AN INTEGRATED LITHOSTRATIGRAPHIC, BIOSTRATIGRAPHIC, AND SEQUENCE STRATIGRAPHIC APPROACH TO PALEOGEOGRAPHIC RECONSTRUCTION: EXAMPLES FROM THE UPPER EOCENE AND LOWER OLIGOCENE OF ALABAMA AND MISSISSIPPI

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Berry H. Tew and Ernest A. Mancini[1]

ABSTRACT

Paleogeographic reconstruction involves determining the spatial and temporal relationships of strata that can represent diverse ancient environments of deposition. The production of a paleogeographic map at a given temporal horizon generally requires that a time datum be drawn between spatially separated stratigraphic intervals that often have different lithofacies which represent the same time interval. This method of reconstruction is often hampered by the fact that chronostratigraphic resolution provided by the most often used tool (biostratigraphy) is commonly inadequate when used in paleogeographic reconstruction across lithologically diverse strata that represent different environments of deposition at a specific temporal horizon. Unconformity-bounded depositional sequences determined from sequence stratigraphic analysis can be used as a basis for paleogeographic reconstruction. Major surfaces associated with depositional sequences present a physical stratigraphic framework that provides relative chronostratigraphic datums which may be used to construct paleogeographic maps. Surfaces associated with a depositional sequence that have chronostratigraphic significance include upper and lower sequence bounding unconformities, transgressive surface, and surface of maximum sediment starvation/maximum transgression. These bracketing surfaces are used as constraints to interpret relative time lines at various points within the sequence. Interpreted time correlative points are then used in conjunction with lithostratigraphic and biostratigraphic relationships to produce paleogeographic maps illustrating the regional distribution of paleoenvironments and rock types at various time horizons within relative sea level cycles.

The Tejas A Gulf Coast (TAGC)-4.3 and TAGC-4.4 depositional sequences of Alabama and Mississippi provide excellent examples of the sequence stratigraphic method of paleogeographic reconstruction. The TAGC-4.3 sequence is a type 2 sequence that includes the Cocoa Sand (shelf margin systems tract), Pachuta Marl (lower transgressive systems tract), and Shubuta (upper transgressive systems tract/lower condensed section) Members of the Yazoo Clay, the Red Bluff Clay/Bumpnose Limestone interval (lower highstand systems tract/upper condensed section), and the Forest Hill Sand (upper highstand systems tract). The TAGC-4.4 sequence includes the Mint Spring Marl Member of the Marianna Limestone (lower transgressive systems tract), the Marianna Limestone (upper transgressive systems tract/lower condensed section), and the Glendon Limestone Member of the Byram Formation (upper condensed section/highstand systems tract).

Application of the methodology outlined above to these sequences indicates that sequence stratigraphy can be a useful tool in paleogeographic reconstruction and can greatly enhance the understanding and interpretation of chronostratigraphic relationships within a depositional basin that might not be resolved using other methods.

INTRODUCTION

Upper Eocene (Bartonian and Priabonian Stages) and lower Oligocene (Rupelian Stage) strata are present in outcrop and in the subsurface in southeastern Mississippi and southwestern Alabama. The outcrops of these strata represent one of the most complete marine and marginal marine Upper Eocene and Lower Oligocene sections in the world. These strata include, in ascending order, the Moodys Branch Formation, the North Twistwood Creek Clay, the Cocoa Sand, the Pachuta Marl and the Shubuta Members of the Yazoo Clay, the Bumpnose Limestone, the Red Bluff Clay, the Forest Hill Sand, the Mint Spring Marl Member of the Marianna Limestone (Mint Spring Formation in Mississippi), the Marianna Limestone, the Glendon Limestone Member of the Byram Formation (Glendon Limestone in Mississippi), the informal "Byram marl" member of the Byram Formation (Byram Formation in Mississippi), and the Bucatunna Clay Member of the Byram Formation (Bucatunna Clay in Mississippi) (Figure 1). The Moodys Branch Formation, the Yazoo Clay, and the Crystal River Formation comprise the Jackson Group and the Bumpnose Limestone, Red Bluff Clay, Forest Hill Sand, Mint Spring Marl, Marianna Limestone, and the members of the Byram Formation (Glendon Limestone, Byram Formation, and Bucatunna Clay in Mississippi) comprise the Vicksburg Group in the eastern Gulf Coastal Plain area (Toulmin, 1967; Raymond and others, 1988; Mancini and Tew, 1988a, b).

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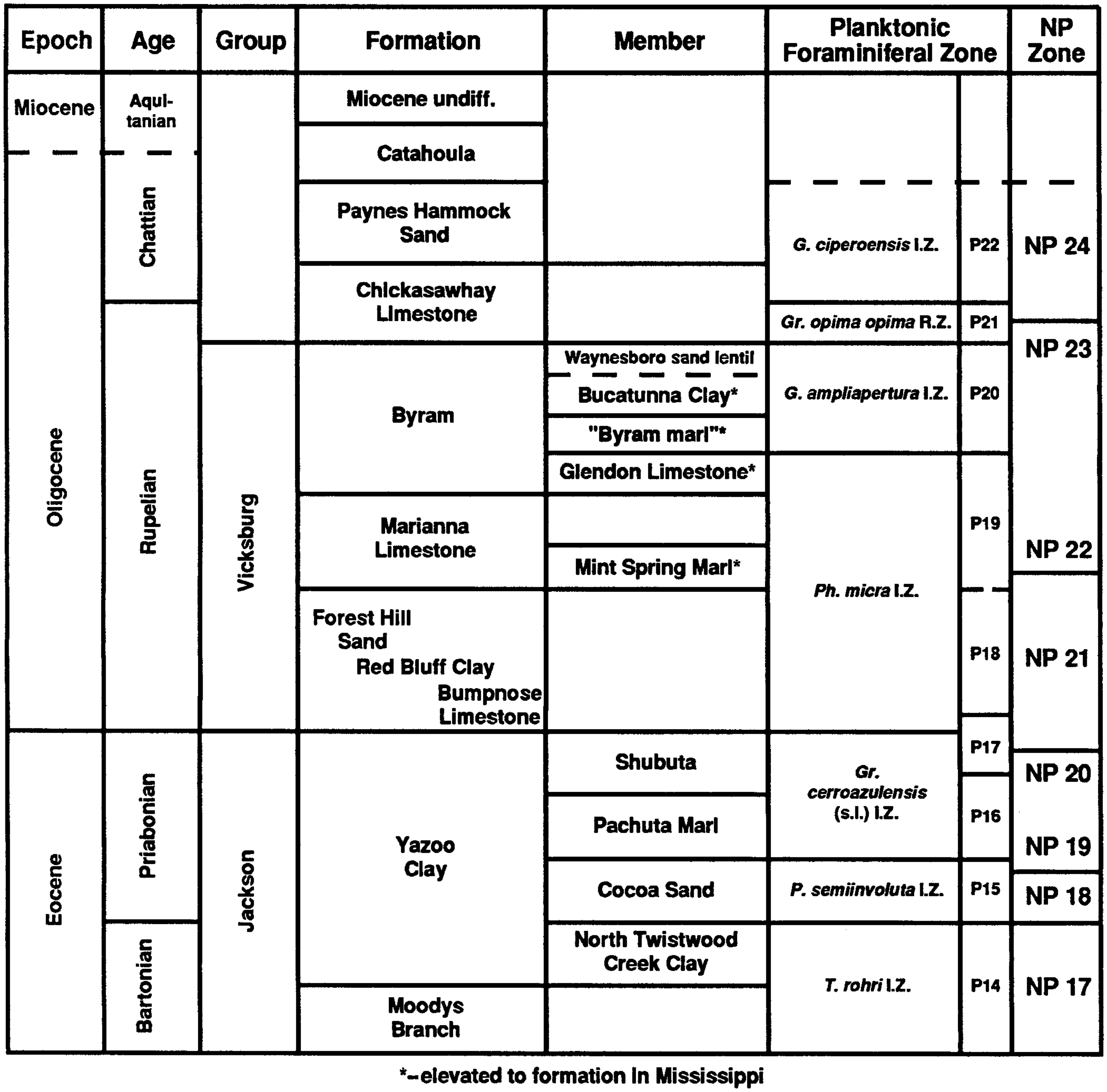

Figure 1. Stratigraphy and biostratigraphy of the Upper Eocene and Oligocene in southeastern Mississippi and southwestern Alabama.

The Jackson Group includes Bartonian and Priabonian age strata, and the Vicksburg Group, along with the lower portion of the overlying Chickasawhay Limestone, approximately represents the Rupelian Stage in European stage terminology (Poag, 1972; Mancini, 1979; Hazel and others, 1980; Stainforth and Lamb, 1981; Bybell, 1982; Siesser, 1983; Mancini and Waters, 1986; Mancini and others, 1988; Raymond and others, 1988). The Rupelian-Chattian Stage boundary is generally placed in the Chickasawhay Limestone (Poag, 1972; Mancini and Tew, 1991). The planktonic foraminiferal and calcareous nannoplankton biostratigraphic zonations of these units, as well as the chronostratigraphic relationships, are shown on Figure 1. These zonations are composited from the works of Poag (1972), Barker (in Blow, 1979), Mancini (1979), Hazel and others (1980), Stainforth and Lamb (1981), Bybell (1982), Siesser (1983), Mancini and Waters (1986), Pettway and Dunn (1990), and Mancini and Tew (1991).

Due to the excellent surface exposures of the Eocene and Oligocene strata in the study area, these rocks have been extensively studied by various workers in terms of classical Gulf Coastal Plain stratigraphy and biostratigraphy. In terms of paleogeography, it has long been recognized that these strata include a predominantly marginal marine to marine terrigenous clastic, western lithosome in Mississippi and a predominantly marine, carbonate eastern lithosome in south-central Alabama and the Florida panhandle (Cooke, 1918; MacNeil, 1944; Huddlestun and Toulmin, 1965; Hazel and others, 1980; Mancini and Waters, 1986; Mancini and Tew, 1986). These lithosomes intertongue and are transitional across southwestern Alabama. While this general paleogeographic setting has been recognized and accepted by most workers, little research has focused on these lithofacies changes in terms of depositional dynamics within the basin as related to relative changes in sea level and concomitant changes in the position of the shoreline (progradation and retrogradation of depositional facies). Relative sea level changes occur in response to the interaction of eustasy, basin subsidence, and sediment supply and result in cyclic, repetitive sequences of genetically related strata that are bounded by surfaces of erosion or nondeposition (unconformities) (Van Wagoner and others, 1988). Sequence stratigraphy is the study of rock relationships within this framework of repetitive, unconformity-bounded depositional sequences and provides a powerful tool to study and understand stratigraphic, lithofacies, and paleogeographic relationships among strata within a depositional basin.

OBJECTIVES

The objectives of this study are (1) to establish the stratigraphy and lithofacies relationships of the Upper Eocene and Lower Oligocene strata that crop out or occur in the subsurface in southeastern Mississippi and southwestern Alabama; (2) to determine the relationships of stratigraphy, lithofacies distribution, and paleogeography to relative changes in sea level and unconformity-bounded depositional sequences utilizing the concepts of sequence stratigraphy; and (3) to use these relationships, where data are sufficient, to reconstruct the paleogeographic setting of the study area during this time period.

These objectives are achieved by study of surface localities and core material of Eocene and Oligocene strata in southeastern Mississippi and southwestern Alabama (Figure 2). Surface exposures include complete, partial, and composite sections of these strata. The most stratigraphically complete of the exposures in the study area include those along the Chickasawhay River in Clarke and Wayne Counties, Mississippi, the exposure at St. Stephens Quarry in Washington County, Alabama, and exposures along Little Stave Creek in Clarke County, Alabama. Core materials from two stratigraphic test holes were used in this study. The Arco St. Stephens core hole was drilled adjacent to the

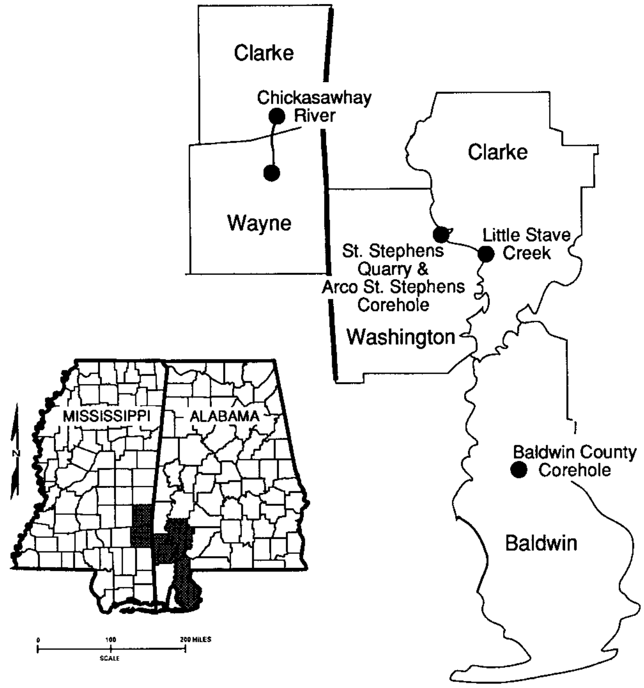

Figure 2. Index map showing localities studied.

surface exposure at St. Stephens Quarry (Figure 2) in Washington County, Alabama, and provided unweathered lithologic samples and precise thickness measurements of the strata exposed at that locality. The Baldwin County corehole was drilled just south of the city of Bay Minette, Alabama, and provided downdip control (Figure 2).

While the above-mentioned localities and cores provide the database from which the majority of interpretations and conclusions in this work were drawn, data from other exposures illustrative of various contact and/or stratigraphic relationships were also integrated into the study as appropriate. In addition, the vast body of data provided in the reports and publications of the Alabama and Mississippi geological surveys, as well as other studies performed by various workers, were invaluable as sources of information which was used to supplement the data from the immediate study area in the regional paleogeographic reconstructions.

STRATIGRAPHY

Jackson Group

The Upper Eocene (Bartonian-Priabonian) Jackson Group includes the Moodys Branch Formation, the Yazoo Clay, and the Crystal River Formation. The Moodys Branch Formation disconformably overlies strata of the Middle Eocene (Lutetian-Bartonian) Claiborne Group in the study area (Toulmin, 1977). The reference locality for the Moodys Branch is in a ravine at Riverside Park, (within the city of Jackson), Hinds

County, Mississippi (Dockery, 1977). At this locality, the Moodys Branch is 17 feet thick and can be divided into a lower unit consisting of 13 feet of greenish-gray glauconitic, fossiliferous, calcareous, argillaceous, fine-grained sand and an upper unit consisting of 4 feet of light bluish-gray glauconitic, fossiliferous, sandy marl (Toulmin, 1977). In southwestern Alabama, the Moodys Branch generally consists of 10 to 20 feet of greenish-gray glauconitic, fossiliferous, calcareous sand and sandy marl (Toulmin, 1977).

The Yazoo Clay, which conformably overlies the Moodys Branch Formation, consists of four members in the study area. These are, in ascending order, the North Twistwood Creek Clay, the Cocoa Sand, the Pachuta Marl, and the Shubuta Members (Murray, 1947, 1963). The North Twistwood Creek Clay Member consists of 40 to 60 feet of greenish-gray to bluish-gray fossiliferous, calcareous, micaceous, silty clay and marl (Murray, 1947; Toulmin, 1977; Mancini and others, 1987). The type locality for the unit is along North Twistwood Creek, near Rose Hill, Jasper County, Mississippi (Murray, 1947, 1963). The North Twistwood Creek Clay Member is disconformably overlain by the Cocoa Sand Member along a sharp, burrowed contact (Mancini and others, 1987). The Cocoa Sand Member includes about 60 feet of gray fossiliferous, calcareous, massive, fine- to medium-grained sand at the type locality near the old Cocoa Post Office, which is close to the town of Melvin, Choctaw County, Alabama (Cooke, 1933; Toulmin, 1977). The unit thins to the east and west from this locality and in some areas, such as Little Stave Creek, Clarke County, Alabama, consists of a thin sandy marl which is difficult to distinguish from the overlying Pachuta Marl Member (Mancini and others, 1987). The type locality for the Pachuta Marl Member is on Pachuta Creek, near Pachuta, Clarke County, Mississippi. In this area and throughout the study area, the Pachuta consists of from 6 to 12 feet of greenish-gray indurated, fossiliferous, argillaceous marl and limestone; authigenic phosphate and glauconite occur in the unit in upward increasing proportions (May, 1974; Toulmin, 1977). In general, the Pachuta is an upward-fining unit that grades into outer marine-shelf clay of the overlying Shubuta Member. The type locality of the Shubuta is along the Chickasawhay River near Shubuta, Clarke County, Mississippi, where the unit consists of about 90 feet of grayish-olive-green blocky to massive, fossiliferous, calcareous clay. The Shubuta thins eastward into southwestern Alabama and then thickens into south-central Alabama where it intertongues with the Crystal River Formation (Toulmin, 1977). In this area, the Crystal River overlies the Pachuta Marl Member and underlies the Bumpnose Limestone, which is correlative with the Red Bluff Clay farther to the west (MacNeil, 1944; Huddlestun, 1965). To the east and into the Florida Panhandle, the other members of the Yazoo Clay (North Twistwood Creek Clay, Cocoa Sand, and Pachuta Marl) also grade into the Crystal River Formation (Huddlestun and Toulmin, 1965). In these areas, the Crystal River is considered to be equivalent to the entire Yazoo Clay stratigraphic interval of Mississippi (Vernon, 1942). The Yazoo interval is also represented by the Crystal River Formation in the subsurface in Baldwin County, Alabama. The type locality of the Crystal River is in the Crystal River Rock Company Quarry, Citrus County, Florida, where the unit consists of 108 feet of white chalky, fossiliferous limestone (Puri, 1953; Moore, 1955). The unit thins to about 60 feet in south-central Alabama, where it consists of white fossiliferous, argillaceous, silty limestone (Mancini and Waters, 1986).

Vicksburg Group

The Lower Oligocene (Rupelian) Vicksburg Group includes, in ascending order, the Bumpnose Limestone, the Red Bluff Clay, the Forest Hill Sand, the Mint Spring Marl Member of the Marianna Limestone (Mint Spring Formation in Mississippi), the Marianna Limestone, the Glendon Limestone Member of the Byram Formation (Glendon Limestone in Mississippi), the informal "Byram marl" member of the Byram Formation (Byram Formation in Mississippi), and the Bucatunna Clay Member of the Byram Formation (Bucatunna Clay in Mississippi). The Byram "marl" member/Formation and the Bucutunna Clay Member/Formation are not included in the unconformity-bounded depositional sequences under discussion here and, thus, will not be treated in this paper.

The Bumpnose Limestone, Red Bluff Clay, and Forest Hill Sand are facies equivalent strata that grade into one another laterally and vertically. In a stratigraphic sense, the Bumpnose may be considered the "lowermost" component of the stratigraphic sequence, and the Forest Hill may be considered the "uppermost." The type area of the Bumpnose Limestone is in the vicinity of Bumpnose road, north of the town of Marianna, Jackson County, Florida (Moore, 1955). In this area, the Bumpnose consists of 16 feet of white chalky, fossiliferous, glauconitic limestone (Moore, 1955). In south-central Alabama, the unit includes about 14 feet of white, glauconitic, fossiliferous, argillaceous limestone (Mancini and Waters, 1986). MacNeil (1944) recognized that the "*Lepidocyclina (Nephrolepidina) chaperi* Lemoine and R. Douville (= *L. (N.) fragilis* Cushman) zone" of the Florida panhandle, later named the Bumpnose Limestone by Moore (1955), was the eastern carbonate equivalent of the Forest Hill/Red Bluff interval of Mississippi and southwestern Alabama. Huddlestun and Toulmin (1965) recognized that the Red Bluff and Bumpnose are laterally gradational across southern Alabama, with the Red Bluff becoming more calcareous eastward and the Bumpnose becoming more argillaceous and arenaceous westward. These workers attributed the westward increase in terrigenous clastic material in the interval to the influence of contemporaneous Forest Hill deltaic deposition to the west-northwest (Huddlestun and Toulmin, 1965). Huddlestun and Toulmin (1965) referred to the Red Bluff/Bumpnose interval in the area of gradation, approximately bordered on the west by the Tombigbee River and on the east by the Alabama River, as the "Red Bluff equivalent." Throughout this area, this stratigraphic interval consists generally of 15 feet or less of interbedded glauconitic, fossiliferous, arenaceous marl to limestone, much like the Bumpnose in its type area, and dark green to brown, glauconitic, fossiliferous marly clay, which resembles the Red Bluff in its type area (Toulmin and others, 1951; Huddlestun and Toulmin, 1965; Glawe, 1967; May, 1974; Waters, 1983; Mancini and Copeland, 1986). Due to the interbedded nature of these lithologic units, the authors will use "Red Bluff/ Bumpnose interval" when referring to this stratigraphic interval in the area of gradation. West of the Tombigbee River, limestone beds become less numerous and are generally overlain by typical Red Bluff lithologic units (Cooke, 1915; Toulmin and others, 1951).

The Red Bluff Clay was named by Hilgard (1860) for exposures of brown to green, ferruginous, glauconitic, fossiliferous, partially indurated clays and marls exposed at Red Bluff along the Chickasawhay River, west of the railroad bridge, 1.5 miles south of the town of Shubuta, Wayne County, Mississippi. In the Wayne County area, the Red Bluff ranges in thickness from 11 to 32 feet and consists mainly of dark gray to light brown, fossiliferous, glauconitic, ferruginous marls and clays (May, 1974; Dockery, 1982; Waters, 1983; MacNeil and Dockery, 1984). The Red Bluff thins to the west as it grades into the basal fluvial and deltaic sediments of the Forest Hill Sand (Dockery, 1982).

The Red Bluff is conformably overlain by and intertongues with the Forest Hill Sand. In central and western Mississippi, where the Red Bluff is absent, the Forest Hill overlies the Yazoo Clay. The equivalence of the Forest Hill and Red Bluff was first recognized by Cooke (1918), who regarded the Forest Hill to represent deltaic deposition occurring to the west of contemporaneous shallow marine deposition, represented by the Red Bluff. This view has since been supported by numerous workers (MacNeil, 1944; Cheetham, 1963; Deboo, 1965; Huddlestun and Toulmin, 1965; Glawe, 1969; May, 1974; Dockery, 1980, 1982; Hazel and others, 1980; MacNeil and Dockery, 1984; Mancini and Waters, 1986; Mancini and others, 1987). This deltaic complex prograded to the east-southeast and delta plain to prodelta sediments were deposited over the Red Bluff Clay and Red Bluff/Bumpnose interval as far west as the Tombigbee River area. The Forest Hill Sand was named by Cooke (1918) to replace the Madison Sands of Lowe (1915). The type locality of the Forest Hill Sand is on the Jackson-Raymond Road, 0.25 mile northeast of Forest Hill School, Hinds County, Mississippi (May, 1974). In general, the Forest Hill is composed of nonmarine to nearshore marine, dark, very fine-to fine-grained sand, silt, and laminated carbonaceous clay with lignite beds near the top and bottom of the unit (MacNeil, 1944; May, 1974). The unit is 100 feet thick in central and western Mississippi and thins to the east (Copeland and Deboo, 1967; May, 1974). At St. Stephens Quarry, 8.8 feet of dark-brown blocky, carbonaceous, sparingly fossiliferous clay was assigned by Glawe (1967) to the Forest Hill Sand. The Forest Hill at St. Stephens is one of the easternmost exposures of progradational sediments associated with the Forest Hill delta complex. Farther to the east, at Little Stave Creek in Clarke County, the Forest Hill is missing.

The Bumpnose Limestone, Red Bluff/Bumpnose interval, Red Bluff Clay, and/or Forest Hill Sand are disconformably overlain by either the Mint Spring Marl Member of the Marianna Limestone (Mint Spring Formation in Mississippi) or the Marianna Limestone, according to geographic location (MacNeil, 1944). The Marianna Limestone was named by Matson and Clapp (1909) for exposures of soft, porous, light-gray to white limestone characterized by an abundance of the larger foraminifera *Lepidocyclina (=Orbitoides) mantelli* (Morton) and the bivalve *Pecten poulsoni* (Morton) in the vicinity of Marianna, Jackson County, Florida. Cooke (1945) designated exposures west of the Chipola River near Marianna as the type locality. Along the Chipola River, Cooke (1945) reported the Marianna to consist of 30 feet of massive, homogeneous, white, chalky limestone. At St. Stephens Quarry, the Marianna is approximately 60 feet thick and consists of soft, white to gray fossiliferous limestone which is slightly glauconitic and argillaceous in the lower part (Glawe, 1967; Mancini and Copeland, 1986). From St. Stephens westward into Mississippi, the Mint Spring Marl (Member/ Formation) is recognized at the base of the Marianna. The Mint Spring, which is vertically and laterally gradational into the limestone facies of the Marianna, was named by Cooke (1918) for exposures of sandy, glauconitic, fossiliferous marl along Mint Spring Bayou near Vicksburg, Warren County, Mississippi. At St. Stephens, the Mint Spring consists of approximately 1.5 feet of yellowish-gray argillaceous, silty, glauconitic, pyritic, fossiliferous marl which disconformably overlies the Forest Hill Sand (Mancini and Copeland, 1986). Rounded clay clasts are common in the basal few inches of the unit directly above the disconformity surface, and burrows filled with Mint Spring material extend down into the clays of the Forest Hill. The upper limestone facies of the Marianna thins and becomes more sandy and glauconitic into Mississippi, and the Mint Spring thickens (Cooke, 1918; MacNeil, 1944; May, 1974). Along the Chickasawhay River, Wayne County, Mississippi, the limestone facies is approximately 40 feet thick and consists of light gray to yellowish-gray argillaceous, fossiliferous limestone (May, 1974). In this area, the Mint Spring, which ranges in thickness from approximately 1 foot to as much as 17 feet, consists primarily of dark gray, argillaceous to arenaceous, fossiliferous, glauconitic marl and disconformably overlies dark laminated clay of the Forest Hill Sand (May, 1974). Rounded clay clasts and broken and abraded shell material are common directly above the disconformity surface. On Mint Spring Bayou near Vicksburg, Warren County, Mississippi, the limestone facies of the Marianna consists of approximately 3 feet of sandy, fossiliferous limestone (Dockery, 1989). This is the westernmost reported occurrence of this facies (MacNeil, 1944; Dockery, 1989). In the Mint Spring

Bayou vicinity, the Mint Spring consists of less than 25 feet of glauconitic, fossiliferous sand and marl that disconformably overlies the Forest Hill Sand (Mellen, 1941; MacNeil, 1944; Dockery, 1989). The base of the Mint Spring is marked by a conglomeratic lag of clay pebbles, fossil fragments, and scattered finely divided lignitic material (Mellen, 1941).

The Glendon Limestone Member of the Byram Formation (Glendon Limestone in Mississippi) conformably and gradationally overlies the Marianna Limestone throughout the study area. In 1916, Cooke, in a still unpublished report to the Mississippi Geological Survey, first proposed the term ''Glendon Limestone'' in reference to the 18 to 20 feet of hard cream-colored to buff, ''semi-crystalline'' (i.e., tightly cemented) limestone overlying the Marianna Limestone at Glendon Station on the Southern Railway in Clarke County, Alabama (Cooke, 1918, 1926; MacNeil, 1944; May, 1974). Near Marianna, Jackson County, Florida, the Glendon overlies the Marianna Limestone and consists of approximately 18 feet of tan to gray dolomite with minor white hard limestone (MacNeil, 1944). At St. Stephens Quarry, Washington County, Alabama, the Glendon is 12 feet thick and consists of interbedded pale blue, argillaceous, silty, glauconitic, fossiliferous limestone and greenish-gray, argillaceous, silty, glauconitic, fossiliferous marl (Mancini and Copeland, 1986). The marl interbeds typically weather to yellowish-brown. In Wayne County, eastern Mississippi, the Glendon ranges from 15 to 36 feet in thickness and consists of hard ledges of medium gray to light-olive gray, fossiliferous limestone interbedded with gray to greenish-gray marl (May, 1974). In Warren County, western Mississippi, the Glendon ranges in thickness from 39 to 49 feet and includes interbedded buff to cream, hard to soft, argillaceous, arenaceous, fossiliferous, glauconitic marl and hard limestone (Mellen, 1941; MacNeil, 1944; Dockery, 1989). The Glendon is disconformably overlain by the Byram ''marl'' Member/Formation.

SEQUENCE STRATIGRAPHIC ANALYSIS AND PALEOGEOGRAPHY

The objective of sequence stratigraphic analysis is to determine genetically related ''packages'' of strata that result from cycles of relative sea level rise and fall. Strata included in these ''packages'' are constrained by the position of sequence-bounding unconformities or correlative conformities. Sequence analysis of geologic strata is based on field observation of lithofacies relationships and distributions, stratal stacking patterns, and contact relationships among units, in combination with geochronology, where available. Geochronology is most often provided by biostratigraphic zonations. Observation of these parameters allows for interpretations of cycles of change in relative sea level, which result in genetic sequences of transgressive and regressive strata and of the surfaces (sequence boundaries) that subdivide the stratigraphic succession into depositional sequences.

In this study, sequence stratigraphic analysis was applied to outcropping and subsurface Upper Eocene and Oligocene strata in southwestern Alabama and southeastern Mississippi. As stated earlier, localities used in this study were chosen based on completeness and continuity of exposure or on the presence of specific stratigraphic and/or contact relationships important to an understanding of the regional sequence stratigraphy. Two continuous cores of the strata studied for this work were also used: one in the area of outcrop in southwestern Alabama (St. Stephens Quarry core) and one in a more downdip position (Baldwin County core). Previously published work was used, where pertinent, to supplement observations made during this study, to more fully understand regional relationships outside of the immediate study area, and to provide the biostratigraphic framework used here to give chronostratigraphic meaning to the interpreted depositional sequences.

The production of a paleogeographic map at a given temporal horizon generally requires that a time datum be drawn between spatially separated stratigraphic intervals that often have different lithofacies which represent the same time interval. This method is often difficult because chronostratigraphic resolution provided by the most often used tool (biostratigraphy) is commonly inadequate when used in paleogeographic reconstruction across lithologically diverse strata that represent different environments of deposition at a specific temporal horizon.

Sequence stratigraphy is a very useful tool in paleogeographic reconstruction. Major surfaces within depositional sequences provide a physical stratigraphic framework that provides constraining relative chronostratigraphic datums which may be used to construct paleogeographic maps. These surfaces are the upper and lower sequence boundaries, the transgressive surface, and the surface of maximum sediment starvation/maximum transgression. Figure 3 is a schematic chronostratigraphic cross section of two stratigraphically adjacent depositional sequences that illustrates the relative time relationships of these major surfaces.

Genetically related depositional sequences are chronostratigraphically constrained by the sequence boundaries underlying and overlying the sequences. Sequence-bounding unconformities are generally diachronous surfaces; however, in all cases, such unconformities separate older rocks of an underlying depositional sequence from younger rocks of an overlying sequence (Mitchum, 1977; Van Wagoner, 1988). Thus, all strata occurring between the sequence boundaries were deposited during the time period represented by one cycle of relative sea level rise and fall.

Within a depositional sequence in which the transgressive surface is not coincident with the basal sequence boundary (as is the case when lowstand and shelf margin deposits occur directly over the lower sequence boundary), this first major marine-flooding

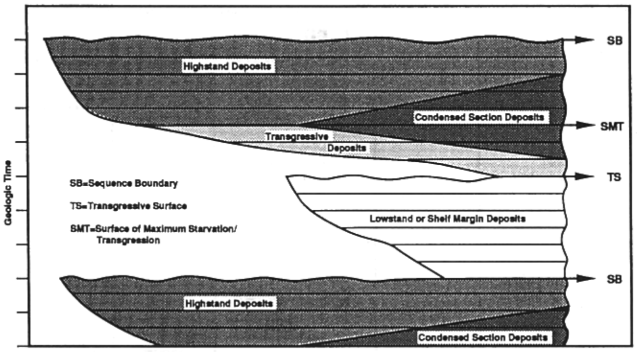

Figure 3. Schematic cross section illustrating the chronostratigraphic significance of major surfaces within a depositional sequence (modified from Loutit and others, 1988).

surface, although also diachronous, provides an important physical stratigraphic marker that separates older rocks from younger rocks within the sequence.

The surface of maximum sediment starvation/maximum transgression in a depositional sequence is another important sequence-stratigraphically defined surface that is helpful in paleogeographic reconstruction. This surface is essentially synchronous and separates the transgressive part of a sequence from the regressive part. Within a given depositional basin, maximum transgression and maximum sediment starvation occur at approximately the same time throughout the basin. Although water depths are drastically different, maximum transgression is ''seen'' at the strandline at the same time as on the outer shelf.

The foregoing discussion provides the framework for construction of paleogeographic maps at various ''times'' within a depositional sequence. The method uses the bracketing surfaces associated with a depositional sequence (upper and lower sequence boundaries, transgressive surface, surface of maximum sediment starvation/transgression) as constraints to interpret quasi-time lines at various points within the sequence. These interpreted time correlative points are then used in conjunction with stratigraphic and lithofacies relationships to produce paleogeographic maps illustrating the regional distribution of paleoenvironments and rock types at various time horizons within relative sea level cycles.

SEQUENCE STRATIGRAPHY OF THE UPPER EOCENE AND LOWER OLIGOCENE STRATA OF SOUTHWEST ALABAMA AND SOUTHEAST MISSISSIPPI

Various aspects of the sequence stratigraphy of Paleogene strata of the eastern Gulf Coastal Plain have been addressed by numerous studies in the past several years (Baum, 1986; Baum and Vail, 1987, 1988; Loutit and others, 1983; Mancini and Tew, 1986 , 1988a, 1991; Tew and Mancini, 1987, 1990; Vail and others, 1987; Mancini and others, 1988; Dockery, 1990).

From their study of the Paleogene strata of the eastern Gulf Coastal Plain, Mancini and Tew (1991) were able to determine the general characteristics of depositional sequences in this area. They reported that a typical type 1 depositional sequence consists of marine-shelf, barrier, and/or marginal marine cross-bedded sands (lowstand deposits) of variable thickness, but generally less than 50 feet thick; marine-shelf glauconitic sands, calcareous clays, silts, marls, and/or limestones (transgressive and condensed section deposits), generally less than 50 feet thick; and marine, marginal marine and/or deltaic sands, silts, clays, and/or lignite (highstand, regressive deposits), generally 100 feet or more thick. Type 2 depositional sequences exhibit the same characteristic environments of deposition, rock types, and thicknesses for the transgressive, condensed section, and highstand deposits (Mancini and Tew, 1991). Lowstand deposits are absent from type 2 sequences and can be replaced by shallow-water, marine-shelf glauconitic sands or sandy limestones (shelf margin deposits).

On the basis of regional stratigraphic, sedimentologic, and paleontologic relationships, five unconformity-bounded depositional sequences that include Upper Eocene and Lower Oligocene strata are recognized here (Figure 4). These are the Tejas A Gulf Coast (TAGC)-4.2, TAGC-4.3, TAGC-4.4, TAGC-4.5, and TAGC-4.6 depositonal sequences, which correspond to the TE3.2, TE3.3, TO1.1, TO1.2, and TO2.1 sequences, respectively, in the earlier terminology of Mancini and Tew (1991). This discussion will focus on the TAGC-4.3 and TAGC-4.4 depositional sequences as examples of the utility of sequence stratigraphic analysis in paleogeographic reconstruction.

TAGC-4.3 Depositional Sequence

The TAGC-4.3 depositional sequence includes the Cocoa Sand, Pachuta Marl, and Shubuta Members of the Yazoo Clay of the Eocene (Bartonian and Priabonian Stages) Jackson Group and the facies equivalent Crystal River Formation and the Bumpnose Limestone, Red Bluff/Bumpnose interval, Red Bluff Clay, and Forest Hill Sand of the lower Oligocene (Rupelian) Vicksburg Group (Figure 4). The sequence is underlain by the TAGC-4.2 sequence which consists of a basal type 1 sequence boundary, transgressive to condensed section deposits (glauconitic sands, marls, and limestones of the Moodys Branch Formation of the Jackson Group) and progradational, regressive highstand deposits (clays of the North Twistwood Creek Clay Member of the Yazoo Clay). The Cocoa Sand Member, where present, or the Pachuta Marl Member and lithofacies equivalent strata, disconformably overlie the North Twistwood Creek Clay Member. At an isolated expo-

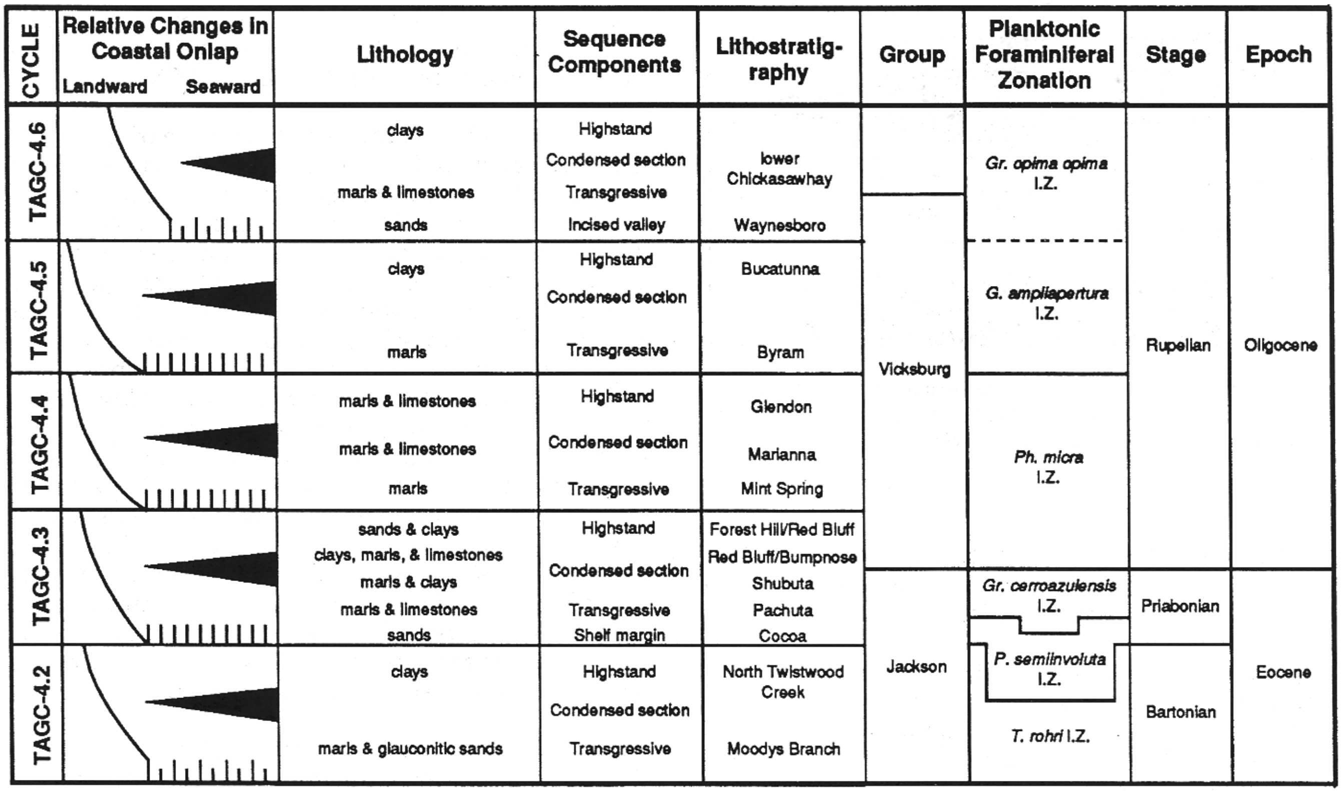

Figure 4. Coastal onlap chart illustrating the sequence stratigraphy of the Upper Eocene and Lower Oligocene strata in southeastern Mississippi and southwestern Alabama.

sure along U.S. Highway 84 in western Washington County, Alabama, the uppermost part of the North Twistwood Creek Clay Member is weathered and burrowed; burrows are partially filled with material from the Cocoa Sand Member above. The contact between the North Twistwood Creek and the Cocoa is sharp and very distinct with light brown, calcareous sand of the Cocoa overlying medium brown, weathered, blocky clay of the North Twistwood Creek. The lower part of the Cocoa Sand Member is conglomeratic and contains rounded phosphate and quartz pebbles. At Little Stave Creek, Clarke County, Alabama, and at Claiborne Bluff, Alabama River, Monroe County, Alabama, the North Twistwood is overlain by sandy marl of the Cocoa. At these localities, the contact is sharp and burrowed, and conglomeratic pebbles are common in the basal part of the Cocoa. The North Twistwood-Cocoa contact is a type 2 sequence boundary which separates highstand strata of the TAGC-4.2 sequence from shelf margin strata of the TAGC-4.3 sequence. This sequence boundary records an abrupt relative sea level fall and basinward shift in coastal onlap after deposition of the upward-shallowing, highstand, marine middle to inner shelf clays of the North Twistwood Creek Clay Member. This interpretation of the physical stratigraphy at the contact is supported by biostratigraphic data. The planktonic foraminiferal zonal boundary between the Bartonian Stage *Truncorotaloides rohri* Interval Zone and the Priabonian Stage *Porticulasphaera semiinvoluta* Interval Zone occurs at the contact of the North Twistwood Creek Clay Member with the Cocoa Sand Member (Mancini and Tew, 1991). These workers determined that planktonic foraminiferal zonal boundaries in Paleogene strata of the eastern Gulf Coastal Plain generally occur at either sequence boundaries or transgressive surfaces (Mancini and Tew, 1991).

The Cocoa exhibits features of an aggradational shelf margin wedge deposit that resulted from the initiation of slow relative sea level rise during the early part of the TAGC-4.3 cycle. Mancini and others (1987), on the basis of benthonic foraminiferal assemblages and planktonic to benthonic foraminiferal ratios, determined that the Cocoa Sand Member was deposited in an inner marine shelf depositional environment. Deposits of the shelf margin systems tract of a type 2 depositional sequence are typically characterized by progradational to aggradational bodies of shallow marine sand that onlap and terminate against the sequence boundary in a landward direction and pinch out against the sequence boundary in a seaward direction (Van Wagoner and others, 1988).

In the study area, the outcrop of the Cocoa Sand Member is limited to a belt across Choctaw, Washington, Clarke , Monroe, Conecuh, and Covington Counties, Alabama; and Wayne and Clarke Counties, Mississippi. Maximum thickness of the unit (approximately 60 feet) occurs in the vicinity of the Alabama-Mississippi state line near the type locality at the Old Cocoa Post Office near Melvin, Choctaw County, Alabama (Cooke, 1933), and the unit thins and pinches out to the southeast in central Covington County, Alabama (Huddlestun and Toulmin, 1965) and to the northwest in western Clarke County, Mississippi (Gilliland, 1980). As noted earlier, observed North Twistwood Creek-Cocoa contacts are sharp and disconformable. The nature of the North Twistwood-Pachuta contact in eastern and central Mississippi is largely unknown because the Yazoo interval is poorly exposed and generally badly weathered. Based on the sequence interpretations made here, this contact should be, at least in part, disconformable, especially in the updip areas that would have been most affected by relative sea level fall.

Downdip and to the east of the Cocoa Sand Member outcrop area, the Yazoo Clay stratigraphic interval grades into carbonates of the Crystal River Formation. In the Baldwin County core, the Crystal River consists of a thick interval of sandy, argillaceous carbonates; no stratigraphic break is observed in this interval. In this core, as in other areas downdip of the Cocoa Sand Member outcrop belt, the TAGC-4.3 basal type 2 sequence boundary is interpreted to be the correlative conformity of the unconformity observed in outcrop, and deposition was continuous in areas below (seaward of) the point to which relative sea level dropped. Unfortunately, no age diagnostic planktonic foraminifera were recovered from this cored interval to aid in correlation of the members of the Yazoo Clay to specific parts of the Crystal River Formation.

Based on sequence relationships, the contact of the Cocoa and the Pachuta is interpreted to be a transgressive surface representing the first significant marine flooding event associated with the onset of rapid relative sea level rise in the TAGC-4.3 cycle. Biostratigraphic evidence supports this interpretation. Planktonic foraminiferal zonal boundaries commonly occur at transgressive surfaces within depositional sequences (Mancini and Tew, 1991). As mentioned above, the Cocoa Sand Member is assigned to the Priabonian *Porticulasphaera semiinvoluta* Interval Zone. The Pachuta Marl Member rests within the Priabonian *Globorotalia cerroazulensis* (s.l.) Interval Zone (Mancini and Tew, 1991). In absence of the Cocoa Sand Member, the zonal boundary between the Bartonian *Truncorotaloides rohri* Interval Zone and the Priabonian *Globorotalia cerroazulensis* (s.l.) Interval Zone occurs at the contact of the North Twistwood Creek Clay Member and the Pachuta Marl Member. In this case, planktonic foraminiferal zonal boundaries occur both at the sequence boundary at the base of a depositional sequence and at the transgressive surface within the sequence. In absence of the intervening shelf margin wedge, the transgressive surface becomes coincident with the basal sequence boundary, and the time represented by the intervening planktonic foraminiferal zone is a stratigraphic hiatus.

The Pachuta Marl Member consists of interbedded, glauconitic, phosphatic, fossiliferous, bioturbated limestone and marl (May, 1974; Toulmin, 1977) and occurs throughout the study area. The Pachuta consists of overall upward-deepening strata as evidenced by the stratigraphically ascending increase in the ratio of planktonic to benthonic foraminifera in the unit (Mancini and others, 1987), by the upward transition from coarser grained lithologies at the base to finer grained lithologies at the top as observed in the St. Stephens Quarry core and along the Chickasawhay River, and by the upward increase in authigenic phosphate and glauconite grains in the unit as observed along Little Stave Creek and in the St. Stevens core. Mancini and others (1987) interpreted the lower part of the Pachuta to have been deposited in a middle shelf depositional environment, grading upward into an outer shelf environment in the upper part of the unit. Strata of the Pachuta Marl Member are the transgressive deposits of the TAGC-4.3 depositional sequence. These strata were deposited above the transgressive surface overlying the Cocoa Sand Member and represent the sedimentological response to the onset of rapid relative sea level rise and increased accommodation within the basin during the TAGC-4.3 cycle. Marine-shelf deposition was established throughout the study area.

The contact of the Pachuta Marl Member with the overlying Shubuta Member is gradational. This relationship is illustrated well in the St. Stephens core, along the Tombigbee River at St. Stephens Quarry, along Little Stave Creek, and along the Chickasawhay River in Clarke County, Mississippi. The Shubuta consists of predominantly glauconitic, calcareous clay that has been interpreted to have been deposited in an outer shelf depositional environment (Mancini and others, 1987). The unit represents a continuation of the upward-deepening that began with the deposition of the Pachuta Marl Member, and the foraminiferal assemblage present in the unit indicates that the Shubuta was deposited in the deepest water of any of the Yazoo members (Mancini and others, 1987). The Shubuta is interpreted to be the lower part of a stratigraphically condensed section in the TAGC-4.3 depositional sequence that records sediment starvation on the outer shelf during maximum transgression of the shoreline during relative sea level rise. The contact of the Shubuta Member with the overlying Red Bluff Clay, Red Bluff/Bumpnose interval, or Bumpnose Limestone is interpreted as the surface of maximum starvation within the condensed section. The surface of maximum starvation also marks the point of change from overall transgression to overall regression within the depositional sequence. Condensed sections, along with the associated surface of maximum starvation, commonly mark the greatest water depth during relative sea level rise and usually develop when the rate of sea level rise is greater than the rate of sediment accumulation. This results in a landward shift of active sediment deposition with concomitant low sedimentation rates seaward (Vail and others, 1984). Sediment starvation is much more pronounced in the eastern part of the study area

(St. Stephens, Little Stave Creek), which was farther off shore than the western area (Chickasawhay River). At the type locality along Chickasawhay River, Clarke County, Mississippi, the Shubuta is approximately 90 feet thick. To the east, the unit thins to approximately 4 feet at St. Stephens Quarry and Little Stave Creek. In addition, planktonic foraminiferal assemblages from these sections indicate that the eastern sections were deposited in deeper water than the western sections (Mancini and others, 1987). The contact of the Shubuta with the Red Bluff Clay along the Chickasawhay River is disconformable and burrowed; however, graphic correlation techniques indicate that little, if any, time is missing along this contact (J.H. Hazel, personal communication, 1987). The contact of the Shubuta Member with the overlying Vicksburg Group at St. Stephens Quarry and Little Stave Creek is disconformable and represents a marine hiatus that is marked by burrowing, glauconite, phosphate grains, and shell hash (Mancini and others, 1987). The duration of the hiatus has been estimated as approximately 288,000 years using graphic correlation methods (Pasley and Hazel, 1990). This contact is the Eocene-Oligocene boundary in the eastern Gulf Coastal Plain. The Shubuta has been assigned to the Upper Eocene (Priabonian) planktonic foraminiferal *Globorotalia cerroazulensis* (s.l.) Interval Zone, and the overlying Vicksburg units have been assigned to the Lower Oligocene *Pseudohastigerina micra* Interval Zone (Mancini, 1979; Mancini and Waters, 1986). Thus, in this case, the planktonic foraminiferal zonal boundary, the Eocene-Oligocene Epoch boundary (Priabonian-Rupelian Stage), and the Jackson-Vicksburg Group boundary are coincident and all occur at the surface of maximum sediment starvation/maximum transgression within the condensed section of the TAGC-4.3 depositional sequence.

The upper part of the condensed section of the TAGC-4.3 sequence is represented by the lower part of Red Bluff Clay, the Red Bluff/Bumpnose interval, or the Bumpnose Limestone in various parts of the study area. These strata mark the beginning of relative sea level fall and concomitant regression in the TAGC-4.3 cycle. The upper part of these strata represent the early highstand deposits of the sequence. Like the Shubuta, this stratigraphic interval thins from west to east. Along the Chickasawhay River, the Red Bluff Clay is approximately 20 feet thick, and the facies equivalent Red Bluff/ Bumpnose thins to 14 feet at St. Stephens Quarry and 12 feet at Little Stave Creek. Along the Chickasawhay River, the Red Bluff consists of soft, glauconitic, fossiliferous clayey marl with regularly repetitive interbeds of indurated fossiliferous, glauconitic, sandy marl (May, 1974; MacNeil and Dockery, 1984). The indurated beds are underlain by scour surfaces interpreted by MacNeil and Dockery (1984) as diastems. This rhythmic interbedding is also apparent in the Red Bluff/Bumpnose interval at St. Stephens Quarry. At this locality, however, the indurated interbeds consist of sandy, argillaceous, fossiliferous, glauconitic limestone, and the softer interbeds consist of glauconitic, fossiliferous marl. The individual soft marl/hard marl-limestone couplets are interpreted to be upward-shoaling, progradational parasequences that are capped by scoured marine flooding surfaces (MacNeil and Dockery's (1984) diastems). The entire parasequence set exhibits overall upward-shallowing as indicated by the decreasing percentage of planktonic foraminifera in the foraminiferal assemblage upward through the section at St. Stephens Quarry (Mancini and others, 1987). Parasequence sets that exhibit these characteristics are typical of the progradational, regressive highstand systems tract within a depositional sequence (Van Wagoner and others, 1988). Upward-shallowing in this stratigraphic succession indicates relative sea level fall.

The Red Bluff Clay and Red Bluff/Bumpnose interval are conformably and gradationally overlain by the Forest Hill Sand, where present. In addition, the Red Bluff laterally grades into the Forest Hill in central Mississippi (Cooke, 1918; MacNeil, 1944; Mancini and others, 1987). The Forest Hill consists of nonmarine to shallow marine strata that have been interpreted as having been deposited in fluvial, deltaic, and prodelta environments which prograded the marine shelf sediments of the Red Bluff and Red Bluff/Bumpnose interval from west to east (Cooke, 1918). These environments of deposition are laterally gradational from west to east, respectively. In Mississippi, the Forest Hill consists of dark, very fine- to fine-grained sand, silt, and laminated carbonaceous clay with lignite beds which are approximately 100 feet thick in western and central Mississippi and thin significantly to the east (Copeland and Deboo, 1967; May, 1974). One of the easternmost exposures of the Forest Hill Sand is at St. Stephens Quarry, where the unit consists of approximately nine feet of blocky, carbonaceous, sparingly fossiliferous clay. The Forest Hill gradationally overlies the interbedded limestone and marl of the Red Bluff/ Bumpnose interval at this locality.

The strata of the Forest Hill Sand are the upper deposits of the highstand systems tract of the TAGC-4.3 depositional sequence and represent the continuation of relative sea level fall and regression which began with deposition of the Red Bluff/Bumpnose interval. Progradational nonmarine, marginal marine, and shallow marine terrigenous clastic rocks are typical of the upper part of the highstand components of depositional sequences in the Paleogene strata of the eastern Gulf (Mancini and Tew, 1991). The Forest Hill is disconformably overlain by the Mint Spring Marl Member (Formation in Mississippi) of the Marianna Limestone, which is part of the overlying TAGC-4.4 depositional sequence.

It should be noted that Dockery (1990), on the basis of local occurrences in west-central Mississippi of channel-fill sands that are stratigraphically equivalent to the Forest Hill Sand, interpreted the Forest Hill-Yazoo (Jackson-Vicksburg, Eocene-Oligocene) contact to be a type 1 sequence boundary in the eastern Gulf Coastal Plain. Dockery (1990) reported that these sands fill channels which are scoured into and disconformably overlie the Yazoo Clay. Scoured fluvial channels must be evaluated in terms of the regional stratigraphic and sequence stratigraphic relationships of the strata involved. Van Wagoner and others (1988, p. 41) caution against the interpretation of "local, contemporaneous erosion and deposition associated with geological processes, such as point-bar development, distributary-channel erosion, or dune migration" as sequence-bounding unconformities and specifically exclude these local phenomena from their definition of sequence boundaries.

TAGC-4.4 Depositional Sequence

The TAGC-4.4 depositional sequence includes the Mint Spring Marl Member of the Marianna Limestone (Mint Spring Formation in Mississippi), the Marianna Limestone, and the Glendon Limestone Member of the Byram Formation (Glendon Formation in Mississippi). All of these units are included in the lower Oligocene (Rupelian) Vicksburg Group (Figure 4). The Mint Spring disconformably overlies the Forest Hill Sand from the vicinity of St. Stephens Quarry northwestward throughout the outcrop belt of Oligocene strata in Mississippi (Mellen, 1941; May, 1974; Mancini and Copeland, 1986). To the southeast, the Marianna Limestone disconformably overlies the Red Bluff/Bumpnose interval or the Bumpnose Limestone (MacNeil, 1944).

The nature of the contact of the Marianna Limestone with the underlying Red Bluff/Bumpnose interval in the southeastern part of the study area is illustrated by a section along Thompson Mill Creek in Monroe County, Alabama, which was described by MacNeil (1944). MacNeil (1944) reported that the contact of the units in this section was disconformable and marked by burrows filled with glauconitic sand extending from the Marianna into the Red Bluff/Bumpnose interval (MacNeil's Red Bluff). MacNeil (1944) stated that the relationship of the Marianna and Red Bluff/Bumpnose interval at Thompsons Mill Creek was characteristic of the contact throughout the area. To the west, at Little Stave Creek, Clarke County, Alabama, the same relationship between the Marianna and the Red Bluff/ Bumpnose interval was observed in this study. West of Little Stave Creek, the Mint Spring occurs below the Marianna Limestone. The contact of the Mint Spring with the underlying Forest Hill Sand is well exposed at St. Stephens Quarry, Washington County, Alabama, and along the Chickasawhay River, Wayne County, Mississippi. At these localities, the contact is sharp, disconformable, and burrowed, and is marked by rounded, indurated clay clasts and an abraded fossil-shell lag in the lower part of the Mint Spring. In Warren County along the Mississippi River in western Mississippi, the contact was described by Mellen (1941, p. 29) as sharp, and he reported the lowermost Mint Spring to be a "basal conglomerate" containing broken and abraded shell material, lignitic wood fragments, and laminated clay pebbles reworked from the Forest Hill Sand below.

In the Baldwin County core, the contact of the Mint Spring with the underlying upper Crystal River/ Bumpnose undifferentiated is very obvious. The contact is sharp, disconformable, and burrowed, and juxtaposes hard, white, slightly phosphatic limestone of the Crystal River/Bumpnose undifferentiated with light brown, very glauconitic, very fossiliferous marl containing numerous specimens of the larger foraminifera *Lepidocyclina mantelli.* Glauconite grains are rounded and abraded, indicating that they are detrital.

Based on the evidence discussed above, the contact of the Mint Spring or Marianna with the underlying Forest Hill Sand, Red Bluff/Bumpnose interval, Bumpnose Limestone, or Crystal River/Bumpnose undifferentiated is a type 2 sequence boundary that forms the base of the TAGC-4.4 depositional sequence. The boundary resulted from relative sea level fall and an abrupt basinward shift in coastal onlap after deposition of the highstand systems tract of the underlying TAGC-4.3 depositional sequence. The magnitude of this relative fall was great enough to subject the entire study area to at least short-lived exposure along the sequence boundary, as evidenced by the presence of an unconformity throughout the area. The correlative conformity of the unconformity has not been recognized, indicating that the paleocoastline retreated south of the study area during the sea level fall.

The Mint Spring and the Marianna Limestone are, in part, lithofacies equivalent, and these units are the transgressive deposits of the TAGC-4.4 depositional sequence. The initiation of relative sea level rise and transgression during the TAGC-4.4 cycle is represented by the Mint Spring or, where the Mint Spring is not present, the lower part of the Marianna Limestone. In general, the Mint Spring is limited to the area that is underlain by the fluvial-deltaic TAGC-4.3 highstand deposits of the Forest Hill Sand, and the clastic constituents of this arenaceous, argillaceous, glauconitic fossiliferous marl to calcareous sand were probably, in part, derived from transgressive reworking of Forest Hill strata. With the onset of transgression, carbonate deposition was initiated in the south-eastern part of the study area, an area that had existed as a persistent carbonate platform, as evidenced by the limestones of the underlying Bumpnose Limestone and Crystal River Formation. To the northwest, the basal part of the Mint Spring in southwestern Alabama and southeastern Mississippi was deposited contemporaneously with the basal Marianna to the southeast. Progressive transgression and retrogradation above these basal beds of the sequence resulted in incremental translation of the shoreline to the north and west. In essence, the upward-deepening Mint Spring-Marianna package followed this relative sea level rise. The sandy marl or sand of the Mint Spring represents a shallower water facies, which is overlain by the deeper water carbonate facies of the Marianna. As noted earlier, the Mint Spring thickens in a westward direction from approximately 1.5 feet at St. Stephens to over 25 feet in western Mississippi. The Marianna thins in the same direction from approximately 60 feet at St. Stephens to about 3 feet in western Mississippi. In addition, calcareous nannoplankton recovered from the Mint Spring and Marianna in Alabama and Mississippi indicate that these strata are diachronous along the outcrop belt (Siesser, 1983; Pettway and Dunn, 1990). From southwestern Alabama to east-central Mississippi, these units can be assigned to the calcareous nannoplankton NP21 Zone; to the west, species diagnostic of the younger NP22 Zone were recovered from these strata (Siesser, 1983; Pettway and Dunn, 1990).

In the Baldwin County core, the Mint Spring consists of approximately two feet of very glauconitic, very fossiliferous marl with rounded glauconite grains and fossil material which grades into the equivalent strata of the Marianna Limestone. These strata include about 0.5 foot of light brown, fossiliferous, bioturbated, glauconitic mudstone gradationally overlain by 6.5 feet of brown foraminifera-rich, bioturbated, carbonate mudstone and 11.5 feet of light brown, blocky, foraminifera-rich, bioturbated, calcareous clay.

The changes in thickness and age of the Mint Spring and Marianna can be interpreted, in part, in terms of relative sea rise in the basin and concomitant differential accommodation for sedimentation associated with this rise. It appears that the initiation of the TAGC-4.4 transgression was relatively rapid, and this deepening event led to a rather abrupt increase in accommodation, especially in more basinal areas. In southwestern Alabama, this rapid deepening event is reflected by the thin, basal, very shallow-water deposits of the Mint Spring overlain by relatively thick, deeper water and upward-deepening carbonates of the Marianna. Downdip in the Baldwin County area, the Mint Spring/Marianna sequence records the initial transgression, followed by rapid inundation. The Mint Spring in the core represents deposition in a relatively shallow-water, high-energy regime, indicated by the presence of numerous large benthonic foraminifera and detrital grains of glauconite. The Mint Spring regime was associated with the beginning of relative sea level rise in the cycle. The foraminiferal-rich, fine-grained sediments of the lower part of the Marianna indicate that deep-water conditions quickly ensued. Deeper water conditions occurred progressively later and were of shorter duration in more landward positions, and, in addition, less accommodation for sedimentation was added in these areas. Further, persistent fluvial-deltaic activity in the Mississippi embayment area probably continued to deliver terrigenous clastic sediment from the northwest into the basin to be incorporated into the Mint Spring and to inhibit carbonate productivity until progressive transgression "pushed" this source of turbidity farther to the north. Maximum transgression is recorded by the thin sequence of Marianna Limestone that occurs in western Mississippi (MacNeil, 1944).

The interpretation of upward-deepening through the Mint Spring/Marianna stratigraphic interval, as well as the interpretation of shallowing from the southeast to northwest is supported by paleoenvironmental analyses of calcareous nannoplankton reported by Pettway and Dunn (1990). These workers indicated an upward decrease in the abundance of shallow-water nearshore taxa accompanied by an increase in the abundance of pelagic calcareous nannofossils in these strata throughout their study area in Alabama and Mississippi (Pettway and Dunn, 1990). Further, they observed higher overall abundances of shallow water forms as compared to pelagic nannofossils in the west than in the east.

The lower part of the transgressive systems tract of the TAGC-4.4 sequence exhibits the overall characteristics of a catch-up transgressive carbonate system as described by Sarg (1988) in his discussion of carbonate sequence stratigraphy. This is particularly true in southeastern Mississippi and southwestern and south-central Alabama. In a catch-up system, carbonate sedimentation lags behind relative sea level rise as a result of rapid rise and/or a relatively low rate of carbonate productivity; fine-grained, mud-rich carbonate rocks dominate the system (Sarg, 1988). In southwestern Alabama and southeastern Mississippi, the Mint Spring, where present, or the basal part of the Marianna Limestone consist of grainy to conglomeratic rocks, which are overlain by a thick sequence of carbonate mudstone to fossiliferous wackestone with generally thin interbeds of fossiliferous packstone.

The nature of these rocks and the stratigraphic relationships are well illustrated at St. Stephens Quarry and in the core that was drilled at that locality. In the core, the Mint Spring consists of approximately 1 foot of soft, arenaceous, argillaceous, very glauconitic, fossiliferous marl with rounded clay clasts and glauconite grains; the Mint Spring overlies dark clay of the Forest Hill Sand along a sharp contact. Shell material in the Mint Spring is broken and abraded. This basal sequence grades into white, moderately hard, slightly glauconitic, very sparsely fossiliferous, bioturbated, carbonate mudstone of the limestone facies of the Marianna. The Marianna in this core is approximately 62 feet thick, which is similar to the measured outcrop thickness of 60 feet for the unit. The lower 40 feet of the limestone facies is dominated by rocks which range from mudstone to wackestone. Fossils, where present, generally consist of larger foraminifera (*Lepidocyclina mantelli*), pectens, and bryozoan fragments. This stratigraphic succession indicates an initial shallow marine, moderately high-energy depositional regime (represented by the Mint Spring) related to early sea level rise, followed by sea level rise and concomitant increase in sediment accommodation (represented by the mudstone and wackestones of the Marianna).

The upper part of the transgressive systems tract of the TAGC-4.4 depositional sequence resembles a keep-up transgressive carbonate system as described by Sarg (1988). Keep-up systems are characterized by rates of sediment accumulation that are able to keep pace with relative sea level rise. Higher relative sedimentation rates in the keep-up system might be due to the slowing of relative sea level rise with a concomitant decrease in the rate of sediment accommodation or to overall higher carbonate productivity after rebound from the effects of the abrupt, rapid, early rise. Keep-up systems are dominated by grain-rich, mud-poor rocks that indicate higher energy, shoaling conditions. The upper approximately 20 feet of the Marianna in the St. Stephens core are dominated by upward-shoaling, foraminiferal-bryozoan-mollusc wackestone to packstone packages. Sarg (1988) has indicated that the late phase of catch-up systems often exhibit characteristics of a keep-up system.

The surface of maximum sediment starvation/maximum transgression in the TAGC-4.4 depositional sequence occurs at or near the contact of the Marianna Limestone with the overlying Glendon. Evidence for sediment starvation in the upper part of the Marianna Limestone was observed in the St. Stephens Quarry core and in the nearby outcropping section. In the core, the upper 2 feet of the Marianna Limestone consist of very glauconitic mudstone which grades from non-glauconitic wackestone/packstone below upward into packstone and grainstone of the basal part of the Glendon. The glauconite consists of mammiform grains and replacements in foraminifera tests; therefore, it is probably authigenic. Authigenic glauconite is often associated with slow sedimentation in a quiet marine setting (Baum and Vail, 1988). Sediment starvation in the upper part of the Marianna is also indicated in the Baldwin County core. The sequence of foraminiferal-rich, fine-grained rocks in this core that are stratigraphically equivalent to the Marianna Limestone has been described previously. It is interesting to note that MacNeil (1944), on the basis of the fact that a sharper faunal break occurred between the Marianna and Glendon in Alabama and southeastern Mississippi than farther to the west, placed a nondepositional marine hiatus at the contact in the eastern areas with concomitant continuous deposition to the west. This observation supports the interpretation that the Marianna-Glendon contact represents a submarine starvation surface associated with maximum transgression in the TAGC-4.4 cycle.

Strata of the Glendon are interpreted as regressive, progradational highstand deposits of the TAGC-4.4 depositional sequence; these deposits reflect relative sea level fall after maximum transgression during the cycle. Above the interval that includes the surface of maximum starvation/transgression, the Glendon consists of a series of upward-shallowing argillaceous marl to grainstone cycles that overlie the homogeneous Marianna Limestone. Throughout Mississippi and Alabama, the Glendon can be recognized by its distinctive alternating beds of indurated and non-indurated rocks and its relatively uniform thickness. In general, the indurated beds consist of cemented, fossiliferous packstone and grainstone, and the softer beds consist of mudstone, wackestone, and argillaceous marl. In the St. Stephens core, which is illustrative of the typical Glendon, the fossiliferous packstone and grainstone are either tightly cemented with blocky calcite pore-filling cements or partially to pervasively leached with only patchy remnant cement remaining between fossil particles. MacNeil (1944) reported similar characteristics in the Glendon at the type locality. In the Florida panhandle to the southeast, the Glendon consists dominantly of dolostone (MacNeil, 1944). Downdip, in the Baldwin County core, the Glendon equivalent consists of about two feet of white, hard, slightly fossiliferous, slightly glauconitic, carbonate mudstone that gradationally overlies the blocky, foraminifera-rich clay of the Marianna.

The Glendon upward-shallowing cycles are interpreted to be regressive, progradational parasequences in the highstand systems tract. These parasequences represent aggrading carbonate cycles that shoal to or near sea level (grainstones) and are then inundated by marine flooding events (finer grained rocks). The successive flooding events are characterized by progressive basinward offlap; thus, the entire parasequence set shows net progradation and regression associated with relative sea level fall.

In the Baldwin County core, the highstand systems tract is represented by only two feet of Glendon equivalent carbonate mudstone. The almost pure carbonate depositional regime represented by this unit indicates significant shallowing above the deep-water, foraminifera-rich, condensed section facies of the Marianna below and is important to the interpretation of the TAGC-4.4 depositional sequence in the core. The Glendon equivalent is truncated by a significant erosional surface.

The strata of the Glendon exhibit the overall characteristics of a keep-up highstand carbonate system as described by Sarg (1988). Keep-up highstand systems tracts are characterized by relatively rapid rates of sediment accumulation and are able to keep-up with paracycle flooding events. These systems are dominated by grain-rich, mud-poor parasequences like those described for the Glendon above.

The Glendon is disconformably overlain by the Byram ''marl'' member (Byram Formation in Mississippi) of the Byram Formation throughout the study area and the contact between these two units is interpreted as a type 2 sequence boundary which caps the TAGC-4.4 depositional sequence.

EASTERN GULF COASTAL PLAIN OLIGOCENE PALEOGEOGRAPHY

General

The paleogeographic implications of regional stratigraphic and lithofacies relationships are discussed below in terms of changes in relative sea level and coastal onlap. Maps illustrating paleogeographic reconstructions at various horizons in depositional sequences produced using the methods outlined previously are presented where data and control allow.

Data for the TAGC-4.3 and TAGC-4.4 depositional sequences allow for detailed paleogeographic reconstructions of these sequences in the study area, and the sequences are used as examples for the technique of using sequence stratigraphic analysis for paleogeographic mapping. To a large degree, these maps were constructed based on observations that were made during the course of this study. Regional stratigraphic information, however, from various sources was incorporated in order to extend these interpretations outside of the immediate study area. These sources are cited as appropriate. In all cases, the paleoshorelines shown on the maps indicate relative configuration and position and in no way imply an absolute shoreline position at any given time.

TAGC-4.3 Sequence

The sequence stratigraphy, lithofacies relationships, and distributions of the strata of the TAGC-4.3 sequence can be used to reconstruct the regional paleogeography for the study area during the time period represented by these rocks. The lower datum for this reconstruction is the type 2 sequence boundary (T1) at the base of the sequence. Figure 5a is a map of the study area which shows the distribution of lithofacies and the interpreted configuration and relative position of the paleoshoreline at the time of maximum relative sea level fall, which resulted in the type 2 sequence boundary after and during deposition of the North Twistwood Creek Clay Member. Highstand deposits of the underlying TAGC-4.2 depositional sequence (marine shelf clays of the North Twistwood Creek Clay Member and marine or nonmarine fluvial-deltaic deposits associated with a persistent Eocene-Oligocene fluvial system in the Mississippi Embayment area to the west) were, in part, exposed to subaerial conditions during this drop in sea level. Along Highway 84 in western Washington County, Alabama, where the North Twistwood Creek Clay Member-Cocoa Sand Member contact is exposed, the uppermost part of the North Twistwood has been weathered to a depth of approximately one foot. This weathered zone possibly represents a soil horizon associated with subaerial exposure of the North Twistwood Creek Clay Member.

In downdip areas that were seaward of the point to which relative sea level dropped, the type 2 unconformity is represented by the correlative conformity, and sedimentation was continuous in these areas. In central and western Mississippi, the correlative conformity occurs in undifferentiated strata of the Yazoo Clay which are lithofacies equivalent to the North Twistwood Creek Clay and the Pachuta Marl Members. In southeastern Alabama and in the Florida panhandle, there is no reported stratigraphic break in the carbonates of the Crystal River Formation (Huddlestun and Toulmin, 1965). The entire Yazoo interval is represented by the Crystal River in the Baldwin County core, and this succession is conformable throughout. In the subsurface of southern Mississippi, the North Twistwood can be recognized as far south as George County, where it is overlain by carbonates of the Ocala Group (Crystal River equivalents) (Williams, 1967). These carbonates are lithofacies equivalents of the Cocoa Sand, Pachuta Marl, and Shubuta Members. Farther south, in Jackson County, Mississippi, the North Twistwood Creek Clay Member grades into the basal carbonates of the Ocala Group (COSUNA, 1988).

The initiation of relative sea level rise during the TAGC-4.3 cycle is recorded by deposition of the Cocoa Sand Member of the Yazoo Clay, which is interpreted as a shelf margin wedge of limited areal extent. The Cocoa Sand Member wedge probably represents, in part, marine erosion and winnowing of the upper part the North Twistwood Creek Clay Member, which commonly has thin beds of sand. Figure 5b shows the known distribution of the Cocoa Sand Member and illustrates the paleogeographic reconstruction of the area after deposition of the unit. This paleogeographic map is drawn using the transgressive surface of the TAGC-4.3 depositional sequence, which is the upper "time" constraint on the Cocoa Sand Member, as the datum horizon (T2). Note that continuous deposition of the Crystal River Formation and lithofacies equivalent carbonates is interpreted in downdip (seaward) areas.

Rapid relative sea level rise above the transgressive surface of the TAGC-4.3 sequence is indicated by the widespread distribution of the overlying upward-deepening marls and limestones of the Pachuta Marl Member of the Yazoo Clay in the study area. The strata of the Pachuta are interpreted as the transgressive deposits of the TAGC-4.3 depositional sequence. The Pachuta is gradationally overlain by the lower part of the stratigraphically condensed section of the sequence, which is represented by the Shubuta Member of Yazoo Clay. The upper contact of the Shubuta with the overlying Vicksburg Group is the surface of maximum sediment starvation/maximum transgression within the depositional sequence.

Figure 5c is a paleogeographic reconstruction showing lithofacies distributions at a "time" horizon (T3) within the transgressive systems tract of the TAGC-4.3 depositional sequence. This horizon (Figure 5c) shows maximum distribution of the Pachuta Marl Member in the study area and is constrained by the transgressive surface and surface of maximum sediment starvation/ maximum transgression in the TAGC-4.3. Note that facies equivalent limestones of the Crystal River Formation were being deposited to the southeast and downdip of the marls and limestones of the Pachuta. In western Mississippi, the Pachuta interval occurs in undifferentiated marine clays of the Yazoo Clay. Nonmarine facies associated with the persistent fluvial system were being deposited to the northwest in the Mississippi embayment. With progressive transgression, this nonmarine interval was "pushed" farther and farther north toward the head of the embayment as the coastline transgressed in that direction. Retrogradation of this fluvial system, which served as a source for terrigenous clastic sediments, was accompanied by concomitant progressive "clearing" of the water from southeast to northwest, which resulted in increased carbonate deposition in areas distal to clastic influx. This is indicated by the southeast to northwest gradation from Crystal River limestones to Pachuta interbedded limestones and marls to clays of the undifferentiated Yazoo sequence in western Mississippi. The interpreted relative position and configuration of the paleoshoreline is shown on Figure 5c.

Figure 5d was constructed using the surface of maximum sediment starvation/maximum transgression in the TAGC-4.3 depositional sequence as the datum (T4). The interpreted relative position and configuration of the paleoshoreline indicates maximum transgression and the deepest landward encroachment of marine sedimentation during the cycle. At the time of maximum retrogradation of the shoreline, deposition of nonmarine fluvial and deltaic equivalents of the Yazoo Clay interval was "pushed" to the farthest northern position within the TAGC-4.3 cycle. Clastic sediments being delivered into the basin by fluvial systems were, in effect, trapped and deposited in more landward positions on the shelf. Basinward, there was progressive sediment starvation, leading to the deposition of stratigraphically condensed section of the TAGC-4.3 sequence, the lower part of which is represented by the Shubuta clay and stratigraphic equivalents. The Shubuta Member of the Yazoo Clay thins from west to east and ranges in thickness from approximately 300 feet in Rankin County, Mississippi, to 3 feet in southwestern Alabama where the unit grades into the Crystal River Formation. West of Rankin County, the stratigraphic equivalents of the Shubuta are included in the undifferentiated Yazoo, so that accurate thicknesses for the these strata cannot be obtained. The entire Yazoo interval, however, thickens from approximately 375 feet in Rankin County to about 525 feet in Warren County, Mississippi. In the southeastern part of the study area at this time, deposition of Crystal River carbonates, which are lithofacies equivalents of the Shubuta, reached as far to the northwest as western Monroe and northern Baldwin and Mobile Counties, Alabama.

Above the surface of maximum sediment starvation/maximum transgression in the TAGC-4.3 depositional sequence, relative sea level began to fall as indicated by the deposition of the upward-shallowing, progradational parasequences of the Red Bluff and Red Bluff/Bumpnose interval in southeastern Mississippi and southwestern Alabama. This relative sea level fall was accompanied by progradation of nonmarine and shallow marine fluvial and deltaic sediments of the Forest Hill Formation from the west-northwest into the basin. The Forest Hill fluvial system represents a continuation of the persistent fluvial system that existed in the Mississippi embayment area. In west-central Mississippi, Forest Hill strata directly overlie the Yazoo Clay (Moore, 1965), and there is evidence to indicate that fluvial channels eroded into the underlying marine clays (Dockery, 1990). To the east, in central and eastern Mississippi, the lower part of the Forest Hill grades into the marine shelf deposits of the Red Bluff Formation (Cooke, 1918; MacNeil, 1944). These rocks, in turn, grade eastward into the interbedded marls and limestones of the Red Bluff/Bumpnose interval and finally into the Bumpnose Limestone (Huddlestun and Toulmin, 1965). Figure 6a is a paleogeographic reconstruction of the area drawn on a "time" horizon (T5) in the highstand systems tract of the TAGC-4.3 depositional sequence and illustrates the relationship of the Forest Hill Sand, the Red Bluff Clay, the Red Bluff/Bumpnose interval, and the Bumpnose Limestone. The interpreted relative position and configuration of the paleoshoreline at this "time" is also shown. With continued relative sea level fall and progradation of the highstand systems tract, sediments associated with the distal part of the Forest Hill fluvial/deltaic system ultimately extended as far to the southeast as St. Stephens Quarry in Washington County, Alabama, where prodelta deposits of Forest Hill overlie marine shelf deposits of the Red Bluff/Bumpnose interval. To the east of this locality, the upper surface of the Red Bluff/Bumpnose interval or Bumpnose Limestone is a disconformity which is overlain by sediments of the succeeding TAGC-4.4 depositional sequence. This type 2 unconformity occurs above the Forest Hill Sand, where present. Figure 6b illustrates the paleogeographic reconstruction of the area after deposition of the Forest Hill. The datum for this reconstruction is the basal type 2 sequence boundary of the overlying TAGC-4.4 sequence (T6).

TAGC-4.4 Sequence

The regional paleogeography of the study area during the time period represented by the TAGC-4.4 depositional sequence can be reconstructed using the sequence stratigraphy and lithofacies relationships and distributions of the strata in this sequence. The lower datum for this reconstruction is the type 2 sequence boundary (T6) at the base of the sequence (Figure 6b). Figure 6b illustrates the interpreted position of the paleoshoreline and areas of subaerial exposure at the time of maximum relative sea level fall after deposition of the underlying TAGC-4.3 sequence. The distribution of the Forest Hill delta system is also shown.

The basal deposits of the Marianna Limestone and the Mint Spring record the initiation of relative sea level rise during the TAGC-4.4 cycle. Figure 6c is paleogeographic reconstruction of the area showing distribution of lithofacies at a "time" horizon (T7) in the lower part of the transgressive systems tract of the TAGC-4.4 depositional sequence. This horizon is constrained by the basal type 2 sequence boundary and the surface of maximum starvation/transgression in the sequence. At this horizon, the paleoshoreline had transgressed to the

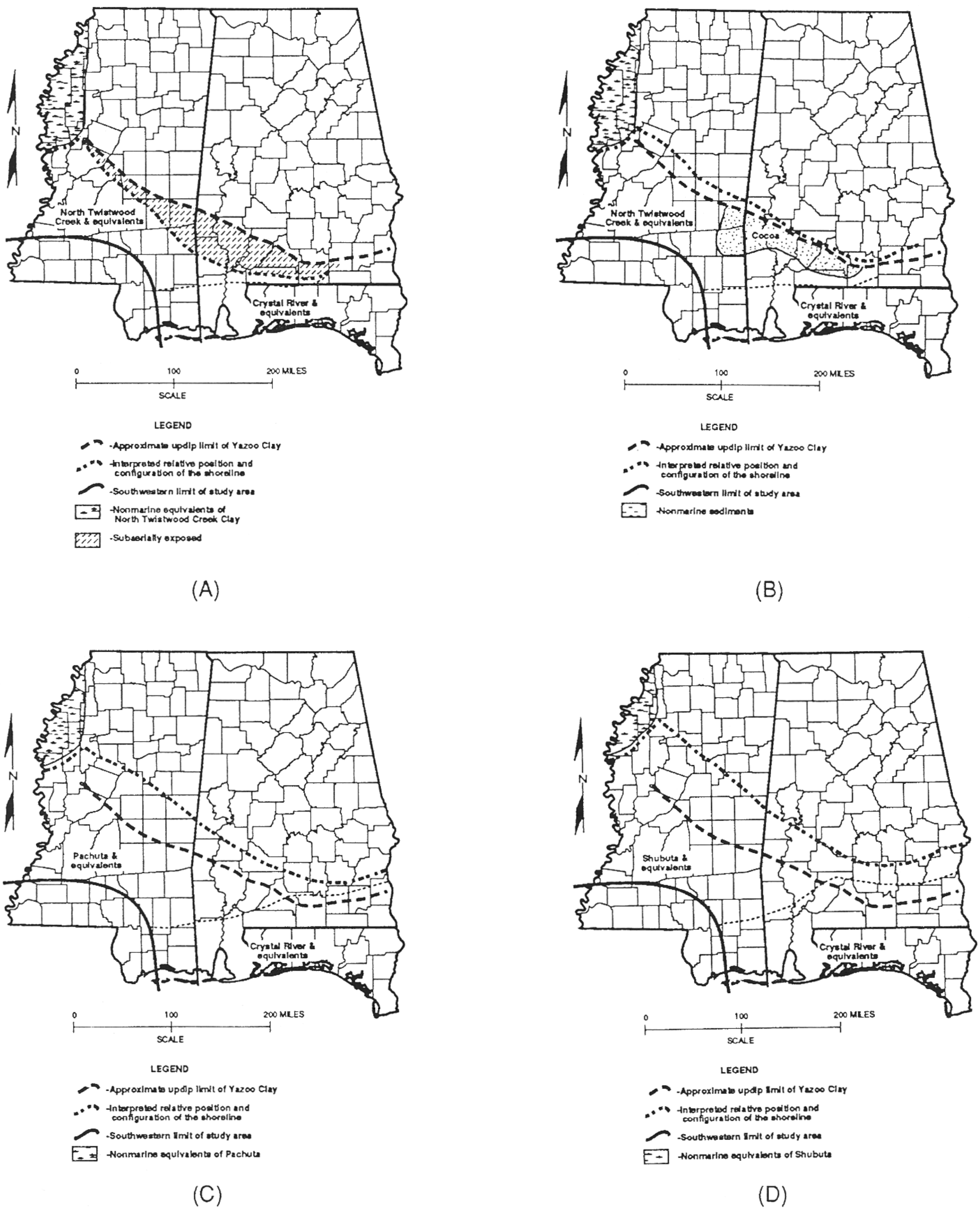

Figure 5. Regional paleogeographic reconstructions at times T1 (A), T2 (B), T3 (C), and T4 (D).

north and west during relative sea level rise and had onlapped, but not overwhelmed, topography associated with the underlying Forest Hill delta system. Note that the distribution of the Mint Spring approximately coincides with the distribution of clastic sediments of the Forest Hill delta as shown on Figure 6b. Terrigenous material in the Mint Spring probably, in part, represents transgressive reworking of the uppermost Forest Hill strata. To the east, carbonates of the Marianna were being deposited in less turbid water.

Figure 6d is a paleogeographic reconstruction using a slightly later "time" horizon (T8) in the transgressive systems tract as a datum. Again, this horizon is constrained by the sequence boundary below and the surface of maximum sediment starvation/maximum transgression above. Differentiation of this reconstruction (T8) from the previous one (T7) is partially based on calcareous nannofossil data, which indicate that the Marianna and Mint Spring are younger in the west than in the east (Siesser, 1983; Pettway and Dunn, 1990). This map illustrates that progressive transgression has pushed the paleoshoreline farther to the west and north. The Forest Hill delta system had been inundated and the Mint Spring was being deposited in central and western Mississippi. In east Mississippi and across Alabama, widespread deposition of the Marianna Limestone was established. In more offshore areas, such as represented by the Marianna equivalent stratigraphic interval in the Baldwin County core, deeper water facies were being deposited in a somewhat sediment-starved setting. This is recorded by the foraminifera-rich carbonates and clays in the core which were discussed earlier.

Maximum transgression in the TAGC-4.4 sequence is represented by the upper part of the Marianna Limestone and lithofacies equivalent rocks. The paleogeographic reconstruction illustrated on Figure 7a is drawn using the surface of maximum sediment starvation/maximum transgression (T9), which approximates the Marianna-Glendon contact, as a datum. Carbonates of the Marianna were being deposited throughout the region, except in more basinal areas as represented by strata in the Baldwin County core. From southeastern Mississippi east, deep water conditions had probably all but completely shut down carbonate productivity. At St. Stephens Quarry, deep-water conditions resulted in a depositional hiatus as reported by MacNeil (1944). The Baldwin County area, which was farther offshore, was receiving very slow pelagic sedimentation as evidenced by the foraminifera-rich clay in the Baldwin County core.

Relative sea level fall is represented by the highstand systems tract deposits of the Glendon in the TAGC-4.4 depositional sequence. Figures 7b and 7c illustrate successive paleogeographic reconstructions based on two "time" horizons in the highstand systems tract (T10 and T11). These datums are constrained by the surface of maximum sediment starvation/maximum transgression below and the sequence boundary above. The strata of the Glendon are interpreted to have been deposited in a rapidly accumulating, prograding, keep-up carbonate system. As such, the upward-shoaling Glendon cycles quickly built to sea level and above, forcing the shoreline basinward. With regression of the shoreline, previously deposited Glendon strata were progressively exposed to subaerial conditions. This was accompanied by the establishment of a freshwater lens in exposed areas that resulted in meteoric diagenesis of the Glendon. This lens was essentially pulled basinward with continued retreat of the shoreline to the south which resulted in greater areas of exposure of the highstand carbonates. A regional subaerial exposure surface is coincident with the sequence boundary overlying deposits of the highstand systems tract of the TAGC-4.4 sequence.

SUMMARY

This study indicates that sequence stratigraphic analysis can be a very useful tool in paleogeographic reconstruction and can greatly enhance the understanding and interpretation of chronostratigraphic relationships with a depositional basin that might not be otherwise apparent.

The Tejas A Gulf Coast (TAGC)-4.3 and TAGC-4.4 depositional sequences of Alabama and Mississippi provide excellent examples of the sequence stratigraphic method of paleogeographic reconstruction. The TAGC-4.3 sequence is a type 2 sequence that includes the Cocoa Sand (shelf margin systems tract), Pachuta Marl (lower transgressive systems tract), and Shubuta (upper transgressive systems tract/lower condensed section) Members of the Yazoo Clay, the Red Bluff Clay/Bumpnose Limestone interval (lower highstand systems tract/upper condensed section), and the Forest Hill Sand (upper highstand systems tract). The TAGC-4.4 sequence includes the Mint Spring Marl Member of the Marianna Limestone (lower transgressive systems tract), the Marianna Limestone (upper transgressive systems tract), and the Glendon Limestone Member of the Byram Formation (highstand systems tract).

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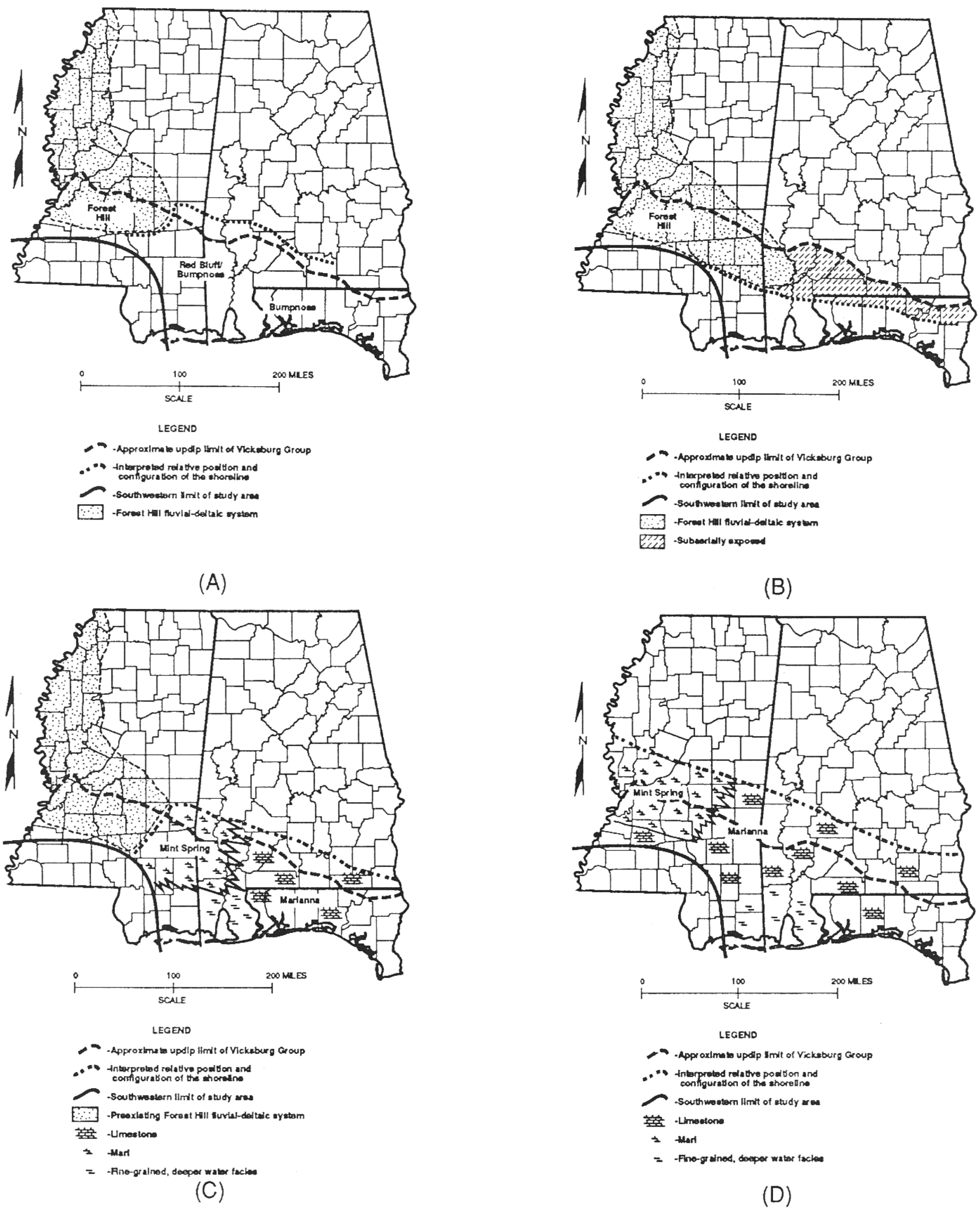

Figure 6. Regional paleogeographic reconstructions at times T5 (A), T6 (B), T7 (C), and T8 (D).

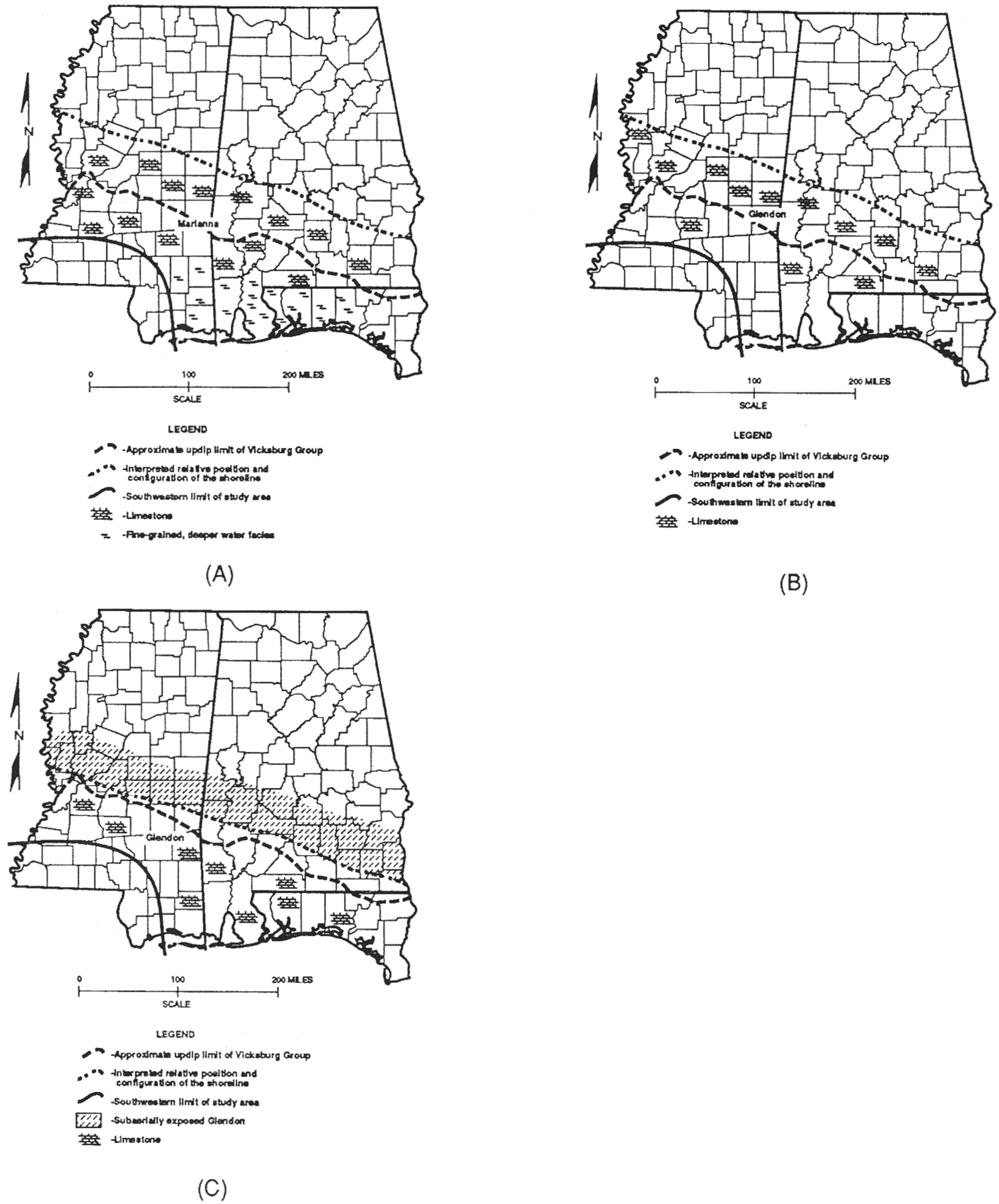

Figure 7. Regional paleogeographic reconstructions at times T9(A), T10 (B), and T11 (C).

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