REGIONAL GEOLOGIC FRAMEWORK OF THE CRETACEOUS, OFFSHORE MISSISSIPPI

A. John Warner

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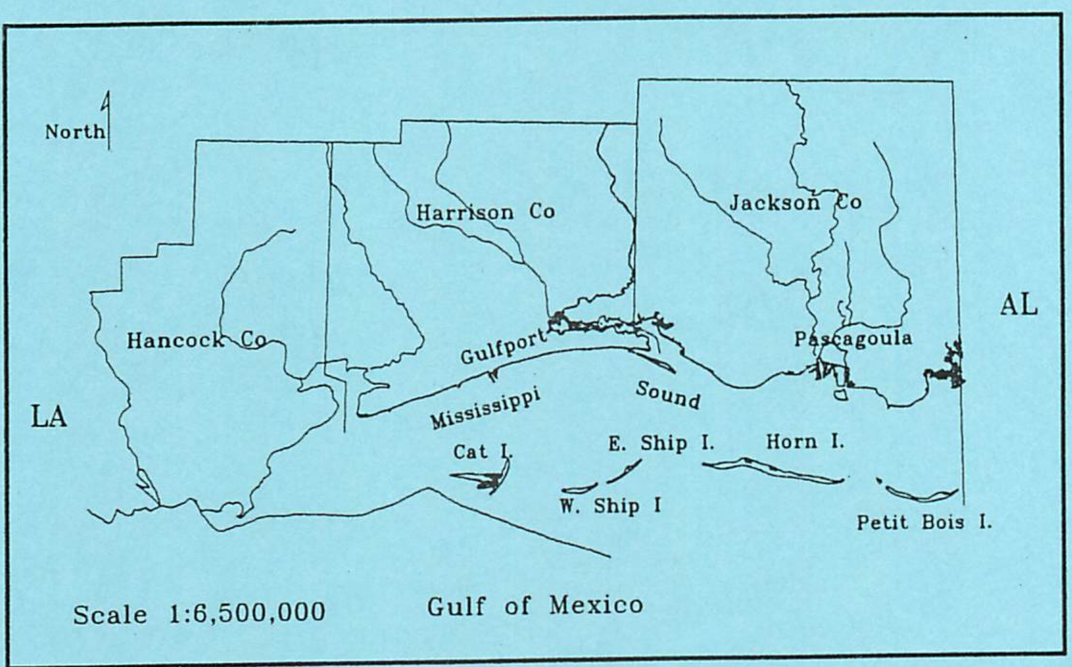

Mississippi Department of Environmental Quality
Office of Geology
S. Cragin Knox, Director

March 1993

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY
OFFICE OF GEOLOGY

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Energy and Coastal Geology Division

REGIONAL GEOLOGIC FRAMEWORK OF THE CRETACEOUS, OFFSHORE MISSISSIPPI

Final Report

by

A. John Warner

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Mississippi Office of Geology

ABSTRACT

The onshore Mississippi Gulf Coast and adjacent State and Federal waters are part of the Mississippi/Alabama Shelf region of the northeastern Gulf of Mexico. This portion of the continental shelf has a gentle basinward slope of less than 1 degree with a water depth of up to 75 meters. Its surface is characterized by fairly low relief features and the sediments are primarily silt and clay. A thick Cretaceous section is present throughout the Mississippi Gulf Coast, though only in the subsurface due to onlap by overlying Tertiary deposits. In the study area, the Cretaceous consists of approximately 9000 feet of fine to coarse terrigenous-sourced clastics, carbonates, and some interbedded evaporites and bioclastic material. The Cretaceous of Mississippi can be divided into the Upper and Lower Cretaceous Series. Through Cretaceous time, there was a general steady rise in sea level with the exception of a regressive sequence during the Aptian Stage of the Lower Cretaceous and during the Cenomanian Stage at the beginning of the Upper Cretaceous. During the Early Cretaceous, clastic sedimentation related to the Laramide orogeny outpaced both this rise in sea level and basin subsidence, resulting in extensive clastic deposition which extended across large areas of the northern Gulf basin, onlapping Late Jurassic sediments. During this period, large deltas were built along the northern Gulf margin. Sea level began to rise again after a period of sea regression, at the beginning of the Late Cretaceous. The amount of terrigenous materials diminished and subsidence slowed; a shallow epicontinental sea covered the study area and a carbonate facies prevailed around the periphery of the Gulf of Mexico basin. As the Cretaceous Period came to a close, the epicontinental seas had reached a maximum highstand resulting in the deposition of predominantly marls and chalks in the study area.

The depositional history of the Mississippi Gulf Coast is favorable for the accumulation and preservation of substantial amounts of organic material and for the development of reservoir quality rocks. Rudistid reefs, porous dolomites, fractured chalks, along with various clastic facies such as delta front, strandline, and coastal plain environments are all present in the area.

INTRODUCTION

This paper discusses the geologic characteristics of the Cretaceous System and the associated oil and gas parameters in coastal Mississippi and the adjacent offshore State and Federal waters. It is intended as a broad framework of reference for the continued exploration on the area.

The Cretaceous strata of the Mississippi Gulf Coast and the adjacent offshore waters range from continental-derived terrigenous sediments to carbonates and shales deposited on the shelf of the continental margin, with anhydrites, salt and other evaporites being deposited in restricted areas. The area of study includes the Cretaceous sediments of coastal Mississippi and the State waters of the Mississippi Sound and adjoining Federal waters of the Mississippi Shelf region (Figure 1). The Cretaceous section is comprised of sand, shale, and a variety of carbonates with some subordinate interbedded evaporites and reef materials. The varying depositional environments account for the varied rock types found in the region. The well and core data indicate depositional environments ranging from fluvial-deltaic to strandline facies to neritic environments. Lack of well control precludes a definitive statement about depositional environment in other than a very local setting or in a general regional perspective. The coastal region of Mississippi has been an anomaly in an otherwise prolific oil and gas habitat of the northern Gulf Coast margin, with only sporadic and sparse exploration having taken place in the region. The large areal extent of the coastal region of Mississippi leaves a vast area open to exploration.

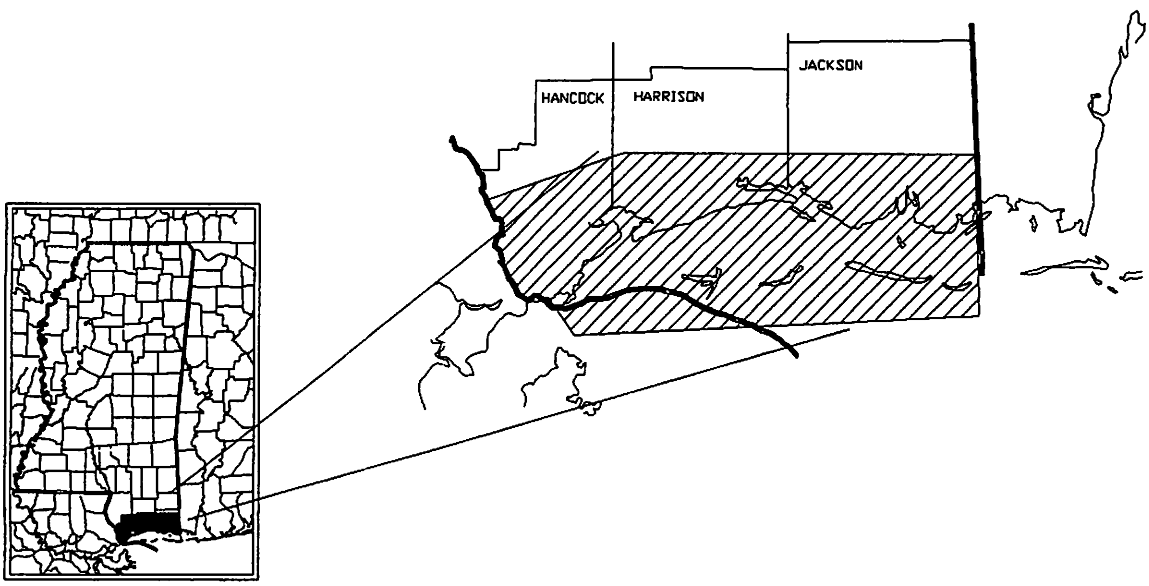


Figure 1. Index map of the study area.

PURPOSE AND SCOPE

The purpose of this study has been to establish a regional geologic framework for the Cretaceous section of coastal Mississippi, offshore State waters, and adjacent Federal waters. Ideas and conclusions of other studies and an extended bibliography have been included in this study in an effort to put the local well data acquired into a regional context. Effort has been made to correlate the sediments of coastal Mississippi with contemporaneous deposits of Alabama and Louisiana. Particular emphasis has been placed on the stratigraphy of the hydrocarbon producing intervals and the structural relationships of these formations. Subsurface data from wells in southern and offshore Mississippi, coastal and offshore Alabama State and Federal blocks, and offshore Louisiana were used to formulate a geologic framework for the purpose of projecting regional stratigraphic, structural, and hydrocarbon trends into the adjacent Federal OCS waters. Electric log analysis, sample assessment from conventional cores and sidewall cores, and lithologic information from mudlog descriptions and cuttings analyses were utilized in the assembling of the stratigraphy of the study area. The structural relationships of the Cretaceous units and their configurations were determined with the use of well data, gravity data, and seismic reflection data. An east-west cross section traversing the Mississippi Sound has been assembled (Figure 2).

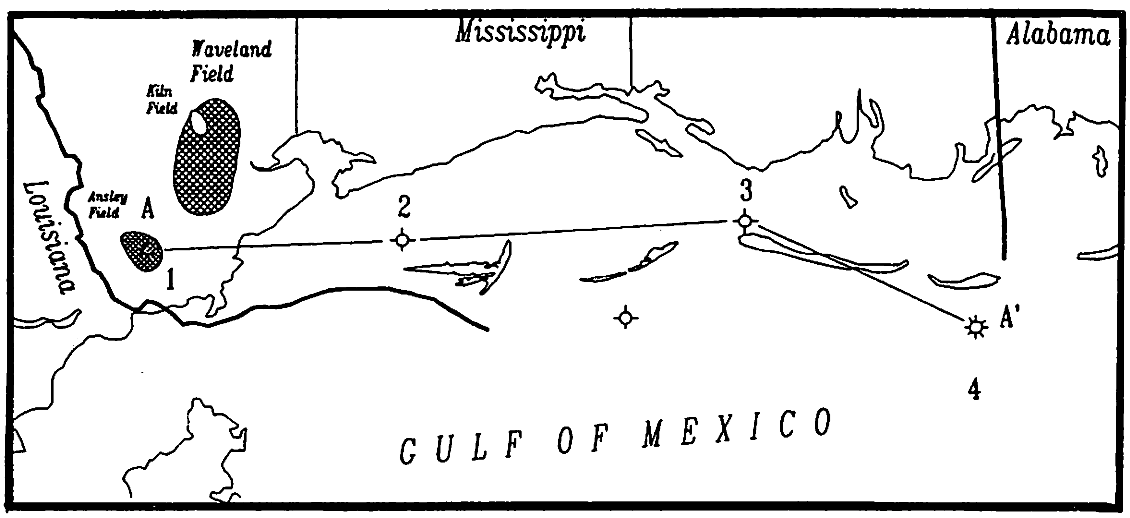


Figure 2. Cross section index map.

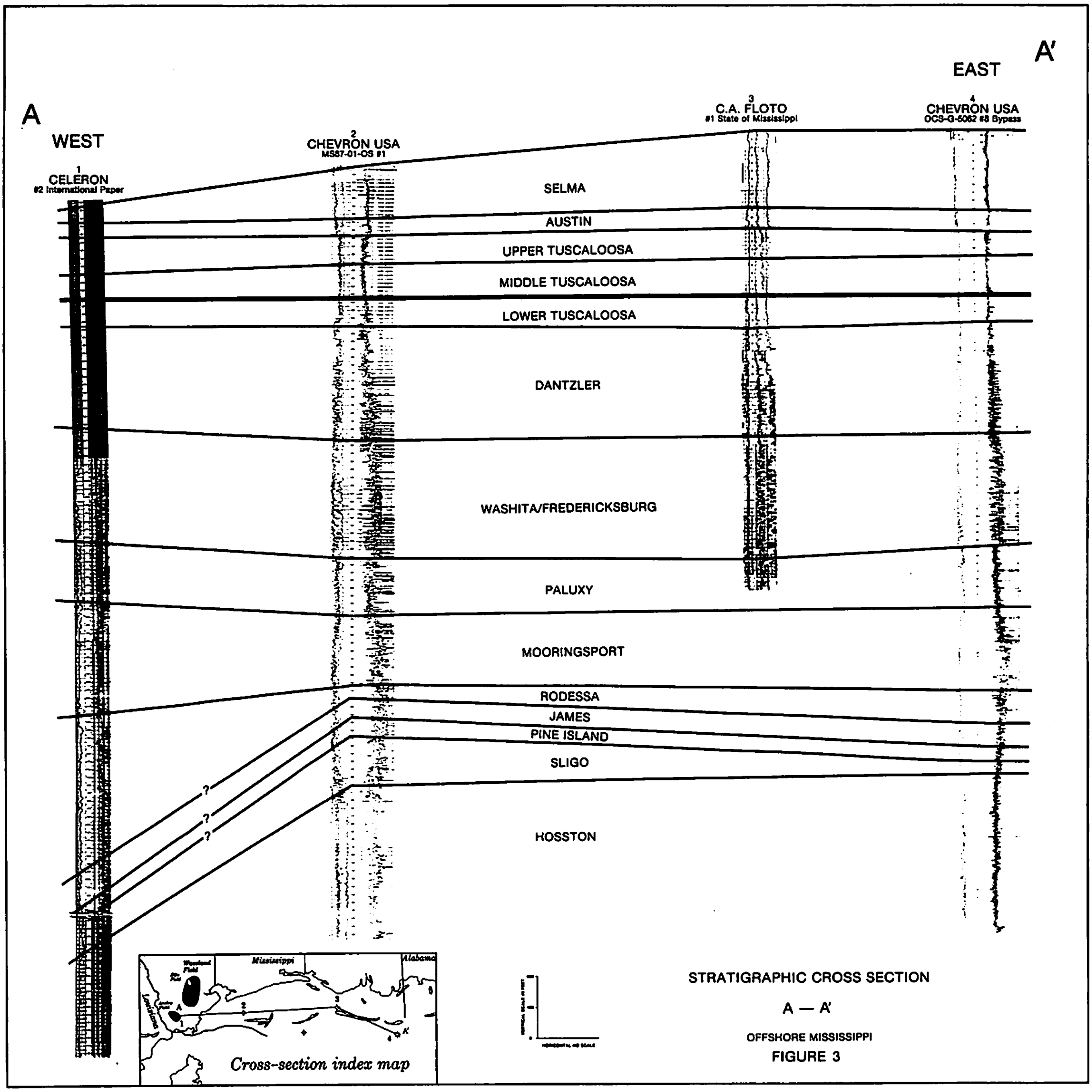
WELLS USED IN CROSS SECTION AND TEXT: (See Figures 2 and 3)	**Designated in text as:**
1. Celeron Oil and Gas Company No. 2 International Paper Company Section 19, Township 9 South, Range 15 West Ansley Field Hancock County, Mississippi	**Celeron #2**
2. Chevron USA Inc. MS87-01-OS #1 Mississippi Sound Block 57 Harrison County, Mississippi	**Chevron MS87**
3. C. A. Floto State of Mississippi #1 Mississippi Sound Block # 48 Latitude 30°15'N Longitude 88°43'48"W Jackson County, Mississippi	**Floto**
4. Chevron USA Inc. OCS-G-5062 #8 Bypass Mobile Area Block 861 Latitude 30°06'50"N Longitude 88°24'17"W Offshore Pascagoula, Mississippi Jackson County, Mississippi	**Chevron 5062**

QUALIFICATION AND DEFINITION OF TERMS

The Mississippi Gulf Coast referred to in this study includes the Mississippi coastal counties of Hancock, Harrison, and Jackson, and parts of George, Stone and Pearl River counties (depending on the paleo sea level), and the offshore Mississippi state waters.

ACKNOWLEDGMENTS

The author would like to express his thanks to Chevron U.S.A., Inc., Unocal Corporation, and Mobil Exploration and Production, U.S.A., Inc., for their contribution of logs and sample data, without which this project could not have been completed.



STRATIGRAPHIC CROSS SECTION

A — A'

OFFSHORE MISSISSIPPI

FIGURE 3

REGIONAL SETTING

The Mississippi Gulf Coast and adjacent State and Federal waters are part of the Mississippi-Alabama Shelf region of the northeastern rim Gulf of Mexico sedimentary basin (Martin, 1978). The Gulf of Mexico basin is the site of deposition of great thicknesses of Mesozoic and Cenozoic sediments, which thin from a maximum basinward thickness of roughly 50,000 feet to a feather edge to the north (Walper et al., 1979). The Mississippi-Alabama portion of the continental shelf has a gentle basinward slope of less than 1 degree with a water depth of up to 75 meters (Kindinger, 1988). Its surface is characterized by fairly low-relief features and is primarily silt and clay dominated. The Mississippi-Alabama Shelf is bounded on the east by the carbonate platforms of the West Florida Shelf and is separated from the Texas-Louisiana Shelf on the west by the Mississippi River Delta (Martin, 1978). To the south, the northern flank of the DeSoto Canyon marks the southern limits of the Mississippi-Alabama Shelf (Figure 4). The minor topographic interruptions of the surface of the Mississippi-Alabama Shelf reflect the underlying features of salt flowage, low-angle growth faults, and other paleohighs and depositional and erosional features such as sand ridges and relict barrier islands (Frazier, 1974).

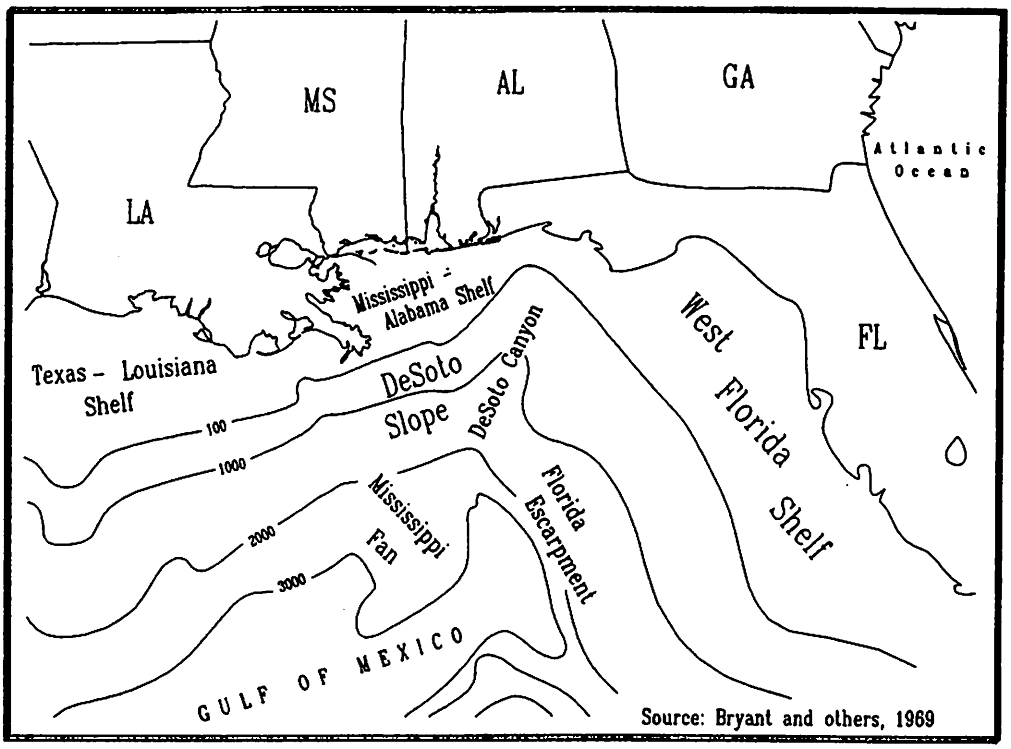


Figure 4. Physiographic map of the northeastern Gulf of Mexico.

STRATIGRAPHY

The Cretaceous System in the northern Gulf Coast consists of approximately 6000 to 9000 feet of fine to coarse terrigenous and marine clastics, carbonates, and interbedded evaporites and bioclastic materials. The section is a gulfward thickening wedge of sediments which pinch out updip to the north. It is part of the thick package of Cenozoic and Mesozoic sediments of the Gulf Coast geosyncline as designated by Barton et al. in 1933. Due to the significant rise in sea level during the Cretaceous Age and probably a corresponding increase in the subsidence rate in the coastal margin, Upper Cretaceous sediments transgressed all older Mesozoic units in the study area (Rainwater, 1960). Also, the Cretaceous section was subsequently onlapped by the overlying Tertiary deposits in the study area. The Cretaceous System in the Mississippi Gulf Coast can be divided into the Upper and Lower Cretaceous Series. The Lower Cretaceous can be divided into the Hosston, Sligo, Pine Island, James, Rodessa, Ferry Lake, Mooringsport, Paluxy, Washita-Fredericksburg, and Dantzler formations. The Upper Cretaceous includes the Lower, Middle, and Upper Tuscaloosa, the Eutaw (Austin), and the Selma formations (Dockery, 1981) (Figure 5).

Generally, there was a steady rise in sea level during the Cretaceous. The sea transgression began during the Lower Cretaceous Hauterivian Stage (Hosston) and culminated in a maximum highstand during the Maastrichtian Stage (late Selma) during the close of the Upper Cretaceous. There were two exceptions to this general sea level rise. Periods of relatively minor sea regressions occurred during the Late Cretaceous Aptian (Rodessa) and Cenomanian Stages (Dantzler-Lower Tuscaloosa); see Figure 6 (Vail et al., 1977).

During the Early Cretaceous, clastic sedimentation, related to the Laramide orogeny, outpaced the rise in sea level and basin subsidence resulting in extensive clastic deposition across large areas of the fairly mature northern Gulf Coastal Plains. Fluvial and deltaic, lagoonal, and strandplain facies graded basinward into carbonate shelf environments onlapping Late Jurassic sediments in the northern Gulf Coast (Figure 7) (Raymond et al., 1988).

During the Late Cretaceous, sea level reached a maximum highstand, the amount of terrigenous materials diminished, and subsidence slowed in the northern Gulf Coast. Shallow epicontinental seas developed and a carbonate facies prevailed around the periphery of the northeastern Gulf of Mexico basin (Figure 8) (Montgomery, 1987). In the Mississippi Gulf Coast, limestones, dolomites, and chalks with some locally interbedded anhydrites were deposited in the warm shallow epicontinental seas. Large reefs developed along the edges of the shallow banks (Rainwater, 1968) creating large expanses of back-reef and other

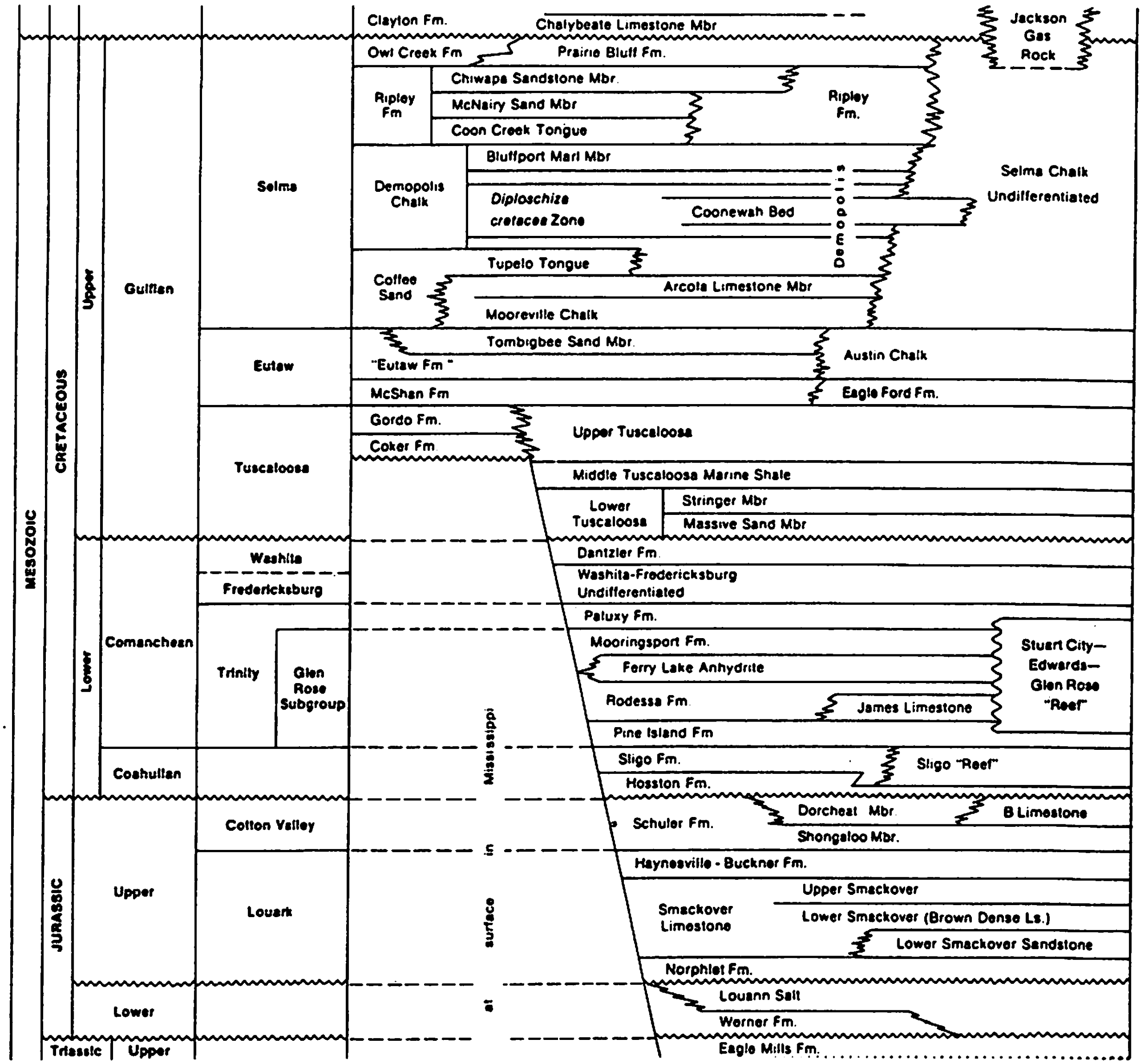


Figure 5. Stratigraphic Column of Mississippi (from Dockery, 1981).

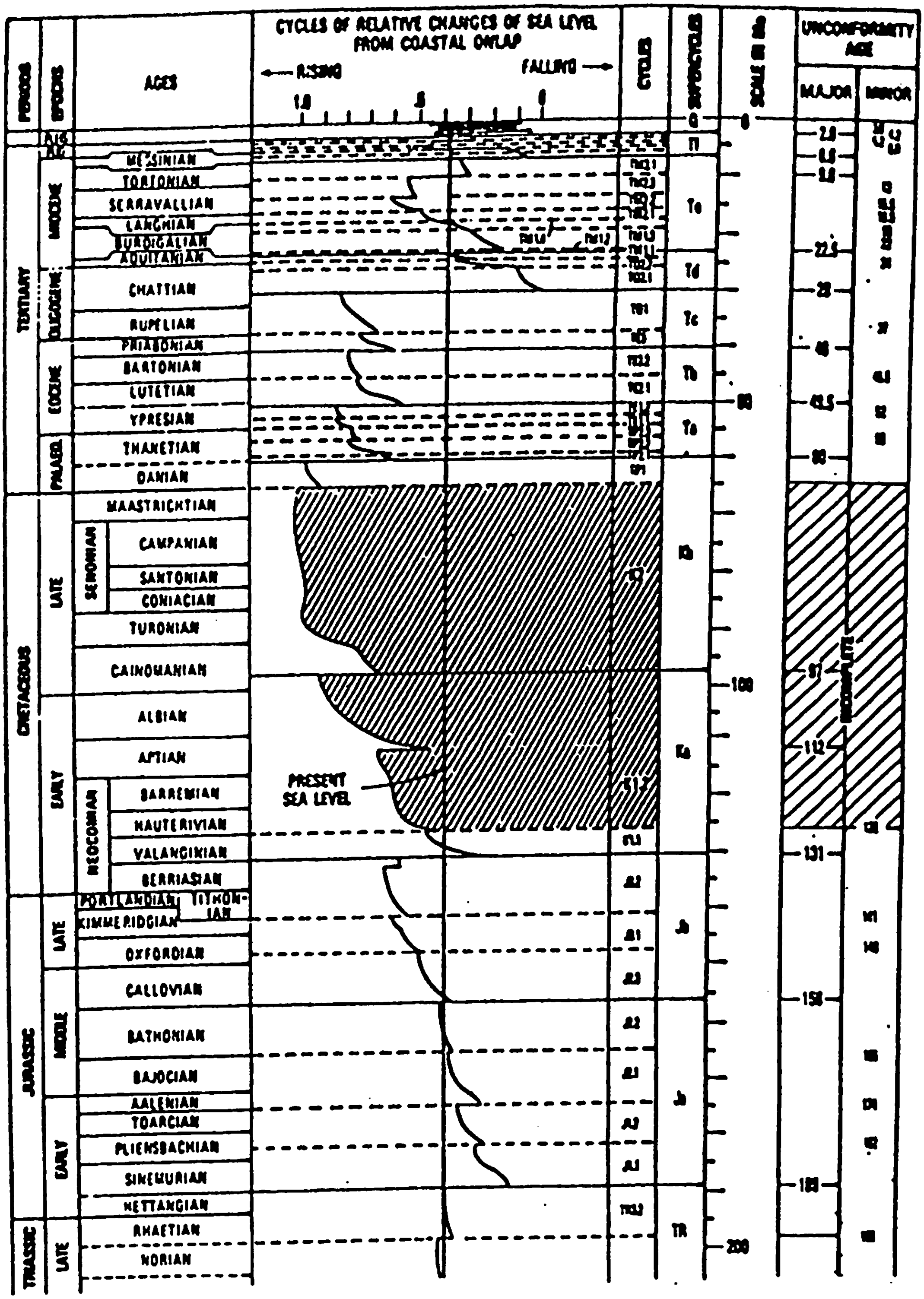


Figure 6. Chart of global relative changes in sea level (modified from Vail et al., 1977).

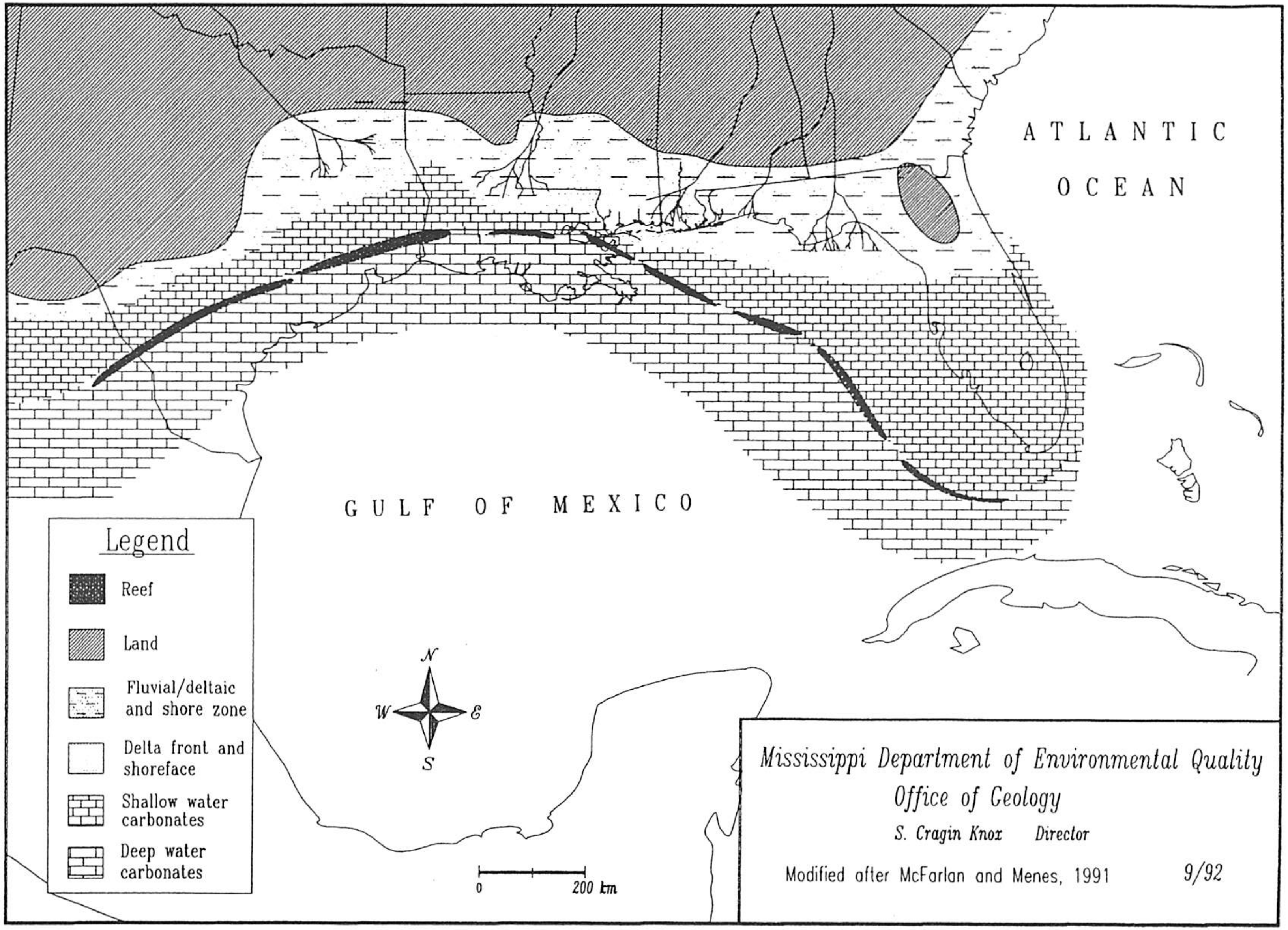


Figure 7. Paleofacies map of the northern Gulf Coast Hauterivian Age (Hosston).

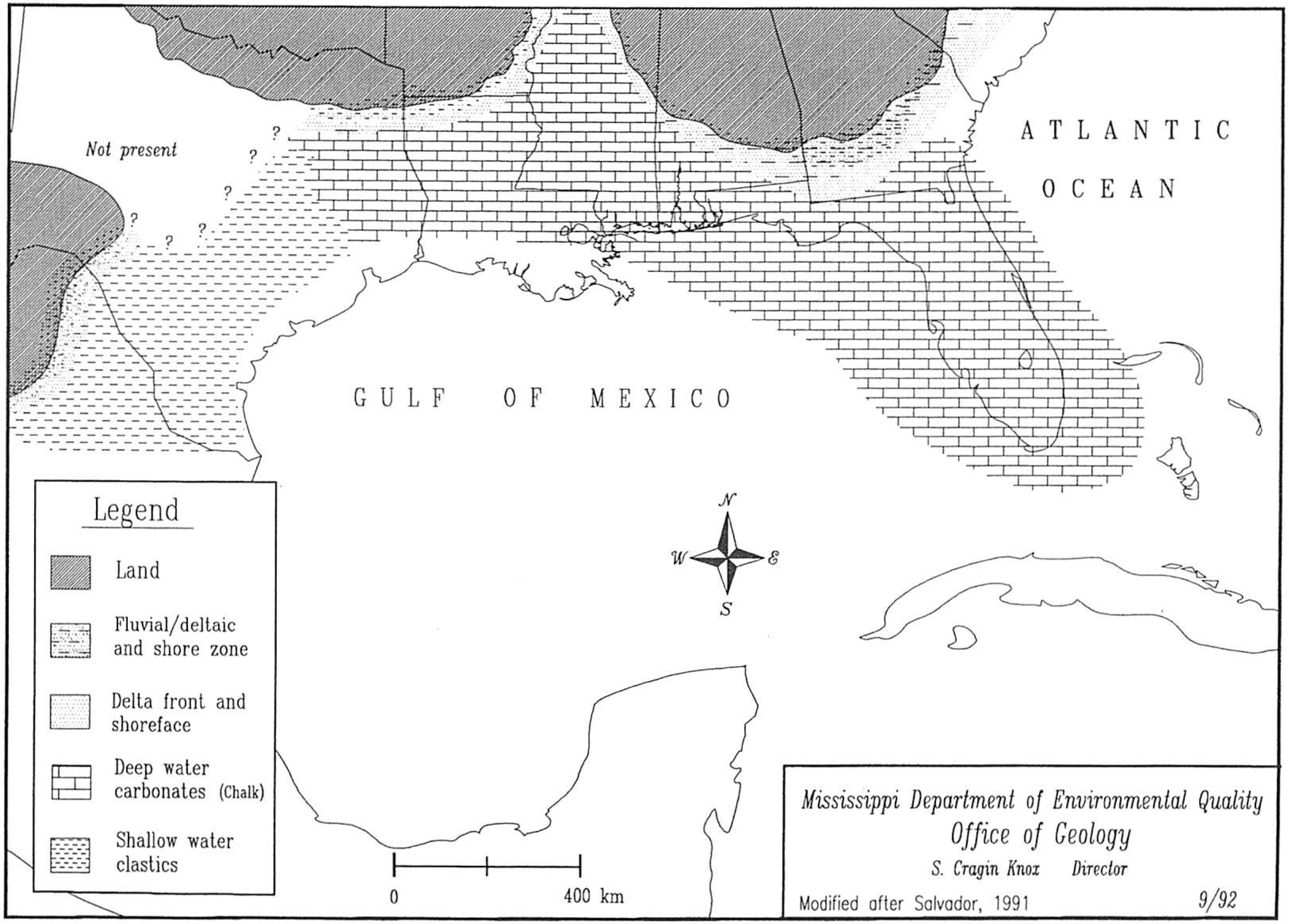


Figure 8. Paleofacies map of the northern Gulf Coast Maastrichtian Age (Selma).

paralic environments in the region. As the Cretaceous Period came to a close, the epicontinental sea had reached its updip limits in the northern Gulf Coast, covering most of Mississippi (Figure 8). Deposition of predominantly marls and chalks prevailed in the Mississippi Gulf Coast (Figure 9).

HOSSTON:

In the Mississippi Gulf Coast, the Hosston ranges from alluvial fine-grained sands to fine gravels. These clastics are interbedded with oxidized backswamp and coastal lake shales in the updip region and shallow water carbonates downdip basinward (Figure 10). There is a general increase in quartz and chert gravel content in the formation to the north into central Mississippi (Rainwater, 1960). Farther to the east, in southwestern Alabama, the Hosston Formation consists of interbedded sands, shales, and mudstones. The sandstones are fine- to coarse-grained, varicolored, micaceous, and slightly lignitic. The shales and mudstones are varicolored, silty to sandy, micaceous, calcareous and slightly fossiliferous. Some shales are lignitic and may contain nodules of limestone (Raymond et al., 1988). In the western part of the study area, in southern Hancock County, Mississippi, log and sample analysis of the Celeron well (Ansley Field) (Figure 2) indicates the Hosston Formation encompasses the stratigraphic section between approximately -19,190 and -17,820 feet (subsea). The 1370-foot section consists of white to dark gray, hard, dense, microfossiliferous, micritic limestone with minor thin beds of dark gray shale suggesting a low-energy, open-shelf environment (Figure 10). To the east, in the Mississippi Sound, the Hosston lies between -18,050 and -16,155 (subsea) feet in the Chevron MS87 well. It is a thicker section (1895 feet) in this well than in the Celeron well. This thinning in the Celeron well is probably due to the positive influence of the Hancock Ridge on deposition. Lithologically, in the MS87 well, the lower Hosston is composed primarily of dark gray to gray to dark brown, hard, microcrystalline, argillaceous (in part) limestones interbedded with minor amounts on dark gray shales and very fine-grained sandstones. This grades upward into a much more terrigenous-sourced clastic section in the upper Hosston which consists of a dominant silt and shale facies. The siltstones are varicolored, moderately consolidated to firm, calcareous cemented, with traces of pyrite, mica, and glauconite. The shales are gray to dark gray, firm to hard, micaceous, arenaceous, and slightly calcareous. Interbedded with these siltstones and shales is a substantial amount of gray to dark gray, firm to hard, argillaceous, oolitic limestone with abundant microfossils. The Floto well did not penetrate the Hosston section. However, in the eastern portion of the Mississippi Sound, log analysis of the section in the Chevron 5062 well (see Figure 2) indicates the Cotton Valley-Hosston contact to be at approximately -17,160 feet

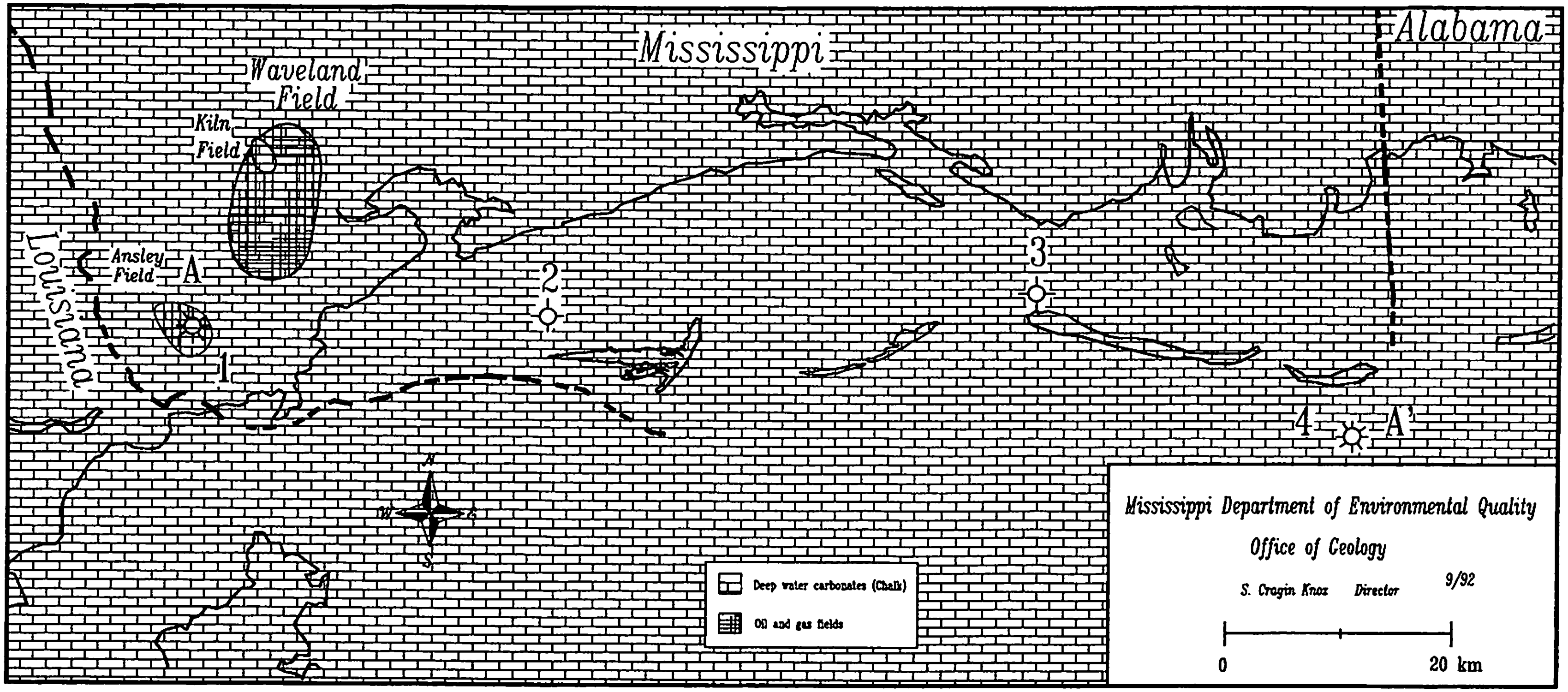


Figure 9. Paleofacies map of the Mississippi Gulf Coast Maastrichtian Age (Selma).

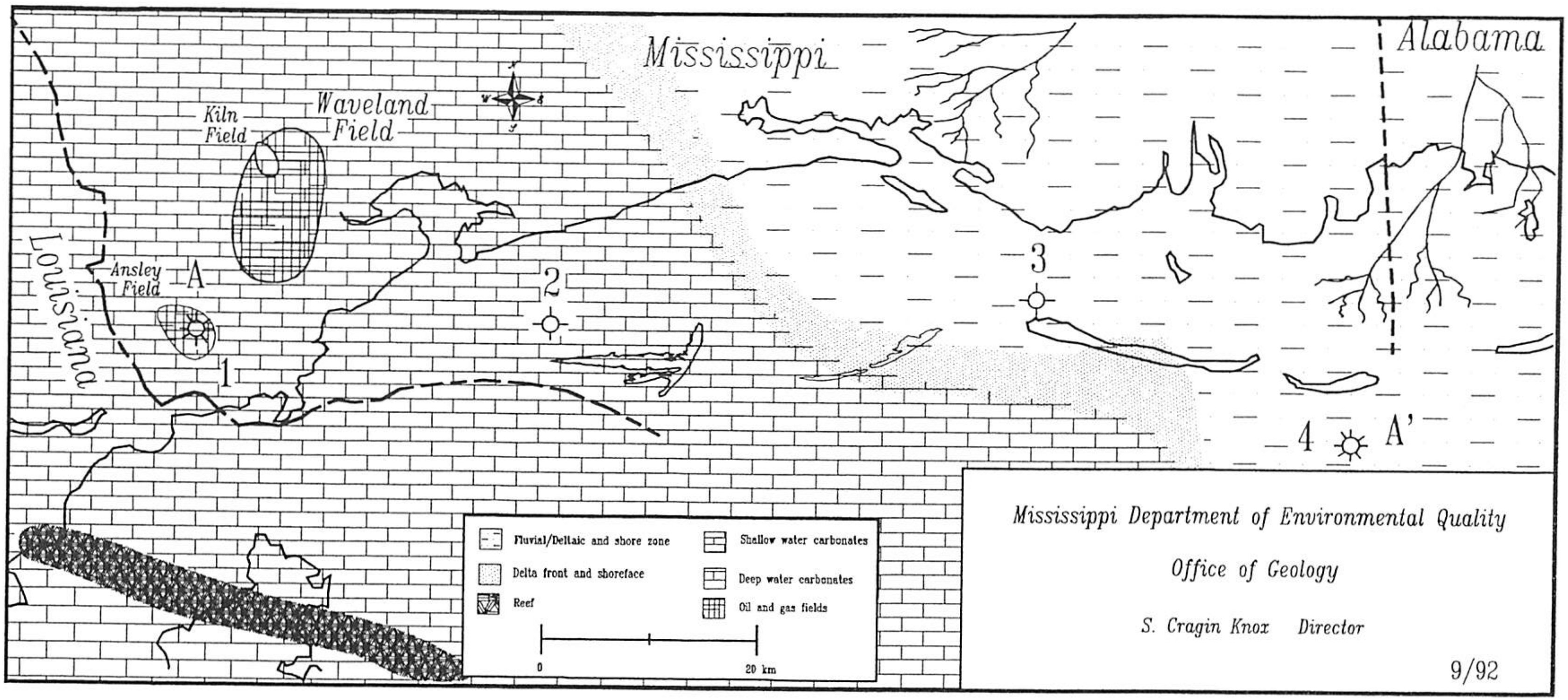


Figure 10. Paleofacies map of the Mississippi Gulf Coast Hauterivian Age (Hosston)

(subsea). The Hosston Formation occupies the interval up to -15,350 feet where it is in contact with the overlying Sligo Formation. In this well, the Hosston is a 1810-foot section of primarily terrigenous clastic sediments. It consists of light gray to dark gray to reddish-brown, firm to hard, micaceous, moderately calcareous shales interbedded with varicolored, very fine-grained to coarse-grained, calcareous cemented sandstones and cream to light gray to white, firm to moderately hard, microcrystalline, oolitic limestones. The author believes the sediments of the latter two wells were deposited as part of large fluvial-deltaic facies (Figure 10).

Throughout the Mississippi-Alabama Gulf Coast, the Hosston Formation overlies the sands and shales of the Cotton Valley Group. In some areas, determining the contact of the Lower Cretaceous Hosston and the Upper Jurassic Cotton Valley is difficult, if not impossible, due to their similar rocks. The end of the Cotton Valley age and the beginning of Hosston age (opening of the Valanginian Stage) was witness to a major sea level regression (see Figure 6)(Vail et al., 1977). This retreating sea and possibly coinciding increase in uplift to the north and/or basin subsidence in the south resulted in extensive erosion in the coastal plains of the northern Gulf Coast and massive deposition of terrestrial-sourced clastic sediments in a marginal marine regressive environment.

SLIGO:

The Sligo Formation conformably overlies the Hosston Formation in the Mississippi Gulf Coast. It is commonly a gray to brown argillaceous and fossiliferous limestone in the area. During the early Sligo (Aptian Stage), a period of continued sea level rise persisted in the Gulf Coast (see Figure 6)(Vail et al., 1977). Sediments were deposited primarily in a shallow shelf facies. The period of predominant Sligo carbonate deposition drew to an end with a regressive sea sequence during the end of the Aptian Stage. More terrigenous clastic sediments were deposited to the north of the study area in a paralic environment as the shore advanced southward. In southern Hancock County, in the Celeron well, the top of the Sligo is at approximately -16,990 feet (subsea). It is 830 feet thick and consists of a carbonate sequence of white to gray, hard, dense, microcrystalline to very finely crystalline limestone with a 350-foot section of dolomitized limestone in the middle of the section. In the Chevron MS87 well, the top of the Sligo Formation is at -15,530 and is approximately 625 feet thick. It is a limestone unit with some increase in siltstone and shale stringers in the lower portion of the section. Predominantly, it is a gray to dark gray to brown, very firm, microcrystalline limestone which is increasingly fossiliferous in the basal section. To the east, in the Chevron 5062 well, log and sample analyses indicate the top of the Sligo at -14,740 feet (subsea); it is in transitional contact with the Hosston Formation at

-15,350 (subsea). It is a 610-foot section of gray to dark gray to brown, very firm, microcrystalline limestone with minor siltstone and shale stringers in the basal portion.

GLEN ROSE "REEF" SUBGROUP:

The Glen Rose Subgroup of the Trinity Group, in the Mississippi Gulf Coast, is comprised of foreslope marls, thin interbedded limestones and clastics, and gray fossiliferous limestones. In the study area, it can be divided into the Pine Island, Rodessa, Ferry Lake, and Mooringsport formations (see Figure 5)(Dockery, 1981). The Glen Rose carbonates thin and become more clastic in composition updip, to the north. Downdip and gulfward, the limestones interfingered with prograding reef complexes (Rainwater, 1968).

PINE ISLAND:

The Pine Island Formation is the oldest formation of the Glen Rose Subgroup. In the Mississippi Gulf Coast, it is primarily a carbonate. Log analysis of the section in the Celeron well indicates the top of the Pine Island is at -16,850 feet (subsea). It consists of a 140-foot section of white to tan to light gray, hard, cryptocrystalline limestone. In the Mississippi Sound (the Chevron MS87 well), the top of the Pine Island is at -15,300 feet (subsea). It is a 230-foot section of light gray to gray to brown, firm to hard, argillaceous, oolitic (in part), microfossiliferous limestone. Farther to the east, in Mobile Area Block 861, log analysis of the section in the Chevron 5062 well indicates the top of the Pine Island is at approximately -14,540 feet (subsea). It is a 200-foot thick, dark gray to gray, firm to moderately firm, oolitic, microcrystalline limestone.

JAMES LIME:

The James Lime is in conformable contact with the underlying Pine Island Formation in the Mississippi Gulf Coast. In the study area, the top of the James Lime is picked at the base of the Rodessa, below the last anhydrite stringer in the section. In the Celeron well, the top of the James Lime is found at -16,510 feet (subsea) and is a 340-foot section of white to tan to light gray, hard, cryptocrystalline limestone. In the Chevron MS87 well, the top of the James is found at the depth of -15,043 feet (subsea). The section is a light gray to brown, soft to hard, slightly calcareous, oolitic limestone with varying amounts of microfossils. In the Chevron 5062 well, the top of the formation is at -14,332 feet (subsea). The 208-foot section consists of dark gray to brown to olive, very firm to hard, argillaceous in part, oolitic in part, microcrystalline limestone.

RODESSA:

The Rodessa Formation conformably overlies the James Lime Formation in the Mississippi Gulf Coast and is the oldest unit of Trinity age. The Rodessa Formation can be difficult to identify in the northern Gulf Coast, where the Ferry Lake Anhydrite is not present to separate it from similar rocks of the Mooringsport Formation. Log and sample data in the study area indicate the section is generally a gray, arenaceous to argillaceous, partly oolitic limestone containing fossil debris and interbedded with thin, hard, fine-grained sandstone, brown granular dolomite, gray to brownish-red micaceous shale and white to buff anhydrite stringers. The Rodessa Formation thickens significantly from the Chevron MS87 well westward to the Celeron well in southern Hancock County. In the Celeron well, the top of the Rodessa is at -14,460 feet (subsea). The section is 2050 feet thick. It is primarily composed of tan to white to light gray, hard, microcrystalline limestone. There are some minor amounts of dolomite, siltstone and shale interbedding. In the Chevron MS87 well, the top of the Rodessa is at -14,895 feet (subsea). The section is 148 feet thick and is primarily a light gray to brown, soft to hard, microcrystalline limestone with light to medium gray, firm to hard, brittle, slightly calcareous shale interbedded. In the basal section, there is an increase in microfossils and the limestone is increasingly argillaceous. In the Chevron 5062 well, the top of the Rodessa is at -14,135 feet (subsea) and is 197 feet thick. The section is a light gray to brown to tan, firm to hard, argillaceous, microcrystalline limestone with minor anhydrite stringers interbedded. The basal section of the formation in a dark gray, very firm, brittle, slightly calcareous shale.

FERRY LAKE:

The Ferry Lake Anhydrite is only locally present in the Mississippi Gulf Coast south of the Wiggins Arch. Where present, it is a massive, white anhydrite interbedded with thin irregular lenses of gray shales, limestones, and dolomites. The Ferry Lake Anhydrite ranges up to 250 feet in thickness, with local areas of nondeposition.

MOORINGSPORT:

In the Mississippi Gulf Coast, the Mooringsport Formation, like the Rodessa Formation, regionally consists of primarily dark gray to reddish-brown, oolitic, fossiliferous limestones interbedded with dark gray shale, varicolored thin sandstone, marl, and thin irregular beds of anhydrite. In southern Hancock County, Mississippi, the top is at a subsea depth that ranges from 13,250 to 13,500 feet and is approximately 1100 to 1200 feet thick. It is a gray, brown, finely crystalline, fractured, bioclastic limestone with several thin lenses of very fine-grained sandstone and anhydrite inclusions. The limestone contains abundant fossil specimens, primarily miliolids and orbitolinids. In Waveland Field, in particular, the Mooringsport was deposited in a back-reef facies resulting in a somewhat uniform section of carbonate mudstones, miliolid and peloidal packstones, orbitolinid packstones and grainstones, and sporadic rudistid-boundstone patch reefs (Baria, personal communication, 1992). To the south, in the Celeron well (Ansley Field), the top of the Mooringsport is at -13,050 feet (subsea) and is approximately 770 feet thick. It is a limestone section with negligible shale and sandstone lenses. The limestone is gray to brown to tan, hard, argillaceous in part, and cryptocrystalline to microcrystalline. In the Chevron MS87 well, the Mooringsport overlies the Ferry Lake equivalent at -14,290 feet (subsea) and is in contact with the overlying Paluxy at -14,000 feet (subsea). The upper section of the unit consists of interbedded very fine-grained, light gray to white, well sorted, friable sandstone and light gray to reddish-brown, firm to hard, argillaceous, calcareous shales. This grades into a light gray to gray, hard, cryptocrystalline limestone in the basal section. In the Chevron 5062 well, to the east, the top of the Mooringsport is at -13,060 feet (subsea) with the base being in conformable contact with the underlying Ferry Lake equivalent at -13,502 (subsea). Here also, the Mooringsport grades from a terrigenous-sourced clastic sediment in the upper section to a more carbonate basal section. The formation consists of predominant dark gray to reddish-brown, firm to moderately hard, micaceous, slightly calcareous shale interbedded with minor amounts of white, very fine- to fine-grained, loosely consolidated sandstone in the upper section. The lower section consists of white to gray, hard, microcrystalline limestone with interbedded gray to dark gray shales and several thin anhydrite stringers.

PALUXY:

The Paluxy Formation conformably overlies the Mooringsport Formation in the Mississippi Gulf Coast. In the Celeron well, the top of the Paluxy is at -12,280 feet (subsea). The 770-foot section grades from a carbonate in the upper Paluxy to a clastic-dominated rock in the lower Paluxy. The upper section consists of white to tan to light gray, hard, microcrystalline limestone. This lithotype grades into a shale- and sandstone-dominated lower section. The shales are gray to dark gray, firm to hard, brittle, sandy, and calcareous in part. The sandstone is gray to tan, firm to hard to friable to unconsolidated, poorly sorted, calcareous cemented, and medium- to very fine-grained. To the east, in the Chevron MS87 well, the top of the Paluxy is at -13,273 feet (subsea) and is 727 feet thick. The Paluxy is again carbonate dominated in the upper portion of the section and grades down to a clastic-dominated rock in the lower half of the formation. The upper section is a cream to tan to light brown, very firm to hard, microcrystalline limestone with a trace of microfossils. In this well, the clastics are predominantly shales with interbedded siltstones. There are few sand-size grains present. The shales are gray to dark gray and red to brown. The shales are firm to hard, fissile, brittle in part, slightly calcareous to very calcareous and arenaceous in part. The siltstones are white to light gray to red, soft to moderately firm, friable, and slightly to very calcareous. The Floto well is "TD" in this formation at a subsea depth of -13,020 feet. The top of the Paluxy in the Floto well is -12,628 feet (subsea). The section of the formation that was drilled consists of dolomite and shale with minor lenses of very fine-grained sandstone. The dolomite is cream to light gray, very hard, and microcrystalline. The shales are red to gray to green, firm to hard, micaceous, and silty in part. Farther to the east in the Chevron 5062 well the top of the Paluxy is at -12,270 feet (subsea). In this locale, the section is 790 feet thick and is a shale-dominated rock with several substantial sandstones present and some limestone stingers interbedded. The shales are dark gray to gray to red to dark brown, very firm to moderately hard, slightly calcareous, arenaceous in part, and slightly micaceous. The sandstones are gray to light gray to white, predominantly well sorted, very fine- to fine-grained, occasionally medium-grained, well sorted, subrounded to subangular, loosely cemented, friable, and slightly calcareous with traces of mica, pyrite, glauconite, and some carbonaceous materials. Structural interpretation of seismic data on the Mississippi Shelf, at the Paluxy Formation level, shows normal southwest dip at the rate of 105 feet per mile with a northwest-southeast strike. Just south of Horn Island, a gentle nosing with a possible closure of seventy-five feet is apparent (Luper, 1985).

WASHITA-FREDERICKSBURG:

The Washita-Fredericksburg Formation stratigraphically occupies the interval between the overlying Dantzler Formation and the underlying Paluxy Formation and is the lower component of the Washita-Fredericksburg Group (Dockery, 1981). According to Vail et al. (1977), sea level continued to rise during the interval of the Washita-Fredericksburg deposition. Dark-gray to reddish-brown marine shales, sandstones and shallow shelf fossiliferous limestones were deposited in the Mississippi Gulf Coast. In the Celeron well, the top of the Washita-Fredericksburg Formation is found at -10,880 feet (subsea), where it is in conformable contact with the overlying Lower Cretaceous Dantzler Formation. It is a 1400-foot section of shales and dolomitic limestones with sandstone stringers interbedded. The sandstones are light gray to white, medium- to fine-grained, moderately well sorted, loosely consolidated, and calcareous. The section grades down to a finer-grained shale with interbedded limestones, with the basal Washita-Fredericksburg being primarily composed of tan to white to light gray, hard, subcrystalline to microcrystalline micrite. In the Chevron MS87 well, the Washita-Fredericksburg occupies the stratigraphic section between -11,797 and -13,273 feet (subsea). The 1476-foot section is also carbonate dominated in the lower portion of the section. However, there is a substantial amount of shale and siltstone in the basal portion of the formation in this well. The limestones are dolomitized to varying degrees and are cream to tan, occasionally light gray, very firm to hard, microcrystalline, with traces of microfossils. The shale is light to dark gray, firm to moderately hard, fissile, micaceous, and slightly calcareous. The siltstone is light gray to gray, very firm to friable, slightly arenaceous, slightly calcareous, with traces of mica and glauconite. In the Floto well, the Washita-Fredericksburg section is much the same. The top of the Washita-Fredericksburg is at -10,980 feet (subsea). It is a 1648-foot section of dolomitized limestone with interbedded shales and siltstones. In the Chevron 5062 well, the top of the Washita-Fredericksburg Formation is at -10,855 feet (subsea) and is 1415 feet thick. There is not a substantial change in the lithology of this section from the Washita-Fredericksburg section in the previous wells. The section is primarily a carbonate section with shales and siltstones interbedded.

DANTZLER:

The Dantzler Formation is the youngest of the formations that make up the Lower Cretaceous sequence and is the upper member of the Washita-Fredericksburg Group (Dockery, 1981). There was brief, but extensive withdrawal of the Cretaceous sea during close of the Lower Cretaceous System (Vail et al., 1977). A renewed transgression followed shortly thereafter, resulting in extensive flooding of the northern Gulf Coast and the deposition of the Upper Cretaceous marine deposits. Log and sample analysis of the Dantzler section, in southern Hancock County, reflects these sea level changes.

In most areas of the northern Gulf Coast, the Dantzler is in unconformable contact with the overlying Upper Cretaceous Lower Tuscaloosa Formation. However, in the study area, evaluation of log and sample data indicates the contact to be conformable. The Dantzler/Lower Tuscaloosa contact is at -9630 feet (subsea) in the Celeron well, with the Dantzler extending down to -10,880 feet (subsea) where it is in conformable contact with the top of the underlying Washita-Fredericksburg Formation. The Dantzler consists of 1250 feet of primarily terrigenous-sourced sand and shales in the upper portion of the formation with an increasing amount of limestones in the lower portion. The sands are white, fine- to medium-grained, loosely consolidated, and slightly calcareous. The grain size decreases to very fine to fine in the lower portion of the section. Also, the proportion of sand decreases as one descends through the section, with shallow water carbonates and fine-grained clastics being present in the basal

Dantzler. The shales are gray to dark gray, firm, slightly calcareous and sandy to varying degrees. In the lower Dantzler, a white to gray, soft to firm, microcrystalline limestone is present in a considerable amount. In southern Hancock County, the basal Dantzler includes a light gray, hard, fine-grained, micaceous, calcareous sandstone (the Cuevas Sand), which is a notable oil and gas reservoir. Eastward along depositional strike, in the Chevron MS87 well, the top of the Dantzler is at -10,355 feet (subsea) and is in contact with the underlying Washita-Fredericksburg Formation at -11,797 feet (subsea). The 1442-foot section is comparable to the section in the Celeron well. The upper part of the section is devoid of carbonates and is primarily sand and shale deposits. The sands are fine- to medium-grained, white to light gray, and loosely consolidated; the shales are gray to dark gray, firm to slightly brittle, and micaceous. As one descends through the section, the percentage of clastics decreases and the amount of limestone increases. The limestones are pale green to white, firm to soft, microcrystalline, and sparingly fossiliferous. There is an appearance of green and dark red shales in this lower portion of the section. In the Floto well, the top of the Dantzler is at -9690 feet (subsea) where it is interpreted to be in conformable contact with the overlying Lower Tuscaloosa. The section extends down to -10,980 feet (subsea) where it is in conformable contact with the Washita-Fredericksburg Formation. This 1290-foot section is also very analogous to the sediments of the previous wells. A sandy upper section grades into a predominant shale section, which grades into a shallow water carbonate in the lower portion of the section. The sands of the upper portion of the Dantzler are white to light gray, unconsolidated to loosely consolidated, fine- to very fine-grained, well sorted, and slightly to moderately calcareous. The percentage of sand decreases as one descends through the section to almost nil in the basal portion of the formation. There is a dominant shale and siltstone facies in the middle of the section which grades down into a shallow water limestone facies in the lower portion of the section. The shales are gray to green to dark gray, firm to brittle, fissile, occasionally sandy, and micaceous in part. Again, there is an appearance of dark red and green shales in the lower portion of the formation. The limestones are buff, tan, light gray, firm to hard, and cryptocrystalline. In the Chevron 5062 well, the top of the Dantzler is at -9430 feet (subsea) and extends down to -10,855 feet where it is in conformable contact with the underlying Washita-Fredericksburg Formation. The 1425-foot section has less sand in the upper section than the wells to the west. However, the basic pattern of nearshore clastic facies grading into a shallow carbonate facies is reflected in this well's electric log and sample data. The upper section of the formation is primarily a siltstone and shale section with fine- to medium-grained sandstones interbedded. The shales are gray to dark gray, firm to moderately hard, occasionally finely micaceous, slightly calcareous, and occasionally carbonaceous.

The subordinate sands are clear to white to light gray, very fine- to fine-grained, loosely to moderately-well consolidated, rounded to subrounded, with slightly calcareous cement. The limestones in the lower portion of the section are white to light gray to tan, moderately firm to hard, microcrystalline, occasionally argillaceous, with traces of pyrite present.

LOWER TUSCALOOSA:

The Lower Tuscaloosa in southern Hancock County, Mississippi, was deposited on the edge of the shelf slightly landward of the flexure of the continental slope. Depositional environments in the area varied from the fluvial/deltaic-littoral facies of southern Hancock County (Ansley Field area and north) to the delta-building deposits on the steep incline of the continental slope, south and basinward of the study area. Uplift to the north and growth faulting along the shelf edge, to the south, has resulted in great differences in the depth in which the top of the Lower Tuscaloosa is found over a very short distance (three to six miles). In southern Hancock County, the top of the Lower Tuscaloosa is approximately -9000 feet (subsea); offshore, to the southwest, it quickly drops to a depth of -16,500 feet (subsea). The eastern limit of the deep Tuscaloosa gas trend of southeast Louisiana (Rigolets Field) lies offshore, just south (three miles) of the southwestern border of the study area. However, in that three miles the nature of the Lower Tuscaloosa changes drastically. This is due to the radical variation in the depositional environment in the two areas. During the time of Tuscaloosa deposition, the southwestern limit of the study area was situated on the periphery of the continental shelf, with a shallow water environment to the north. Just to the south is the flexure of the continental shelf which is the onset of a deep water environment.

Stratigraphically, the Lower Tuscaloosa is at the base of the Upper Cretaceous (Gulfian) Series; it overlies Lower Cretaceous sediments of the Dantzler Formation and underlies the Upper Cretaceous shales of the Middle Tuscaloosa (Dockery, 1981)(Figure 5). In updip areas, the contact between the Dantzler and the Lower Tuscaloosa is unconformable. However, after evaluation of deposition patterns and sample data, the author believes the contact between the Dantzler and the Lower Tuscaloosa to be transitional in the study area.

The beginning of the Lower Tuscaloosa (Cenomanian Stage) was a period of major sea regression (Figure 6)(Vail et al., 1977). Depositional environments graded upward from alluvial plain through deltaic to marine deposits as a period of sea transgression followed in the latter part of the Cenomanian Stage. In the Mississippi Gulf Coast, the Lower Tuscaloosa can be divided into the Massive Sand Member and the Stringer Sand Member. The Massive Sand, usually the basal unit of the Lower Tuscaloosa, is recognized on an electric log by a high SP signature and low induction and laterolog resistivity curves

(Devery, 1982). Overlying the Massive Sand Member is the Stringer Sand Member. The Stringer Member is a section of gray, fine- to medium-grained sandstone with some interbedded shales and mudstones. The Stringer Member is of fluvial-deltaic origin and therefore is characteristically discontinuous and is found in various thicknesses (Chasteen, 1983). The Stringer Sand Member can be recognized on the electric log by a higher SP and resistivity curve than the overlying Middle Tuscaloosa shale section.

In southern Hancock County, in the Celeron well, the top of the Lower Tuscaloosa is found at -9270 feet (subsea). It is in contact with the Lower Cretaceous Dantzler Formation at -9630 feet (subsea). It is a 360-foot section of white to light gray to gray, fine- to medium-grained, loosely consolidated, sightly calcareous sandstones, light gray to gray, soft, calcareous siltstones, and gray to dark gray, firm, fissile shales. To the east, in the Chevron MS87 well, the top of the Lower Tuscaloosa is at -10,003 feet (subsea) and in contact with the Dantzler at -10,355 feet (subsea). It is a 352-foot section of sands, silts, and shales. The sandstones are white to light gray, very fine- to fine-grained, subangular to subrounded, slightly calcareous, and loosely to moderately well consolidated. The siltstones are light gray to gray, moderately firm, arenaceous, calcareous, and micaceous in part. The shales are light to dark gray, occasionally brown, firm to brittle, fissile, calcareous, with traces of pyrite, mica, and silt. Farther to the east, in the Floto well, the top of the Lower Tuscaloosa is at -9250 feet (subsea) and is in contact with the top of the Dantzler at a depth of -9690 feet (subsea). The 440-foot section consists of white to light gray, fine- to medium-grained, loosely consolidated sandstone interbedded with gray to black, micaceous, calcareous shale. Large-grained, well-rounded, quartz pebbles are present in the lower portion of the section. In the Chevron 5062 well, the top of the Lower Tuscaloosa is at -9080 feet (subsea) and is in contact with the underlying Dantzler at -9430 feet (subsea). The section consists of a 350-foot section of interbedded sands, silts, and shales. The sandstones are predominantly light gray to white, occasionally light brown, very fine- to fine-grained, moderately well consolidated, well sorted, calcareous, with glauconite inclusions. The siltstones are light gray to gray, moderately firm, slightly calcareous, and occasionally carbonaceous. The shales are gray to dark gray, firm to moderately hard, finely micaceous, and slightly calcareous.

Using subsurface well data from the Floto well and wells to the north onshore, a regional strike of northwest-southeast and a dip of approximately 60 feet per mile to the southwest at the Lower Tuscaloosa depth has been determined (Luper, 1985).

MIDDLE TUSCALOOSA:

The sea continued to transgress during the Middle Tuscaloosa interval and subsequently the fluvial-deltaic sediments of the Lower Tuscaloosa were covered by the deposition of the marine shales of the Middle Tuscaloosa in much of the northern Gulf Coast, including the study area. In the Celeron well, the top of the Middle Tuscaloosa is at -8840 feet (subsea). It is a 430-foot section of marine sediments which consist of gray to dark gray, soft to firm, slightly calcareous shales with minor amounts of interbedded very fine-grained sands and silts. In the Chevron MS87 well, the top of the Middle Tuscaloosa is at -9542 feet (subsea) and is 461 feet thick. It is also a marine shale, gray to dark gray, moderately firm, micaceous, slightly to moderately calcareous, arenaceous in part, with traces of pyrite. In the Floto well, the top of the marine shale is at -8790 feet (subsea). The section is also primarily a gray to dark gray, micaceous shale. In the Chevron 5062 well, the top of the section is at -8602 feet (subsea). It is a 478-foot section of marine sediments consisting of a gray to dark gray, moderately firm to firm, calcareous, slightly carbonaceous shale as the primary rock type. There are minor amounts of very fine-grained sandstones and siltstones interbedded and a dark brown, firm to hard, microcrystalline limestone bed in the basal portion of the unit.

UPPER TUSCALOOSA:

Terrigenous-sourced clastics continued to be deposited in a shallow shelf, marine environment as sea level continued to rise and the shoreline retreated to the north and northeast. In the Celeron well, the top of the Upper Tuscaloosa Formation is found at -8480 feet (subsea); it is a 360-foot section of primarily dark gray to gray, firm to moderately hard shale with minor interbedded white to light gray, very fine- to fine-grained sands and siltstones. In the Chevron MS87 well, the top of the Tuscaloosa is at -9224 feet (subsea) and consists of a 318-foot section of gray, moderately firm, micaceous, calcareous, argillaceous shale with interbedded gray, moderately firm, arenaceous, calcareous siltstone. To the east, in the Floto well, the top of the Upper Tuscaloosa is at -8408 feet (subsea) and the unit is 382 feet thick. The section consists of light gray to white, very fine- to fine-grained, calcareous, sparingly glauconitic sandstone interbedded with green to dark gray, micaceous shale. Farther east, in the Chevron 5062 well, the top of the Tuscaloosa is at -8290 feet (subsea). The section is 312 feet thick and is predominantly a shale with minor amounts of interbedded sands and siltstone. The shales are gray to dark gray, firm to moderately hard, calcareous, and occasionally carbonaceous and glauconitic. The sandstones are white to light gray, moderately well consolidated, very fined-grained, well sorted, rounded to subrounded, and calcareous cemented.

AUSTIN:

Sea level continued to rise during the latter part of the Upper Cretaceous Series (see Figure 6) (Vail et al., 1977). From the Coniacian Stage through the Maastrichtian Stage the shoreline continued to retreat to the north, covering the Gulf Coast margins in a shallow epicontinental sea which resulted in the deposition of predominantly marls and chalks in the study area. This chalk section can be divided into the Selma and the Austin groups with the Selma overlying the Austin (Dockery, 1981).

In the Celeron well in southern Hancock County, the top of the Austin Chalk is at -8290 feet (subsea) and the unit is approximately 190 feet thick. It consists of white to light gray, soft to firm, microfossiliferous limestone with light gray shale and siltstone stringers in the basal section of the formation. Eastward, in the Chevron MS87 well, the top of the Austin Chalk is found at a depth of -8994 (subsea). It is a 230-foot section of light gray, moderately firm, microcrystalline chalk which grades into an argillaceous, microfossiliferous limestone. In the Floto well, the top of the Austin Chalk is found at -8308 feet (subsea) and the unit is 100 feet thick. Its composition is primarily the same as in the Celeron well with the addition of minor amounts of light gray bentonite and dolomite. In the Chevron 5062 well, the top of the Austin is found at -8017 feet (subsea). It is a 273-foot section of interbedded white to light gray, soft to firm, calcareous chalk and dark gray to black calcareous shales with minor silt and sand stringers.

SELMA:

The Selma Group conformably overlies the Austin Chalk in the Mississippi Gulf Coast. As the Cretaceous Period came to an end, the transgressing sea had reached a maximum highstand (Vail et al., 1977). Large expanses of the northern Gulf Coast were covered in a shallow epicontinental sea (Figure 8). Chalks and marls were deposited in the study area (Figure 9). In the Celeron well, the top of the Selma is found at -8090 feet (probably an incomplete section due to faulting). It is a 200-foot section of white to grayish-white, soft to moderately firm, microcrystalline chalk. In the Chevron MS87 well, the top of the Selma is found at -8338 feet (subsea). It is a 656-foot section of predominantly light gray to white, very firm to hard, microcrystalline chalk with minor amounts of interbedded marls and gray shales. To the east, in the Floto well, the top of the Selma is found at -7165 feet (subsea) and consists of an 1143-foot section of light gray to grayish white chalk. Farther east, in the Chevron 5062 well, the top of the Selma is found at -6993 feet (subsea). Log and sample data indicate a 1024-foot section of predominantly white to light gray, soft to firm, calcareous chalk with subordinate stringers of dark gray to gray, firm to hard, calcareous, slightly carbonaceous shale. Also present are thin, infrequent, silt and sand stringers. Structural interpretation of seismic data on the Mississippi Shelf, at the Selma Chalk level, shows normal southwest dip at the rate of approximately 120 feet per mile (Luper, 1985).

PETROLEUM

The offshore waters of Mississippi have an attractive, and at present an untested, oil and gas resource potential in the form of thick, shelf-margin Cretaceous-age sediments. Oil and gas are produced from most of the units of Cretaceous age in the central and northeastern Gulf Coast. The depositional history of the area is favorable for the accumulation and preservation of substantial amounts of organic material and for the development of reservoir quality rocks.

In the Mississippi Gulf Coast, production has been established from several Cretaceous formations. In southern Hancock County (Figure 2), Ansley Field has produced 686,731 bbl. of oil and 15,042,967 mcf of gas from the basal Dantzler/upper Washita-Fredericksburg Cuevas Sand since its discovery in 1955. Kiln Field, in southern Hancock County (Figure 2), has produced 107,957 bbl. of oil and 22,226 mcf of gas from the Cuevas Sand since its discovery in 1959. Waveland Field (Figure 2), discovered in 1965, produces from Lower Cretaceous Rodessa, Mooringsport, Paluxy, and Washita-Fredericksburg reservoirs. The primary producing intervals are in the Mooringsport Formation with a secondary interval in the Rodessa Formation. The Ferry Lake Anhydrite is present only on a very limited local level and not very anhydritic when present.

Waveland Field is a broad stratigraphic trap situated on the Hancock Ridge, a south-plunging salient of the Wiggins Arch. Production is from the section of a back-reef facies consisting of the orbitolinid packstones and grainstones. Porosity in the field is to a degree a function of the type of and the diagenesis of the forams (orbitolinids found in packstone and miliolids found in grainstone). When the orbitolinids are the primary foram present, the pore spaces are restricted by the nature of the small and sinuous pore-throat; this allows only gas to flow and restricts the flow of water. A problem in Waveland is the production of water. If there is too much porosity and permeability, water production is too great. The ideal situation is limited porosity and therefore limited water production. The miliolid facies (and the leaching of the miliolid tests) results in a porosity (10 - 17%) and permeability (7 md) such that there is a greater tendency to produce water with gas, which usually results in the well being noncommercial. Production is also controlled by fracturing of the reservoir rocks. A map of cumulative production shows that the best producing wells lie on the crest of the Hancock Ridge (north-south trending). This is a function of the fracturing, which allows migration through the interbedded shales. The fracturing is greatest on the apex of the structure. The better production occurs when an east-west fracture pattern is present. Development wells drilled east or west of a producing well show pressure communication while wells located to the north do not (Baria, personal communication, 1992). The source rock for Waveland Field is thought to be the Mooringsport limes and shales even though analysis indicates a low kerogen content. Cumulative production at Waveland Field, as of 1/1/91, is 2,437,725 bbl. of oil and 150,657,420 mcf of gas (Mississippi State Oil and Gas Board, 1991).

To the west of the study area, in Louisiana state water-bottom tracts in Lake Borgne, over 351,000 bbl. of condensate and 47 Bcf of gas have been produced (as of 1/1/91) from Rigolets Field, a deep (15,000'+) Upper Cretaceous Tuscaloosa oil and gas field. Rigolets Field, completed by Chevron U.S.A. in June 1975 (Petroleum Information Corporation, 1980), is presently the easternmost extension of production in the Edwards (Cretaceous) Reef Trend which extends across central Louisiana (Devery, 1982).

Northeast of the Mississippi Sound area, production from Cretaceous-age sediments of the Tuscaloosa Group was first established in 1950 at South Carlton Field (Clarke and Baldwin counties, Alabama) and followed up in 1952 at Pollard Field (Escambia County, Alabama). Cumulative production from these two fields is 19,232,155 bbl. of oil as of January 1991 (Alabama State Oil and Gas Board, 1990). Even closer to the area of study, Citronelle Field (Mobile County, Alabama) proved productive in upper and lower Rodessa pools. This field, discovered in 1955, has produced 151,114,347 bbl. of oil and 13.5 Bcf of gas, as of January 1991 (Alabama State Oil and Gas Board, 1990). Dantzler, Washita-Fredericksburg, and Paluxy pay were logged by Pruet Production Company in two Baldwin County, Alabama, wells in 1985, sparking renewed interest in exploration for Cretaceous-age reservoirs in southwestern Alabama and southeastern Mississippi (Oil and Gas Journal, 1985).

For many years there has been a viable offshore oil and gas industry in Louisiana and in more recent years in Alabama. Exploration in Mississippi's state waters has not been as robust as its neighbors. The first offshore well was drilled in 1952. Gulf Refining Company spudded the #1 Gulf Melben northeast of Grand Island in Block 95 of the Mississippi Sound. The well was drilled to a depth of 10,571 feet (Lower Cretaceous) and was plugged and abandoned in September 1952 as a dry hole. In 1954, the C. A. Floto was drilled in Block 48 of the Mississippi Sound near Horn Island off the coast of Jackson County, Mississippi. The well was drilled to a depth of 13,041 feet (Paluxy) and was abandoned with no shows of oil or gas reported. In 1956, the J. Willis Hughes Company drilled the No. 3 State of Mississippi in the St. Louis Bay, Block 23, off the coast of Hancock County. The well was drilled to a depth of 9996 feet (Lower Tuscaloosa) and abandoned in November 1956. Mississippi's offshore waters were not tested again until Sapphire Exploration and Production drilled the No. 1 State of Mississippi south of Ship Island in Block 90 of the Mississippi Sound. The well was drilled to a depth of 5927 feet in the *Heterostegina* "Reef" Formation of the Upper Oligocene. In September 1986 the well was abandoned as a dry hole. In December 1988, Chevron spudded the No. 1 Mississippi Sound, Block 57, off the coast of Long Beach, Mississippi. This was the first well to test Jurassic sediments in the Mississippi Sound. The well was drilled to 23,550 feet (Norphlet). In October 1989, the well was plugged and abandoned as a dry hole. In November 1984, Chevron spudded the OCS-G-5062 well in Mobile Area Block 861, south of Pascagoula, Mississippi. This well was drilled to a total depth of -21,425 feet (subsea). Production was established in the Jurassic Norphlet Formation. To date, there has been no Cretaceous production established from the Mississippi offshore waters.

CONCLUSIONS

Oil and gas are produced from most of the units of the Cretaceous in the central and northeastern Gulf Coast. In the Mississippi Gulf Coast, production has been established in several of these Cretaceous units. The depositional history of the area is favorable for the accumulation and preservation of substantial amounts of organic material and for the development of reservoir quality rocks. Rudist reefs, porous dolomites, fractured chalks, along with various terrigenous clastic facies such as delta fronts, strandline, and coastal plains environments are all present in the study area (Rainwater, 1968).

The principal producing horizons in the study area have been the structure-related traps associated with the Hancock Ridge in Hancock County. Due to the presence of the Wiggins Arch extending east-west across southern Mississippi from Louisiana to the western side of Mobile Bay, a restricted basin (the Mississippi Interior Salt Basin) was present during the primary period of salt deposition of the early Jurassic to the north of the Wiggins Arch. This allowed massive beds of salt to accumulate in the basin. Salt-related structures are the primary producing structures in the Mississippi Interior Salt Basin. South of the Wiggins Arch, the sea was relatively free to circulate and the salt deposition was minimized. Thus few salt-related structures are present in this rigid platform-like area south of the Wiggins Arch in the Mississippi Gulf Coast. Therefore, in the future, the majority of the oil and gas exploration efforts will probably be stratigraphic in nature.

Though production to date has been from structure-related traps associated with the Hancock Ridge in Hancock County, sparse exploration of the Cretaceous interval has taken place in the remaining Gulf Coast area. Thus, there is a substantial area that is left for future oil and gas exploration.

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