of extensive recognizable horizons needed for stratigraphic applications. Coastal deposits are a heterogeneous assemblage of deltaic, lagoonal, lacustrine, palustrine, eolian, and fluvial clastic facies and local calcareous reef facies. Even major time boundaries, as between geologic series, are not fully resolved. Surficial Quaternary deposits overlie the truncated subcrops of Tertiary strata and generally are distinguishable, although some contacts between Pleistocene and underlying Pliocene deposits have been a historical source of controversy. Glacially related terraces are characteristic of the Pleistocene Epoch, and alluvium of aggrading streams typifies the Holocene.

INTRODUCTION

The U.S. Geological Survey began a series of studies in 1978 to investigate regional ground-water systems in the United States. Natural hydrologic

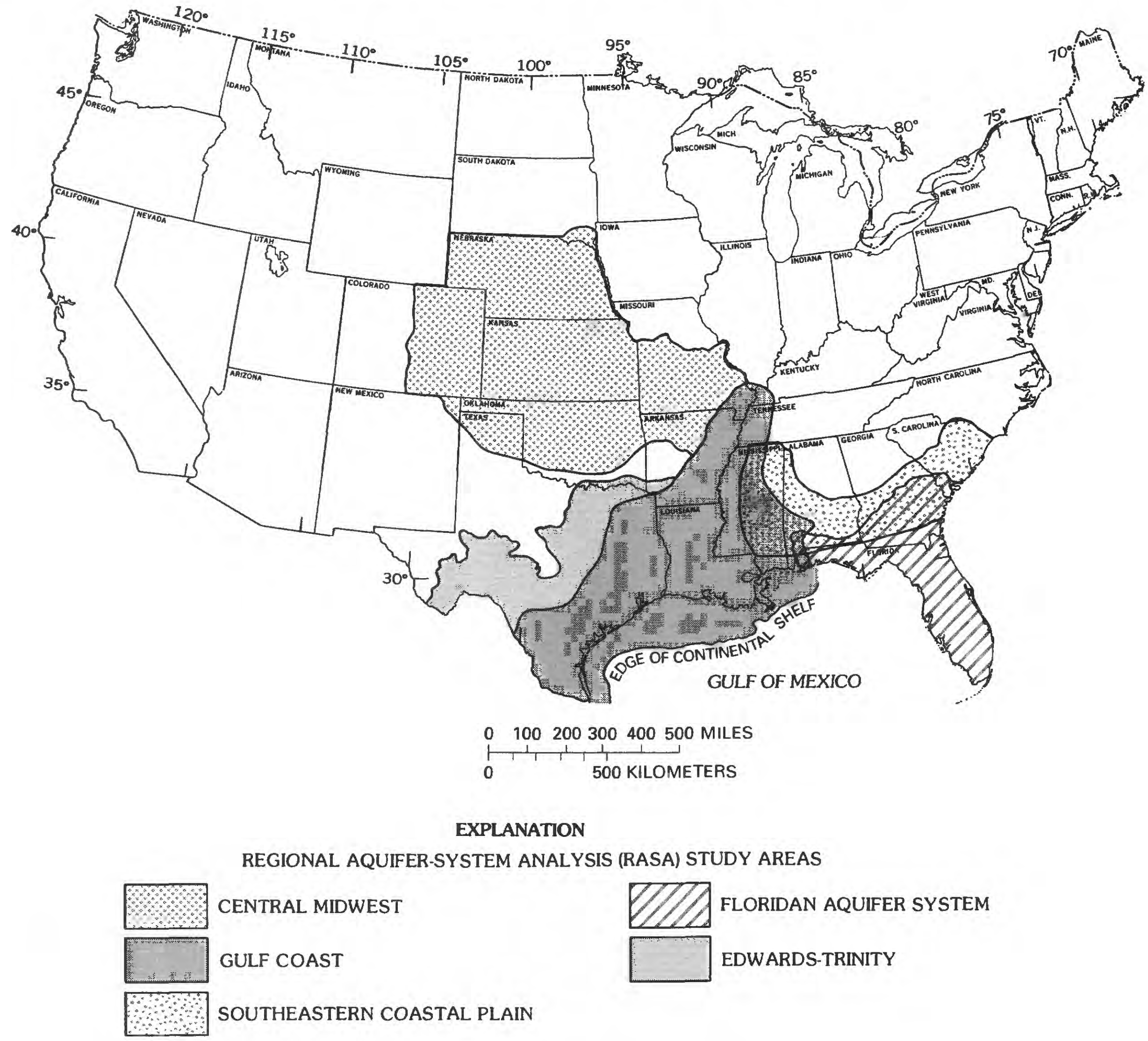

FIGURE 1.—Relation of Gulf Coast Reginal Aquifer-System Analysis study to adjacent Regional Aquifer-System Analysis studies. From Grubb (1986).

boundaries, rather than political boundaries, determined areas to be studied. This program, called the Regional Aquifer-System Analysis (RASA) program, is intended to define geohydrologic and geochemical characteristics of ground-water systems of regional scope (Bennett, 1979; Sun, 1986). The Gulf Coast RASA encompasses all major aquifer systems in Cenozoic deposits in the Gulf Coastal Plain in addition to late Cretaceous units locally. The study area is about 290,000 square miles and includes Alabama, Arkansas, Florida, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas (fig. 1). Included in the total is about 60,000 square miles of offshore area in the Gulf of Mexico.

This report presents a generalized discussion of the post-Cretaceous geology of the Gulf Coastal Plain from a regional perspective. In so doing, major tectonic events and structural features are discussed insofar as they affected Cenozoic sedimentation. Depositional trends and patterns are related to cyclic Tertiary environments that produced alternating marine and continental sequences. All major stratigraphic units that comprise these deposits are described and fixed with respect to their equivalency within the regional framework.

Two companion reports (Hosman and Weiss, 1991; Weiss, 1992) describe the subdivision of Cenozoic deposits in the study area into aquifers and confining units for analysis of regional ground-water flow. This report presents a subdivision of Cenozoic deposits into rock- and time-stratigraphic units. It also describes the heterogeneity of the sediments and geologic correlation problems that influenced the delineation of the geohydrologic units described in the two

TABLE 1.—*Geologic units and geohydrologic units of the gulf coast aquifer systems*

[Confining units are defined as the massive clay section (with interbedded sands) of the Midway Group and the undifferentiated Jackson and Vicksburg Groups that are recognizable on geophysical logs. The recognizable lithologic unit many not be equivalent to the geologic unit as determined by fossils or other means of correlation and dating, because the upper or lower part of either the Midway Group or the undifferentiated Jackson and Vicksburg Groups may be sandy and therefore included in the adjacent aquifer or permeable zone. The Midway confining unit was referred to as the coastal uplands confining system, and the Vicksburg-Jackson confining unit was referred to as the coastal lowlands confining system by Grubb (1984, p. 11)]

GEOLOGIC UNIT			MISSISSIPPI EMBAYMENT AQUIFER SYSTEM	TEXAS COASTAL UPLANDS AQUIFER SYSTEM
SYSTEM	SERIES	GROUP	GEOHYDROLOGIC UNITS	GEOHYDROLOGIC UNITS
QUATERNARY	PLEISTOCENE and HOLOCENE		Mississippi River Valley alluvial aquifer	Not present
TERTIARY	EOCENE and OLIGOCENE	JACKSON and VICKSBURG	Vicksburg-Jackson confining unit	Vicksburg-Jackson confining unit
	EOCENE	CLAIBORNE	Upper Claiborne aquifer	Upper Claiborne aquifer
			Middle Claiborne confining unit	Middle Claiborne confining unit
			Middle Claiborne aquifer	Middle Claiborne aquifer
			Lower Claiborne confining unit	Lower Claiborne confining unit
			Lower Claiborne-Upper Wilcox aquifer	Lower Claiborne-Upper Wilcox aquifer
		WILCOX	Middle Wilcox aquifer	Middle Wilcox aquifer
	PALEOCENE		Lower Wilcox aquifer	Not present
		MIDWAY	Midway confining unit	Midway confining unit

GEOLOGIC UNIT			COASTAL LOWLANDS AQUIFER SYSTEM
SYSTEM	SERIES	GROUP	GEOHYDROLOGIC UNITS
QUATERNARY	HOLOCENE		Permeable Zone A
	PLEISTOCENE		
TERTIARY	PLIOCENE		Permeable Zone B
			Permeable Zone C
	MIOCENE		Zone D confining unit
			Permeable Zone D
			Zone E confining unit
			Permeable Zone E
	EOCENE and OLIGOCENE	JACKSON and VICKSBURG	Vicksburg-Jackson confining unit[1]

companion reports mentioned above. The relation of the geohydrologic units to geologic units is shown in table 1.

PREVIOUS WORK

A vast number of geologic and geohydrologic studies have been conducted in the project area. With few exceptions, these studies were of one or more counties. Preeminent among the few regional works is G.E. Murray's (1961) classic presentation of the geology of the Atlantic and Gulf Coastal Province. Other reports of regional scope were produced by a study of the geohydrology of the Mississippi embayment; these include reports on the general geology (Cushing and others, 1964), aquifers in Quaternary deposits (Boswell and others, 1968), and aquifers in Tertiary deposits (Hosman and others, 1968). J.N. Payne (1968, 1970, 1972, and 1975) made a series of studies of the geohydrologic significance of lithofacies of principal water-bearing geologic units in the Claiborne Group (Eocene), primarily in the Mississippi embayment. In addition to geohydrologic evaluations, Payne suggested depositional systems and environments for the units studied.

METHOD OF STUDY

Most of the geohydrologic data used in this study were from geophysical logs of oil test wells, which are abundant throughout most of the area. Approximately 1,000 (pl. 1) logs were selected on a basis of spatial distribution and the degree to which they represented regional characteristics. Where possible, a spacing of approximately 20 miles was maintained. Data from these logs were entered into a master computer log file. (A list of the logs and tabulation of the coded data is presented in Wilson and Hosman (1988).) An earlier report based on these data describes the geohydrologic framework of the study area (Hosman, 1988), and reports by Hosman and Weiss (1991) and Weiss (1992) delineate regional hydrologic units as used in the ground-water flow modeling phase of the study. Determinations of the tops and thicknesses of all major geologic units as used in this report are also based on this same log file.

Structure and isopach maps of the major geologic units were initially made by using Surface II, a computer contouring program (Sampson, 1978), which performed a linear interpolation of the randomly spaced log data to create maps based on uniformly spaced 5-mile intervals. Geologic judgment was used to refine the maps, which were intended to depict regional trends. The same system was used to produce geologic sections (pls. 2–3) that reflect interpolated data along a continuous straight line of section (locations on pl. 4) rather than only point data at individual wells. Wells within 5 miles of the line of section were projected to the line of section, and extrapolated values provided control between wells.

Interpretations regarding depositional patterns and history were aided by maps showing sand percentage of the major hydrologic units (Hosman and Weiss, 1991; and Weiss, 1992). Although the maps are of hydrologic units, the hydrologic units largely conform to geologic units, and much of the descriptive matter is common to each.

GEOLOGIC HISTORY

Cenozoic deposition in the study area was largely controlled by catastrophic geologic events that took place at the end of the Paleozoic Era. The basic configuration of the Gulf Coast geosyncline and the Mississippi embayment began with deformation of the Paleozoic surface prior to Mesozoic deposition. Folding associated with the Ouachita orogeny formed the deep geosyncline that served as a catch basin for subsequent sedimentation, and downwarping and downfaulting proceeded further in response to the weight of sediment accumulation. The Mississippi embayment, the result of associated downwarping and rifting, is a southward-plunging trough that opens into the geosyncline proper. Continued deepening of the embayment as the result of sediment load has been moderate as compared to that which took place in the geosyncline. Faulting has been active from the Mesozoic through the present in both basins.

Mesozoic deposition produced vast accumulations of sediment in the Gulf Coast geosyncline and lesser but nonetheless substantial amounts in the Mississippi embayment. Triassic and Jurassic deposits of unknown thickness filled and deepened the geosyncline. Subsequent advances of Cretaceous seas left mostly marine deposits as far north as the northernmost limit of the Mississippi embayment and laid the floor for Cenozoic sediments that were to follow.

STRUCTURAL FEATURES AND MAJOR TECTONIC EVENTS

The Mississippi embayment trough and the Gulf Coast geosyncline are the controlling tectonic elements upon which structural features and trends of smaller scale are superimposed (fig. 2). In the northern part of the Mississippi embayment for example, a complex system of faults in southeastern Missouri and northeastern Arkansas roughly parallels the axis of the embayment. This fault zone, the New Madrid fault zone, is still active and is associated with the epicenter of the New Madrid earthquake of 1811–12, the most intense quake of record in the conterminous United States. The fault zone is within a major graben or rift responsible for the downfaulting of the upper end of the embayment trough.

The Pascola arch (fig. 2) is another structural feature in the northern part of the Mississippi embayment. Its axis extends southeastward across southeastern Missouri and into western Tennessee. The flexure, although gentle, reflects the pre-existing surface of the Paleozoic basement rock and affects the configuration and thickness of overlying Mesozoic and Cenozoic strata.

North of and flanked by the Monroe uplift, the Desha basin is an important depocenter in southeastern Arkansas. The basin is a local but very pronounced feature superimposed on the western flank of the embayment and was of sufficient magnitude to significantly affect both Mesozoic and Cenozoic deposition. The greatly increased thickness of the strata here indicates a subsiding basin that closely followed the tectonic pattern of its parent structures, the geosyncline and embayment. The axis of the Desha basin appears as a fork to the axis of the Mississippi embayment and arcs northwestward from the intersection of the axes in the vicinity of the Mississippi River adjacent to southeastern Arkansas.

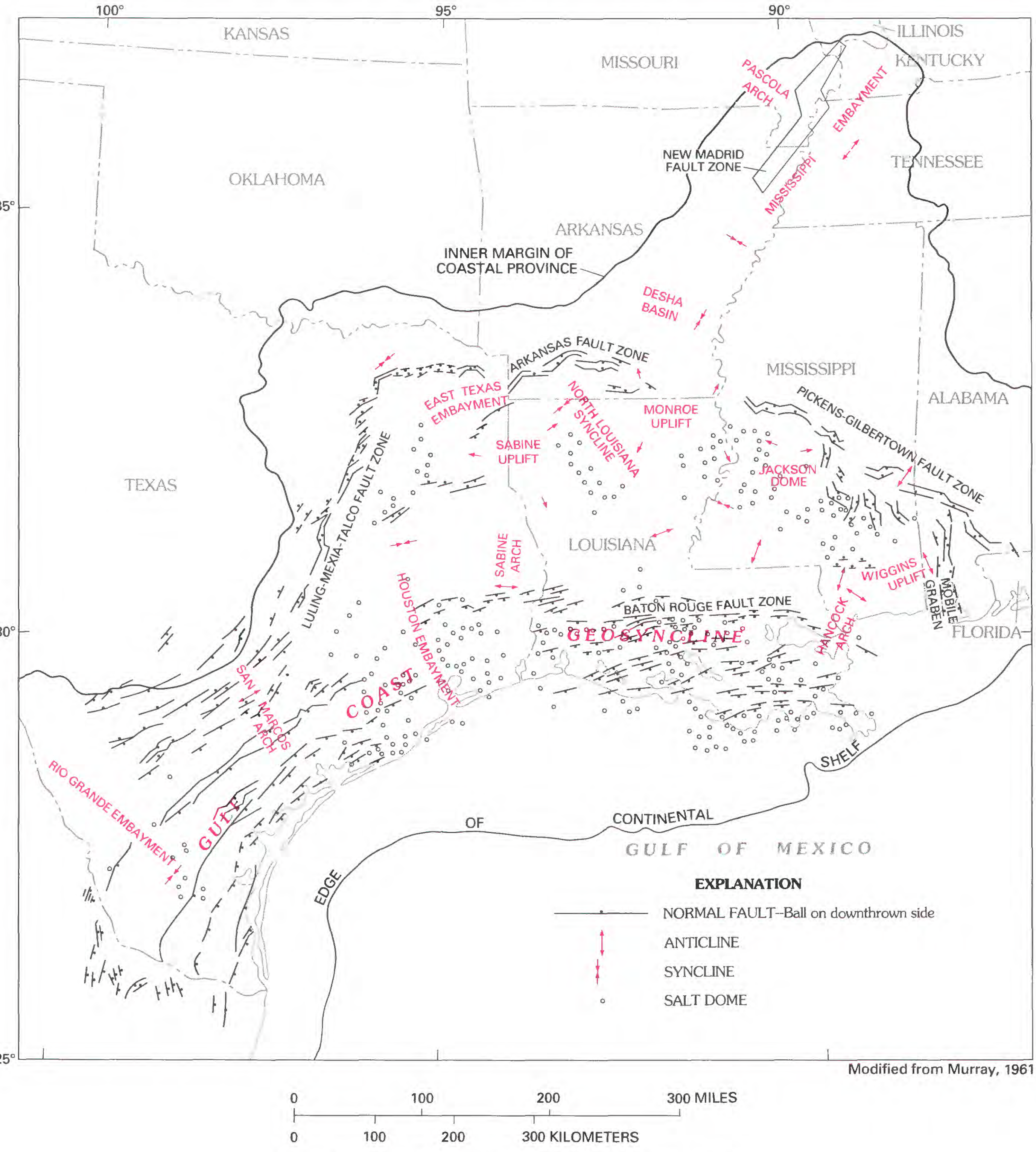

FIGURE 2.—Major structural features of the Gulf Coastal Plain

Three major structural highs, the Sabine uplift, Monroe uplift, and Jackson dome, are roughly aligned in an eastern trend across the Mississippi embayment in the approximate latitude of northern Louisiana. The largest of these (fig. 2, pl. 4), the Sabine uplift, occupies more than 5,000 square miles in the northwestern corner of Louisiana with a lesser part in northeastern Texas. The uplift is underlain by a high area in the basement rocks, of which little is known except that crystalline rock has been penetrated by a few deep wells. The oldest sedimentary rocks in the Sabine uplift probably are of Jurassic age. The uplift was submerged during the early part of the Tertiary Period as indicated by the presence of marine clay of the Midway Group. Overlying Wilcox Group deposits form the surface, and the uplift has remained a positive area since that time. The exposed Wilcox is ringed by outcropping Claiborne Group units (pl. 4) and is generally considered to represent the areal extent of the uplift. Many minor local structural elements are superimposed upon the uplift, but these are of no particular significance on a regional scale. A flexure of low structural relief, the Sabine arch, extends southward from the uplift to the Gulf (fig. 2).

About the same size as the Sabine uplift, the Monroe uplift lies between it and the Jackson dome to the east. It lies mostly in the northeastern corner of Louisiana with parts in the southeastern corner of Arkansas and west-central Mississippi. Although it lacks the more obvious surface expression of the Sabine uplift, its location and sheer size gave it significant influence over Tertiary deposition in that it greatly constricted the Mississippi embayment between it and the Jackson dome. The top of the uplift has always been broad and relatively flat, causing thinning of Tertiary strata over its entire area. As mentioned previously, a pronounced syncline, the Desha basin, formed off the northern flank of the Monroe uplift. The position of the syncline with respect to the uplift indicates the probable structural relation of the two. A biostromal limestone bank as much as a few hundred feet thick developed on the top of the Monroe uplift during Late Cretaceous-early Tertiary (Paleocene Midway) time. The clay facies, regionally typical of the lithology of these strata, contemporaneously was deposited downslope. The top of the uplift must have been undergoing slow submergence during this period to maintain the shallow-water environment necessary to sustain the sedentary organisms that accumulated to form this reeflike structure. The rate of submergence increased during late Paleocene, and the calcareous deposits gave way to typical marine clay of the Midway Group. The reefal limestone became a highly productive hydrocarbon reservoir known informally as the Monroe gas rock.

Movement that began with an igneous intrusion at the end of the Cretaceous Period and continued at least until Oligocene time created the Jackson dome in west-central Mississippi; it is the most pronounced structural feature for its size in the study area. Its structural relief is exceeded only by that of salt domes. Tertiary strata that are draped over the dome more than double in thickness off the structure. At the time of biostromal development on the Monroe uplift, during the transition from Late Cretaceous to early Tertiary, a similar event was taking place at the Jackson dome as many hundreds of feet of limestone reef formed on the top surrounded by an argillaceous facies. Toward the end of the Paleocene normal deposition resumed over the dome, and Midway Group clay covered the reef. Deposition over the dome continued through the Eocene, but the area has been exposed since.

The Luling-Mexia-Talco fault zone extends generally northeastward across southern and southeastern Texas near the updip limit of Tertiary deposits. In northeastern Texas the trend of the zone turns eastward. It is part of a regional fault zone that continues across southern Arkansas, central Mississippi, and into southwestern Alabama. The belt of faults follows the strike of the sediments and is probably associated with the sinking of the Gulf Coast geosyncline, as displacement increases with depth. The zone is a system of en echelon grabens several miles across and normal faults. The downfaulted strata, whether in grabens or on the downfaulted side of a single normal fault, are generally thicker than those on the upthrown side. The faulting has been active throughout the Cenozoic up to and including the present.

The other two fault zones in this regional trend, the Arkansas and the Pickens-Gilbertown fault zones (fig. 2), appear to be continuations of the Luling-Mexia-Talco fault zone. They are aligned but are separated by the Monroe uplift and the axis of the Mississippi embayment. The Arkansas fault zone crosses southern Arkansas from the west and terminates at the western flank of the Monroe uplift. The Pickens-Gilbertown fault zone curves around the northern flank of the Jackson dome and then trends southeastward across central Mississippi into southwestern Alabama. The faults in both of these zones are of the same nature and origin as those in the Luling-Mexia-Talco fault zone of Texas.

Additional strike-oriented growth faulting occurs in zones of varying extent throughout the Gulf Coastal Plain. All are associated with subsidence of the Gulf Coast geosyncline, and at least some are still active. The Baton Rouge fault zone is an example of an active fault with evidence of current movement. More than 100 miles in length, the fault passes east through Baton Rouge, Louisiana. Some structures built over the fault plane have experienced misalignment or foundation damage as a result of movement of the fault.

A few faults, mostly in the southeastern part of the Gulf Coastal Plain, are at approximately right angles to the general strike of the growth-fault system. The reasons for the origin and orientation of these faults are not known and may lie in the basement complex. Of these, the most notable is the Mobile graben. Several miles in width and at least 100 miles long, the landward expression of the graben extends northward from the coast at Mobile, Alabama. As it nears its northern inland extent, it arcs northwest to more or less parallel the Pickens-Gilbertown fault zone. The graben is pronounced and easily recognizable at the surface and, in fact, forms the depression that is Mobile Bay. A highway tunnel that crosses the upper end of the bay is in the graben.

The Wiggins uplift (fig. 2) is an arcuate feature that begins in the southwestern corner of Alabama and crosses southern Mississippi with its axis striking west-northwest. The axis of the uplift bifurcates in the southeastern corner of Mississippi, and a shorter segment arcs southwestward toward the southeastern tip of Louisiana; this southern limb has been referred to as the Harris arch (also Hancock ridge).

The East Texas embayment and the North Louisiana syncline (fig. 2) form a single major geosyncline that arcs around the northern half of the Sabine uplift to which it is the rim syncline. The syncline is much closer to the Sabine uplift in Louisiana than it is in Texas and is deepest north and west of the uplift. The initial deformation that produced this large negative area was probably associated with the Ouachita orogeny and persisted through Claiborne time as a depocenter. It was open at the south to the Gulf Coast geosyncline, at least during the Cenozoic, and has not received sedimentation since the withdrawal of the sea at the end of Claiborne time. The East Texas embayment displays the distinctive surficial features of a syncline with successively older geologic units cropping out on both limbs. As the embayment merges with the Gulf Coast geosyncline and loses its identity as a major depression, its general trend proceeds southward to the gulf as the more gentle flexure of the Houston embayment.

The Rio Grande embayment in southern Texas (fig. 2) is a more pronounced depression than is the Houston embayment. The two embayments are separated by the San Marcos arch. The axis of the Rio Grande embayment trends east-southeast, whereas the axis of the San Marcos arch strikes more southeast.

Salt domes occur in profusion in the Gulf Coastal Plain (fig. 2). The largest concentration of domes is in a wide band that extends along the coast from the southeastern corner of Texas to the southeastern tip of Louisiana. Another band of domes extends from northeastern Texas, across northern Louisiana into south-central Mississippi. The domes all emanate from the same mother bed of salt, the Louann Salt. The exact geologic age of the Louann Salt has not been agreed upon by all workers in the field; estimates range from Permian to Late Jurassic and bracket various age ranges within that spread. Current thinking probably leans toward an Early to Late Jurassic age, possibly beginning in Late Triassic.

It is not within the scope of this investigation to explain or hypothesize the processes involved in the accumulation of vast thicknesses of salt and subsequent diapirism, processes that are still not thoroughly understood. Suffice it to say that the plastic flow of bedded salt into pillows or similar structures began in Late Jurassic and Early Cretaceous time in response to density differences between the salt and the accumulating overburden. Further upward plastic flow from the pillows in the form of diapirs, or domes, gave continuing relief from growing pressure of the overburden. Thus, the domes probably grew more or less penecontemporaneously with surrounding sedimentation. This explanation is actually a simplified account of the downbuilding theory and satisfactorily explains the formation and growth of most domes in the Gulf Coast area. Domal growth and movement was not a smooth, steady process but rather a series of pulses of isostatic adjustments as changing equilibriums were met. Movement was not actual upward thrusting as much as it was the dome's remaining essentially in place as sediments around it subsided while underlying salt flowed inward toward the dome. Faulting and thickening of some strata adjacent to the dome resulted from and accompanied the rim-syncline effect thus produced. Some domes do not fit this pattern and appear to have been more actively intrusive in that they penetrated substantial thicknesses of overburden after it had accumulated over the dome.

Varying thicknesses of caprock overlie most of the salt domes. Consensus has not been reached regarding formation of caprock, but the most widely accepted explanation of the process postulates that the caprock represents impurities in the salt that remain after dissolution and removal of the salt by the actions of ground water (Halbouty, 1979, p. 45). The residual less soluble impurities, predominantly anhydrite, are concentrated and compacted by overburden until the caprock becomes sufficiently thick and impervious as to prevent further dissolution of the salt. Secondary alteration of the caprock yields limestone and gypsum, and commercially developable deposits of sulfur are not uncommon.

The diameter of most of the domes ranges from 1 to 3 miles, but the structural disturbance at and around salt domes varies much more than does the size. The area immediately over the dome may be flat or a gentle upward flexure, or it may be a complex graben system with large displacements or anything in between. Faulting at the flanks of the dome may be essentially nonexistent or it may be so complex as to defy interpretation by available geophysical technology; displacements of thousands of feet have been measured. Changes in dip of affected strata vary greatly, and reversals are common in rim synclines. Both thickening and thinning of adjacent strata occur, depending upon location of the deposition with respect to the dome and timing of the deposition with respect to rim subsidence. The multitude of stratigraphic relations associated with domal tectonics created a variety of trap situations for the accumulation of hydrocarbons, and the petroleum reservoirs thus created have been prolific producers of oil and gas.

Although the structural features associated with salt domes may appear quite extreme and can have deformities of considerable magnitude, the effects are restricted to the vicinity of the domes and do not significantly affect regional tectonic patterns.

DEPOSITIONAL PATTERNS

PRE-CENOZOIC

Knowledge of pre-Cretaceous geology in the Gulf Coastal Plain is very limited, especially in the southern part of the area where extreme depths of these strata place them beyond the depths of interest to petroleum wildcat drillers or the reach of their equipment. Paleozoic and Mesozoic rocks flank Cenozoic coastal deposits at the surface adjacent to the study area at its updip boundary.

CENOZOIC

The encroachment of the Midway sea at the close of the Cretaceous Period began a succession of alternating marine and nonmarine depositional cycles that lasted throughout the Paleocene and Eocene Epochs. The marine interval during which sediments of the Midway Group were deposited, the longest and most expansive of the Cenozoic depositional cycles, lasted the entire Paleocene Epoch. During this transgression, the sea extended as far as the apex of the Mississippi embayment, which made it the largest of the Tertiary seas. Subsequent deposition is in an offlap sequence, and each later marine transgression was of successively smaller extent as the margin of the inundated area migrated seaward toward the present coastline. Some incursions of the sea were only partial and did not extend as far inland as when the entire Gulf Coastal Plain was submerged. Deposition in the study area resulting from these episodic oceanic transgressions is mostly dense marine clay. The clay grades to a calcareous facies downdip toward and in the Gulf Coast geosyncline. The sea did not occupy the Mississippi embayment after the Eocene Epoch; deposition was restricted to the southern part of the Gulf Coastal Plain for the remainder of the Tertiary.

The sediments of continental and near-shore origin that were deposited during periods of marine regression are updip facies of the deep-basin clay. The southern extent of these deposits was controlled by the distance of the retreat of the sea from the coastal plain, and the thickness was controlled by the duration of the withdrawal. The maximum point of withdrawal was the Gulf Coast geosyncline, and marine deposition there was continuous. Thus, a marine-facies equivalent exists for the entire continental sequence.

The basic pattern of nonmarine deposition was repeated throughout the Tertiary with similar environments reestablished with each emergence of the land. The coastal zone is typified by zones of deltaic deposits, commonly in lobate patterns, interspersed with beach and bar systems. The deltas are coalescent and intermesh with one another and with interdeltaic shore and shallow-marine deposits such that great thicknesses of interbedded sand, silt, and clay were formed. Organically rich palustrine and lagoonal deposits are closely associated with the coastal environment and commonly occur as peat and lignite interbedded with the clastic sediments.

Landward of coastal depositional environments, fluviolacustrine sedimentation produced great thicknesses of sand and clay. To a lesser extent gravel was deposited with some fluvial sand, primarily in younger sediments and terrace deposits associated with Pleistocene interglacial periods. The Gulf Coastal Plain has been low lying and mostly flat and featureless throughout its entire Cenozoic history. Drainage systems, similar to those of the present, were established and were the principal agents responsible for the distribution of sediment. A central system along the axis of the Mississippi embayment trough must have been the predominant drainage and depositional control every time the coastal plain was elevated above the sea. Unable to drain the entire coastal plain, this system would have been flanked by other gulfward-flowing systems much in the same manner that exists at present.

Although deltaic and offshore deposition continued during the Quaternary Period, continental depositional patterns underwent a radical change. Glacial meltwaters during the Pleistocene Epoch left a series of terrace deposits that corresponds to interglacial periods. The coarse sands and gravels of the terraces show a stepped distribution in the Coastal Plain and appear as dissected remnants in the Mississippi embayment to the north. The youngest Quaternary deposits, those of Holocene age, are alluvial deposits in the flood plains of major streams and interdeltaic and other coastwise deposits.

STRATIGRAPHIC EFFECTS

The cyclic deposition that persisted throughout most of the Tertiary Period in the coastal plain produced alternating sequences of sediments of two predominant lithologic types, sand and clay. The continental sands range from thin discontinuous beds interbedded with clay to massive sands hundreds of feet thick. Most sands within a given continental unit are considered to be interconnected to one degree or another; thicknesses of the sands and the interbedded clays may change abruptly. Although individual sand beds may not be traceable on a regional scale, the larger units containing them are identifiable, primarily on the basis of the marine clays that bound them.

Regionally extensive marine-clay deposits provide the principal basis for subdividing the coastal-plain sediments into geologic units. Where the clays are present they provide the mappable horizons necessary for the determination of stratigraphic relations. Some fossiliferous marine beds associated with the clays provide paleontological evidence to supplement and verify lithologic correlations. Such marker beds are invaluable where similar lithologic sequences can be difficult to place stratigraphically.

Stratigraphic differentiation of sediments in the Gulf Coastal Plain began with traditional geologic mapping of surface exposures and expanded as subsurface data became available. Early work confined to local studies or politically bounded areas was extended and correlated at both intrastate and interstate levels in areas where the geologic units were present in the subsurface. Some units that occur only in the subsurface have been identified almost entirely on the basis of information derived from geophysical logs, which are principally a result of oil and gas exploration.

PHYSIOGRAPHIC CHARACTERISTICS

The physiography of an area is governed by the rocks that underlie its surface and the erosional and tectonic forces that act upon it. As most of the Tertiary and Quaternary sediments in the Gulf Coastal Plain fall into two major classes, sand and clay, erosional processes have had similar effects throughout the area. The more resistant sand layers underlie ridges or cuestas, and the less resistant clay has produced topographic lows. Tectonic movements have altered physical placement or configuration of the geologic units in places, but the basic erosional patterns remain the same.

The belt of deltaic and interdeltaic sediments that typifies the emerged Gulf segment of the coastal plain is a flat, low-lying area with marshes and swamps as common features. This area grades landward to a band of steplike deposits and terraces of relatively young geologic age. The inner or uplands region, developed on differentially eroded alternating fine to coarse detrital material, appears as belted topography. Sandy strata form the cuestas that may become bands of hills as erosion progresses. The sands are resistant to erosion because they absorb rainfall, thereby reducing surface runoff. As the belts of hills and valleys follow outcrop trends, they generally parallel the coast and the outline of the Mississippi embayment. Soils developed on each geologic unit commonly support a distinctive flora so that vegetation is an aid in identifying both physiographic features and underlying type of rock. Physiographic nomenclature used in this study (fig. 3) is the same as that used by Fennemann (1938) and Murray (1961).

Paleocene Series

Terrain developed on Paleocene sediments, mostly Midway Group clay, underlies parts of the East Texas Timber Belt. The timber belt is an expression of soil and vegetation and is not a topographic feature. Northwest of the timber belt the Midway clay becomes the gulfward part of the Black Prairie of Texas and Arkansas. East of the Mississippi River, the Midway forms part of the Red Hills of Kentucky, Tennessee, Mississippi, and western Alabama. The Pontotoc Ridge in Mississippi and Tennessee is supported in part by limestone in the Clayton Formation, which is the basal unit of the Midway Group. West of the ridge, the Flatwoods of Mississippi and Tennessee are underlain by the Porters Creek Clay, the massive clay unit of the Midway Group.

Eocene Series

The East Texas Timber Belt overlies parts of all Eocene sediments and follows particular soils developed on exposures of these deposits. It is not a

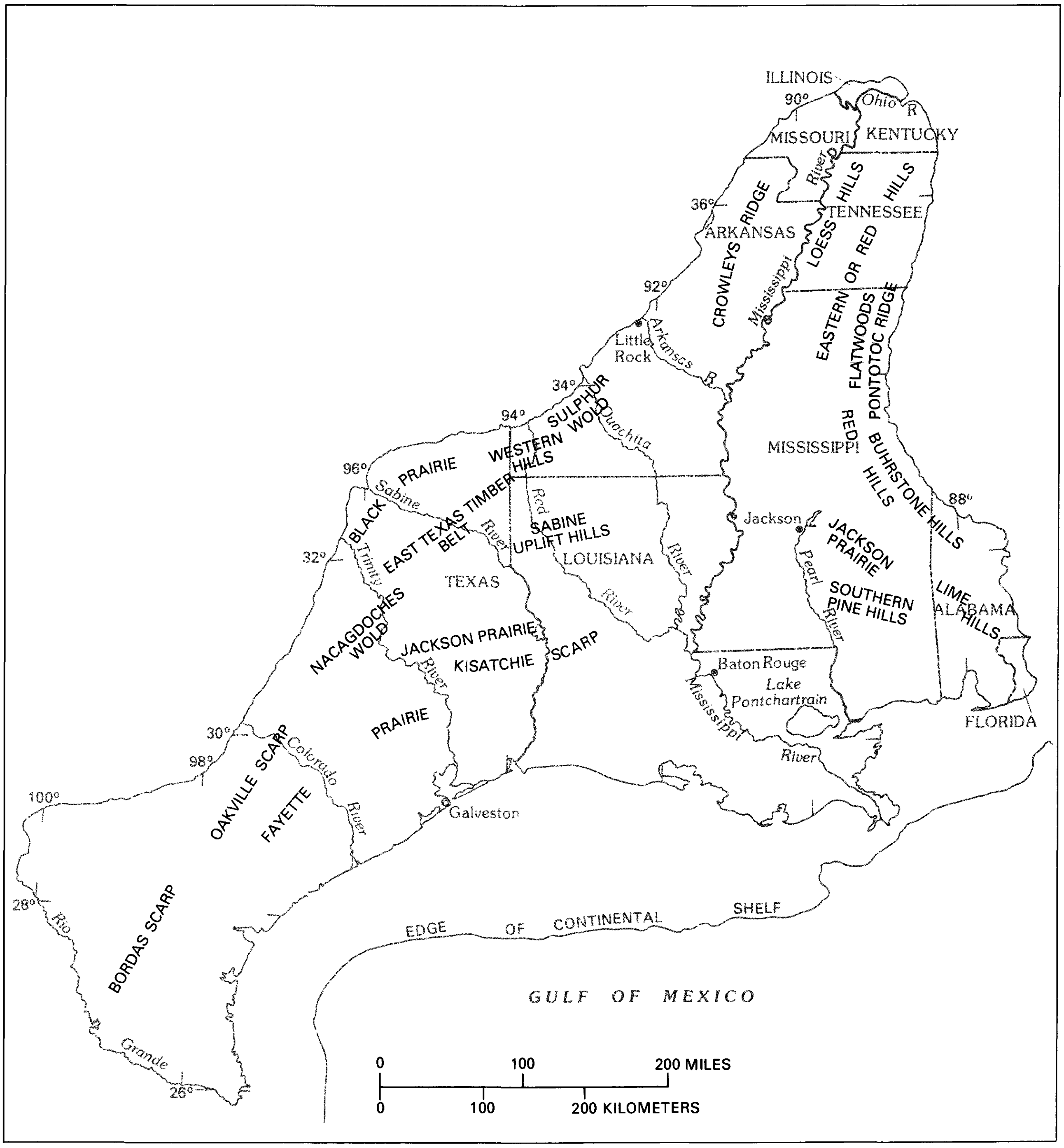

FIGURE 3.—Physiography of the Gulf Coastal Plain.

topographically distinct area but encompasses several topographic belts that are recognized physiographic features.

The Western Hills near the vicinity of the juncture of Texas, Arkansas, and Louisiana (fig. 3) are a series of rolling hills of low relief that are formed on outcropping deposits of the Wilcox and lowermost Claiborne Groups. The Wilcox Group, generally composed of interbedded sand and clay beds, is sufficiently sandy in this area to produce a hilly topography as it combines with the overlying Carrizo Sand (basal Claiborne unit) in resistant ridges. Outcropping Wilcox and Claiborne strata also combine to form hills of generally low relief in the area of northwestern Louisiana and northeastern Texas overlying the Sabine uplift. Here, the Wilcox outcrop is roughly a large circular area ringed by Claiborne outcrops. As with the Western Hills, the sandy parts of these deposits are the hill formers. Ironstone, which in places is abundant in the Claiborne Group, adds to the resistance of sand layers where present.

The Red Hills (or Eastern Hills) (fig. 3) of Kentucky, Tennessee, Mississippi, and western Alabama are also underlain by deposits of the Claiborne and Wilcox Groups. The Red Hills are a partly dissected cuesta of generally gentle slopes with 200 to 400 feet of relief. Bright colors resulting from weathering of the underlying rocks gave the hills their name. In southwestern Alabama the cuesta trends slightly northeastward where it overlies the Clayton Formation (basal unit of the Midway Group). The Buhrstone Hills or Cuesta lie within the Red Hills belt but are topographically distinct. Extending into east-central Mississippi from western Alabama, the hills are the most rugged topography in the Gulf Coastal Plain with local relief as much as 300 to 400 feet. The Tallahatta Formation (Claiborne Group) in this area contains highly indurated sand beds that are responsible for the rugged nature of the hills. Northward, the sands in the Tallahatta become less consolidated, and the hills gradually fade into more gentle cuestas.

The Sulphur and Nacogdoches Wolds are similar cuestas developed on Eocene sediments. The Sulphur Wold (fig. 3), in northeastern Texas and southwestern Arkansas, is formed on sand beds of the Wilcox Group. A highly dissected cuesta, it becomes less distinct westward into Texas. The Nacogdoches Wold is most prominent in east-central Texas and extends a short distance into west-central Louisiana. It owes its existence in large part to the high iron content of some sand beds in the Claiborne Group. They are cemented with iron silicate and are extremely resistant to erosion; the iron content is sufficient in places to be of ore quality. The cuesta is developed primarily on the Weches (Texas) and Cane River (Louisiana) Formations but is also on iron-cemented sands in the Reklaw Formation and Queen City Sand. The escarpment area of the cuesta is typically eroded to a hilly topography, and the dip slope is gently rolling.

In southwestern Alabama the Lime Hills (fig. 3) are a group of hills developed on the truncated surface of an anticline. The area is not large, about 20 by 50 miles, but is topographically rugged. Jackson Group beds in this area are limestone, and the indurated Claiborne Group sandstone that forms the Buhrstone Hills to the north was brought to the surface by the uplift. These two highly resistant rock types account for the uncommon ruggedness of the area. Westward across Mississippi, Louisiana, and Texas, the Jackson Group outcrop is predominantly clay. The Jackson Prairie, a gently rolling lowland, is developed on this extensive band of relatively nonresistant clays.

Oligocene Series

Outcropping strata of the Vicksburg Group (or Formation) comprise most or all of the exposed rocks of Oligocene age. They are lithologically similar to Jackson deposits and are included in parts of the Jackson Prairie terrain.

Miocene Series

The Bordas, Oakville, and Kisatchie Escarpments (fig. 3) merge to form an aligned series of scarps formed on lower Miocene deposits that extends across southern Texas into central Louisiana. The combined escarpment is quite pronounced and marks the southern border of the Jackson Prairie. It is also the beginning of the final descent of land surface to the sea. The Southern Pine Hills are formed on a corresponding cuestalike feature east of the Mississippi River. Some local black belts are developed on calcareous clays of the Fleming Formation in east Texas and southwestern Louisiana.

Pliocene Series

Pliocene deposits represented by the Citronelle Formation overlie Miocene sediments to help form the Southern Pine Hills (fig. 3). The Citronelle is sandy and gravelly; it is highly permeable and not readily erodable. Citronelle-Pleistocene relations are not adequately established, and what is mapped as Pleistocene terrace by some is shown as Pliocene Citronelle Formation by others.

Pleistocene Series

A succession of three to five terraces flank major stream valleys of the Gulf Coastal Plain and are attributed to depositional and erosional cycles associated with glacial activity during the Pleistocene Epoch. A mantle of loess as much as 100 feet thick blankets the bluff east of the Mississippi River and produces a distinctive rugged topography. The Loess Hills (fig. 3) extend in a band 5 to 15 miles wide southward from the Ohio River nearly to the Gulf of Mexico. Because of its peculiar erosional properties, the loess is incised by deep narrow stream valleys flanked by very steep slopes to nearly vertical cliffs. Crowleys Ridge is an erosional remnant that extends about 200 miles from southeastern Missouri into northeastern Arkansas. It rises 100 to 250 feet above the surrounding flood plain and ranges in width from about 3 miles in its southern part to nearly 12 miles in the northern part. Pleistocene gravel and loess commonly occur on its upper surface.

Holocene Series

Physiographic features associated with Holocene deposits are mostly of fluviatile origin and are the products of relatively recent erosion and deposition. The Mississippi River flood plain, delta, and deltaic islands, for example, are Holocene features as are the flood plains and deltaic plains of other major drainage systems in the Gulf Coastal Plain. Coastal lagoons, swamps, marshes, beaches, mudflats, and stranded beaches are all of recent development and undergo constant evolution in response to changes in current, migration of drainage systems, and wave action. Also susceptible to modification by wave and current action are the barrier bars and islands common to the coastline. Major storms periodically alter low-lying Holocene topography.

Some rounded eminences of low to moderate relief along the Texas and Louisiana coast are topographic expressions of salt domes. Their diameters are on the order of 1 mile, and relief generally is in tens of feet. Because of their topographic prominence in otherwise featureless terrain, they are commonly referred to as islands.

STRATIGRAPHY

Cenozoic deposits in the Gulf Coastal Plain range in age from Paleocene to Holocene and are both nonuniformly and incompletely differentiated. Although workers in the various states in the study area are in general overall agreement regarding stratigraphic correlations, some nomenclatural differences exist as well as differences in the degree to which some units have been subdivided (table 2). For example, an individual formation in one state may be identified in another state but consist of several members. Similar differences are especially true of groups and units whose grouping is based on their age. Differentiation within these larger units ranges from none to very detailed. Because of local facies changes, some stratigraphic interpretations based on outcrop study areas cannot be extended for significant distances into the subsurface. For similar reasons, some units are present only in the subsurface. The age of some Gulf Coastal Plain strata, primarily Oligocene and younger, if not in controversy is at least uncertain.

PALEOCENE SERIES

Paleocene deposits in the Gulf Coastal Plain overlie Upper Cretaceous rocks (pl. 4) and include sediments of the Midway Group (Smith, 1886) and part of the Wilcox Group (Crider and Johnson, 1906). The contact between the Midway Group and the underlying Upper Cretaceous strata is a major disconformity in much of the Gulf Coastal Plain. In some areas, however, a break in deposition is not apparent. In either case the change in faunal assemblages is drastic, many Mesozoic forms having become extinct. Some species survived in considerably modified form, and new species appeared. This hiatus marks the demise of the dinosaurs and the beginning of the rise of mammals.

Early work placed the top of the Midway stage within the Wilcox Group at the base of the *Ostrea thirsae* or *Ostrea multilirata* zone, which also marked the top of the Naheola Formation; Midway was used synonymously with Paleocene. Because the Naheola Formation was not recognized throughout the Gulf Coastal Plain, many workers placed the top of the Midway Group (and hence, the top of the Paleocene) at the top of the Porters Creek Clay or equivalent. Recent palynological studies by Frederiksen, Bybell, and others (1982); and Frederiksen, Gibson, and Bybell (1982) determined the presence of fossil spores of Paleocene age in sediments in the lower part of the Wilcox Group, and the U.S. Geological Survey now considers the top of the Paleocene Series to be within the Wilcox Group in most of the Gulf Coastal Plain (Gibson, 1982). For the purposes of this report, discussion of the Wilcox Group is included with that of the geologic units of the Eocene Series.

MIDWAY GROUP

The rocks of the Midway Group (pl. 5) are characterized by the most uniform lithology in the Gulf Coastal Plain. The lengthiest and most extensive marine encroachment of the entire study area resulted in deposition of hundreds to a few thousand feet of clay marked only at the top and bottom by a change in lithology, mostly transitional. The Midway crops out around the updip perimeter of the study area in a band that varies in width from less than 1 mile to about 20 miles; the widest parts of this band are in Mississippi and Alabama (pl. 5). The Midway rocks are covered by Quaternary alluvium at most places along the northwestern flank of the Mississippi embayment from the vicinity of Little Rock, Arkansas, to the southern tip of Illinois.

CLAYTON FORMATION AND EQUIVALENTS

The Clayton Formation (Langdon, 1891), called the Kincaid Formation (Gardner, 1933b) in Texas, is the basal Midway unit. It is present throughout the area and is divided into the Pine Barren Member (MacNeil, 1946) and McBryde Limestone Member (MacNeil, 1946) in southwestern Alabama. Marine in origin, the Clayton Formation is mostly composed of limestone, calcareous sand, and sandstone, which grade to marl and calcareous silts and clays downdip. It is generally less than 100 feet thick in the subsurface but is thinner in places due to nondeposition or erosion. Thicker sections of 100 to 200 feet occur in parts of southeastern Mississippi and southwestern Alabama; it has been suggested that these thick sections may be, at least in part, a facies of the Porters Creek Clay.

PORTERS CREEK CLAY AND EQUIVALENTS

The Porters Creek Clay (Safford, 1864), called the Wills Point Formation (Penrose, 1890; Plummer, 1927) in Texas, is present throughout the area and represents the bulk of the Midway Group. It ranges in thickness in the subsurface from a few hundred feet in the Mississippi embayment to more than 2,500 feet in southern Texas. It thins updip but can be several hundred feet thick at the outcrop. It also thins markedly over major uplifted tectonic structures. The Porters Creek is mostly a dark-gray to black, blocky, micaceous clay and may be arenaceous in places in and near outcrop areas where minor sand beds occur. In the northern part of the Mississippi embayment the Porters Creek includes some interbedded or thinly laminated fine sand and gray clay.

The top of the Porters Creek Clay is generally readily identifiable on electric logs as a fairly distinct contact between a massive uniform clay and sandy overlying sediments. However, in places the change is very gradational as the sediments become coarser upward in a transition zone that may be several tens to more than 100 feet thick.

The Tippah Sand Lentil (Lowe, 1915) is a member of the Porters Creek Clay in northern Mississippi. It is a fine-grained glauconitic sand, becoming coarser and more glauconitic in the upper part. It also locally contains ferruginous concretions or layers.

The Matthews Landing Marl Member (Smith, 1886) is the uppermost member of the Porters Creek Clay in southeastern Mississippi and Alabama. It is thin, generally less than 10 feet thick, and composed of sandy, glauconitic, fossiliferous marl containing a distinctive marine fauna. Northward in Mississippi it becomes a thin marl and eventually disappears in that direction. Where it does exist, it is a distinctive marker bed.

NAHEOLA FORMATION

The Naheola Formation (Smith, 1886) is recognized in southern Mississippi and Alabama. It is the uppermost stratigraphic unit of the Midway Group in that area and directly overlies the Porters Creek Clay. Lithologically, it is very similar to the overlying deposits of the Wilcox Group in its arenaceous-argillaceous-carbonaceous nature and is included in the Wilcox by many workers for that reason. It is as much as about 200 feet thick, and its upper surface is defined by the base of the *Ostrea thirsae* beds.

The Naheola Formation is divided into the Oak Hill Member (Toulmin and others, 1951) and the Coal Bluff Marl Member (Smith, 1886) in western Alabama. The Oak Hill Member is the lowermost and overlies the Porters Creek Clay. It generally consists of a thinly laminated fine sand and silty clay; in places a bed of lignite occurs at the top of the member and marks the contact with the overlying Coal Bluff Marl Member. The Coal Bluff Marl Member is composed of marine sand and clay, and includes a fossiliferous bed.

EOCENE SERIES

Eocene deposits in the Gulf Coastal Plain are represented by sediments of the Wilcox Group (Formation in Illinois and Kentucky), Claiborne Group, and Jackson Group (Formation in Kentucky, Missouri, and Tennessee). The base of the Eocene Series is variously placed within the Wilcox Group, at the top of the Naheola Formation, or at the top of the Porters Creek Clay, as previously discussed.

The top of the Eocene Series is stratigraphically placed at the top of deposits of the Jackson Group or Formation. Difficulty in identifying that contact on electric logs has caused many workers to lump the Jackson deposits with immediately overlying similar deposits of Oligocene age.

TABLE 2.—Correlation chart of Cenozoic

[Chart shows geologic names of Cenozoic units in the Gulf Coast as used by the U.S. Geological Survey. Horizontal alignment implies at least general correlation where exact and accommodating geologic-age boundaries.

ERATHEM	SYSTEM	SERIES	TEXAS: Southern	TEXAS: Southeastern and northeastern	LOUISIANA	ARKANSAS: Southern	ARKANSAS: Northeastern	MISSOURI	ILLINOIS
CENOZOIC	QUATERNARY	HOLOCENE PLEISTOCENE	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium, loess, and terrace deposits	Alluvium, loess, and terrace deposits	Alluvium and terrace deposits
	TERTIARY	PLIOCENE	Goliad Sand	Goliad Sand	Southwestern: Foley Formation Mamou Member Steep Gully Member Southeastern: Citronelle Formation				
		MIOCENE	Fleming Formation Oakville Sandstone	Fleming Formation	Fleming Formation Blounts Creek Member Castor Creek Member Williamson Creek Member Dough Hills Member Carnahan Bayou Member Lena Member				
		OLIGOCENE	Catahoula Tuff Frio Clay	Catahoula Sandstone	Catahoula Sandstone Vicksburg Formation				
		EOCENE	Jackson Group: Whitsett Formation Manning Clay Wellborn Sandstone Caddell Formation	Jackson Group: Whitsett Formation Manning Clay Wellborn Sandstone Caddell Formation	Jackson Group: Yazoo Formation Moodys Branch Marl	Jackson Group: Undifferentiated	Jackson Group: Undifferentiated	Jackson Formation	
		EOCENE	Claiborne Group: Yegua Formation Laredo Formation El Pico Clay Bigford Formation Carrizo Sand	Claiborne Group: Yegua Formation Cook Mountain Formation Sparta Sand Weches Formation Queen City Sand Reklaw Formation Carrizo Sand	Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Cane River Formation Carrizo Sand	Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Cane River Formation Carrizo Sand	Claiborne Group: Cockfield Formation Cook Mountain Formation Memphis Sand	Claiborne Group: Cockfield(?) Formation Cook Mountain(?) Formation Memphis Sand	
		EOCENE / PALEOCENE	Wilcox Group: Undifferentiated	Wilcox Group: Undifferentiated	Wilcox Group: Undifferentiated Dolet Hills Formation Naborton Formation	Wilcox Group: Undifferentiated	Wilcox Group: Flour Island Formation Fort Pillow Sand Old Breastworks Formation	Wilcox Group: Flour Island Formation Fort Pillow Sand Old Breastworks(?) Formation	Wilcox Formation No Wilcox deposits identified as being of Paleocene age.
		PALEOCENE	Midway Group: Wills Point Formation Kincaid Formation	Midway Group: Wills Point Formation Kincaid Formation	Midway Group: Porters Creek Clay Clayton Formation	Midway Group: Porters Creek Clay Clayton Formation	Midway Group: Porters Creek Clay Clayton Formation	Midway Group: Porters Creek Clay Clayton Formation	Midway Group: Porters Creek Clay Clayton Formation

units in the Gulf Coastal Plain

equivalency is not obvious. Vertical space occupied by a unit has no relation to any physical parameter of the unit but was dictated by space requirements for listing units Modified from Hosman (1988)]

KENTUCKY	TENNESSEE	MISSISSIPPI — Northern	MISSISSIPPI — Central and southern	ALABAMA	FLORIDA
Alluvium, terrace, and loess deposits	Alluvium, terrace, and loess deposits	Alluvium, terrace, and loess deposits	Alluvium, terrace, and loess deposits	Alluvium and terrace deposits	Alluvium and terrace deposits
			Citronelle Formation Graham Ferry Formation	Citronelle Formation	Citronelle Formation
			Pascagoula Formation Fort Adams Member Homochitto Member Hattiesburg Clay	Undifferentiated	Pensacola Clay Escambia Sand Member Tampa Limestone
			Catahoula Sandstone Tatum Limestone Member Paynes Hammock Formation Chickasawhay Limestone Vicksburg Group: Bucatunna Formation Byram Formation Glendon Formation Marianna Formation and Mint Spring Formation Forest Hill and Red Bluff Formations	Catahoula Sandstone Tatum Limestone Member Paynes Hammock Formation Chickasawhay Limestone Vicksburg Group: Bucatunna Formation Byram Formation Glendon Formation Marianna Formation and Mint Spring Formation Red Bluff, Forest Hill, and Bumpnose Formations	Catahoula Sandstone Tatum Limestone Member Chickasawhay Limestone Bucatunna Formation Byram Formation Marianna Formation Bumpnose Formation
Jackson Formation	Jackson Formation	Jackson Group: Undifferentiated	Jackson Group: Yazoo Formation Shubuta Member Pachuta Marl Member Cocoa Sand Member North Twistwood Creek Member Moodys Branch Marl	Jackson Group: Yazoo Formation Shubuta Member Pachuta Marl Member Cocoa Sand Member North Twistwood Creek Member Moodys Branch Marl	Ocala Limestone Moodys Branch Formation
Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Tallahatta Formation	Claiborne Group: Cockfield Formation Cook Mountain Formation Memphis Sand	Claiborne Group: Cockfield Formation Cook Mountain Formation Sparta Sand Zilpha Clay Winona Sand Tallahatta Formation	Claiborne Group: Cockfield Formation Cook Mountain Formation Gordon Creek Shale Member Potterchitto Sand Member Archusa Marl Member Sparta Sand Zilpha Clay Winona Sand Tallahatta Formation Neshoba Sand Member Basic City Shale Member Meridian Sand Member	Claiborne Group: Gosport Sand Lisbon Formation Tallahatta Formation Meridian Sand Member	Claiborne Group: Lisbon Formation Tallahatta Formation
Wilcox Formation No Wilcox deposits *identified as being* of Paleccene age	Wilcox Group: Flour Island Formation Fort Pillow Sand Old Breastworks Formation	Wilcox Group: Undifferentiated	Wilcox Group: Hatchetigbee Formation Bashi Formation Tuscahoma Formation Nanafalia Formation Fearn Springs Member	Wilcox Group: Hatchetigbee Formation Bashi Formation Tuscahoma Sand Bells Landing Marl Member Greggs Landing Marl Member Nanafalia Formation Grampian Hills Member "Middle" member Gravel Creek Sand Member	Wilcox Group: Hatchetigbee Formation Bashi Formation Undifferentiated
Midway Group: Porters Creek Clay Clayton Formation	Midway Group: Porters Creek Clay Clayton Formation	Midway Group: Porters Creek Clay Tippah Sand Lentil Clayton Formation	Midway Group: Naheola Formation Porters Creek Clay Matthews Landing Marl Member Clayton Formation	Midway Group: Naheola Formation Coal Bluff Marl Member Oak Hill Member Porters Creek Clay Matthews Landing Marl Member Clayton Formation McBryde Limestone Member Pine Barren Member	Midway Group: Undifferentiated

WILCOX GROUP (FORMATION)

The Wilcox Group (Crider and Johnson, 1906) (pl. 6), called Wilcox Formation in Illinois and Kentucky, is undifferentiated in Texas and parts of Arkansas, Louisiana, and Mississippi where it lacks regionally mappable units. It has a maximum thickness of more than 1,200 feet in the Mississippi embayment and becomes thousands of feet thick gulfward in most of the southern part of the area. Wilcox strata are typically heterogeneous and consist mostly of arenaceous-argillaceous deposits that are carbonaceous to varying degrees. Lignite is common, in fact the Wilcox section was called the Lignitic by early workers. Much of the Wilcox is deltaic in origin, and the strata become more marine gulfward. The deltaic beds of the Wilcox Group are composed of thinly laminated very fine sands, silts, and clays. Other Wilcox deposits include river sands, lignitic sandy clays, lagoonal and lacustrine clays, and discontinuous beds of lignite. The deposits are complexly interbedded and appear extremely discontinuous in any straight-line transect. Continuity in other directions or circuitously is doubtless present to varying degrees and distances, as would be expected with continental deposition. Wilcox Group deposits, as noted previously, are of late Paleocene to Eocene age.

The base of the Wilcox Group sediments locally may form a gradational contact with the underlying Midway Group, but the lithologies of the two are distinctly different. The Wilcox is characterized by the coarser sandy materials of both deltaic and nonmarine origin, whereas the Porters Creek Clay is a typical marine clay. On some geophysical logs the contact between the two appears transitional with no detectable break in deposition. Where the basal sand of the overlying Claiborne Group is present, the upper contact of the Wilcox Group can be quite sharp. The thinly laminated sandy clays and fine sands of the Wilcox sharply contrast with the coarser gray sands of the Claiborne. The contact is unconformable, and the Claiborne was deposited on an eroded Wilcox surface.

The Wilcox Group crops out in a band that parallels the coastline and the margins of the Mississippi embayment. The outcrop band ranges in width from less than 1 mile to as much as 25 miles in Texas in the western part of the area to as much as 30 miles in Mississippi in the eastern part (pl. 6). The outcrop is covered by Quaternary alluvial deposits at most places along the northwestern flank of the Mississippi embayment from the vicinity of Little Rock, Arkansas, to the southern tip of Illinois. The Wilcox crops out and subcrops in a roughly circular area of several thousand square miles overlying the Sabine uplift (pl. 6). It also crops out in a small, elliptically shaped area in southwestern Alabama as a result of local structural deformation that brought the Wilcox to the surface where it is surrounded by younger sediments.

NANAFALIA FORMATION

The Nanafalia Formation (Smith, 1886) of Paleocene to early Eocene age is recognized by the U.S. Geological Survey as the basal formation of the Wilcox Group in Alabama and central and southern Mississippi. It contains the *Ostrea thirsae* beds that mark the beginning of the Eocene Series. The Nanafalia generally consists of sand, marl, and clay and varying amounts of kaolinitic and bauxitic material. In Alabama it is made up of the Gravel Creek Sand Member, the unnamed middle member, and the Grampian Hills Member.

The Gravel Creek Sand Member (LaMoreaux and Toulmin, 1959) is composed of crossbedded medium- to coarse-grained sand with thin interbeds of fine gravel. The middle member, primarily glauconitic sands and sandy clays, bears the *Ostrea thirsae* in abundance. The overlying Grampian Hills Member (LaMoreaux and Toulmin, 1959) also contains *Ostrea thirsae* but in lesser quantity than the middle member. The Grampian Hills Member is predominantly gray clay with beds of glauconitic sand and sandstone. Locally, hard, siliceously indurated rock has been formed.

The Fearn Springs Member (Mellen, 1939) of the Nanafalia Formation in central and southern Mississippi is equivalent to the Gravel Creek Sand Member of Alabama. It includes a basal coarse sand and an upper laminated fine sand and gray clay.

TUSCAHOMA SAND (FORMATION)

The Tuscahoma Sand (Smith and others, 1894), called Tuscahoma Formation in Mississippi, is a heterogeneous section of arenaceous-argillaceous sediments several hundred feet thick that probably represents the bulk of the Wilcox Group deposits in Alabama and central and southern Mississippi. Equivalent sediments in western Florida are undifferentiated. The Tuscahoma is of late Paleocene to Eocene age. Composed of discontinuous and lenticular beds of fine sand, gray clay, and laminated fine sand and clay, it is also very lignitic. The lignite occurs both bedded and disseminated. The lower part of the Tuscahoma Sand becomes glauconitic in the western part of Alabama where two members are recognized, the Greggs Landing Marl Member (Smith, 1886) and the Bells Landing Marl Member (Smith, 1883). These highly fossiliferous marine units disappear northwestward in Mississippi.

BASHI FORMATION

Formerly the Bashi Marl Member (Heilprin, 1882) of the overlying Hatchetigbee Formation, the Bashi Formation overlies the Tuscahoma Sand (Formation) in Alabama, western Florida, and central and southern Mississippi. It is a fossiliferous marine unit of Eocene age containing glauconitic calcareous sands with accretionary structures.

HATCHETIGBEE FORMATION

The Hatchetigbee Formation of Eocene age (Smith, 1886) is the uppermost rock unit of the Wilcox Group in Alabama, western Florida, and central and southern Mississippi. It is composed primarily of interbedded fine to medium sands and finely micaceous silts and clays. The sands and clays are lignitic, and lignite beds are also present.

OLD BREASTWORKS FORMATION

The Old Breastworks Formation, Fort Pillow Sand, and Flour Island Formation (Moore and Brown, 1969) were defined on the basis of sample and electric-log analysis of a test well drilled in western Tennessee near the axis of the Mississippi embayment. The three units were delineated in an area where the Wilcox Group had hitherto been undifferentiated. Correlations have been extended into Missouri and northeastern Arkansas, where they are also recognized by the U.S. Geological Survey (Mesko, 1988).

The lowermost unit, the Old Breastworks Formation of Paleocene age, is a light-olive-gray, micaceous clayey silt that is typically lignitic. Its contact with the underlying Porters Creek Clay is gradational and is difficult to determine on electric logs. The Old Breastworks is a clayey, silty, downdip facies of the lower part of the Wilcox Group and is present primarily along the axis of the Mississippi embayment. It changes to a sand facies updip and becomes part of the overlying and overlapping Fort Pillow Sand.

FORT PILLOW SAND

In the axial part of the upper Mississippi embayment the Fort Pillow Sand of Paleocene to early Eocene age occupies roughly the middle one-third of the Wilcox Group. It is a fine to coarse sand that generally thickens downdip toward the axis of the embayment (Parks and Carmichael, 1989). Some local thickening, mostly in the lower part, occurs in the updip facies. The Fort Pillow Sand may be equivalent, at least in part, to the Nanafalia Formation.

FLOUR ISLAND FORMATION

The Flour Island Formation of Eocene age is the uppermost unit of the Wilcox Group in its area of occurrence and is mostly a lignitic silt, thinly interbedded with clay and fine sand. It is glauconitic and slightly calcareous in the lower part (Moore and Brown, 1969).

NABORTON FORMATION

The only differentiation of the Wilcox Group in Louisiana recognized by the U.S. Geological Survey is in the northwestern part of the State where the lower part of the Wilcox is divided into two formations. These are the Naborton and the Dolet Hills Formations (Murray, 1948), which are Paleocene in age but are placed in the Wilcox on the basis of lithology. They are probably equivalent in part to the Naheola Formation. The Naborton Formation is the basal unit in the Wilcox in this area where it also crops out; its maximum thickness is about 200 feet. It is calcareous and is composed chiefly of thinly laminated, fine to medium sands, clays, and lignitic silts.

DOLET HILLS FORMATION

The Dolet Hills Formation has a maximum thickness of about 125 feet. It contains massive fine to medium sands and lesser amounts of clay and lignite. It is immediately overlain by undifferentiated Wilcox sands and clays, also of Paleocene age.

BERGER AND SALINE FORMATIONS AND DETONTI SAND

The Wilcox Group in the Arkansas bauxite area, a mining site immediately southwest of Little Rock, has been divided into three Eocene units: the Berger Formation, Saline Formation, and Detonti Sand (Gordon and others, 1958). These authors felt that perhaps only the Berger Formation was Wilcox and the other two units should more appropriately be assigned to the Claiborne Group. However, they treated all three as Wilcox to avoid conflict with the Arkansas geologic map. Subsequent mapping

(Hosman, 1982) agreed with their interpretation that only the Berger Formation belongs in the Wilcox Group. The Berger Formation is chiefly lignitic sand and clay with bauxitic and kaolinitic interbeds. The Berger-Saline-Detonti units are not treated further in this report nor included in table 2 because of their very limited areal extent and indefinite stratigraphic classification.

CLAIBORNE GROUP

Except in the southern tip of Illinois, strata of the Claiborne Group (Conrad, 1848) are present throughout the Gulf Coastal Plain. They crop out in all of the other States in the study area; the subcrops are overlain by Quaternary alluvial deposits in Missouri and Arkansas north of the Arkansas River except where exposed in places at Crowleys Ridge.

The Claiborne Group in the Gulf Coastal Plain is widely thought of as a classic example of strata produced by alternating marine-nonmarine depositional cycles. Extensive marine clays with subordinate amounts of marls and glauconitic sands, rich in fauna, provide a basis for dividing the Claiborne into major units that are reasonably identifiable and mappable on a regional scale. Intervening continental deposits generally consist of sand beds of varying thickness and continuity with discontinuous lenses of interbedded clay. Although differences in nomenclature remain, state-to-state correlations within the Claiborne are satisfactorily established (table 2).

The Carrizo Sand of Texas, Arkansas, and Louisiana is the same unit as the Meridian Sand Member of the Tallahatta Formation of Mississippi and Alabama (Hosman, 1962; Payne, 1975). The remainder of the Tallahatta plus the Winona Sand and the Zilpha Clay are equivalent to the Cane River Formation of Louisiana and Arkansas and the Reklaw Formation, Queen City Sand, and Weches Formation of southeastern and northeastern Texas (Payne, 1972) and the Bigford Formation and El Pico Clay of southern Texas (Eargle, 1968). The Sparta Sand is recognized in southeastern and northeastern Texas (Payne, 1968), southern Arkansas, Louisiana, Kentucky, and Mississippi (Hosman and others, 1968; Davis and others, 1973), and is called the Lisbon Formation in Alabama and Florida. In southern Texas the Sparta Sand and overlying Cook Mountain Formation combine to form the Laredo Formation (Eargle, 1968). Except for Alabama and Florida, the Cook Mountain Formation is recognized throughout the rest of the area. The Cockfield Formation is recognized in all states except in Texas, where it is called the Yegua Formation (Payne, 1970) and in Alabama, where equivalent rocks are called the Gosport Sand (not identified in Florida). In Tennessee, Missouri, and northeastern Arkansas the Memphis Sand occupies the entire Claiborne section from the top of the Wilcox Group to the base of the Cook Mountain Formation (Hosman and others, 1968).

TALLAHATTA FORMATION

In Mississippi, Alabama, Kentucky, and Florida the Tallahatta Formation (Dall, 1898) is the basal formation of the Claiborne Group. It is equivalent to the Carrizo Sand and the lower part of the Cane River Formation of Louisiana and Arkansas and to the Carrizo Sand, Reklaw Formation, and Queen City Sand of Texas. In central and southern Mississippi the Tallahatta Formation contains the Meridian Sand Member, Basic City Shale Member, and the Neshoba Sand Member. In Alabama only the Meridian Sand Member is recognized.

The Meridian Sand Member (Lowe, 1933) (pl. 7) of the Tallahatta Formation was deposited on an eroded Wilcox surface and varies in thickness. It may be thin or missing or as much as a few hundred feet thick, depending in some degree upon the topography of the underlying Wilcox. The thickness probably averages about 100 feet. The Meridian typically is crossbedded and composed of fine to very coarse quartz sand. Its contact with the underlying deposits is marked by the carbonaceous content of the Wilcox strata. The Meridian Sand Member is continuous with and the direct equivalent of the Carrizo Sand of Arkansas, Louisiana, and Texas.

In central and southern Mississippi the Basic City Shale Member (Brown and Adams, 1943) of the Tallahatta Formation overlies the Meridian Sand Member. It comprises beds of sparsely fossiliferous light-colored claystone, siltstone, and shale. Very hard and resistant layers of orthoquartzite (buhrstone) commonly form ledges, which make the unit distinctive and readily recognizable in the field. The Basic City becomes sandy in northwestern Mississippi and is not recognized in that part of the State.

The Neshoba Sand Member (Thomas, 1942) of the Tallahatta Formation is about 50 feet thick in central Mississippi and thickens northward. It is composed primarily of fine micaceous quartz sand with some gray clay. It is locally glauconitic, but is not fossiliferous. The Neshoba Sand Member and underlying Basic City Shale Member are equivalent to the lower part of the Cane River Formation of Louisiana and Arkansas and, in part, to the Queen City Sand and underlying Reklaw Formation of Texas.

CARRIZO SAND

The Carrizo Sand (Owen, 1889) (pl. 7), equivalent to the Meridian Sand Member of the Tallahatta Formation, is the basal Claiborne unit in Texas, Louisiana, and Arkansas. It underlies the Reklaw Formation in eastern Texas, the Bigford Formation in southern Texas, and the Cane River Formation in Louisiana and Arkansas. In Arkansas it extends as far northward as the central part of the Mississippi embayment, beyond which it becomes the basal part of a larger unit, the Memphis Sand. It crops out in a narrow band adjacent to the Wilcox Group outcrop in the southwestern part of the study area and around the western side of the Sabine uplift. The Carrizo was deposited on an uneven eroded Wilcox surface and thus varies in thickness; it is absent in places that were probably topographic highs. The Carrizo is mostly 100 to 300 feet thick in the Mississippi embayment but thickens to more than 1,200 feet in south Texas. It is distinctly different from Wilcox sands in that it is much coarser and is not lignitic. The sand is light gray to brownish gray, fine to coarse, and micaceous. In places the Carrizo is ferruginous and produces a bright color upon weathering, as in outcrops or derived soils. The upper strata may contain thin light-gray or yellowish clay lentils. The Carrizo may be very distinctive in outcrop due to its generally massive nature and conspicuous crossbedding.

WINONA SAND

In Mississippi, where it ranges in thickness from about 10 to 50 feet, the Winona Sand (Lowe, 1919) overlies the Tallahatta Formation. It is composed of sand and clay and is highly glauconitic and fossiliferous. Northward, it changes to a nonmarine sand facies and is not differentiated.

ZILPHA CLAY

The Zilpha Clay (Thomas, 1942) is recognized only in Mississippi and overlies the Winona Sand. It is a dark-gray marine clay, is only slightly fossiliferous, and is carbonaceous and glauconitic. The section from the Basic City Shale Member through the Zilpha Clay is equivalent to the Cane River Formation of Louisiana and Arkansas and to the Reklaw-Queen City-Weches sequence of Texas. The Zilpha Clay is as thick as 75 feet in outcrop and thickens in the subsurface.

CANE RIVER FORMATION

The Cane River Formation (Spooner, 1926) (pl. 8) of Louisiana and Arkansas is predominantly a marine clay that is several hundred feet thick in the subsurface. It is glauconitic and calcareous in part. It also contains sandy clay, marl, and thin beds of fine sand. The upper clay can be carbonaceous. In southwestern Arkansas the middle part of the Cane River is sandy and is probably equivalent to the Queen City Sand in adjacent parts of northeastern Texas. The Cane River Formation changes to a sand facies northward in the central part of the Mississippi embayment at about the 35th parallel and is no longer present beyond that point.

REKLAW FORMATION

The Reklaw Formation (Wendlandt and Knebel, 1929) conformably overlies the Carrizo Sand in northeastern and southeastern Texas. In places the contact is distinct but in others appears gradational and difficult to distinguish. The Reklaw Formation is composed largely of a sequence of dark stratified shales and sands. The lower part of the Reklaw is a glauconitic sand that is fossiliferous in many places. The glauconitic beds may be associated with thin limonitic lenses. The Reklaw is partly nonmarine in areas where the upper beds are ferruginous lignitic clay. It is equivalent to the lower part of the Cane River Formation and probably to the Basic City Shale Member of the Tallahatta Formation.

QUEEN CITY SAND

In southeastern and northeastern Texas the Queen City Sand (Kennedy, 1892) overlies the Reklaw Formation and is equivalent to the Neshoba Sand Member and the Winona Sand of Mississippi. It has no recognized direct correlatives in Louisiana and Arkansas, but the middle part of the Cane River Formation in southwestern Arkansas contains a sandy section that resembles the Queen City. The Queen City is predominantly light-gray to grayish-brown, very fine to medium quartz sand that is typically crossbedded and lenticular. It contains interbeds of dark carbonaceous shale, silt, and impure lignite. Glauconite occurs in places, but whether it is primary or redeposited has not been determined. Southwestward, in the Rio Grande embayment, the Queen City Sand loses its identity in a facies change.

WECHES FORMATION

The Weches Formation (Ellisor, 1929) overlies the Queen City Sand and is widely referred to as a greensand because of its predominantly glauconitic content. The dark-green sands that make up the bulk of the unit are highly crossbedded, lenticular, and interbedded with the thin beds of dark-gray to black glauconitic clay and shale. The Weches is highly fossiliferous and easily distinguished from overlying and underlying formations. The bedded glauconite, while not pure, is generally free of sand. Impurities are mostly argillaceous materials and fossil shells. Leaching of the bedded glauconite deposits has concentrated the iron in places so as to produce ore in sufficient quality and quantity to be of economic value. Much of the ore occurs as outliers, capping hills, or capping mesas where it either forms the surface or is covered by a few feet of Sparta Sand. Mining has removed the Weches so completely in some places that accuracy of geologic maps is affected.

BIGFORD FORMATION

In extreme southern Texas the Bigford Formation (Trowbridge, 1923a, 1923b; and Stephenson, 1952) overlies the Carrizo Sand and underlies the El Pico Clay. It is a sandier facies of the Reklaw Formation with which it interfingers on the east flank of the Rio Grande embayment and is a direct equivalent. The Bigford consists of interbedded continental and palustrine sands and lignite and thin strata of brown and gray fossiliferous and gypsiferous marine clays and silts. It also contains cannel coal beds.

EL PICO CLAY

The El Pico Clay (Eargle, 1968) is present only in extreme southern Texas and represents a facies equivalent of the section that included the Queen City Sand and the Weches Formation to the northeast. It contains calcareous light-gray to light-greenish-gray claystone with interbeds of gray sandstone. The sand contains biotite, is glauconitic in places, and commonly contains abundant plant fossils. The El Pico, with the underlying Bigford Formation, has been the primary source of cannel coal for several large mines.

SPARTA SAND

One of the most widely recognized geologic units in the Gulf Coastal Plain, the Sparta Sand (Vaughn, 1895; restricted by Spooner, 1926) (pl. 9) is identified by that name in most of the area. It extends as far northward as the underlying Cane River Formation, that is, to the central part of the Mississippi embayment. Beyond that limit, the Sparta is a part of a larger unit, the Memphis Sand, a stratigraphic unit that includes the Sparta Sand and all underlying units to the top of the Wilcox Group (table 2).

The Sparta Sand is composed mostly of very fine to medium unconsolidated quartz sand that is sufficiently ferruginous in places to form limonitic orthoquartzite ledges, generally in the lower part of the unit. The upper part is glauconitic in places. The sand is commonly laminated or crossbedded. It is primarily beach and fluviatile sand with subordinate beds of sandy clay and clay. The clay is light gray and chocolate colored and may be carbonaceous. The Sparta ranges in thickness from less than 100 feet in places near the outcrop to more than 1,000 feet near the axis in the southern part of the Mississippi embayment. Lignite and other organic material are common in the Sparta. With the exception of some plant remains associated with the clay beds, the Sparta is not particularly fossiliferous.

COOK MOUNTAIN FORMATION

The Cook Mountain Formation (Kennedy, 1892) (pl. 10) is a predominantly marine deposit that is present throughout most of the study area. It is generally less than 200 feet thick in the Mississippi embayment but thickens to more than 900 feet in southern Louisiana and southern Texas. Its relation to overlying and underlying units is somewhat gradational in places. In central and southern Mississippi outcropping lithofacies have been divided (Thomas, 1942) into the Archusa Marl Member, the Potterchitto Sand Member, and the Gordon Creek Shale Member. This subdivision cannot be extended into the subsurface where the Cook Mountain generally is composed of two lithologic units in the central and eastern part of the Gulf Coastal Plain. The lower part is glauconitic, calcareous, fossiliferous, sandy marl or limestone, and the upper part is sandy carbonaceous clay or shale, which is locally glauconitic. To the west, in Texas, it is mostly clay, shale, and sandy shale, with lesser amounts of sand, glauconite, limestone, and ferruginous concretions. The clays are bluish gray to black, colloidal, and contain calcareous layers. The Cook Mountain in southern Texas contains a larger proportion of sand and sandy clays. The glauconite is disseminated throughout the formation rather than in individual beds and may be redeposited in part. An interesting type of ferruginous concretion (Burt, 1932) found in the Cook Mountain Formation of south Texas has a core containing a fossil crab. The concretions average a little more than 2 inches in diameter and occur in the middle part of the formation. The Cook Mountain thickens downdip as the clay facies gradually becomes the predominant lithologic type.

LISBON FORMATION

In southern Alabama and the panhandle of Florida the Lisbon Formation (Aldrich, 1886) is equivalent to the Winona Sand, Zilpha Clay, Sparta Sand, and Cook Mountain Formation of Mississippi. In the outcrop the Lisbon Formation is composed of fossiliferous glauconitic calcareous sand and sandy limestone. In the subsurface it contains interbedded calcareous sand and clay and minor limestone beds that are partly fossiliferous and glauconitic. The Lisbon Formation becomes more calcareous gulfward.

LAREDO FORMATION

The Laredo Formation (Gardner, 1938) of south Texas, equivalent to the Sparta Sand and the Cook Mountain Formation, is considerably sandier than are Cook Mountain beds to the northeast, where the equivalent section is chiefly clay. The Laredo Formation crops out for about 80 miles along the Rio Grande downstream from Laredo, as the course of the river is nearly parallel to the strike of the formation. The Laredo consists of thick ferruginous sandstones and glauconitic sands at the top and bottom of the formation, separated by a middle clay section. The unit is highly fossiliferous and brightly colored and distinctive in exposures.

COCKFIELD FORMATION

The Cockfield Formation (Vaughn, 1895) (pl. 11) or its direct equivalents, the Yegua Formation of Texas and the Gosport Sand of Alabama, is present throughout the Gulf Coastal Plain except for the southern tip of Illinois and the panhandle of western Florida. Lithologically, it is very similar to deposits of the Wilcox Group and was deposited under similar conditions. It is composed of discontinuous and lenticular beds of lignitic to carbonaceous, fine to medium quartz sand, silt, and clay and is generally sandier in the lower part. The Cockfield Formation is of nonmarine origin and represents the youngest continental deposits of the Eocene Series in the Gulf Coastal Plain.

GOSPORT SAND

The Gosport Sand (Smith, 1907) of southern Alabama is famous for its fossil content; in fact, it has been described (Murray, 1961) as "a bed of fossils with interstitial coarse sand, glauconite, and clay; from place to place interbedded dark carbonaceous clays and fine sands are present." It is correlative with the Cockfield Formation, with which it interfingers in the vicinity of the Alabama-Mississippi State line.

YEGUA FORMATION

The Texas equivalent of the Cockfield Formation and Gosport Sand, the Yegua Formation (Dumble, 1892) (pl. 11), is present along the entire Gulf Coastal Plain of Texas where it has a maximum thickness of more than 1,800 feet. The Yegua Formation is composed predominantly of massive, laminated, and crossbedded deposits of fine to medium sand. It also contains sandy clays and clays; dark-chocolate-brown clay is more common in the lower part of the unit, and light gray and greenish-gray clay is common in the upper part. Thin lignite beds and glauconitic sands are present in places, as are ferruginous and calcareous concretions.

JACKSON GROUP (FORMATION)

Deposits or equivalents of the Jackson Group (Conrad, 1856) (pl. 12), called Jackson Formation in Missouri, Kentucky, and Tennessee, are present throughout the Gulf Coastal Plain, except for the southern tip of Illinois. In the panhandle of western Florida equivalent sediments are called the Moody's Branch Formation and the Ocala Limestone. The Jackson sea was the last marine inundation of the Coastal Plain to occupy the Mississippi embayment, and most Jackson Group sediments are of marine origin. Some nonmarine beds are present in the central and northern parts of the Mississippi embayment. Relations with underlying deposits are both conformable and disconformable. Disconnected erosional remnants are all that remain of Jackson Group deposits north of the approximate latitude of the Arkansas-Louisiana State Line, and an accurate estimation of the extent of the Jackson sea would be difficult to make. South of the Jackson outliers, the Jackson deposits crop out in a band about 2 to 50 miles wide that roughly parallels the coastline from the Rio Grande to southwestern Alabama.

The Jackson Group is not differentiated in Arkansas and northern Mississippi (table 2). In Missouri, Kentucky, and Tennessee these deposits are recognized by the U.S. Geological Survey as the Jackson Formation and are not further subdivided.

Although the Jackson deposits are generally thought of as being marine in nature, some updip nonmarine clastic facies exist in the Desha basin and northern part of the Mississippi embayment. As subsidence in the Desha basin and the northern part of the Mississippi embayment gradually ceased, these areas were no longer fully open to the sea. Lacustrine, palustrine, and lagoonal environments provided the setting for the deposition of near-marine and nonmarine facies as evidenced by interbedded and crossbedded silts, silty and argillaceous sands, fine sands, and some thin layers of lignite. The sea has not reentered the Mississippi embayment since the Desha basin filled with sediment and emerged as elevated land surface subject to erosion.

Marine facies of the Jackson Group (Formation) sediments in the Desha basin and elsewhere have varying lithologies. In the western part of the Gulf Coastal Plain they are more arenaceous and contain pyroclastic material as a result of the beginning of a period of volcanic activity to the west and northwest. The Jackson sediments conformably overlie the Yegua Formation deposits and typically consist of shallow-water marine and beach sands, clays and tuffaceous clays, and tuffs. The sands are fine to medium and thin bedded with lentils of coarse, well-rounded, and polished sand and are slightly fossiliferous in places. To the east, in the central part of the Gulf Coastal Plain, the Jackson becomes more fossiliferous and argillaceous as deeper water clays dominate the lithology. The relation of the Jackson to underlying deposits is disconformable, with glauconitic sand and sandy marl at the base of the Jackson deposits. The clay is predominantly dark gray to blue and may be calcareous to varying degrees. The calcareous content of the Jackson sediments increases eastward as marls and soft limestones become the predominant lithologies. It is in the eastern part of the Gulf Coastal Plain (Mississippi and Alabama) that the Jackson Group has been the most subdivided.

MOODYS BRANCH MARL (FORMATION)

The basal unit of the Jackson Group in Louisiana, Mississippi, and Alabama, the Moodys Branch Marl (Meyer, 1885; Lowe, 1915), is called the Moodys Branch Formation in the panhandle area of western Florida where the Jackson Group is not recognized and the Moodys Branch disconformably overlies Claiborne Group beds. The Moodys Branch is a highly fossiliferous, glauconitic, sandy marl that becomes less sandy and more calcareous upward. In places it contains thin interbeds of indurated marl or impure limestone that form ledges in outcrop.

YAZOO FORMATION

The Yazoo Formation (Lowe, 1915) is the uppermost, primarily argillaceous, unit of the Jackson Group in Louisiana, Mississippi, and Alabama. It is subdivided into four members in Mississippi and Alabama (Murray, 1947). The lowest member, the North Twistwood Creek Member (originally North Creek Clay), is composed of bluish marl and calcareous clay that weathers into nodular caliche. The Cocoa Sand Member (Cushman, 1925) overlies the North Twistwood Creek Member and consists of a fine yellow sand with soft, white, calcareous and large hard, yellow, sandy marl inclusions. The Pachuta Marl Member of eastern Mississippi and western Alabama contains light-gray to white, partly indurated glauconitic fossiliferous marl; white, chalky, irregularly indurated marlstone; and yellow, sandy, hard limestone with prints of fossils. The uppermost member of the Yazoo Formation, the Shubuta Member, consists of light-greenish-gray to white, highly calcareous clay and contains small, white, calcareous concretions.

OCALA LIMESTONE

The Ocala Limestone (Dall and Harris, 1892) overlies the Moodys Branch Formation in the western panhandle of Florida. It is equivalent to and interfingers with the Yazoo Formation near the Alabama-Mississippi State Line. The Yazoo represents the argillaceous facies of Jackson Group deposition in that part of the Coastal Plain, and the Ocala is its calcareous equivalent. It is chiefly composed of friable limestone and marly limestone. The Ocala Limestone is present throughout almost the entire State of Florida, but the western panhandle is the beginning of an increasingly argillaceous facies to the west.

WHITE BLUFF FORMATION

In southeastern Arkansas where the Jackson Group has been differentiated into two formations (not recognized by the U.S. Geological Survey and not shown in table 2), the basal unit is the White Bluff Formation, and the overlying and interfingering unit is the Redfield Formation (Wilbert, 1953). The White Bluff Formation has been subdivided into three members, the Caney Point Marl, Pastoria Sand, and Rison Clay Members. The various rock units of the Jackson Group in southeastern Arkansas, at least in part, are facies of one another and do not necessarily appear in an orderly vertical sequence. The Desha basin was the controlling influence over the Jackson Group depositional environments as the sea invaded and regressed. During the invasion of the Jackson sea, the calcareous Caney Point facies was deposited in the southern part of the basin area while the clastic Pastoria facies was being deposited in the northern part. As the sea retreated, the Rison Clay facies was deposited in a lagoonal or near-marine environment while the nonmarine Redfield Formation facies developed to the north. The Caney Point Marl Member both interfingers with and underlies the Pastoria Sand Member in a typical offlap relationship. The Caney Point Marl Member is a highly fossiliferous calcareous glauconitic clay that resembles the Moodys Branch Marl of Louisiana and Mississippi. It is limited to the lower part of the White Bluff Formation. The Pastoria Sand Member is a dark-gray argillaceous sand that is carbonaceous and contains thin glauconite stringers in the lower part. It is coextensive with the White Bluff Formation in the updip reaches of its occurrence. The Rison Clay Member is limited to the upper part of the White Bluff Formation and is composed predominantly of thin-bedded silty clay and blocky clay beds with thin, discontinuous concentrations of molluscan fossils scattered randomly within the unit. Lignite fragments and fossilized leaves occur locally.

REDFIELD FORMATION

The Redfield Formation is a nonmarine deposit that both overlies and interfingers with the White Bluff Formation. From north to south it successively overlies the Pastoria Sand Member and the Rison Clay Member. The Redfield is largely composed of thinly laminated silts and silty sands and clays and some blocky clay. The sand is crossbedded in places and commonly contains abundant carbonaceous material such as lignite and plant remains. It is devoid of marine fossils and glauconite. The Redfield Formation represents continental deposition following filling of the Desha basin and final retreat of the Jackson sea.

CADDELL FORMATION

The lowermost unit of the Jackson Group in Texas is the Caddell Formation (Dumble, 1915), which rests conformably on the Yegua Formation. It ranges in thickness from about 30 to 300 feet. The composition of the Caddell is variable but generally tends to be of marine origin in the lower part and less marine to nonmarine in the upper, although in places it is essentially a fossiliferous glauconitic marl. The lower part commonly contains locally fossiliferous gray calcareous sandstone and ferruginous sandstone concretions; chocolate-colored and greenish calcareous clays contain calcareous fossiliferous sandstone concretions, selenite crystals, and some glauconite. The upper part of the Caddell locally contains lignitic chocolate-colored shales and interbedded thin sands, grayish-brown sandy clays containing seams of sulfur, sandy clays with plant fragments, and gray clays with gypsum and sulfur.

WELLBORN SANDSTONE

The Wellborn Sandstone (Kennedy, 1893) overlies the Caddell Formation and ranges in thickness from less than 100 to more than 300 feet. Its lower part consists of massive gray, locally quartzitic sandstone with some fossiliferous marine clay beds. The middle part is a marine facies composed of highly fossiliferous sandy, glauconitic, marly blue clays and a minor amount of light-chocolate-brown clays. The uppermost part of the Wellborn Sandstone is a massive gray to white argillaceous sandstone. It is locally quartzitic and contains impressions of plant stems.

MANNING CLAY

The essentially nonmarine beds of the Manning Clay (Dumble, 1915) overlie the Wellborn Sandstone to a total thickness of 250–350 feet. The Manning Clay consists of beds of carbonaceous chocolate-colored lignitic clay alternating with two major beds of gray sandstone. The clay beds also contain thin interbeds of tan sand and sandstone, gray tuffaceous sandstone, and lignite. The two intervening sandstones are flaggy and ripple marked and alternate with thin interbeds of green shale and volcanic glass. Interbeds of sand and sandy shale and diatomaceous shale are present, and fossiliferous marine shale beds occur locally.

WHITSETT FORMATION

The Whitsett Formation (Dumble, 1924) is mostly nonmarine crossbedded sand and sandstone interbedded with some tuffaceous shale and fine sandy tuff but locally contains a few marine lentils. The sands are interbedded with greenish-gray and yellow waxy or carbonaceous clays and sandy clay and some volcanic ash. The formation is noted for its opalized wood and chalcedony as well as for fossil leaves. Aragonite is common, as are dark septarial concretions. The sand beds are fossiliferous in places and generally are fine to medium grained but are very coarse and conglomeratic at some outcrop locations. A boulder horizon in the lower part of the Whitsett is exposed at some localities, as is an underlying massive, indurated, quartzitic sandstone. The maximum thickness of the Whitsett Formation is about 135 feet.

OLIGOCENE SERIES

The contact between Oligocene Series sediments and the underlying Eocene sediments in the eastern part of the Gulf Coastal Plain is commonly indistinguishable on a lithologic basis, especially as depicted on geophysical logs. The marine beds are differentiated on the basis of a distinct paleontological break that is not reflected by a change in the lithology. Most of these marine deposits in the lower part of the Oligocene belong to the Vicksburg Group or equivalent strata. Above the predominantly marine sequence in the Oligocene deposits, the sediments become more arenaceous and contain increasing amounts of volcanically derived material in the southern part of the area where tuffaceous sandstones and bedded tuff occur in the lower part of the Miocene section.

RED BLUFF FORMATION

The Red Bluff Formation (Hilgard, 1860) is recognized as a facies of the lower part of the Forest Hill Formation. Although both units have been variously placed in the Jackson and Vicksburg Groups by earlier workers, they are currently considered Oligocene and occupy a stratigraphic position between the two groups. In eastern Mississippi the Red Bluff is fossiliferous brownish or greenish glauconitic clay and sandy clay containing irregular masses of fine-grained ferruginous rock (orthoquartzite). The Red Bluff grades eastward into Alabama to fossiliferous glauconitic marl, limestone, or calcareous clay.

FOREST HILL FORMATION

As mentioned previously, the Forest Hill Formation (Cooke, 1918) is in an intermediate position between the Jackson and Vicksburg Groups. It conformably overlies the Jackson Group and extends across southern Mississippi and into western Alabama. In southeastern Mississippi the Forest Hill is predominantly carbonaceous crossbedded or laminated sand and argillaceous sand that locally contains glauconitic and fossiliferous lenses. It is locally ferruginous to varying degrees. Westward, the Forest Hill is fossiliferous in the upper part in places and contains some lenses of lignite and lignitic clay. To the east, into Alabama, it becomes black, partly fossiliferous clay in its entirety.

BUMPNOSE FORMATION

The Bumpnose Formation (Moore, 1955), in the western panhandle area of Florida, is the equivalent of the Red Bluff-Forest Hill sequence. It is primarily a fossiliferous, somewhat granular, white crumbly limestone.

VICKSBURG GROUP

Except where underlain by recognized earlier Oligocene deposits as discussed above, the sediments of the Vicksburg Group (Conrad, 1848) lie upon those of Jackson age (pl. 12). Composed of a variety of marine lithologies, the Vicksburg Group (Formation in Louisiana) is recognized more by its faunal assemblages than as a distinct rock type. Lithology varies from arenaceous and argillaceous to marl and limestone. Calcareous content generally increases downdip and southeastward.

MARIANNA AND MINT SPRING FORMATIONS

In southern Mississippi and southwestern Alabama the Marianna and Mint Springs Formations (Johnson, 1892; Cooke, 1918) are the basal units of the Vicksburg Group; the Marianna Formation is also recognized in the western panhandle area of Florida. The Marianna Formation is primarily a light-gray to white fossiliferous and porous limestone, glauconitic marl, and calcareous clay. It is well known in the area as "chimney rock" for its popularity as a building material in early homes. A facies change occurs in the lower part of the Marianna westward across Mississippi to form the Mint Spring Fomation, which is a glauconitic, fossiliferous, and partly argillaceous sand.

GLENDON FORMATION

The Glendon Formation (Hopkins, 1917) overlies the Marianna Formation in Alabama and Mississippi.

The Glendon is mainly composed of indurated crystalline limestone. This yellowish and pinkish limestone forms ledges in its outcrop and is interbedded with softer, very fossiliferous limestone.

BYRAM FORMATION

The Byram Formation (Casey, 1902) overlies the Glendon Formation in Mississippi and Alabama and the Marianna Formation in the Florida panhandle. The Byram is highly fossiliferous and generally several tens of feet thick. Its lithology varies, as it is composed of interbedded glauconitic marl, sandy marl and sand, and thinner beds of impure limestone, clay, and sand. It is recognized in Mississippi, southwestern Alabama, and northwestern Florida.

BUCATUNNA FORMATION

The uppermost unit in the Vicksburg Group in Mississippi and Alabama is the Bucatunna Formation (Blanpied and others, 1934), a formation that is also present in northwestern Florida. The Bucatunna contains carbonaceous clays and silts and crossbedded sands and is not as fossiliferous as the Byram Formation, although it does have fossiliferous glauconitic lenses. It is partly composed of volcanically derived materials in the form of tuffaceous and bentonitic beds and is generally less than 60 feet thick.

CHICKASAWHAY LIMESTONE

The Chickasawhay Limestone (or Formation as originally defined by Blanpied and others, 1934) consisted of lithologically distinct upper and lower units. Later work (MacNeil, 1944) restricted the Chickasawhay to the lower of these two units where it occurs in central and southern Mississippi and southwestern Alabama. (Usage of the Chickasawhay as extended into northwestern Florida does not appear to have recognized the two-unit distinction.) It is composed primarily of fossiliferous gray chalky marls, limestones, and clays. About 30 feet thick in the outcrop, the Chickasawhay becomes several thousand feet thick in the subsurface.

PAYNES HAMMOCK FORMATION

The upper part of the section originally designated Chickasawhay is now recognized as the Paynes Hammock Formation (MacNeil, 1944) in central and southern Mississippi and southwestern Alabama. It is generally less than 30 feet thick in the outcrop and consists of fossiliferous blue clays, claystones, and marls. As with the Chickasawhay, the Paynes Hammock Formation thickens greatly in the subsurface to thousands of feet.

FRIO CLAY

The Frio Clay has been the source of confusion and the subject of controversy for many years since its initial definition (Dumble, 1894) on the basis of surface exposures. Different workers have considered the Frio to be Eocene or Oligocene, and it has been placed in various positions within the Claiborne and Jackson Groups. Current usage generally considers the Frio Clay at the surface to be Oligocene and probably the time equivalent of the Vicksburg Group. Its relation to subsurface equivalents remains in controversy among geologists. It is overlapped by Miocene deposits except for a narrow band of outcrop a little more than 100 miles long in southwestern Texas. The Frio is typically composed of massive dark clays (greenish-gray, red, and blue) that are gypsiferous, laminated, and interbedded with sandy clays, sand, and sandstone. Siliceous and calcareous concretions occur in the strata. It is generally sparsely fossiliferous but contains beds of fossiliferous brown marl in the lower part.

CATAHOULA SANDSTONE (TUFF)

The Catahoula Sandstone (Catahoula Tuff in southern Texas) was originally described (Veatch, 1905) from exposures in central Louisiana. It was later recognized in Texas, Mississippi, and southern Louisiana, largely on the basis of subsurface correlations. The Catahoula is not fossiliferous, and correlations and age determinations remain uncertain. It is considered by some geologists to be entirely Miocene, but the prevailing usage, including that by the U.S. Geological Survey, designates the Catahoula as both Oligocene and Miocene. The Catahoula Sandstone is composed primarily of interbedded tuffaceous clays, sands, and sandstones. The interbedding is somewhat irregular, and individual strata are commonly discontinuous. A tuffaceous siltstone occurs in the lower part. The Catahoula becomes more pyroclastic westward and is a tuff in southern Texas.

Downdip, the Catahoula rapidly thickens gulfward to thousands of feet in the subsurface. In the deeper subsurface, at depths of about 2,000 to 4,000 feet below sea level, a gulfward-thickening wedge of fossiliferous marine clay appears in the upper half of the Catahoula. This clay is called the Anahuac Formation and is quite familiar to geologists in the oil industry. The section beneath the Anahuac is commonly referred to as the "Frio" Formation, causing additional confusion because of the similarity in name with the Frio Clay, with which it is not correlative. The stratigraphic relations between the Catahoula, Anahuac, and "Frio" are not yet satisfactorily established. Neither the Anahuac nor the "Frio" Formation is recognized by the U.S. Geological Survey.

In Alabama, the western panhandle of Florida, and central southern Mississippi the Tatum Limestone Member (Eargle, 1964) is recognized as the lower part of the Catahoula Sandstone. The name replaces "*Heterostegina* zone" and similar appelations used to designate the strata on the basis of the characteristic foraminifera. The unit is fossiliferous and consists of sandy limestone, marl, glauconitic calcarenite, and calcirudite. It thickens westward from less than 100 feet to about 300 feet.

MIOCENE SERIES

Deposition during the Miocene Epoch in the Gulf Coastal Plain was basically in a regressive environment. However, many temporary reversals in various locations produced minor cycles within the overall depositional pattern. These relatively brief interludes resulted in the interspersion of fossiliferous marine strata in otherwise nonmarine sediments and provide the faunal basis that has been used for attempts at subsurface correlation. The bulk of Miocene deposits (pl. 13) is a heterogeneous assemblage of deltaic, lagoonal, lacustrine, palustrine, eolian, and fluvial clastic facies; minor calcareous reefal facies are locally present.

In cross section along the dip of the beds, Miocene deposits appear as a great, rapidly gulfward thickening mass (pls. 2, 3). Typically, the sediments are complexly interbedded sands, silts, and clays in the updip, more clastic part of the section; in the direction of Mississippi and Alabama, an eastward, increasingly argillaceous trend is superimposed on the regional pattern. Volcanically derived materials occur as tuffaceous beds, chiefly in the western part of the coastal plain. As the section thickens downdip, it becomes increasingly fine grained and argillaceous, then increasingly calcareous in the deep-basin facies. Growth faulting is common, and beds can thicken several to many times over on the downthrown side of a fault. Identification of growth faults is complicated by the inherent discontinuity of the strata that also has prevented satisfactory differentiation within the Miocene, or even uniformly accepted recognition of its boundaries.

Most of the differentiation of the coastal Miocene deposits has been restricted to areas where they are at and near the surface. Criteria used for such differentiation have not been extended successfully into the subsurface. Some subsurface correlation has been done to a limited extent on the basis of fossiliferous marine beds, but this correlation is of a local nature and does not provide the lithologic or paleontologic criteria necessary for the establishment of regionally recognizable geologic units. The complexity and heterogeneity of the myriad facies making up Miocene strata preclude development of continuous horizons and have frustrated attempts at regional differentiation. In the eastern part of the study area, some differentiation has been done in Mississippi and the panhandle of Florida but not in Alabama, at least as currently recognized by the U.S. Geological Survey. Texas and Louisiana share partially similar recognition of units that can be identified in areas to the west.

A stratigraphic framework of Miocene deposits, or the attempt to define one, is well described by Baker (1979) as "* * * complex and controversial, perhaps more so than any other Cenozoic units. Geologists do not agree which units on the surface or in the subsurface are Miocene nor do they agree as to the relationship of the surface and subsurface units. The correct relationship may never be determined because faunal markers, which exist in places in the subsurface, do not extend to the outcrop; and the heterogeneity of the sediments does not facilitate electrical-log correlations.

HATTIESBURG CLAY

In Mississippi the Hattiesburg Clay (or Formation as originally defined by Johnson, 1893) comprises the middle and lower parts of the Miocene deposits immediately above the Catahoula Sandstone, which it conformably overlies. The Hattiesburg Clay has been traced into Alabama, Louisiana, and Texas, but the name is not in common usage in those States, although it is recognized in those States by the U.S. Geological Survey. It is correlative with the lower part of the Fleming Formation of Louisiana and Texas. The Hattiesburg is composed of massive nonmarine blue and gray clays with some sands and sandstones; it is as much as 450 feet thick in Mississippi.

PASCAGOULA FORMATION

The Pascagoula Formation (McGee, 1891) is recognized as the upper part of the Miocene sediments in Mississippi. As with the Hattiesburg Formation, recognition of the unit has been extended into Alabama and Louisiana, but the name is not in common usage. It is composed mostly of blue, green, and gray clays containing interbedded sands and lesser amounts of sandstones. Locally calcareous beds are fossiliferous, predominantly with mollusk shells. The Pascagoula contains two members, the Homochitto Member and Fort Adams Member (Brown and Guyton, 1943). The Homochitto overlies the lower part of the Pascagoula and contains beds of sand, blue-green clay, and silt. Very coarse sand or fine gravel is at the base of the member. The Homochitto is overlain by the Fort Adams Member, which is composed of calcareous green clay, indurated blue claystone, compact sand, and light coarse sand.

PENSACOLA CLAY

The Pensacola Clay (Puri and Vernon, 1964), originally identified in the western panhandle of Florida, extends into southern Alabama. It thickens from about 380 feet in the type area to more than 1,000 feet in the subsurface. It is composed of two unnamed clay members separated by the Escambia Sand Member (Puri and Vernon, 1964). The clay members are generally light to dark gray and may be brownish gray locally. The Escambia Sand Member is relatively thin and light to brownish gray. It is composed of fine- to coarse-grained quartz sand. The Pensacola Clay does not appear to have any identified direct correlatives.

FLEMING FORMATION

The Fleming Formation (Kennedy, 1892) was first identified on the basis of surface exposures in southeastern Texas and was recognized as extending into western and central Louisiana. In southern Texas the Fleming is predominantly clay, but the sand content increases eastward until it is mostly sand in the extreme eastern part of the State. The clay beds are of many different colors: yellow, green, red, pink, blue, brown, gray, greenish gray, and purplish gray. The strata are calcareous and contain a thin layer of chalky limestone as well as crossbedded sands in places. Calcareous nodules and reworked Cretaceous fossils are common. Stratified gray, brown, or yellow sands may contain abundant fossilized palm wood. About 200 feet thick in the outcrop, the Fleming Formation is thousands of feet thick in the subsurface.

In central Louisiana the Fleming Formation has been divided into six members (Fisk, 1940). In ascending order they are the Lena, Carnahan Bayou, Dough Hills, Williamson Creek, Castor Creek, and Blounts Creek Members. The basal unit, the Lena Member, is predominantly gray silty clay containing varying thicknesses of calcareous clays and some siliceous silts and pyroclastic lentils. Foraminifera are in the calcareous beds and carbonaceous materials in the gray clays. The Carnahan Bayou Member overlies the Lena and is composed chiefly of siltstones that contain intercalated sand lenses and interbeds of brackish-water clays and tuffaceous materials. It is more than 125 feet thick in the outcrop. The Carnahan Bayou Member underlies the Dough Hills Member, which is a sequence of silty clays that is as much as 135 feet thick in the outcrop. The clay strata are calcareous near the center of the unit, and the lower part contains opalized nodules locally. The Williamson Creek Member overlies the Dough Hills, and the contact is based on the existence of numerous sand lentils in its basal part. The sand lentils are distributed throughout the unit, which is primarily a thick (about 500 feet) section of nonmarine silts and silty clays with local tongues of brackish-water clays. The Castor Creek Member, which overlies the Williamson Creek Member, is composed of brackish-water calcareous clays and noncalcareous silts. The uppermost member of the Fleming Formation in Louisiana, the Blounts Creek Member, is a thick sequence of alternating beds of silty clays and sands. Individual beds are several feet thick, and the total thickness of the unit is about 500 feet.

OAKVILLE SANDSTONE

South of the Brazos River in southern Texas the Oakville Sandstone (Dumble, 1894) is a sandy facies of the lower part of the Fleming Formation. It directly overlies the Catahoula Tuff and is readily distinguishable from it and the overlying Fleming by its predominantly sandy character. The Oakville is a completely nonmarine clastic deposit composed of coarse sands and sandstone, grits and gritstone, and silt with subordinate amounts of interbedded clay. The sands are irregularly bedded, being variously massive, laminated, or crossbedded. Some strata contain redeposited Cretaceous fossils, petrified-wood fragments, pebbles, clay pellets, or calcareous nodules. Thickness of the Oakville ranges from about 200 feet to more than 500 feet. Downdip in the subsurface the Oakville sands merge and interfinger with sands and clays of the marine facies of the Miocene section.

PLIOCENE SERIES

Pliocene deposits (pl. 14) are, for the most part, very similar to those of the Miocene Series but may differ somewhat lithologically. For example, Pliocene sediments are generally more arenaceous and thinly interbedded than those of the Miocene. The clays are less calcareous and the sands more lignitic. Nevertheless, the Pliocene deposits are difficult to distinguish from underlying Miocene deposits, and the precise contact is based on faunal criteria. In addition, distinguishing between Pliocene and overlying Pleistocene deposits has caused and continues to raise problems for geologists attempting to differentiate those sediments.

GRAHAM FERRY FORMATION

In central and southern Mississippi, deltaic sediments of the Graham Ferry Formation (Brown and others, 1944) overlie the Pascagoula Formation (Miocene). The Graham Ferry Formation is composed of predominantly nonmarine and brackish-water deposits, but it does contain some marine fossils locally. It is as much as about 1,000 feet thick in the subsurface in coastal Mississippi.

CITRONELLE FORMATION

The Citronelle Formation (Matson, 1917) disconformably overlies the Graham Ferry Formation and underlies Pleistocene deposits, from which it is difficult to distinguish in downdip facies. Sediments of the Citronelle are chiefly nonmarine sands and clays and are very graveliferous near its landward margin. The deposits are mostly gray but weather to red and yellow. Problems with assigning a geologic age to the Citronelle and establishing its correlative position have persisted since its initial designation. The U.S. Geological Survey follows the Pliocene age assignment, and it is thus recognized in this report; for compatibility with the regional framework and subsurface correlations, surficial post-Miocene deposits east of the Mississippi River are shown as Pleistocene.

FOLEY FORMATION

The Foley Formation with its two members, the Steep Gully and Mamou Members (Jones and others, 1954), represents Pliocene deposition in southwestern Louisiana. The Foley Formation does not crop out, as its beveled subcrop is covered with a veneer of Pleistocene materials. The predominant lithology is fine- to medium-grained sand with interbeds of gray-green to brown laminated clay. The sands are commonly lignitic, and the upper part of the Foley is finer grained than the lower. The lower member, the Steep Gully Member, consists of a sequence of irregularly and discontinuously interbedded sands and clays. The sands are uniformly fine to medium grained. The clay interbeds, some of which are laminated, are light gray, grayish green, and blue. The base of the Steep Gully Member overlies the *Rangia johnsoni* zone, which is considered the top of Miocene deposits. The Mamou Member is the upper member of the Foley Formation. Although it is distinctively different from the underlying Steep Gully Member, the contact between the two is gradational. The sands of the Mamou Member are finer grained, more lignitic, and more micaceous than those of the Steep Gully Member; the clays are generally darker.

GOLIAD SAND

In Texas, the Goliad Sand (Lonsdale and Day, 1933) overlies the Fleming Formation. The Goliad has basal strata of coarse sediments, which include cobbles, gravel, clay balls, and wood fragments. Its irregular bedding suggests river-bottom sediments. The upper part of the Goliad is predominantly sand, some of which is cemented with calcium carbonate or has a matrix of caliche. The indurated beds are discontinuous, and the sands are whitish to pinkish gray and range from medium fine to very coarse. Black chert grains are abundant in places. The interbedded clays are grayish and locally marly. The Goliad Sand contains some vertebrate and invertebrate fossils in the lower part but generally is not considered to be a very fossiliferous unit.

PLEISTOCENE SERIES

Pleistocene deposition in the Gulf Coastal Plain was dominated by the erosional and sedimentary cycles associated with glaciation. Coastwise terraces exhibit the stepped relations produced by successive onslaughts of glacial meltwater, whereas Pleistocene terrace deposits to the north in the Mississippi embayment appear as dissected remnants. A general depositional pattern typical of glacial cycling is evidenced by the sediments of the continental terraces.

The lower part of a terrace section is commonly gravel or sand and gravel. These materials grade finer upward to sand, silt, and clay. Isolated beds of gravel may exist within the sandy middle section. Downdip, the coarser terrace clastic materials merge with silty deltaic deposits, which grade to clay of the marine facies under the continental shelf. Northward, primarily in the Mississippi embayment, a blanket of Pleistocene loess covers much of the surface of uplands and ridges.

HOLOCENE SERIES

Holocene deposits in the study area are of two principal types, river alluvium and coastal deposits. Alluvium underlies the flood plains of all major drainage systems in the study area, the largest of which is that of the Mississippi River. The flat-lying flood-plain deposits typically are sand and gravel in the lower part and silt and clay in the upper. Deltaic fans of silts and clays are formed by the finer sediment load deposited when river gradient is reduced to zero at the Gulf of Mexico and the velocity decreases to the point that sediments no longer can remain in suspension. Other deposition continues in coastal marshes where flood waters of coastal streams lose their sediment load and along the shore where eroded deltaic sediments are redeposited.

SUMMARY

The Gulf Coast RASA, a study of the major aquifer systems in Cenozoic deposits in the Gulf Coastal Plain, encompasses an area of about 290,000 square miles and includes all or parts of ten States: Alabama, Arkansas, Florida, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas. Cenozoic deposition in the study area was controlled by two major structural basins, the Gulf Coast geosyncline and the Mississippi embayment. The Mississippi embayment is, in effect, a north-trending limb of the Gulf Coast geosyncline into which it opens.

The deformation that created the Gulf Coast geosyncline and the Mississippi embayment began with downwarping and downfaulting at the end of the Paleozoic Era. During the Mesozoic Era vast thicknesses of Triassic and Jurassic deposits accumulated in the geosyncline, which continued to subside in response to the sediment load. Deposition expanded northward during the Cretaceous Period when the sea invaded the Mississippi embayment, leaving a succession of marine deposits that became the floor for subsequent Cenozoic deposition.

Cenozoic deposition was affected and controlled by tectonic features that were in place or forming at the time of deposition. The deposits were displaced, or to a lesser extent deformed, in areas where postdepositional tectonics took place.

Some of the major structural features are in the Mississippi embayment. In the northern part of the embayment, the New Madrid fault zone of southeastern Missouri and northeastern Arkansas is a complex system of faults, which is still active and is the epicenter of major earthquakes. Also in the northern part of the embayment, the Pascola arch is a subtle flexure that extends southeastward across southeastern Missouri and into western Tennessee. To the south, in southeastern Arkansas, the Desha basin is a pronounced synclinal depocenter whose axis forks northwestward from the axis of the Mississippi embayment; Cenozoic sediments thicken considerably in the basin, whose subsidence closely followed the pattern of its parent structures, the geosyncline and embayment. The Sabine uplift is a major uplift of more than 5,000 square miles that lies in the northwestern corner of Louisiana and adjoining Texas; its surface expression is quite pronounced, with a large area of exposed Wilcox deposits ringed by outcropping Claiborne Group units. The Sabine arch is a subtle flexure that extends southward from the Sabine uplift to the Gulf. East of the Sabine uplift and of about the same size, the Monroe uplift affected Tertiary deposition by constricting the Mississippi embayment in the area between it and the Jackson dome to the east; the Desha basin lies off the northern flank of the Monroe uplift. Of great structural relief, the Jackson dome also had a pronounced effect on Tertiary deposition in west-central Mississippi, where Tertiary strata are more than double in thickness off the structure. Reef formation during the transition from late Cretaceous to early Tertiary played a part in the development of both the Monroe uplift and the Jackson dome.

The Gulf Coast geosyncline is more or less bounded along its northern updip extent by a belt of three major fault zones that follows the strike of the sediments and is probably associated with the sinking of the geosyncline, as displacement increases with depth. The zones form a system of en echelon grabens and normal faults. The Luling-Mexia-Talco fault zone extends northeast across southern and southeastern Texas to northeastern Texas where it turns eastward. The Arkansas fault zone, which appears to be a continuation of the Luling-Mexia-Talco fault zone, crosses southern Arkansas from the west and terminates at the Monroe uplift. In central Mississippi the Pickens-Gilbertown fault zone curves around the northern flank of the Jackson dome and then trends southeastward into southwestern Alabama. Other strike-oriented growth faulting is common throughout the Coastal Plain, and some of the faults remain active. A few faults, mostly in the southeastern part of the Gulf Coastal Plain, are approximately at right angles to the general strike of the growth-fault system; the Mobile graben, which forms the depression that is Mobile Bay, is the most notable of these.

Anticlines and synclines in the Gulf Coastal Plain generally are gentle flexures, some of which are adjacent and alternate. The Wiggins uplift crosses southern Mississippi in a west-northwest line that arcs eastward into southwestern Alabama. In southeastern Mississippi the axis of the uplift bifurcates, and a shorter segment, the Hancock arch, arcs southwestward toward the southeastern tip of Louisiana. The East Texas embayment-North Louisiana syncline forms a rim syncline to the Sabine uplift. The geosyncline arcs around the northern half of the Sabine uplift and received sediments through Claiborne time. Where the East Texas embayment merges southward with the Gulf Coast geosyncline, it loses its pronounced identity, and its trend becomes a less pronounced flexure, the Houston embayment. The southeast-trending San Marcos arch flanks the Houston embayment to the southwest. Southwest of the San Marcos arch, the Rio Grande embayment in the southern tip of Texas trends east-southeast and is a more pronounced depression than is the Houston embayment.

Salt domes abound in the Gulf Coastal Plain and are mostly concentrated in two bands. The largest band extends along the coast from the southeastern corner of Texas to the southeastern tip of Louisiana. An inland band of domes extends from northeastern Texas, across northern Louisiana, and into south-central Mississippi. The domes all resulted from the plastic flow of salt from the mother bed, the Louann Salt. The salt flows in response to density differences between the bedded salt and the overburden as the weight of the overburden increases with accumulation in a sedimentary basin. The degrees of intrusion, structural deformation, development of rim synclines, and local thickening or thinning of surrounding strata vary widely, more so than does the diameter of the domes, which is generally 1 to 3 miles.

Cenozoic deposition in the Gulf Coastal Plain and Mississippi embayment began with the invasion of the Midway sea at the close of the Cretaceous Period. The ensuing Paleocene and Eocene Epochs of the Tertiary Period saw repeated cycles of marine and nonmarine deposition as the sea alternately transgressed and regressed. Each major transgression was less than the preceding one, which left the sediments in an offlap sequence; some intermediate partial incursions did not inundate the entire area. Marine deposits in the area are typically dense clay with minor amounts of calcareous strata. The intervening continental and near-marine sediments grade from deltaic and other interdeltaic and near-shore deposits to landward fluviolacustrine sands and clays. The last major marine invasion into the Mississippi embayment was by the Jackson sea near the end of the Eocene Epoch, after which Tertiary deposition was limited to the southern part of the Gulf Coastal Plain. Deltaic, interdeltaic, and offshore deposition continued during the Quaternary Period, but glaciation during the Pleistocene Epoch became the major influence on landward sedimentation. Coarse sand and gravel terrace deposits were left in the Coastal Plain as well as the Mississippi embayment by meltwaters during interglacial periods. The Holocene Epoch is characterized by alluvial deposition in the flood plains of aggrading streams.

The physiography of the Gulf Coastal Plain and Mississippi embayment is the result of the nature of the sediments and the effect of tectonics and erosion upon the sediments. Sands and clays are the predominant rock types in the area, and each produces characteristic geomorphologic patterns. Sands, being generally more resistant to erosion, tend to underlie ridges and cuestas. Less resistant clays produce topographic lows.

The belts of exposed geologic units of a particular lithology or groups of lithologically similar units underlie specific terrains that were developed upon them. Paleocene deposits form the East Texas Timber Belt, Black Prairie, Red Hills, Pontotoc Ridge, and Flatwoods. Eocene deposits underlie the most physiographic features, which include the East Texas Timber Belt, Western Hills, Red Hills, Buhrstone Hills, Sulphur Wold, Nacogdoches Wold, Lime Hills, and Jackson Prairie. The Jackson Prairie is also underlain by Oligocene deposits. The Bordas, Oakville, and Kisatchie Escarpments are on Miocene deposits as are the Southern Pine Hills and local black belts, which are also underlain by Pliocene deposits. Terraces, the Loess Hills, and the upper surface of parts of Crowleys Ridge are of Pleistocene age. The Mississippi River flood plain and delta are the dominant Holocene physiographic features, which include other flood plains, deltaic plains, and low-lying coastal topography. Some salt domes have produced rounded eminences of low relief locally referred to as islands.

Differentiation of Cenozoic geologic units in the Gulf Coastal Plain is not uniform, but correlations of major units are in general acceptance, allowing for nomenclatural differences and subdivision of units in one area but not in another. Geologic-age determinations are generally more reliable in sediments of Paleocene and Eocene age than in sediments of Oligocene age and younger.

Paleocene deposits make up the Midway Group and part of the Wilcox Group. The Midway Group is composed of the Clayton Formation (Kincaid Formation in Texas), a basal calcareous unit, and the Porters Creek Clay (Wills Point Formation in Texas), a thick marine clay, in most of the area. In Alabama and part of Mississippi additional units are identified, and the Naheola Formation is included at the top of the Midway.

The Wilcox Group (Formation in Illinois and Kentucky) of Paleocene and Eocene age is undifferentiated in much of the study area. It largely consists of interbedded sands, silts, and clays, mostly continental and deltaic in origin. In Louisiana, the lower part is divided into the Naborton and Dolet Hills Formations. The Wilcox is divided into the Old Breastworks Formation, Fort Pillow Sand, and Flour Island Formation in Tennessee, Missouri, and northeastern Arkansas. In Mississippi the Nanafalia, Tuscahoma, Bashi, and Hatchetigbee Formations compose the Wilcox Group. Some units are further divided into members in parts of the State. In Alabama, the Bashi and Hatchetigbee Formations are recognized.

Formations of the Claiborne Group represent alternating cycles of marine and nonmarine deposition. Marine depositional environments produced extensive clays with subordinate amounts of marls and glauconitic sands. Intervening continental beds are composed of sands and clays of varying extent and thickness. The basal Claiborne unit in Texas, Arkansas, and Louisiana is the Carrizo Sand, which is the same unit as the Meridian Sand Member of the Tallahatta Formation of Mississippi and Alabama. The remainder of the Tallahatta Formation plus the Winona Sand and the Zilpha Clay are equivalent to the Cane River Formation of Louisiana and Arkansas and the Reklaw Formation, Queen City Sand, and Weches Formation of southeastern and northeastern Texas and the Bigford Formation and El Pico Clay of southern Texas. The Sparta Sand is recognized in southeastern and northeastern Texas, southern Arkansas, Louisiana, Kentucky, and Mississippi, and is called the Lisbon Formation in Alabama and Florida. The Sparta Sand and overlying Cook Mountain Formation are equivalent to the Laredo Formation in southern Texas. The Cook Mountain Formation is recognized throughout the rest of the area except for Alabama and Florida. The Cockfield Formation is recognized except in Texas, where it is called the Yegua Formation and in Alabama, where it is called the Gosport Sand (not identified in Florida). In Tennessee, Missouri, and northwestern Arkansas the Memphis Sand is equivalent to all units between the top of the Wilcox Group and the base of the Cook Mountain Formation.

Most deposits of the Jackson Group (Formation in Missouri, Kentucky, and Tennessee) are of marine origin and resulted from the last inundation of the Coastal Plain that extended into the Mississippi embayment. In the western part of the Coastal Plain the Jackson deposits are more arenaceous and contain pyroclastic material. North of the approximate latitude of the Arkansas-Louisiana State Line, disconnected erosional remnants are all that remain of Jackson Group deposition. The Jackson Group is not differentiated in northern Mississippi but contains the Moodys Branch Marl and Yazoo Formation in central and southern Mississippi, Louisiana, and Alabama. The Moodys Branch contains two members. In northeastern Arkansas the Jackson Group is not subdivided. Although the differentiation is not recognized by the U.S. Geological Survey, the Jackson Group has been divided into the White Bluff and Redfield Formations in southern Arkansas. The White Bluff is further subdivided into three members that are partial facies of each other. The Caddell Formation, Wellborn Sandstone, Manning Clay, and Whitsett Formation compose the Jackson Group in Texas.

Oligocene deposits in the eastern part of the Gulf Coastal Plain are mostly marine in origin and are distinguished from underlying Eocene deposits chiefly by faunal content. Except in southeastern Mississippi and southwestern Alabama, where the lowermost Oligocene units are the Bumpnose and Forest Hill Formations, the Vicksburg Group (Formation in Louisiana) lies directly on the Jackson Group. The Mint Spring, Marianna, Glendon, Byram, and Bucatunna Formations compose the Vicksburg Group. The Chickasawhay Limestone, Paynes Hammock Formation, and Catahoula Sandstone represent the remainder of Oligocene deposition in that part of the Coastal Plain. The same formations are recognized in the western panhandle of Florida except for the Red Bluff, Mint Spring, Glendon, and Paynes Hammock Formations.

In the southwestern part of the Coastal Plain the Oligocene deposits are more arenaceous. The pyroclastic content increases toward southern Texas, and the Catahoula Sandstone (Miocene and Pliocene) becomes the Catahoula Tuff. The Catahoula Tuff is underlain by the Frio Clay.

Miocene deposits are a heterogeneous assemblage of deltaic, lagoonal, lacustrine, palustrine, eolian, and fluvial clastic facies and local calcareous reefal facies. The deposits become increasingly finer and thicker gulfward. Growth faulting is common, and beds can thicken markedly on the downthrown side of faults. Differentiation of Miocene deposits has been done mostly at surface exposures and to a very limited extent in the subsurface where criteria necessary to recognition of significant geologic horizons are lacking. The Hattiesburg Clay is the middle and lower part of the Miocene section in Mississippi. It has been traced into other states, but the name is not in common usage. The Pascagoula Formation overlies the Hattiesburg and is composed of two members, the Homochitto and Fort Adams Members. The Pensacola Clay with its member, the Escambia Sand Member, is the upper part of the Miocene deposits in the western panhandle of Florida and has been traced into adjacent parts of Alabama. The Fleming Formation of Texas has been extended into western and central Louisiana where it contains six members, the Lena, Carnahan Bayou, Dough Hills, Williamson Creek, Castor Creek, and Blounts Creek Members. In southern Texas the Oakville Sandstone is a sandy facies of the lower part of the Fleming Formation.

Pliocene deposits are difficult to distinguish from both underlying Miocene and overlying Pleistocene deposits. They are generally more arenaceous and thinly bedded than Miocene sediments, the clays less calcareous, and the sands more lignitic. The Graham Ferry Formation of Mississippi overlies the Miocene and underlies the Citronelle Formation, which is also recognized in Alabama, the western panhandle of Florida, and southeastern Louisiana. In southwestern Louisiana the Foley Formation represents Pliocene deposition and contains two members, the Steep Gully and Mamou Members. The Goliad Sand is the equivalent unit in Texas.

Quaternary deposition in the Gulf Coastal Plain is represented by sediments of both the Pleistocene and Holocene Series. Pleistocene deposits are mostly in the form of terraces that are associated with glacial periods; some uplands and ridges, mostly in the Mississippi embayment, have a surficial cover of Pleistocene loess. Holocene deposition includes flood-plain sediments of major streams, deltas, and other coastal areas of sedimentation.

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