A. Stratigraphy of Subsurface Neogene and Quaternary Sediments in Southern Jackson County, Mississippi

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U.S. Geological Survey Open-File Report 01-415-A

Stratigraphic and Paleontologic Studies of the Neogene and Quaternary Sediments in Southern Jackson County, Mississippi

2001

ABSTRACT

The shallow subsurface stratigraphy of southwestern Jackson County, Mississippi, is described using lithologic data from three new stratigraphic coreholes and eleven pre-existing water wells. On the basis of cores, descriptions of cuttings, and geophysical logs, seven informal Neogene and Quaternary units are recognized in the upper 200 to 350 ft of section beneath the Prairie terrace and the Belle Fontaine coastal area adjacent to Mississippi Sound.

The oldest studied unit, unit 1, is a widespread section of Pliocene(?) sediments. It consists of dominantly fine-grained, marginal-marine deposits and corresponds to the upper part of the Pascagoula Formation of prior usage. Above this older unit, unit 2 (Pliocene), unit 3 (Pliocene?-Pleistocene?), and unit 4 (Pleistocene?) are fining-upward, fluvial-estuarine, valley-fill sections consisting of sparingly fossiliferous basal sands and overlying fine-grained deposits. These units vary in thickness from 30 ft to 180 ft and rest on erosional contacts having tens of feet to more than one hundred feet of relief within the study area. Unit 2 generally corresponds to the Graham Ferry Formation of prior usage, and units 3 and 4 correspond, at least in part, to the Citronelle Formation as previously defined in the subsurface of Jackson County.

Above unit 4, unit GB and unit PB collectively correspond to the Pleistocene Gulfport, Biloxi, and Prairie Formations of prior usage. Located along the modern coast, unit GB consists of a 20- to 60-ft-thick, coarsening-upward, late Pleistocene section of nearshore-marine and barrier sediments. Further landward, the 15- to 75-ft-thick unit PB underlies the coast-parallel Prairie terrace. Unit PB is physically similar to units 1, 2, and 3 and may also represent valley-fill sedimentation. The weathering characteristics of unit PB (oxidation colors at depths of 10 to 20 ft), and its fining-upward sediment-distribution pattern, seemingly conflict with existing interpretations of these sediments as part of the late Pleistocene, highstand-marine section represent by unit GB.

Holocene coastal deposits in the study area include a spit-marsh complex at Belle Fontaine Point and estuarine, tidal-marsh, and tidal-flat deposits in Davis and Graveline Bayous.

INTRODUCTION

This report describes the physical stratigraphy of shallow subsurface Neogene and Quaternary sediments in the coastal area of western Jackson County, Mississippi (fig. 1). In this area, sparingly fossiliferous and lithologically repetitive Neogene sections consist of sand- and clay-dominated intervals that alternate vertically at scales of tens to hundreds of feet and vary significantly in thickness along their lateral extent. Historically, these deposits have proven difficult to subdivide into units that can be traced regionally, or even locally, with confidence (Otvos 1988, 1991). A better understood Quaternary section consists of a single complex of Pleistocene coastal and marine sediments and a variety of Holocene shoreline and estuarine deposits (Otvos, 1991, this volume; Otvos and Howat, 1992; Gohn and others, this volume).

Herein, we use information from three new stratigraphic coreholes and a network of pre-existing water-wells (pl. 1) to interpret the stratigraphy and depositional history of approximately the upper 350 ft of Neogene and Quaternary sediments in the coastal area between Ocean Springs and the Pascagoula River (fig. 1). Two east-west-oriented cross sections employing geophysical logs from the studied coreholes and water wells are the focus of the study (pl. 1).

Acknowledgments. We thank John A. Garrison, Jr. (1992 USGS Junior Fellow Program) for acquiring and cataloging the water-well geophysical logs used in this study and William Oakley (USGS, Jackson, Mississippi) for supplying the geophysical logs. The new coreholes were drilled by a USGS drill crew in 1990 (Donald Queen , Chief Driller). Reviews by Ervin G. Otvos (Gulf Coast Research Laboratory), Jack L. Kindinger (USGS) and James P. Owens (USGS) substantially improved this report.

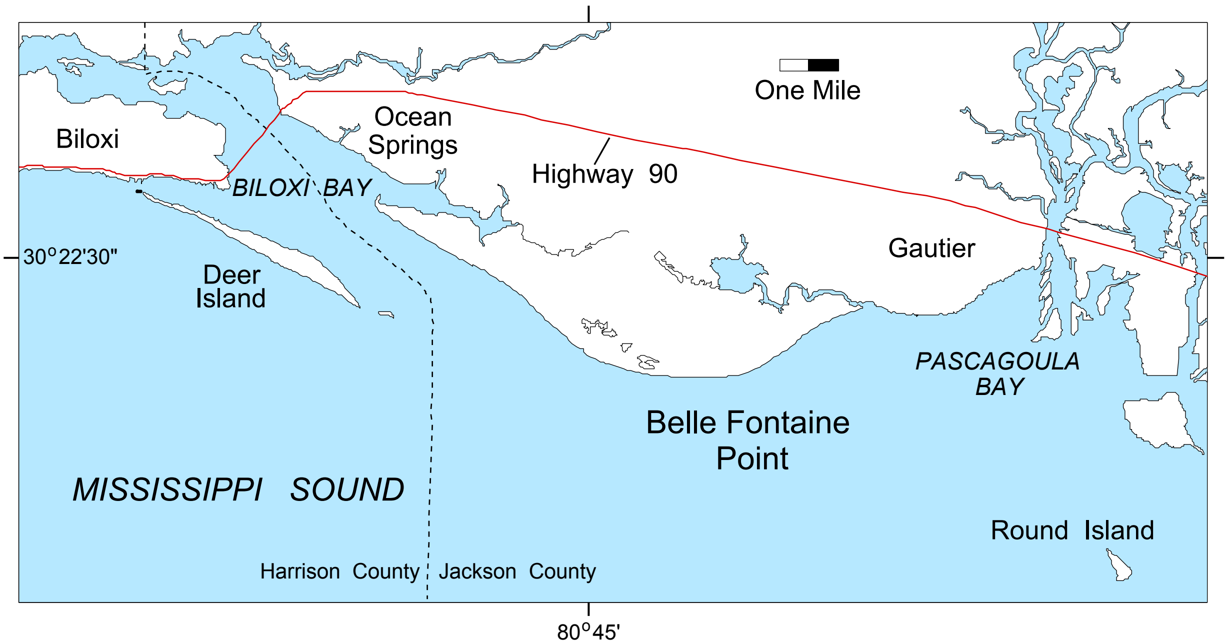
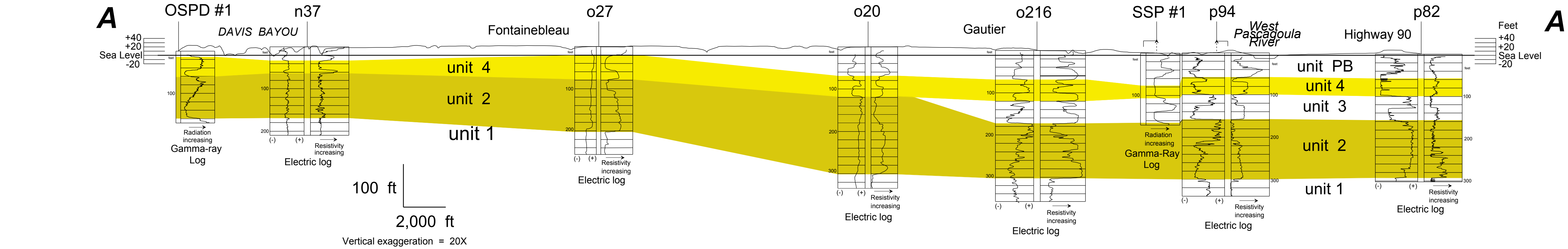
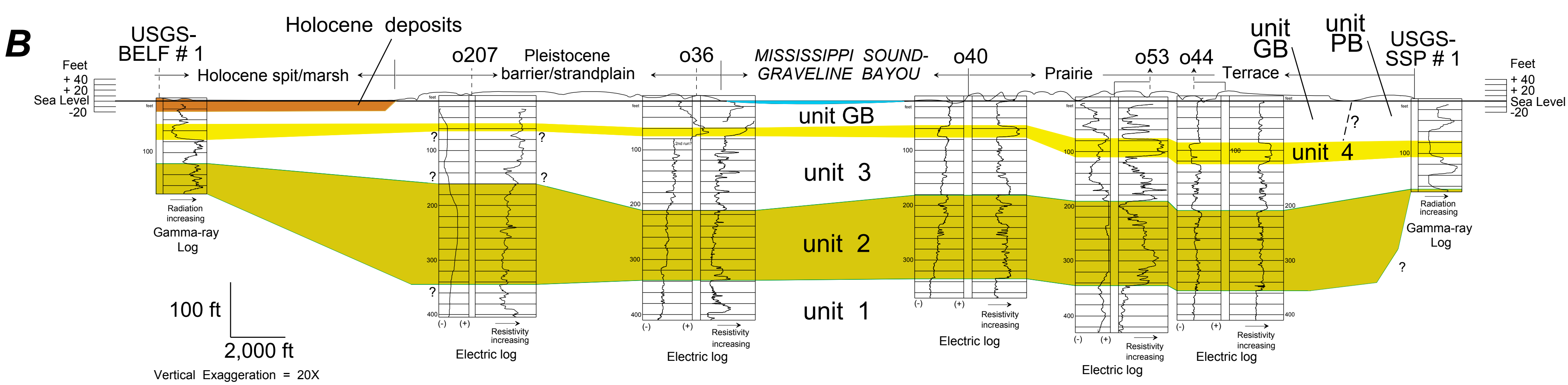


Figure 1. Location of the study area between Ocean Springs, Gautier, and Belle Fontaine Point in western Jackson County, Mississippi.





Elevation	Date	Data Source for Register
10	5/18/90	This report
6	5/15/90	This report
5	5/9/90	This report
20	5/26/58	Log header
20	1960	Harvey et al., 1965, pl. 13; Harvey and Shows, 1963
21	1960	Harvey et al., 1965, pl. 13; Harvey and Shows, 1963
10	2/4/60	Log header
10	12/17/58	Log header
10	6/20/60	Log header
8	2/65	Log header
10	8/3/72	Log header
12	2/16/73	Log header
3	6/23/60	Harvey and others, 1965, pl. 13
8	7/23/59	Harvey and others, 1965, pl. 13

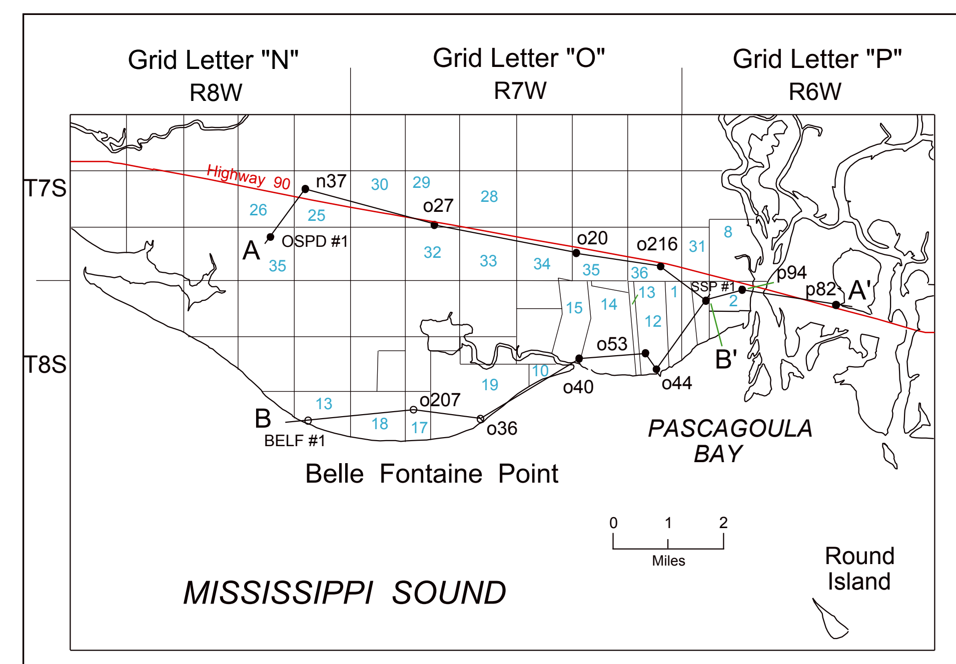


Plate 1. Stratigraphic cross sections in western Jackson County, Mississippi.

PREVIOUS WORK

Subsurface Neogene Section

Brown and others (1944) and Harvey and others (1965; also see Harvey and Shows, 1963) are the principal references for subsurface Neogene stratigraphy in Jackson County. Both reports contain several cross sections through the present study area and adjacent areas. Section A-A' of Harvey and others (1965, plate 10) is of particular interest because it has four wells in common with section A-A' of this report (pl. 1); these two sections roughly coincide with highway 90 in western Jackson County. Additional reports on the shallow subsurface geology of the coastal areas of Jackson County, and (or) adjacent areas in Mississippi and Alabama, include: Otvos (1973, 1982, 1987, 1988, 1991, 1994), Colson and Boswell (1985), Mink and others (1988), Smith (1989, 1991), Otvos and Howat (1992), Raymond and others (1993), and Champlin and others (1994).

Brown and others (1944) and Harvey and others (1965) mapped several subsurface Neogene units across Jackson County, including the Pascagoula Formation (Miocene), the Graham Ferry Formation (Pliocene), and the Citronelle Formation (Pliocene and (or) Pleistocene), as well as overlying late Pleistocene terrace deposits. Otvos (1988, 1991), however, noted that the pre-Citronelle units are difficult to interpret because of the general absence of faunal or lithologic markers in those intervals.

Quaternary Section

As summarized by Otvos (1982, 1991, this volume) and Otvos and Howat (1992), the Pleistocene section in the coastal area of Jackson County and adjacent counties consists of a single complex of fluvial to marine sediments of late Pleistocene age. Otvos divides this complex into the Gulfport, Biloxi, and Prairie Formations.

The Gulfport Formation consists of the sands underlying a discontinuous series of geomorphically distinct barriers and strandplains located along or near the modern shoreline, of which one is shown on figure 2. Gradationally below the barrier sands of the Gulfport , shelly subtidal marine sands and clays of the Biloxi Formation rest on pre-late Pleistocene deposits and extend offshore from the Gulfport barriers. Gohn and others (this volume) characterize these units as representing a prograding, low-energy shoreline in which offshore to lower shoreface deposits (Biloxi Formation) are overlain by upper shoreface, foreshore and backshore deposits (Gulfport Formation). Landward of the Gulfport barriers, the 20- to 25-ft-high, low-relief, coast-parallel Prairie terrace (fig. 2) is underlain by fluvial deposits of the Prairie Formation above an estuarine facies of the Biloxi Formation, as described by Otvos (1991) and Otvos and Howat (1992).

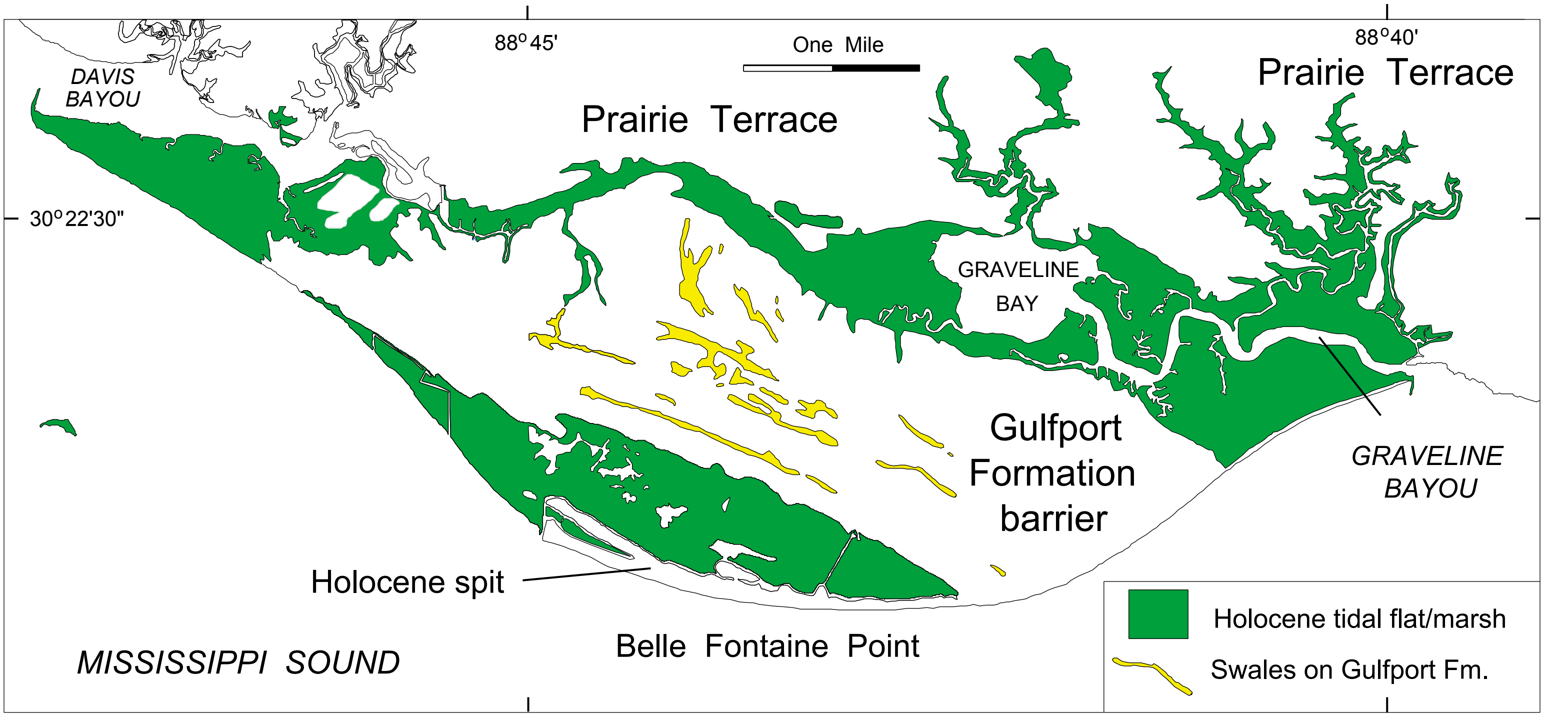


Figure 2. Generalized geomorphic map showing the principal land features in the Belle Fontaine area.

Holocene deposits in the study area include the tidal-flat, tidal-marsh, and subtidal estuarine sediments of Davis Bayou and Graveline Bayou (fig. 2). In addition, a narrow, Holocene spit and associated marsh form much of the shoreline at Belle Fontaine Point west of a Pleistocene headland developed on the Gulfport Formation barrier south of Graveline Bayou (Otvos, 1982, this volume; Gohn and others, this volume). A narrow, thin Holocene barrier also is present along the seaward margin of Graveline Bayou.

STRATIGRAPHIC MODEL

Except for the late Pleistocene and Holocene coastal and marine deposits, the lithologic variations and physical relationships of the shallow-subsurface units in the study area can be characterized using the electric log for water well p94 (fig. 3). In this well, the upper 340 ft of section consists of alternating sand-dominated sections and clay- or silt-dominated sections. The sand sections vary in thickness from about 20 ft to nearly 100 ft, whereas the intervening fine-grained sections are typically thinner.

As seen in the available cores, the contacts where sand overlies clay or silt are typically sharp and erosional. These contacts show minor relief, and erosional intraclasts are common at the bases of the sands. In contrast, the contacts where clay or clayey silt overlies sand are typically gradational across several inches to several feet. Regionally, the basal contacts of the sand units have several tens of feet of relief.

The sharp, erosional basal contacts of the sand sections make excellent unit boundaries that can be readily identified on geophysical logs as well as in cores. Therefore, the four sand-over-clay contacts seen in well p94 and the other drill holes are used to define four subsurface units of approximately formation rank (fig. 3). Each unit consists of a lower sand section and an upper clay-silt section, both of approximately member rank. As such, each stratigraphic unit represents a large-scale, fining-upward cycle of sedimentation that is bounded above and below by unconformable contacts.

These four units are identified, from older to younger, as the numerically designated units 2, 3, and 4, and an undifferentiated Prairie and Biloxi unit, unit PB, located only beneath the Prairie terrace (figs. 2, 3). An additional unit, unit 1, is recognized beneath the lowest studied unconformity. We do not suggest any formal nomenclature for these units because of the small number of studied drill holes and the limited geographic coverage of this report.

Two late Quaternary units also are described, an undifferentiated Gulfport and Biloxi unit (unit GB) beneath and seaward of the Gulfport Formation barriers, and a unit consisting of the Holocene coastal deposits (pl. 1). These two units do not physically resemble the other units; in particular, the coarsening-upward and locally shelly character of unit GB is unique in the study area.

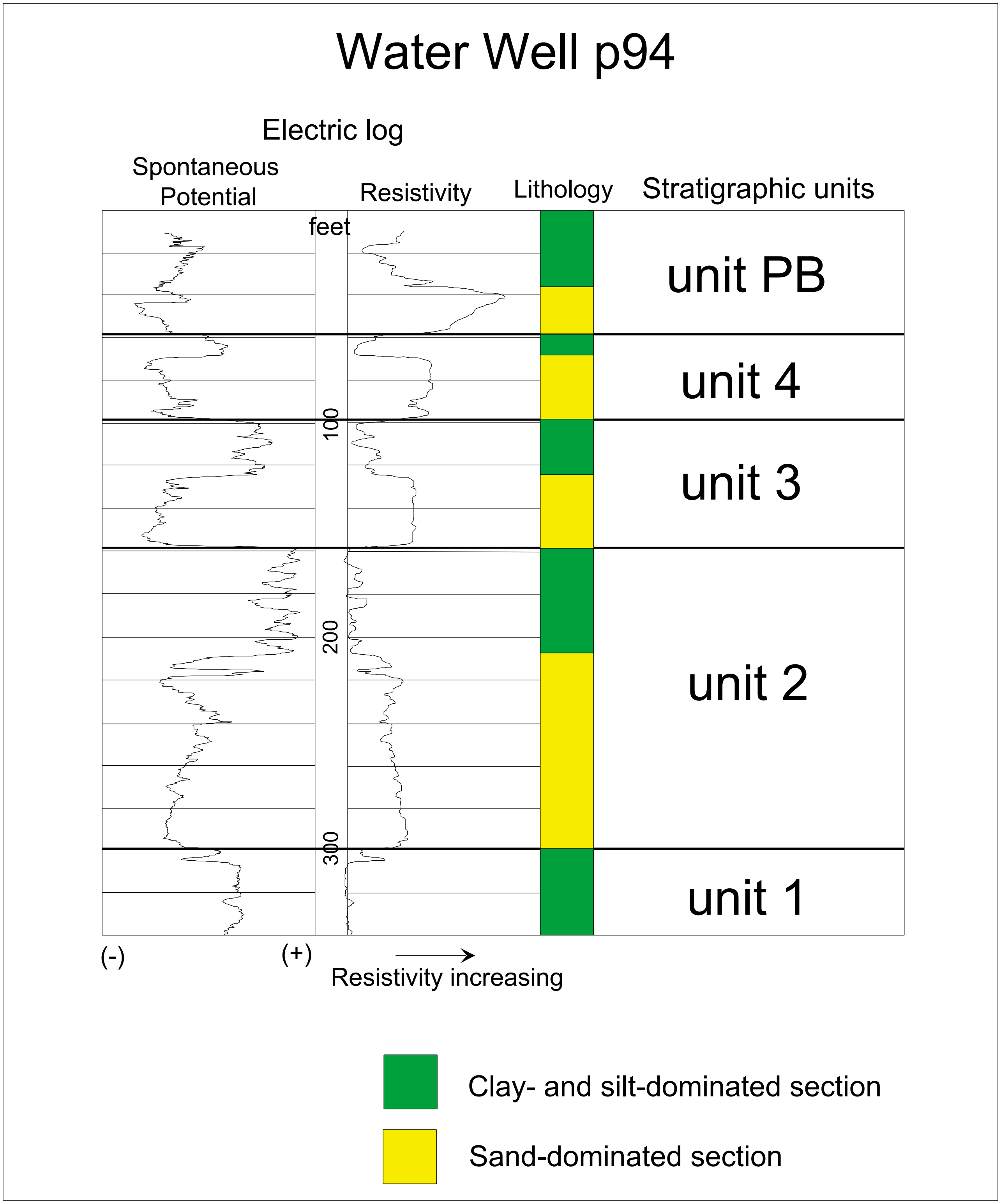


Figure 3. Electric log, generalized lithologic column, and stratigraphic units for water well p94. See plate 1 for the well locations.

The lithologies, thicknesses, distributions, and ages of these seven stratigraphic units, and their relationships to earlier defined formations, are discussed in the following sections. Emphasis is placed on the pre-late Pleistocene section; the late Pleistocene and Holocene sections are described in greater detail elsewhere in this volume (Otvos, this volume; Gohn and others, this volume).

METHODS

Descriptions of the units in the new cores are abridged from those in Gohn and others (1992). The assessments of grain size and sorting, mineral percentages, and colors are all semi-quantitative visual estimates made using standard charts and visual aids. All of the indicated colors describe completely dry samples. The new stratigraphic coreholes are Belle Fontaine #1 (BELF #1), Ocean Springs Police Department Firing Range (OSPD #1), and Shepard State Park #1 (SSP #1) (pl. 1).

STRATIGRAPHIC UNITS

Unit 1

Unit 1 consists of a dominantly fine-grained section that underlies the thick sand section in the lower part of unit 2 (pl. 1). Although this fine-grained section appears to be at least one hundred feet thick locally beneath coastal Jackson County (Harvey and others, 1965), only the upper few tens of feet were studied for this report, primarily as background for the discussion of unit 2. Hence, the base of unit 1 is not fixed in this report.

Drill-hole sections

OSPD #1 core

Unit 1 was sampled only in the OSPD #1 corehole where two cores were recovered just below the unit 1-unit 2 contact at 158.2 ft (Gohn and others, 1992). The upper core (163.0 ft to 158.2 ft) consists of nearly two feet of silty clay. This clay contains numerous slickensided fractures and is mottled with moderately high-chroma colors in its upper half (dark yellowish orange, 10YR6/6; moderate yellow, 5Y7/6) that grade down to very pale orange (10YR8/2) mottled with dark yellowish orange (10YR6/6). The clay grades downward into friable, clayey and silty, very fine sand that is yellowish gray (5Y7/2) to pale olive (10Y6/2). This latter lithology is also present in the deeper core (166.2 ft to 165.0 ft). The entire recovered section of unit 1 is noncalcareous. The slickensided fractures and the moderately high chroma (even when dry) of the uppermost foot of section suggest that it is a weathering horizon.

Water wells

Lithologic logs for wells n37, o20, o27, p82, and p94 (Harvey and Shows, 1963) list sand-over-clay contacts whose depths are compatible with the top of unit 1 as picked from the geophysical logs for those wells. Typically, each lithologically defined contact is within 10 ft of the corresponding geophysically defined contact. The upper part of unit 1 in these wells is primarily described as gray or green, locally fossiliferous clay.

Geophysical logs

Electric logs indicate dominantly fine-grained sections in unit 1 that contrast with sand-dominated sections in the overlying lower part of unit 2. Only a few well-sorted sands are seen locally in unit 1, as in wells o207 and o36 (section B-B', pl. 1; also see Harvey and others, 1965, section A-A'). This contrast is most apparent on the resistivity logs where low-resistivity, fine-grained sediments of unit 1 are overlain by the high-resistivity sands of unit 2. A positive (righthand) shift of the spontaneous potential curve from its position in unit 1 to its position in the lower part of unit 2 also is apparent on many of the logs. These differences in electric-log patterns are discussed at greater length in the following section that describes the geophysical-log patterns of unit 2.

Distribution, correlation, and age

Broadly correlative fine-grained sections of unit 1 are present immediately below unit 2 in all of the studied water wells on sections A-A' and B-B' (pl. 1). The contact between these units on section A-A' correlates closely with the contact between the Pascagoula Formation and the overlying Graham Ferry Formation as characterized and mapped by Harvey and others (1965, plate 10) on their section A-A'. Earlier, Brown and others (1944, plate 12) had placed this formation boundary about 150 ft deeper in the Gautier area and even deeper at Ocean Springs and areas to the west. Herein, we recognize a general correlation of unit 1 of this report with the upper part of the Pascagoula Formation as used by Harvey and others (1965).

No direct evidence was generated during this study for the age of unit 1. Constraints on the age of these deposits are provided, however, by fossils in lower and higher beds. The small bivalve *Rangia* (*Miorangia*) *johnsoni* (Dall, 1893) (see taxonomic review by Campbell and Otvos, 1992) is present at depths of about 900 ft and below in the Jackson County coastal area (Brown and others, 1944; Harvey and Shows, 1963; Harvey and others, 1965; Campbell and Otvos, 1992; Champlin and others, 1994) in beds assigned to the Pascagoula Formation by Harvey and others (1965). While this species is traditionally used as a guide fossil for the late Miocene, Campbell and Otvos (1992) suggest that its range may extend from the late middle Miocene into the late Miocene and possibly the earliest Pliocene. Biostratigraphic correlation of the Pascagoula Formation with part of the Miocene Pensacola Clay and the "Miocene coarse clastics" of Alabama on the basis of *R*. (*M*.) *johnsoni* has been suggested by Otvos (1988, 1994), Campbell and Otvos (1992), Raymond and others (1993), and Champlin and others (1994).

In contrast, palynomorphs indicate a Pliocene age for unit 2 of this report (Willard and Edwards, this volume). The restriction of *Rangia* (*Miorangia*) *johnsoni* to depths of 900 ft and below in the study area, and the presence of Pliocene fossils in unit 2 at depths of about 80 to 170 ft suggests that only Pliocene sediments are represented by unit 1 on plate 1. Hence, the age of unit 1 is provisionally designated herein as Pliocene(?).

Unit 2

Unit 2 is the oldest unit studied in detail for this report. It is the thickest and probably the most readily correlated unit in the study area.

Drill-hole sections

A complete section of unit 2 in the western part of the study area was sampled in the OSPD #1 corehole. Partial sections of the unit were sampled in the BELF #1 and SSP #1 coreholes.

OSPD #1 core

The interval between depths of 158.2 ft and 61 ft in the OSPD #1 core is assigned to unit 2 (pl. 1). This interval is about equally divided between a lower section of well-sorted, very fine to fine sand and an upper section of less well-sorted, clayey silt and very fine sand; the transition between these sections is gradational across several feet of section (Gohn and others, 1992).

The lower few feet of unit 2 consist of yellowish-gray (5Y8/1) to pinkish-gray (5YR8/1), loose, very well sorted, very fine to fine sand. The basal contact with the underlying clay of unit 1 is undulating and sharp. Scattered clay intraclasts (sand-sized to 0.5 in) are present in the basal few inches of unit 2. Above this basal interval, very similar sand (minus the intraclasts) is present up to a depth of 115 ft. This entire interval (158.2 ft to 115 ft) is noncalcareous and lacks observable fossils.

Above 115 ft, unit 2 consists of yellowish-gray (5Y7/2, 5Y8/1) to pale orange (10YR8/1), silty very fine sand and clayey silt to very fine sand. These lithologies are sparingly micaceous and noncalcareous; they contain small amounts of detrital sand-sized plant material. Pale-olive (10Y6/2) silty clay is a minor lithology in this interval. All of these fine-grained lithologies typically contain small, cylindrical, clay-lined burrows.

BELF #1 core

Approximately 55 ft of the upper part of unit 2 was penetrated in the BELF #1 corehole between depths of 175.3 ft and 120.2 ft. This section consists of three repeating lithologies: light-olive-gray (5Y6/1), silty and slightly clayey, very fine to fine sand; grayish-yellow (5Y8/4) clayey silt to very fine sand; and olive-gray (5Y4/1), dense, silty clay. All three lithologies contain clay-lined and unlined, sand-filled, cylindrical burrows and sparse to locally common, disseminated, sand-sized plant fragments. Clay and silt intraclasts are common at the bases of the very fine to fine sands. Abundant molds of small pelecypod valves (about 0.2 inches in diameter) are present from 150 ft to 148.6 ft, and scattered, chalky, sand-sized macrofossil fragments are present in the lowest 3 ft of recovered section. Except for these occurrences, and the plant fragments, no other macrofossils were seen in unit 2 in the BELF #1 core.

SSP #1 core

Only the uppermost part of unit 2 was penetrated in the SSP #1 corehole between depths of 170 ft and 165.1 ft. In the top foot of section, irregular blocks of very pale orange (10YR8/2), noncalcareous silty clay are cut or engulfed by grayish-orange (10YR7/4), noncalcareous, silty, very fine sand. An additional 3 ft of similar noncalcareous, friable, silty very fine to fine sand was recovered below the clay-bearing interval.

Water wells

Harvey and Shows (1963) and Harvey and others (1965, graphic lithologic logs on plate 10) provide lithologic descriptions for sediments in several water wells that are assigned herein to unit 2. In the eastern half of section A-A' (pl. 1), unit 2 sands in wells o20, p82, and p94 are described as gray or greenish gray, "salt and pepper", and medium to coarse grained or even very coarse grained. The "salt-and-pepper" appearance apparently results from a moderate abundance of heavy minerals. A coarsening-downward trend is noted for the unit 2 sand in well p82. To the west along section A-A', unit 2 is described primarily as fine sand with some clay in wells o27 and n37. This trend toward finer grain size in the western wells is compatible with the dominantly very fine to fine grain size of unit 2 sands in the OSPD #1 core. The fine-grained upper part of unit 2 in wells o20, p82, and p94 is consistently referred to as greenish in color (Harvey and Shows, 1963).

Lithologic summary

Unit 2 is a large-scale fining-upward unit that grades from well-sorted, very fine to fine sands (west) or medium to coarse sands (east) at its base to clayey silts and muddy very fine sands at its top. Compared with the overlying units, unit 2 contains comparatively few clay beds and no gravel. The fine-grained upper part of unit 2 is typically burrowed but contains only sparse body fossils.

Geophysical logs

The boundaries of unit 2 are readily apparent on the electric and gamma-ray logs (sections A-A' and B-B', plate 1). The high resistivities and low gamma-ray values of the sandy lower part of the unit strongly contrast with the opposite patterns in the fine-grained section of the underlying unit 1. Similarly, the low resistivities and high gamma-ray values for the fine-grained upper part of unit 2 contrast with the opposite patterns in the sand sections at the bases of units 3 and 4 where they overlie unit 2.

Two other electric-log patterns distinguish unit 2 on the cross sections. First, on seven of the eleven spontaneous-potential logs, there is a clear right-hand (positive) shift in the position of the curve where it passes upward from the fine-grained unit 1 section into the basal unit 2 sand or, in some cases, at a higher location within the unit 2 sand. This atypical "reversed" spontaneous-potential curve results when a sand aquifer contains groundwater that is fresher (lower salinity) than the borehole drilling fluid (Keys, 1990). This log pattern is rare in the younger units.

Second, there is a strong shift in the position of the spontaneous-potential curves between the fine-grained unit 1 section and the fine-grained section at the top of unit 2. In nearly every case, this clay baseline is located farther to the right (positive) in the fine-grained beds of unit 2 than in unit 1. This baseline shift may result from consistent differences in compaction or composition between the two fine-grained sections or it may result from differences in salinities among the sand aquifers in units 1, 2, 3, and 4 (Serra, 1986).

Distribution

Complete or partial sections of unit 2 are present in all of the studied drill holes. Substantial changes in the unit's thickness are seen on the cross sections (plate 1). Thicknesses of 130 ft to 180 ft are typical of the drill holes at the eastern end of both sections, whereas thickness of about 100 ft are present at the western end of section A-A'. This strike-parallel change in thickness is produced, in part, by the east-to-west rise of the unit's basal contact. Nearly 150 ft of relief is present on the basal contact between well o216 and corehole OSPD #1 (section A-A', pl. 1). This east-to-west reduction in thickness would be even greater if erosion along the base of unit 3 had not reduced the thickness of unit 2 in the eastern part of the study area. About 100 ft of relief is present on the top of unit 2 along section A-A'.

Correlation and age

The boundaries and other defining characteristics of unit 2 do not differ in any significant way from the definition of the Graham Ferry Formation used in the subsurface by Harvey and others (1965, especially their section A-A', plate 10). However, the positions of the contacts for unit 2 of this report and the Graham Ferry Formation of Harvey and others (1965) do differ significantly from those originally used by Brown and others (1944) for the Graham Ferry Formation.

Although not agreeing with the use of the name "Graham Ferry Formation", Otvos (1988, 1991) suggested a Pliocene age for this interval on the basis of correlations with fossiliferous Pliocene units in offshore Alabama and the western Florida panhandle. New palynomorph data (pollen and dinoflagellate floras) from unit 2 in the BELF #1 and OSPD #1 cores also indicate a Pliocene age for unit 2 (Willard and Edward, this volume).

Unit 3

Drill-hole sections

Complete sections of unit 3 in the SSP #1 and BELF #1 drill holes were cored with good recovery. Unit 3 probably does not extend as far west as the OSPD #1 corehole although a section of very fine sand at 72.8 ft to 61.0 ft in that core might represent unit 3. This possibility is not shown on plate 1.

SSP #1 core

In this core, unit 3 is represented by a 58.7-ft-thick section of sand and clay between depths of 165.1 ft and 106.4 ft (pl. 1). The lower contact is a sharp textural and color boundary with about 0.5 inches of erosional relief visible in the core. The lower two feet of unit 3 consists of loose, well-sorted, pinkish-gray (5YR8/1) to white, noncalcareous, fine to coarse sand. This sand contains common dispersed exotic light-gray (N7 to N8) clay clasts as large as 1.0 inch and similar-sized intraclasts derived from underlying silt to very fine sand at the top of unit 2.

Above the basal 2 ft and below a depth of about 140 ft, the lower part of unit 3 consists of loose, well-sorted, very fine to medium sand. This sand is typically pinkish-gray (5YR8/1), noncalcareous, and massive. Trace amounts to a few percent of sand-sized plant material are dispersed throughout the sand. Bedding is defined only by a few thin (less than 0.1 inch) continuous to discontinuous clay laminae (some of which are bifurcated flasers) at 145 to 144 ft, by 0.5-inch-thick concentrations of plant material at 157.9 ft and at 148 ft, and by a thicker concentration of plant material at 157.6 to 157.1 ft. A gradational change from the sand in the lower part of unit 3 to an overlying clay occurs between 142 ft to 138 ft in the core. In this interval, lenticular beds and other discontinuous irregular layers of loose to friable, yellowish-gray (5Y8/1) very fine to fine sand or fine to medium sand are interbedded with grayish-green (10GY5/2) silty clay on a 0.1- to 2-inch scale.

Between 138 ft and 121 ft, the section consists of noncalcareous, typically massive, silty clay. The clay is dominantly light olive gray (5Y6/1) to grayish yellow green (5GY7/2) but is mottled with moderate yellowish brown (10YR5/4), dark yellowish brown (10YR4/2), and moderate olive brown (5Y4/4). Sparse, sand-sized to 0.5-inch plant fragments are dispersed throughout the clay. The upper 4 ft of the clay contains abundant unlined, subvertical, cylindrical to irregular, sand-filled burrows that are 0.1 to 0.5 inches in diameter. The burrows are filled with friable, noncalcareous, very fine to fine sand derived from above a sharp but irregular (burrowed) contact at 121 ft. Friable, noncalcareous, silty very fine to fine sand is present between the burrowed clay at 121 ft and a similar burrowed clay at 112.5 ft. This sand is locally light gray (N7), light olive gray (about 5Y7/1), or pale yellowish brown (10YR6/2), and contains locally sparse to common intraclasts (up to 0.5 inches) of gray-green silty clay. Sparse sand-sized plant fragments occur throughout the interval. This sand is faintly color- and texture-mottled throughout, which suggests bioturbation.

Greenish-gray (10GY5/2), locally silt-laminated, silty clay is present from 112.5 ft to 108 ft. This clay is lithologically similar to the clay at 138 ft to 121 ft and contains the same type of sand-filled burrow.

The top 1.5 ft of unit 3 (108 to 106.5 ft) consists of pale olive (10Y6/2), loose to friable, noncalcareous, silty very fine to fine sand containing sparse, 0.25-inch-diameter roots. A thin discontinous layer of wood is present in the lower part of this interval at 107.8 ft.

BELF #1 core

The 44.2-ft-thick section between 120.2 ft and 76 ft in the BELF #1 core is assigned to unit 3. The basal contact is sharp and burrowed with about 1 inch of relief visible in the core. The lower part of the unit, from the basal contact to about the 109-ft depth, consists of unfossiliferous, pinkish-gray (5YR8/1), well-sorted very fine to fine sand. Exotic clasts (sand-sized to 0.5 inches) of medium-light-gray (N6) silty clay are common in the basal few inches of the unit. The basal sand grades across the 111-ft-to-108-ft interval into loose to friable, massive, noncalcareous, clayey and silty very fine sand. Across this interval, the sediment color changes upward from pinkish gray (5YR8/1) to grayish yellow (5Y8/4) mottled with moderate yellow (5Y7/6); the color change corresponds to upward increases of the silt and clay fraction and an upward decrease of the sand fraction.

The muddy very fine sand is broadly gradational across depths of 99 ft to 97 ft into noncalcareous, pervasively fractured, dense silty clay that contains a few 0.5- to 2-ft-thick layers of clayey silt. The fractures in the clay are typically slickensided. The clay is typically grayish-yellow-green (5GY7/2) with dusky-yellow (5Y6/4) staining, primarily along fractures, whereas the uppermost foot of this fine-grained section is yellowish-gray (5Y7/2). The siltier beds are pale olive (10Y6/2). Sparse sand-sized plant fragments are dispersed throughout this fine-grained interval between about 98 ft and the top of the unit at 76 ft.

Water-well sections

Along section A-A' (pl.1), unit-3 sands are described as fine to medium grained (well p82) or medium to coarse grained (well p94) (Harvey and Shows, 1963; Harvey and others, 1965). The fine-grained upper part of unit 3 in these two wells is described as buff or gray in color. The indication of shells in this unit by Harvey and others (1965, pl. 10) was not substantiated by the new coreholes examined for this study.

Lithologic summary

Unit 3 is a large-scale fining upward section that is similar in many respects to unit 2. However, unit 3 contains more silty clay in its upper part than does unit 2, whose upper beds consist primarily of clayey silt and clayey very fine sand.

Geophysical logs

The fining-upward character of unit 3 is apparent on the geophysical logs. High-resistivity sands are present in the bottom half of the unit, while low-resistivity, high-gamma-ray clays dominate the upper half. Thin sands (up to 10 ft thick) are present in the upper part of the unit in a few drill holes, as, for example, in the SSP #1 core.

Distribution

Unlike unit 2, unit 3 has a restricted distribution on the cross sections. It is present only in the eastern wells on section A-A', pinching out to the west between drill holes o216 and o20 (plate 1). Where present on A-A', unit 3 is about 50 ft to 60 ft thick. Unit 3 is more widespread on section B-B' and is present in all of the studied wells on that section. However, it thins to the east and the west, being about 80 ft to 130 ft thick locally in the center of section B-B' and about 45 to 60 ft thick at the ends of the section. Relief in excess of 40 ft is present along the base of unit 3. Unit 3 is overlain by unit 4 in all of the studied drill holes.

Correlation and age

Unit 3 corresponds, in the Gautier area, to the lower part of an undifferentiated unit consisting of the Citronelle Formation and terrace deposits mapped by Harvey and others (1965). Unit 3 probably also corresponds to the lower part of the Citronelle Formation as used by Otvos (1973, p. 4-7) in the same area.

There is no positive evidence for the age of unit 3 resulting from this study. A single palynomorph sample from unit 3 in the BELF #1 core lacks pollen of the exotic genus *Pterocarya*, which is present in several samples from underlying unit 2 in the BELF #1 and OSPD #1 cores (Willard and Edwards, this volume). In addition, this palynomorph assemblage contains *Picea* (spruce) and has other characteristics that make it similar to late-glacial Pleistocene assemblages (Willard and Edwards, this volume). However, the high density and advanced induration of the clays in unit 3 are more suggestive of a Neogene age. Therefore, a provisional Pliocene(?)-Pleistocene(?) age is assigned herein to unit 3.

Unit 4

Drill-hole sections

Substantial thicknesses of unit 4 were sampled with good recovery in the three coreholes. Unit 4 is also present in all of the studied water wells.

BELF #1 core

The uniformly sandy section between depths of 76 ft and 47.5 ft in the BELF #1 core is assigned to unit 4 (pl. 1). The basal contact is sharp and irregular with minor relief. The basal few inches consists of noncalcareous, gravelly fine to very coarse quartz sand; gravel lithologies include clay intraclasts, chert, and phosphate.

Above the basal gravelly sand, unit 4 consists entirely of well-sorted, loose quartz sand that grades from fine to very coarse grained near the base to very fine to fine grained at the top. Sparse disseminated, sand-sized plant fragments and local concentrations of wood occur throughout the unit. Very sparse, scattered, sand-sized mollusk fragments are present between depths of 57 ft and 49 ft. Most of the sand is grayish-pink (5R8/2) and less commonly very pale orange (10YR8/2). This unit-4 section is erosionally truncated along the base of overlying marine sediments in unit GB (Biloxi Formation) (Otvos, this volume; Gohn and others, this volume).

OSPD #1 core

The section between depths of 61 ft and 14 ft in the OSPD #1 core is assigned to unit 4. A sharp basal contact is overlain by 13.5 ft of loose to friable, well-sorted, noncalcareous quartz sand that fines upward from medium to very coarse grained at the bottom to very fine to medium grained at the top. Sparse, disseminated, sand- to granule-sized silt intraclasts are present in the basal foot.

Above this sand, unit 4 consists of dense, greenish-gray (5GY6/1, 5G6/1) and medium gray (N4), sandy and silty clay (47.5 ft to 27.1 ft), and yellowish-gray (5Y8/1), moderately well-sorted silt to very fine sand (27.1 ft to 14 ft). The upper 1.3 ft of the unit is very pale orange (10YR8/2) mottled with grayish orange (10YR7/4) and dark yellowish orange (10YR6/6). These sediments (47.5 ft to 14 ft) are sparingly micaceous and noncalcareous, and they contain sparse, disseminated, sand-sized plant debris throughout. Sparse, sand-filled, unlined burrows are present in the clay below a depth of 39 ft, and possible clay-lined burrows are present in the silt to very fine sand above 27.1 ft. The upper contact is placed at 14 ft where well-sorted, very fine to medium sand of unit PB overlies silt to very fine sand at the top of unit 4.

SSP #1 core

The section between depths of 106.4 ft and 78.7 ft in the SSP #1 core is assigned to unit 4 (plate 1). The basal contact is sharp with minor relief and is inclined at a low angle. The upper contact with overlying unit PB is more difficult to determine and is placed provisionally at a change in grain size (coarser above) within a thick sand interval. In this core, unit 4 consists only of fine to very coarse sand that locally contains fine gravel. The gravel fraction consists of quartz and lesser amounts of clay clasts and phosphate. The sand is noncalcareous and typically light-gray (N7), very light gray (N8), or grayish orange pink (5YR7/2).

The sand-dominated section between 106.4 ft and 57 ft in SSP #1 is interpreted as an amalgamated section in which sand at the base of unit PB erosionally overlies sand in unit 4. A similar section of unit-4 sand directly overlain by unit-PB sand is present in well p82 (section A-A', pl. 1). This interpretation is facilitated by the presence of fine-grained deposits at the top of unit 4 in nearby wells o216 and p94 (pl. 1; Harvey and Shows, 1963) that have not been eroded along the base of unit PB.

Water well sections

The lower part of unit 4 in well p94 is described as yellow to white sand and gravel, whereas the upper part is described as carbonaceous brown clay (Harvey and Shows, 1963; Harvey and others, 1965). The amalgamated sand sections of units 4 and PB are described as sand and gravel in well p82. Unit 4 is less readily recognized on the lithologic logs for wells n37, o20, and o27; a section of fine sand at 43 ft to 63 ft in well N37 may indicate an atypically fine-grained section of unit 4.

Lithologic summary

Unit 4 is a large-scale fining-upward section that is similar to units 2 and 3. However, the sands in unit 4 are typically coarser than those in the older units; unit 4 is the only unit to contain a significant amount of fine gravel. Where not removed by erosion along the bases of overlying units, the upper part of unit 4 consists of dense clays and silty very fine sands.

Geophysical logs and Distribution

Unit 4 is present in all of the studied drill holes. The basal contact is readily recognized on electric logs where the typically thin (20 to 30 ft), high-resistivity basal sand overlies fine-grained deposits at the top of unit 3, or similar deposits at the top of unit 2 where unit 3 is missing. The upper contact is similarly configured along section A-A' (pl. 1) where high-resistivity sands at the base of unit PB overlie finer grained deposits at the top of unit 4. As discussed above for the SSP #1 core, the upper fine-grained deposits of unit 4 are locally missing due to erosion along the base of unit PB.

Unit 4 is significantly truncated along section B-B' (pl. 1). In drill holes BELF #1, o207, o36, and o40, late Pleistocene marine deposits of unit GB rest on the basal sand of unit 4. This same interpretation is provisionally extended to wells o53 and o44 on section B-B'. In these two wells, fine-grained sections above the basal unit-4 sand contain three or four thin sand beds and appear more similar to unit GB in the BELF #1 core than to the sand-dominated section of unit PB in the SSP #1 core.

Substantial relief is present along the base of unit 4. On section A-A' (pl. 1), the base rises 50 to 60 ft from east to west in a manner similar to the base of unit 2. A few tens of feet of relief are also seen on section B-B'; for example, the basal contact drops over 40 ft between wells o40 and o44.

Correlation and age

Unit 4 was included in the undifferentiated section of Citronelle Formation and terrace deposits mapped at the top of the Jackson County section by Harvey and others (1965). It also represents part of the Citronelle Formation as used by Otvos (1973) in the Ocean Springs-Gautier area and is largely equivalent to the undifferentiated Pleistocene alluvium shown on figure 4 of Otvos and Howat (1992).

No positive evidence for the age of unit 4 was generated from the new cores. Constraints on the age of this unit are limited to the Pliocene age of unit 2 and the late Pleistocene age of overlying unit GB (Otvos and Howat, 1992; Cronin this volume; Willard and Edwards, this volume). However, the absence of exotic pollen species in a sample from unit 4 in the OSPD #1 core, and the similarity of the pollen and dinocyst assemblages in that sample to modern assemblages in the Jackson County area (Willard and Edwards, this volume), suggest a Pleistocene rather than a Neogene age for unit 4. Accordingly, a provisional Pleistocene(?) age is assigned to unit 4.

Unit PB

Unit PB is the youngest recognized unit underlying the Prairie terrace, as that feature is defined in western Jackson County by Otvos (1991) and Otvos and Howat (1992). These authors assign this section to the Prairie Formation (fluvial deposits) and an underlying estuarine facies of the Biloxi Formation.

Drill-hole sections

SSP #1 core

The section between 78.7 ft and the top of the SSP #1 core is assigned to unit PB. The basal 3.7 ft consists of loose, well-sorted, noncalcareous, fine to very coarse sand.

This sand is light pinkish gray (5YR8/1) and contains very sparse sand-sized plant fragments.

Above an unrecovered interval from 75 ft to 63.2 ft, the section consists of loose to friable, light-pinkish-gray (5Y8/1), slightly muddy, very fine to medium sand. This lithology grades across depths of 58 ft to 56 ft into yellowish-gray (5Y8/1), friable, silt to very fine sand. Similar silts and very fine sands continue upward to 35.1 ft, interrupted from 45 ft to 40.2 ft by a bed of noncalcareous, dense, silty clay. This clay is yellowish gray (5Y8/1) mottled with dark yellowish orange (10YR6/6).

Higher in the section, fine to very coarse sand, and locally fine to medium sand, are present from 35.1 ft to 18.5 ft. These sands are moderately well sorted and locally humate rich. Colors range from very pale orange (10YR8/2) to pinkish gray (5YR8/1) below 30 ft to yellowish gray (5YR8/1) mottled with dark yellowish orange (10YR6/6) and very pale orange higher in the interval. Within this section, a 2-ft-thick bed at 32 ft to 30 ft consists of grayish-green (10GY5/2), noncalcareous clay containing common sand-filled, unlined burrows with oxidized margins.

Above 18.5 ft, cores were recovered only from 15 ft to 13.5 ft and from 10 ft to 9.6 ft. They consist of dense, slightly micaceous, noncalcareous, silty and sandy (very fine) clay. The clay is very light gray (N8) mottled with moderate red (5R5/4) and dark yellowish orange (10YR6/6).

OSPD #1 core

A thin section of unit PB is present between a depth of 14 ft and the top of the hole. Above a 2-ft-thick unrecovered interval (16 ft to about 14 ft), the section between 14 ft and 8 ft consists of well-sorted, loose to friable, very fine to medium sand. The sand is white at the top and grades down to dark yellowish orange (10YR6/6). There was no recovery in the upper 8 ft of the corehole.

Geophysical logs

In the eastern half of section A-A' (pl. 1), unit PB consists of a basal 20-ft-thick sand overlain by a section of alternating sands and fine-grained deposits. Hence, the general appearance of this unit on the logs is similar to the large-scale, fining-upward patterns of units 2, 3, and 4. The basal sand typically has a high resistivity value and a strongly negative spontaneous potential curve that contrasts with opposing patterns in the finer grained beds at the top of underlying unit 4. The basal sand also is present on the western end of section A-A' but much of the overlying fine-grained sections is absent in that area. The presence of amalgamated sand sections where unit PB sands erosionally lie on unit 4 sands has been noted above (drill holes SSP#1 and p82).

Distribution, correlation, and age

Unit PB consists of all sediments above unit 4 and below the surface of the Prairie terrace. This definition differs only in local detail from the definition of the Prairie Formation and underlying estuarine facies of the Biloxi Formation mapped beneath the Prairie terrace by Otvos (1991) and Otvos and Howat (1992). Hence, unit PB is present in all wells on section A-A' (pl. 1), which is located on the Prairie terrace, but is present only in the SSP #1 corehole on section B-B', which is primarily located seaward of the Prairie terrace. A thin section of Holocene estuarine sediments is possibly included at the top of unit PB in well p82, which is located at the southwestern corner of Marsh (Lowery) Lake in the Pascagoula River valley.

Water wells o44 and o53 (section B-B') are located at the seaward edge of the Prairie terrace where it meets Mississippi Sound. In the interpretation of Otvos and Howat (1992, fig. 4), these two wells would contain the transition from marine deposits of the Biloxi Formation and overlying coastal-barrier deposits of the Gulfport Formation (unit GB herein) to fluvial deposits of the Prairie Formation and estuarine deposits of the Biloxi Formation (unit PB herein).

The base of unit PB rises nearly 50 ft from east to west on section A-A' (pl. 1). As a result, the unit thins from 60 ft to 80 ft in the east to 35 ft or less in the west. In some western drill holes, OSPD #1 and o27 for example, unit PB consists only of sand.

The age of unit PB was not determined directly during the present study. Otvos (1991) and Otvos and Howat (1992) assign this interval (their Prairie Formation and underlying estuarine facies of the Biloxi Formation) to the same late Pleistocene cycle of paralic and marine deposition as the Gulfport Formation barrier sands and the marine facies of the Biloxi Formation (unit GB).

Although the data are limited, the character of the clays and sands in unit PB at depths of 10 to 18 ft in our SSP #1 and OSPD #1 cores suggests the possibility of an older age. These sediments are mottled with moderately high-chroma colors (in dry samples), including moderate red (5R5/4), grayish-orange (10YR7/4), and dark yellowish orange (10YR6/6). Harvey and Shows (1963) describe the upper 21 feet of section in well o27 as greenish-gray, very sandy clay mottled with red streaks. The significantly great depths to which oxidation colors (red and orange) are present permit speculation that the sediments underlying the Prairie terrace have had a lengthy weathering history and that they might be older than late Pleistocene in age.

Unit GB

Unit GB is equivalent to the Gulfport Formation and the marine facies of the Biloxi Formation as used by Otvos (1975, 1991) and Otvos and Howat (1992). This unit was sampled only in the BELF #1 corehole during the present study.

Drill-hole sections

BELF #1 core

Unit GB in the BELF #1 core consists of shallow-marine sediments between depths of 47.5 ft and 25 ft. This section comprises interbedded shelly sands and clays in its lower part and shelly sands in its upper part. Gohn and other (this volume) describe this section in greater detail. Similar sediments at similar depths in a nearby corehole on Belle Fontaine Point are assigned to the Biloxi Formation by Otvos and Howat (1992, fig. 4).

Additional drill holes

The lithologic log for water well o40 describes macro- and microfossiliferous clay with a few thin beds of medium sand between the top of the hole and a depth of 84 ft (Harvey and Shows, 1963). This section is similar to unit GB in the BELF #1 core, but probably extends only to a depth of about 55 ft in well o40, judging from its electric log (section B-B', pl. 1).

Althought the Gulfport and Biloxi Formations have been used in their modern sense for at least 20 years (Otvos, 1973, 1975), type sections apparently had not been established. Recently, Otvos and Howat (1992, table 3) described type sections in a core from Gulfport in eastern Harrison County, Mississippi. This core consists of 25.25 ft of muddy sand, fine sandy mud, and silty very fine sand of the Biloxi Formation below 31.75 ft of fine to medium sand of the Gulfport Formation. The Biloxi section is macro- and microfossiliferous, whereas the Gulfport section is apparently barren of calcareous fossils.

Distribution, correlation, and age

Unit GB is present in drill holes BELF #1, o207, o36, o40, and possibly o53 and o44 on section B-B' of (pl. 1). Wells o36 and o207 were drilled into the large Gulfport Formation barrier that forms part of the shoreline at Belle Fontaine Point (fig. 2). About 60 ft of unit GB is interpreted to be present in well o36; a 50-ft section is inferred from the poor-quality log for well o207. The upper part of unit GB (Gulfport lithology) is missing in the BELF #1 core due to nondeposition and perhaps to erosion along the base of the Holocene section. Approximately the upper 80 ft of section in wells o53 and o44 are provisionally assigned to unit GB. A thin section of Holocene sediments in Graveline Bayou is included in unit GB on section B-B' (pl. 1).

Correlation of of unit GB with the Gulfport Formation and Biloxi Formation is inherent in the definition of the unit. Otvos (1991) assigns a late Pleistocene age to these formations (and the Prairie Formation) and considers them to represent a single cycle of highstand sedimentation during the last interglacial episode. Fossils from unit GB in the

BELF #1 core are compatible with that age (Cronin, this volume; Wingard, this volume; Gohn and others, this volume).

Holocene Coastal Deposits

Holocene coastal sediments were recovered only from the Belle Fontaine #1 corehole. The upper 25 ft of this core consist of muddy fine sands and sandy muds that represent sedimentation on the landward side of the westward-advancing spit at Belle Fontaine Point (Otvos, this volume; Gohn and others, this volume). A similar Holocene section is present at the western end of the spit (Otvos and Howat, 1992, fig. 4). The distribution of unstudied Holocene tidal marshes, tidal flats, and tidal-channel or estuarine bayous, as well as the Belle Fontaine spit and marsh, are shown on figure 2.

PRE-HOLOCENE DEPOSITIONAL HISTORY

Units 1 through 4

The Pliocene to Pleistocene(?) units 2, 3, and 4 have similar physical characteristics, thereby suggesting a common mode of origin. Their salient characteristics include: 1) erosional basal contacts with many tens of feet of relief within the study area, 2) fining-upward sediment distribution patterns, 3) lateral variations in maximum grain size with the coarsest sands in each unit concentrated where the unit is most deeply entrenched, and 4) low-diversity ichnofaunas and a paucity of body fossils. These characteristics suggest that units 2, 3, and 4 represent fluvial to estuarine sedimentation in incised paleovalleys during periods of rising sea level, as described, for example, by Van Wagoner and others (1990, p. 31).

Below the top of unit 1, at least two sands with fining-upward profiles are present locally at depths of 400 to 600 ft (Harvey and others, pl. 10). The presence of these unsampled sands suggests that unit 1 may constitute the top of another fluvial-estuarine cycle of sedimentation and that additional cycles may be present below the unit-1 cycle.

The high-relief basal contacts of units 2, 3, and 4 represent an erosional topography developed on the underlying unit(s) during a sea-level lowstand. Such topography is particularly apparent on section A-A' (pl. 1) where the basal contacts of units 2 and 4 rise from east to west and unit 3 pinches out to the west. Unit PB also has the same thickness pattern. The possibility that structures have controlled the locations of these paleovalleys through time is suggested by the fact that their deepest parts are all adjacent to, and perhaps beneath, the modern Pascagoula River valley (fig. 1; pl. 1).
The fining-upward sediment distribution reflects initial fluvial sand accumulation and subsequent muddy estuarine sedimentation caused by the raising of base level, the resulting reduction in stream competence, and the ultimate flooding of the paleovalleys during sea-level rise. The concentration of the coarsest sands in the deepest parts of the

unit 2 and unit 4 paleovalleys suggests a general restriction of the larger channels to the main axes of the valleys. The low-diversity ichnofaunas (typically one or two forms) and the scarcity of calcareous body fossils in units 2, 3, and 4 reflect the marginal-marine character of their sediments.

Dinoflagellate floras in these units also suggest nonmarine to marginal-marine conditions (Willard and Edwards, this volume). All of the productive palynologic samples from units 2, 3, and 4 in the OSPD #1 and BELF #1 cores contain freshwater algae and most contain common reworked Cretaceous and early Tertiary dinocysts. Sparse marine dinocysts accompany the freshwater algae and reworked dinocysts in only two of seven samples.

Viewed inter-regionally, the presence of these fluvial-estuarine sections of Pliocene and Pleistocene(?) age beneath late Pleistocene marine beds, and the absence of accompanying Pliocene marine beds, contrast strongly with the Pliocene sedimentary record of the southeastern Atlantic Coastal Plain. Onshore Pliocene sections in Virginia and the Carolinas contain a large percentage of calcareous marine beds. These marine beds extend inland as much as 50 miles, and locally more, and they underlie terraces of significantly higher elevation than do adjacent (seaward) Pleistocene marine deposits (Cronin and others, 1984; McCartan and others, 1984; Owens, 1989). Differences in regional tectonics apparently produced large differences in the elevations of late Neogene shorelines between the southeastern Atlantic Coastal Plain and the central Gulf of Mexico Coastal Plain.

Unit PB and Unit GB

Units PB and GB contain the coastal and paralic sediments assigned by Otvos (1982, 1991) and Otvos and Howat (1992) to the Pleistocene Biloxi, Gulfport, and Prairie Formations. Otvos (1991, this volume), Otvos and Howat (1992), and Gohn and others (this volume) interpret the unit GB sediments as nearshore-marine and barrier-strandplain deposits that represent a high sea level during the last interglacial period.

The physical similarity of unit PB to units 2, 3, and 4 suggests a similar origin, namely, fluvial-estuarine sedimentation in an incised paleovalley. This origin potentially conflicts with the existing interpretation of the physically equivalent Prairie Formation as a high-stand paralic unit that is genetically associated with the Gulfport and Biloxi Formations (Otvos, 1991; Otvos and Howat, 1992). Additional corehole data for the shallow-subsurface section beneath the Prairie terrace are probably necessary to resolve this apparent conflict.

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