SURFACE GEOLOGY OF

JACKSON COUNTY, MISSISSIPPI

By

Lindsey Stewart
And
James E. Starnes, RPG

Open-File Report 285

Mississippi Department of Environmental Quality
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In Cooperation with the Office of Land and Water Resources

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State Geologist

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This map prepared under the supervision of
James E. Starnes, RPG

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Introduction

Jackson County, located in Southeast Mississippi on the Gulf Coast, is one of the most important industrial areas in the state. It has been the subject of numerous studies, and several surface geology maps of the area have been previously published. One of the earliest geologic maps that included Jackson County was a statewide map by Eugene W. Hilgard, published just before the American Civil War in 1860. On this map, the surface geology of Jackson County was mapped as the Coastal Pliocene deposits and the Grand Gulf Group. The Grand Gulf Group was named for exposures in Mississippi near the community of Grand Gulf in Claiborne County and extended south to Fort Adams in Wilkinson County. The first subdivision of the Grand Gulf Group into the Catahoula, Hattiesburg, and Pascagoula Formations by the Mississippi State Geological Survey, was published in Bulletin No. 16 by Lowe (1920), *Road Making Materials of Mississippi*. It was also the first reference of the Citronelle Formation published by the Survey. The Citronelle Formation was named by Matson (1916) for outcrops that occur in Citronelle, Alabama, and was first mapped in Mississippi by E. N. Lowe (1925) in Bulletin No. 20, *Geology and Mineral Resources of Mississippi*. Two of the more detailed maps of Jackson County were published by Brown, et al (1944) and later by Harvey, et al (1965). Brown was likely the first to map the lower Pleistocene terraces separately from the Citronelle, realizing that the lower terraces were much younger. Brown also recognized the Graham Ferry as being a separate depositional unit from the Pascagoula Formation. Harvey mapped the terraces that occur at lower elevations in Jackson County as Pleistocene terraces, but most of the higher elevations were mapped as Citronelle. Both Brown and Harvey included the Graham Ferry and Pascagoula Formations on their maps, but much of the area that Brown mapped as Graham Ferry and Pascagoula was mapped as Citronelle by Harvey. More recent work by Marble and Crellin (1995 unpublished) found the Graham Ferry Formation to be present at the surface over a larger area than previously thought. They concluded that much of the area in the northwestern part of the county mapped as Citronelle by Brown, et al and Harvey, et al was in fact weathered Graham Ferry. Further work by Stewart, Everett, and Marble (1995 unpublished) revealed that other areas previously mapped as the Citronelle Formation in the northeastern part of the county were terraces associated with episodic changes in sea levels during the Pleistocene and were much younger than the Citronelle. Unfortunately, the work by Marble, et al and Stewart, et al was never formally published.

The purpose of this study and present report is to update the geologic map of Jackson County to reflect the earlier findings of Marble, et al and Stewart, et al and to provide a better understanding of the relationship between the surface geology and shallow sub-surface geology. This work aided the study of ground water resources in Jackson County, and a companion report has been published on this subject *Ground Water Resources of Jackson County*, Open-File Report 286. The most striking difference between the earlier geologic maps of Jackson County and the present map is the absence of the Citronelle Formation, and the more detailed mapping of the terraces, Graham Ferry, and Pascagoula Formations. Another change from the reports by Brown, et al and Harvey, et al is the reintroduction of the Grand Gulf Group nomenclature, Table 1. The Grand Gulf Group as presented here includes the interval between the base of the Catahoula and the top of the Graham Ferry. This interval is still being subdivided by the Mississippi Office of Geology into individual formations, but establishing a contact between them is very difficult at times. It appears that deposition of these formations was continuous throughout time in Jackson County, with the only difference between them being a change in the environment in which they were deposited. Therefore, it seems appropriate to group these intervals together as the Grand Gulf Group when the entire interval is being referenced, and then subdivide them as individual formations when mapping in local areas. The authors hope that this work will help to simplify the nomenclature and resolve some of the issues that have long hindered the mapping of these intervals in the past.

Surface Geology

General Discussion:

The surface geology of Jackson County can be divided into four parts: the alluvium of the Pascagoula and Escatawpa Rivers and their tributaries, river terraces, coastal terraces, and uplands. The uplands include the Graham Ferry and Pascagoula Formations. Both of these formations were deposited in very similar environments, and there is very little difference in appearance or composition between the two. Subdivision of these formations is based on geologic age which is supported by fossil evidence. The Graham Ferry is Pliocene in age, while the Pascagoula Formation is late Miocene. Brown, et al (1944) mapped these formations together as undifferentiated Graham Ferry and Pascagoula, noting the difficulty of dividing these units. Harvey, et al (1965) mapped the Graham Ferry Formation along the stream valleys on the west side of the Pascagoula River and the Pascagoula Formation along the southern edge of Red Creek but did not recognize either of the two on the east side of the river. In this report, on Plate 1, the Graham Ferry Formation, shown in grey, is present at the surface in the northwestern part of the county and in a few places along the Mississippi and Alabama state line. The Pascagoula Formation, mapped in a rose color, is exposed on the slopes of the terrace-capped hills in the northeastern part of the county. As shown on Plates 2 & 3, the Graham Ferry and Pascagoula Formations dip into the subsurface and are unconformably overlain by alluvium and terraces to the south. The alluvium and terrace deposits can easily be distinguished from the uplands by topography alone. Surfaces of the alluvium and terrace deposits are characterized by a flat to gently sloping topography, while the surfaces of the Graham Ferry and Pascagoula Formations are more rugged and hilly. Brown divided the terraces in Jackson County into the Pamlico sand, Low terrace, High terrace, and the Citronelle Formation. The Pamlico and the Low terrace were mapped along the coast and along the lower reaches of the Pascagoula and Escatawpa Rivers. The terraces that occur at higher elevations in the northeastern part of the county were mapped as High terrace, and those in the northwestern part of the county were mapped as the Citronelle Formation. Brown differentiated between the High terrace and Citronelle on the basis of topography. Harvey, et al (1965) mapped the Pamlico and (Low) Terrace very much like Brown, but he included all of the high terraces east and west of the Pascagoula River in the Citronelle Formation. He also included much of the area that Brown mapped as undifferentiated Graham Ferry and Pascagoula in with the Citronelle. Marble and Crellin (1995 unpublished) found that the Graham Ferry Formation was present at the surface over most of the area in the northwestern part of Jackson County, with a few residual terraces on the highest hilltops. In an effort to better understand the terraces in Jackson County, Stewart, Everett, and Marble (1995 unpublished) subdivided the terraces based on the elevations of the surfaces, and mapped them as individual units. It was noted that the terraces in Jackson County were very similar in elevation to the terraces mapped by Cooke (1965). Cooke began delineating the terraces on the Atlantic coast in the 1920's while working with the United States Geological Survey (USGS) and continued working down the east coast, around the Florida peninsula, and into the Gulf Coast area. Cooke concluded that the terraces along the Gulf Coast were stratigraphically equivalent to the terraces on the Atlantic coast, and the terraces as mapped in this report agree with Cooke's findings. Table 2 provides a comparison of the terraces as discussed in this report to those recognized by Brown, Harvey, and Cooke.

Alluvium:

The Pascagoula River basin is a very prominent feature in Jackson County, having a broad alluvial plain that divides the county east and west. This basin was formed by erosion and down-cutting of the Pascagoula River into the underlying formations during the latter part of the Pleistocene when sea levels were much lower than today. After being eroded, a subsequent rise in sea level submerged the basin, and sediment deposited from the Pascagoula River flowing into the bay formed the broad flat alluvial plain that is seen today (Figure 1). The basin is a little over five miles wide in the northern part of the county, and the alluvium in that area has a thickness of about 60 feet. The Escatawpa River has a comparatively smaller basin that trends from north to south on the east side of the county and flows into the Pascagoula River from the east, just north of the City of Moss Point. Red Creek is another major tributary of the Pascagoula River. It has a general northwest to southeast flow and enters the Pascagoula River basin just south of the northern boundary of Jackson County. Red Creek is incised into the underlying Graham Ferry and Pascagoula Formations and, in general, forms the northern limit of the Graham Ferry. Several minor tributaries flow into the Pascagoula or Escatawpa river basins and their associated alluvium is mapped as such. Streams in the western part of the county are much younger than the

Pascagoula and Escatawpa Rivers and have much smaller basins. These rivers flow directly into Biloxi Bay.

River Terraces:

The terraces that parallel the Pascagoula and Escatawpa Rivers were deposited in the same way as the broad flat plain of the Pascagoula River basin was formed. These terraces have been given local names that relate to the locations where flat benches occur. From the lowest to the highest, these terraces and their elevations are: Wade at 50 feet, Big Point at 70 feet, Hurley at 100 feet, Harleston at 130 feet, and Movella at 150 Feet (all elevations are relative to mean sea level - msl). Examples of these terraces are shown on Figures 2–6. Each successive higher terrace is an older terrace, with the Movella terrace being the highest and the oldest in the study area. As would be expected, the older terraces are typically more eroded than the younger terraces and more difficult to delineate. The terraces are relatively thick. Some, such as the Pamlico, have a thickness in excess of 100 feet. Contacts between the terraces are commonly masked by colluvium deposited on the slopes of the eroded surface between the upper terrace and lower terrace. This gives a more gentle appearance of the transition from one terrace to another. A scarp separating the Hurley and Big Point terraces has been preserved, however, and is located between the communities of Wade and Hurley on Highway 614. Surrounding land at the base of the scarp is very flat, with an elevation of 45 to 50 feet, and the topography at the top of the scarp is also flat, with an elevation of about 70 feet. The difference in elevation between the terraces, and the fact that there is a scarp separating them, is an indication that they were deposited by different stream systems at different times and are not stratigraphically equivalent to one another. Even though the contacts between some of the other terraces are not as definitive as the one between the Wade and Big Point terraces, each terrace was deposited in a similar manner and each interval should be regarded as an individual mapping unit.

Coastal Terraces:

The coastal terraces were formed in much the same way as the river terraces, but they parallel the coast and were deposited in a near-shore coastal environment. These terraces and their elevations, from the lowest to the highest, are: Pamlico at 25 feet, Big Ridge at 50 feet, and Good Hope at 70 to 100 Feet. Examples of these terraces are shown on Figures 7–9. The Pamlico terrace, as mapped here, includes the interval between present day sea level and 30 feet above sea level. A flat bench typically occurs at an elevation of around 25 feet on the Pamlico surface, but the Pamlico also includes two other flat benches at approximate elevations of 5 and 10 feet above sea level. Brown, et al (1944), and Harvey, et al (1965) treated the Pamlico as a separate geological unit from the other terraces, most likely due to the previous work by Cooke (1945). The Pamlico terrace was named by Stephenson (1912) for exposures in the area of Pamlico Sound in North Carolina. Other names have been introduced for this interval by some authors, but, due to its large regional extent and the general acceptance of the Pamlico name elsewhere, it seems appropriate to continue the use of the Pamlico nomenclature in this report. The thickness of the Pamlico terrace varies depending on location, but it generally appears to be thicker than the other coastal terraces. Based on well samples and geophysical well logs, the Pamlico terrace may be up to 140 feet thick in some places along the coast, and it thins to the north where it truncates along the southern edge of the Big Ridge and Wade terraces. The southern boundary of the Big Ridge terrace coincides with the northern limit of the Pamlico terrace and includes the interval from 30 feet up to an elevation of 50 feet. A flat bench occurs at an elevation of about 50 feet on the crest of the terrace and is equivalent to the higher elevations of the Wade River terrace. The estimated thickness of the Big Ridge terrace is 25 to 30 feet just north of the contact with the Pamlico terrace and thins to the north where it grades into the Good Hope terrace. The Good Hope terrace is actually the combination of two terraces that occur at elevations of 70 and 100 feet. Although these terraces were deposited at different times, the contact between the two is gradational and could not be reliably mapped as separate terraces. The surface of the Good Hope terrace is slightly rolling and includes the interval that lies between 50 to 110 feet in elevation. This interval is equivalent to the combined Big Point and Hurley river terraces. The Good Hope terrace is 25 to 30 feet thick where it is exposed at outcrop along the south side of Bluff creek. It is characterized as fine-grained clayey sand that weathers to a dark red brick color. The contact with the underlying Graham Ferry Formation is unconformable, and where observed along outcrop there is a pronounced contrast in the bedding between the two.

Graham Ferry Formation:

The Graham Ferry Formation was named by Brown et al (1944) for exposures of deltaic deposits on the west side of the Pascagoula River in Section 38, Township 5 South, Range 7 West, shown on Figures 10-11. Brown differentiated the Graham Ferry from the underlying Pascagoula Formation based on fossil evidence which indicated that the Graham Ferry was younger than the Pascagoula Formation. Other than age, there is very little difference between the two. They were both deposited in deltaic to near-shore marine environments and are very similar in composition. However, the Graham Ferry does appear to be a little more terrestrial than the underlying Pascagoula. Clays in the Graham Ferry tend to weather to a reddish orange to tan color, having a characteristic mottled appearance on outcrop. Pascagoula clays occasionally weather to a red color in places but, having less iron content, they commonly maintain a medium grey color on outcrop. Although the contact between the Graham Ferry and Pascagoula Formations was not observed at the surface in Jackson County, it appears that the Graham Ferry Formation is a continuation of the Pascagoula depositional system, and it is assumed that the contact between the two is conformable. The formation dips into the subsurface and is overlain by terrace deposits and stream alluvium. Figure 12 is a photo of the Hurley terrace overlying clays of the Graham Ferry Formation, and on Figures 13 &14, the unconformable contact between the Graham Ferry and the overlying Good Hope terrace is shown. There are distinct differences in the bedding and lithological composition between the Graham Ferry and the overlying terraces. On outcrop, a fresh exposure of Graham Ferry is typically composed of clean cross-bedded sands, silty sands, and light to medium gray clay (Figures 15-17), and the terraces are generally composed of clayey sands that weather to a dark red color which are easy to distinguish from the Graham Ferry. Reports of gravel and woody material are common in the shallow subsurface where the Graham Ferry sands have been drilled by water well drillers, particularly in the central part of the county and east of the Pascagoula River. Heavy minerals are also common in the sand intervals as shown on Figure 18. Some residual terraces are present on the west side of the Pascagoula River at higher elevations overlying the Graham Ferry Formation, but they are too limited in aerial extent to be mapped.

Pascagoula Formation:

The Pascagoula Formation is the oldest unit exposed at the surface in Jackson County. It was named by Johnson (1893) for exposures located along the Chickasawhay River at a place locally known as Shell Landing in Section 28, Township 1 North, Range 7 West, Greene County, Mississippi. At this location, the Pascagoula Formation is fossiliferous and is characterized by the mollusk fossil *Rangia johnsoni*. Where *Rangia johnsoni* is present the formation is considered to be Pascagoula, but the lack of *Rangia johnsoni* does not preclude an interval from being part of the formation. In Jackson County, the Pascagoula Formation is generally composed of clays and sands with some small gravel that were deposited in a near-shore estuarine to deltaic environment. Exposures of the Pascagoula Formation can be found on the slopes of hills and along the stream valleys in the northeastern corner of the county (Figure 19), and the tops of those hills are capped with terraces which unconformably overlie the Pascagoula. Access to outcrops of the Pascagoula Formation in Jackson County is fairly limited due to the sparse number of roads in the area in which it outcrops and much of the area being covered with vegetation. Clays of the Pascagoula Formation can be seen along the banks of the Escatawpa River when the water is low, and cross-bedded sands of the Pascagoula can be observed in a sandpit just to the north of the Jackson County line in George County, Section 31, Township 3 South, Range 5 West, (Figures 20 & 21). The Pascagoula Formation dips to the south beneath the Graham Ferry and overlying terrace deposits. Where the terrace deposits overlie the Pascagoula Formation the contact is unconformable, and as previously discussed, the contact with the Graham Ferry Formation appears to be conformable. The Pascagoula also appears to conformably overlie the Hattiesburg Formation although this contact is not exposed at the surface in Jackson County.

Citronelle Formation (Terrace):

Although the Citronelle "Formation" is not represented on the geologic map in this report, it requires some discussion since it has been previously mapped on earlier maps of Jackson County. The Citronelle Formation was named by Matson (1916) for outcrops that occur in Citronelle, Alabama along the Mobile and Ohio Railroad (now abandoned). The Citronelle Formation has long been a subject of controversy. Depending on the researcher, the area they were mapping, and the intervals they included in the formation, the age assigned to the Citronelle has varied from Miocene to Pleistocene with a thickness up to 500 feet. Excellent discussions on this subject are given in Geology and Mineral Resources Bulletins for Forrest County by Foster (1941); George County by Williams, Jr. (1967); and Clarke County by Gilliland (1980). Isphording (1971) noted that the inclusion of sands from underlying formations was likely the cause of much of the confusion in mapping the Citronelle. At the type locality, the formation (terrace) is composed of non-marine fine clayey sand that weathers to a red brick color with no apparent bedding (Figure 22). The interval mapped as Citronelle is clearly associated with a terrace that occurs at 340 to 350 feet in elevation where the town of Citronelle is located. The flat surface, shown in yellow on Figure 23, is the crest of the terrace, and Figure 24 is a photo of the terrace west of town. A change in slope occurs at 340 feet and then another change occurs at 300 feet. The increase in slope below 300 feet, as shown on the topographic map, seems to correspond to a change in lithology from clayey sand as described above to a clean unconsolidated sand which is more susceptible to erosion. A cross-bedded sand, as shown in Figure 25, subcrops beneath the clayey sand shown in Figure 22. The contact between the red clayey sand and the cross-bedded sand varies considerably (as much as 20 feet) and is obviously unconformable. This same unconformable contact between these two intervals can be found in sandpits to the east and south of the town Citronelle. On the east side of town, an unconformable contact between a red clayey sand similar to that at the Citronelle type locality and underlying cross-bedded sand is shown on Figure 26. At an elevation of about 10 to 20 feet below the contact as shown on Figure 26 (about 290 feet) Stephen P. Jennings with the Alabama Geological Survey has recently discovered an interval containing marine fossils. At present, the fossils do not appear to be age diagnostic, but the fact that the fossils are marine suggests that the underlying sands could possibly be Miocene in age. Many workers in the past have mapped both the cross-bedded sands and the overlying clayey sands together as the Citronelle Formation, but the sands are obviously two totally different depositional sequences separated by an unconformity. It is the author’s opinion that the use of the term Citronelle should be restricted to the clayey sand interval at the type locality that generally occurs at an elevation above 300 feet. Furthermore, the Citronelle Formation nomenclature should be discontinued in favor of the term Citronelle terrace.

The terraces that occur at lower elevations (below 340-350 feet) have also been mapped as Citronelle by other workers (Brown, et al 1944; Harvey, et al, 1965; and Williams, Jr. 1966). It was thought that the Citronelle dipped to the south and that the lower terrace elevations were due to subsidence. Brown, et al and Harvey, et al both reported that the Citronelle dipped into the subsurface beneath the coastal terraces in Jackson County, but they mistakenly included the underlying sands of the Pascagoula and Graham Ferry Formations with the Citronelle. The Pascagoula and Graham Ferry Formations definitely dip into the subsurface, but the Citronelle and other lower terraces do not. The similarity in elevations of the lower terraces across the Gulf Coastal plain and those on the east coast, support the conclusion that they were each deposited as separate terraces as a result of changing sea levels during the Pleistocene. On the present map of Jackson County, all of the lower terraces are regarded as individual depositional sequences unrelated to the Citronelle Terrace.

The higher terraces in the south-central part of Mississippi at elevations of 450 feet, 500 feet, and 550 feet have also been mapped as Citronelle. Many authors have considered these terraces to be more characteristic of the type section for the Citronelle Formation than the original type location at Citronelle, Alabama. These terraces are typically comprised of sand and gravel with discontinuous lenses of silt and clay that were deposited by the ancient Ohio and Tennessee Rivers that once flowed down the Mississippi Embayment and across the southern part of the state. Figures 27-38 are examples of these terraces and the sand and gravel deposits associated with them. The 550 foot terrace, as shown on Figure 27, is named for the location at the Magee Airport in Simpson County. When this terrace was originally deposited it likely extended over most of South Mississippi, but post-depositional erosion has removed much of the terrace and reworked it into lower terraces such as that at Brookhaven (500 foot terrace, Figure 31) and Crystal Springs (450 foot terrace, Figure 35). Unlike the Citronelle and other lower terraces, the higher terraces do appear to dip into the subsurface and are likely equivalent to the Graham Ferry which is Pliocene in age. With regard to the fact that the higher terraces are older than the Citronelle terrace and were deposited in completely different depositional environments, it is appropriate that these terraces should be mapped as individual units. The precise correlation of the higher terraces with the Graham Ferry is beyond the scope of this report, and more work will certainly be needed to determine the relationships of these intervals. The stratigraphic position of the Citronelle terrace being younger than the Graham Ferry (higher terraces) and older than the lower terraces would place the Citronelle time-wise in the late Pliocene to early Pleistocene, and the thickness would be about 40 to 50 feet, which is considerably less than has been previously mapped.

Subsurface Geology

The subsurface geology in Jackson County consists of sediments of the Grand Gulf Group of late Oligocene to Pliocene age and the overlying Pleistocene terraces. The Grand Gulf Group includes, in ascending order, the Catahoula, Hattiesburg, Pascagoula, and Graham Ferry Formations. These formations are further divided into lower and upper intervals, such as the Lower and Upper Graham Ferry, and so on. The methodology for subdividing the Grand Gulf Group is discussed in MDEQ Office of Geology Open-File Report 284, *Geohydrologic Cross-Sections of the Grand Gulf Aquifer System in Southern Mississippi* by Hoffmann, et al (2017). The contacts between these formations are at times difficult to delineate, but by first determining the dip (slope) of the underlying marine units and using established geologic methods and principals, the Grand Gulf Group can be reasonably subdivided into individual formations. The dip rate for the marine units underlying the Grand Gulf Group in Jackson County was established on cross-sections published in MEQ Office of Geology Open-File Report 286, *The Ground Water Resources* *of Jackson County* by Stewart (2017), and the overlying formations were subdivided with respect to this dip. These cross-sections were constructed for the purpose of evaluating the availability of ground water resources in Jackson County, and more emphasis was put on the deeper formations than the shallower intervals. In order to gain a better understanding of the relationship between the Grand Gulf Group and the overlying terraces for this report, it was necessary to construct cross-sections that were more focused on the shallow subsurface intervals. The distribution of the sands and clays, as can be seen on these cross-sections, is typical of the multiple depositional environments in which they were deposited, and the difficulty in subdividing the Graham Ferry and Pascagoula intervals is quite apparent. Four cross-sections were constructed, two oriented north to south (Plate 3) and two oriented east to west (Plate 4). The locations of these cross-sections are shown on Plate 2, and a list of the wells used in constructing these cross-sections is given in Table 3. The tops of the Lower Pascagoula and Upper Hattiesburg intervals on these cross-sections were transposed directly from the cross-sections in Open-File Report 286, and the dip of these intervals served as a basis to further subdivide the Upper Pascagoula and Graham Ferry intervals. As shown on Cross Sections A-A′ and B-B′ (Plate 3), the apparent dip of the Pascagoula and Graham Ferry is to the south, and on Cross Sections C-C′ and D-D′ (Plate 4) there is some slight dip to the west. The formations thicken from north to south and slightly to the west, indicating a basin that subsided to the south-southwest during deposition. The Pleistocene terraces are flat lying and unconformably overlie the Pascagoula and Graham Ferry Formations. As shown on Cross Section A-A′, the Upper Graham Ferry subcrops beneath the Pamlico and Big Ridge terraces in the southern part of the county and is exposed at the surface in the central part. The Lower Graham Ferry crops out in the northern part of the county, and the Pascagoula is exposed at the base of the slope along Red Creek. East of the Pascagoula River, as shown on Cross Section B-B′, the Graham Ferry Formation is entirely subcropping beneath the Pamlico and Wade terraces, and the Upper Pascagoula is exposed at the surface in the northern part of the county. On Cross Section C-C′, the Upper Graham Ferry subcrops beneath the Pamlico, Big Point and Good Hope terraces where they occur on the west side of the Pascagoula River, and on the east side, the Lower Graham Ferry subcrops beneath the Pamlico and Wade terraces. As shown on Cross Section D-D′, the Graham Ferry is entirely subcropping beneath the Pamlico terrace and alluvium of the Pascagoula River. The thickness of the Pamlico terrace, as shown on these cross-sections, was based on Brown's (1944) interpretation of drill cuttings from water wells, and the thicknesses of the other terraces were based on the interpretation of well cuttings and direct observations made of these terraces on outcrop.

Geomorphic Features

In addition to the flat terrace surfaces in Jackson County, there are three geomorphologic features of particular interest: the Big Ridge scarp, the Big Ridge Island, and the ancient course of the Pascagoula River. These features are quite helpful in understanding the depositional history of the area, beginning with the Big Ridge terrace and continuing with the deposition of the older terraces and recent sediments in the Pascagoula River Basin.

Big Ridge Scarp:

An east-west trending scarp is evident to the north of D'Iberville and Ocean Springs and is known locally as the Big Ridge scarp. It extends approximately fourteen miles from a point near the Tchoutacabouffa River, south of Interstate 10, to Highway 57 northeast of Ocean Springs. As shown in yellow on Figure 39, the toe of the scarp is at an elevation of about 25 to 30 feet and the top is 45 feet above present mean sea level. Some authors have attributed the existence of the scarp to faulting (Otvos, 2011; and Galicki and Schmitz 2016), while others have concluded that the scarp was formed by wave action when the Pamlico terrace was being deposited and sea levels were 20 to 25 feet higher than present msl (Cooke, 1966; Carlston, 1950; and Brown, 1944). A northwest to southeast cross-section (E to E', Figure 40) was constructed across the scarp to determine if a fault could be detected in the subsurface. The location of the cross-section is shown on Figure 41. The northern well is located at the top of the scarp on the southern edge of the Big Ridge terrace, and the southern well is located about a mile to the southeast on the Pamlico terrace. Sands in the Upper and Lower Graham Ferry Formations appear to correlate fairly well between the two wells with an apparent dip of ten to fifteen feet, and the Pamlico terrace appears to be a completely different depositional sequence than the Big Ridge terrace. If a fault were present between the two wells, you would expect considerably more displacement than the ten to fifteen feet of apparent dip shown on the cross-section, and the difference in elevation between the two terraces appears to be due to depositional processes and not faulting. In addition, there are numerous discontinuous scarps at the same elevation as the Big Ridge scarp mapped by Carlston and others along the northern Gulf of Mexico and the Atlantic Coast. Some of these scarps can be mapped for miles and are inarguably wave-cut scarps which were formed as a result of changes in sea levels. You would expect that the Big Ridge scarp would have been formed in the same way as those scarps found elsewhere. An example of a recent wave-cut scarp is shown on figures 42 and 43. The scarp was cut into the Pamlico terrace, and the base of the scarp is at present day sea level while the top is at an elevation of about 20 feet. This scarp is clearly the result of wave action during the Holocene and is analogous to the Big Ridge scarp. The theory of faulting by Otvos, and by Galicki and Schmitz is not supported by the available subsurface information, nor is there any other evidence of shallow faulting elsewhere along the Mississippi Coast. Since these scarps occur at about the same elevation as other scarps along the northeastern Gulf of Mexico and Atlantic Coast and parallel the present day coastline, the authors are in agreement with Cook, Carlston, and Brown and conclude that the Big Ridge scarp was formed by wave action and not faulting.

Big Ridge Island:

Another prominent geomorphic feature located north of the Big Ridge scarp is shown in yellow on Figure 44. This is a low relief ridge that trends northwest to southeast and is a little more than four miles long and generally less than a half-mile wide. The crest of the ridge is at 50 to 55 feet above msl and is the highest surface on the Big Ridge terrace. It appears to have been deposited as an island when sea levels were 40 to 50 feet higher than today. When sea levels retreated during the Illinoian glacial stage the island was left behind, and it is now a reminder of the depositional history of the past. It would seem that an emerged island such as this would be rare, but this type feature is common on the Atlantic Coast (MacNeil, 1949). A few emerged islands or bars are also present on the surface of the Pamlico terrace on the western end of the Mississippi Coast in Hancock County. Deer Island, which is located along the present day shoreline at the mouth of Biloxi Bay, is very similar in size and orientation to Big Ridge Island. If sea levels were to drop twenty feet, the shoreline would move south of the barrier islands and Deer Island would be left high and dry, very similar to Big Ridge Island today. The emerged land between what is now the present day shoreline and the barrier islands would appear very much like the surface of the Big Ridge terrace, and a new wave cut scarp would likely be created south of the islands. This is a process that has occurred repeatedly during the Pleistocene and is an example of how the coastal terraces and scarps were formed around the northern Gulf of Mexico and along the Atlantic Coast.

Ancient Course of the Pascagoula River:

The ancient course of the Pascagoula River is the last of the geomorphic features to be discussed here. As shown on Figure 45, meander scars on the surface of the Pamlico terrace are an indication that the Pascagoula River once flowed across the terrace in a northwest to southeast direction beginning at a point north of the town of Escatawpa and entering the Mississippi Sound east of the City of Pascagoula at Grand Bay. The Escatawpa River was likely intercepted by the Pascagoula River in the Orange Grove area at that time. Figure 46 is a photo of Bayou Cumbest, which was once part of the ancient course of the combined Pascagoula and Escatawpa Rivers near the location where they flowed into the Sound. Both of these rivers have changed courses over the years, with the Pascagoula River steadily migrating to the west and the Escatawpa River making an almost ninety-degree turn to the west in the Orange Grove area and flowing into the Pascagoula River north of the City of Moss Point. The valley of the present day Pascagoula River was likely formed during the last glacial maximum about 20 thousand years ago when sea levels were much lower. After a rise in sea level to its present stage approximately 5 to 6 thousand years ago, the basin was filled with sediment by the Pascagoula River forming a broad, flat alluvial plain. Again, if sea levels were to drop twenty feet, erosion and down-cutting by the Pascagoula River would resume, and the Pascagoula River would likely continue to migrate to the west. The remaining dissected alluvial plain would be left as a terrace, and the meander scars on the terrace would look very similar to those found on the Pamlico. This process has been repeated many times during the Pleistocene; however, the meander scars on the Pamlico are much younger and better preserved than those on the older river terraces.

Changes in Sea Levels and Coastal Stability

The highest terrace that Cooke (1945) originally recognized on the east coast was the Hazlehurst (or Brandywine) terrace at an elevation of 275 feet. Later, while mapping terraces in the Mississippi River Basin, Cooke (1965) identified a terrace that occurred at an elevation of approximately 360 feet and named it for the town of Morley, Mo. where it was located. He noted that residual terraces were present at similar elevations on the east coast but were highly dissected and difficult to map. He also recognized the probability that the Morley terrace was correlative with the Citronelle terrace in Alabama. In his report on the *Emerged Quaternary Shore Lines in the Mississippi Embayment*, Cooke (1965) went into great detail as to how the river terraces were deposited in "drowned valleys" during sea level high stands and eroded during sea level low stands. The Citronelle terrace in this report is considered to be the highest river terrace associated with a sea level high stand. Each of the terraces that occur at progressively lower elevations was deposited during interglacial periods, and they provide a record of the sea level stand-stills that were of sufficient duration for these terraces to have been deposited. A graph of the distribution of interglacial periods and glacial maximums for the last 450 thousand years is shown on Table 4. Ages of these interglacial periods and glacial maximums have been determined from marine isotopes as discussed by Railback (2015), Table 5. The Pamlico is the lowest terrace mapped in Jackson County and was deposited during the last interglacial stage which occurred from 70 to 130 thousand years ago (Doar, III 2014). Cooke noted that more than one terrace could be deposited during one interglacial stage as is the case with the Pamlico having terraces that occur at elevations of approximately 20 to 25 feet, 10 to 13 feet, and 5 to 8 feet. Cooke attributed this to pauses in sea levels as they were retreating from interglacial high stands. After deposition of the Pamlico terrace, sea levels continued to decline during the Wisconsin glacial period to a depth of approximately 400 feet below present day sea level. This occurred during the last glacial maximum about 20 thousand years ago (Shackleton, 1969; and Fairbridge, 1961). From this point, as indicated on Table 4, sea levels rose fairly rapidly and reached present day sea level about five to six thousand years ago. Sea levels have been fairly stable since only varying a few feet either up or down.

Cooke recognized that after the deposition of the Hazlehurst (Brandywine) terrace, the younger terraces were deposited at progressively lower elevations. He attributed this to the overall lowering of sea levels due to increases in capacity of the ocean basins caused by down-warping of the ocean floor. Another possible explanation of the lowering of sea levels is the ever increasing volume of water trapped in the pore spaces of sediment in subsiding basins. There is a tremendous volume of water below land surface in the Mississippi River basin alone. Although some of this water is returned to the surface naturally through submarine seeps or mechanically by water wells, there has been an overall loss of water from the surface of the earth. The combination of ocean floors subsiding and loss of water to the subsurface provides an explanation for the deposition of the Citronelle terrace at an elevation of 340 feet, and each of the other terraces being deposited at progressively lower elevations. Some authors, however, have attributed the cause of terraces occurring at elevations well above present day sea level to be due to uplift of the earth's crust (Otvos, 2011; and Galicki and Schmitz 2016). The theory of the terraces being uplifted is not supported by the available subsurface data. The regional cross-sections published by Hoffmann, et al (2017) in MDEQ Office of Geology, Open-File Report 284, and the cross-sections by Stewart (2017) in MDEQ Office of Geology, Open-File Report 286, indicate that the basin in Jackson County was subsiding to the south-southwest during the deposition of the Grand Gulf Group, and there is no indication of uplift post deposition of the Graham Ferry. The terraces on the cross-sections in this report (Plates 3 & 4) are shown to be flat lying, having an unconformable contact with the underlying Graham Ferry and Pascagoula Formations. Cooke's rationale for the increase in capacity of the ocean basins being the cause for the terraces occurring at lower elevations over time is a much more plausible explanation than the periodic uplifting of the earth's crust.

In contrast to the theory of the earth's crust being uplifted along the Mississippi Coast, other studies have concluded that much of south Mississippi, including the coastal area, is subsiding (Shinkle and Dokka, 2004). A report published by NOAA on the *Rates of Vertical Displacement at Benchmarks in the Lower Mississippi Valley and the Northern Gulf Coast* indicated that the Mississippi Gulf Coast is subsiding. There are, however, several problems with this report. To begin with, the location of the reference point for the survey was at Grand Isle in south Louisiana where the land surface is known to be subsiding. The elevation of this point was estimated rather than surveyed, so the accuracy of this elevation is questionable. This estimated elevation was used to compute new elevations for the other benchmarks in the study, and the vertical displacement over time was calculated for each of these benchmarks based on these new elevations. The report does acknowledge that if the estimated elevation of the benchmark at Grand Isle is incorrect, then the vertical displacement of the benchmarks would also be incorrect. This report relied on leveling data that was collected over many years and acknowledges that there may be some variation in benchmark elevations due to data being generated using different equipment and procedures from one survey to the next. Another variance in methodology that could cause errors in elevations was introduced by changing from the vertical datum of 1929 to NAVD of 1988. Most of the earlier benchmark elevations were based on the 1929 vertical datum, and by converting these elevations to the NAVD 1988, a correction had to be made. Consequently, there are multiple points in which errors could occur in calculating the vertical displacement of individual benchmarks. Shinkle and Dokka calculated that the land surface along the Mississippi Gulf Coast was subsiding at varying rates, with the highest rate to the west and the lowest to the east. For the period between 1971 and 1977 (the last period that they calculated subsidence for the Pass Christian and Biloxi areas) they concluded that the land surface in the Pass Christian area was subsiding at a rate of around 8 mm/yr, and the Biloxi area was subsiding at a rate of approximately 2 mm/yr. The benchmarks that were used to calculate the subsidence rates in both of these areas are located either on or in close proximity to the Pamlico terrace. As previously discussed, the Pamlico terrace was deposited from 70 to 130 thousand years ago, and the elevation of the terrace is the same in Pass Christian as it is in Biloxi. If subsidence was occurring as Shinkle and Dokka reported, the Pamlico terrace would not occur as it does at the same elevation across the entire Mississippi Coast. Stearns MacNeil (1949) came to the same conclusion in a USGS report on terraces in Florida and Georgia. In his discussion on the stability of the coastal area extending from Virginia to Florida, he noted that the Pleistocene terraces and scarps occurred at essentially the same elevations along the coast, and there was little to no evidence of subsidence from Maryland southward. The same can be said for the Gulf Coast of Mississippi, Alabama and West Florida. As previously discussed, the Pleistocene terraces present in these areas are at essentially the same elevations as those on the East coast. If the coastal areas of the northern Gulf of Mexico or the Atlantic Coast were subsiding, it is highly unlikely to be occurring at the same rate on both coasts. The coastal areas in South Louisiana and East Texas are subsiding mainly due to being on the down-thrown side of active growth faults, and to sediment loading. Neither of these situations is present on the Mississippi Gulf Coast. There is no evidence of faulting in the shallow subsurface, and prior to the deposition of the Pleistocene sediments, the Pliocene and Miocene intervals underwent an extended period of erosion. Therefore, there has been an overall loss of sediment in the coastal counties since the deposition of the Graham Ferry Formation. In light of the similarities in terrace elevations and the lack of a mechanism to cause subsidence, the Mississippi Gulf Coast appears to have been stable for several thousand years.

Prehistoric archaeological sites located along the Mississippi Gulf Coast further substantiate that the coastal area is stable. There are numerous prehistoric archeological sites on the coast; those shown on Figure 47 are only a representative sampling. The conspicuous lack of sites along the beach from Pass Christian to Biloxi is due to shoreline erosion. Any sites that were once present on that stretch of beach would have been destroyed by wave action. The selected archaeological sites often include shell middens which were very close to sea level when they were first inhabited. They are still located close to sea level today, essentially in their original position, and they vary in age from Archaic to Mississippian. A table of the archeological periods and their associated time intervals is presented below. Several of the archaic sites may be as much as 5,000 years old, while the Mississippian sites are much younger. This establishes a period of approximately 4,000 years during which there was little to no subsidence along the coast. If the Mississippi coast was subsiding as reported by Shinkel and Dokka, these archaeological sites would certainly be below sea level today. Since this is not the case, these prehistoric archaeological sites further support a stable coastline.

Archaic Period - 10,000 to 2,500 years before present
- Early Archaic - 10,000 to 8,000 BP
- Middle Archaic - 8,000 to 5,000 BP
- Late Archaic - 5,000 to 2,500 BP

Woodland Period - 500 BC to 1,000 AD
- Early Woodland - 500 BC to 0 AD
- Middle Woodland - 0 AD to 500 AD
- Late Woodland - 500 AD to 1,000 AD

Mississippian Period - 1,000 AD to 1540 AD
- Early Mississippian - 1,000 to 1,200 AD
- Middle Mississippian - 1,200 to 1,400 AD
- Late Mississippian - 1,400 to 1540 AD

Summary

The Geologic Map of Jackson County, as mapped in this report, is an update of the maps by Brown, et al (1944) and Harvey, et al (1965), and it also reflects the findings of Marble, et al and Stewart, et al based on field observations made in the 1990's. Each of the terraces in Jackson County was mapped in more detail, and a considerable effort was made to delineate the Pascagoula and Graham Ferry Formations at the surface. Subsurface techniques were used to project the Pascagoula and Graham Ferry Formations to the surface, and to determine their relationship to the overlying terraces. It was determined through this work that the Pascagoula and Graham Ferry Formations dip into the subsurface to the south, and that the terraces unconformably overlie these formations. Much of the area that had previously been mapped as the Citronelle Formation by Brown and Harvey was determined to be weathered sands and clays of the Pascagoula and Graham Ferry Formations. This project benefited from having the Office of Geology's drilling rig available to drill stratigraphic test holes in areas where there were few outcrops to observe at the surface. The drilling rig also provided an advantage to the authors over previous workers to be able to recognize the difference between the terrace deposits and weathered outcrops of the Pascagoula and Graham Ferry Formations. It is the authors' hope that this work will provide a framework for subdividing the Pleistocene terraces and a methodology for mapping the Grand Gulf Group.

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Section II

Tables

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Graham Ferry</td><td rowspan="3">Post
Graham Ferry
Undifferentiated</td></tr>
<tr><td rowspan="2">Pleistocene</td><td colspan="2">Pamlico</td></tr>
<tr><td colspan="2">Terraces</td></tr>
<tr><td rowspan="18">Tertiary</td><td rowspan="2">Pliocene</td><td rowspan="10">Grand Gulf Group</td><td colspan="3" rowspan="2">Graham Ferry</td><td>Upper Graham Ferry</td></tr>
<tr><td>Lower Graham Ferry</td></tr>
<tr><td rowspan="5">Miocene</td><td colspan="3" rowspan="2">Pascagoula</td><td>Upper Pascagoula</td></tr>
<tr><td>Lower Pascagoula</td></tr>
<tr><td colspan="3" rowspan="2">Hattiesburg</td><td>Upper Hattiesburg</td></tr>
<tr><td>Lower Hattiesburg</td></tr>
<tr><td rowspan="4">Catahoula</td><td colspan="2">Upper Catahoula</td><td>Upper Catahoula</td></tr>
<tr><td rowspan="7">Oligocene</td><td colspan="2">Tatum Limestone</td><td rowspan="3">Lower Catahoula</td></tr>
<tr><td>Paynes Hammock Fm.</td><td rowspan="8">Chick.-Vicksburg-Jackson Undif.</td></tr>
<tr><td>Chickasawhay Ls.</td></tr>
<tr><td colspan="2" rowspan="4">Vicksburg Group</td><td>Bucatunna & Byram Undif.</td><td rowspan="8"></td></tr>
<tr><td>Glendon Ls.</td></tr>
<tr><td>Marianna & Mint Spring Undif.</td></tr>
<tr><td>Forest Hill & Red Bluff Undif.</td></tr>
<tr><td rowspan="4">Eocene</td><td colspan="2" rowspan="2">Jackson Group</td><td>Yazoo Fm. Undif.</td></tr>
<tr><td>Moodys Branch Fm.</td></tr>
<tr><td colspan="2" rowspan="2">Claiborne Group</td><td colspan="2">Cockfield Fm.</td></tr>
<tr><td colspan="2">Cook Mountain Fm.</td></tr>
</table>

Table 1: Stratigraphic Section and Subdivision of Grand Gulf Group in Jackson County

(Modified from Hoffmann, et al, 2017)

Comparison of Terrace Classifications to Previous Work

Terraces in Jackson Co. This Report				Cooke (1966)		Brown (1944)	Harvey (1965)
Stream Terraces	Coastal Terraces	Map Interval	Terrace Elv.		Terrace Elv.		
	Pamlico	0' to 30'	25'	Pamlico & Silver Bluff	6' & 25'	Pamlico	Pamlico
Wade	Big Ridge	30' to 50'	50'	Talbot	42'	Low Terrace	Terrace
Big Point	Good Hope	50' to 80'	70'	Penholoway	70'	High Terrace & Citronelle	Citronelle
Hurley		80' to 110'	100'	Wicomico	100'		
Harleston		110' to 130'	130'	Not Recognized	Not Recognized		
Movella		130' to 180'	150'	Okefenokee & Sunderland	145' & 170'		
Agricola		190' to 230'	220'	Coharie	215'		
Lucedale		250' to 270'	270'	Hazlehurst	275'		
Sand Hill		280' to 300'	300'	Not Recognized	Not Recognized		
Citronelle		300' to 350'	340'	Morley	360'		

Note: All elevations are relative to sea level (MSL)

Table 2

Wells Used in Jackson County Cross Sections

Cross Section A to A'

Map No.	USGS No.	Well Owner	Well Name	Sec	Town	Range	Latitude	Longitude	Elv.
1	O549	St. Andrews		7	8S	7W	30.362500	-88.721389	14' GR
2	O422	City of Gautier	HWY 57	7	7S	7W	30.447222	-88.718333	20' GR
3	K32	Vancleave High School		16	6S	7W	30.523611	-88.689167	21' GR
4	F22	USGS	Test Well	27	5S	7W	30.574717	-88.678972	78' GR
5	B27	Jenkins	Home Well	34	4S	7W	30.653711	-88.678347	143' GR
6	B105	Miss. Off. Of Geology	Test Well	22	4S	7W	30.682778	-88.671111	16' GR

Cross Section B to B'

Map No.	USGS No.	Well Owner	Well Name	Sec	Town	Range	Latitude	Longitude	Elv.
7	P145	Ingalls Shipbuilding	East Bank Well #2	5	8S	6W	30.356322	-88.560783	10' GR
8	P501	City of Pascagoula	Test Well Market Street	1	8S	6W	30.383056	-88.536667	10' GR
9	Q434	City of Moss Point	Hardy Well	18	7S	5W	30.438411	-88.525514	10' GR
10	L28	Charles Ladner	Home Well	36	6S	6W	30.479100	-88.540156	15' GR
11	L183	Jackson Co. Utility Auth.		13	6S	6W	30.529999	-88.543889	18' GR
12	H241	Miss. Off. Of Geology	Test Well	30	5S	5W	30.576083	-88.525333	35' GR
13	Oil Test	Amoco Production Co.	No. 1 Cumbest Unit 13-11	13	5S	6W	30.609788	-88.540742	63' DF
14	C130	Jackson Co. Utility Auth.	Test Well	36	4S	6W	30.649444	-88.535555	51' GR
15	C127	Jackson Co. Utility Auth.	Test Well	13	4S	6W	30.702222	-88.546111	80' GR

GR Ground Level DF Derrick Floor

Table 3

Wells Used in Jackson County Cross Sections

Cross Section C to C'

Map No.	USGS No.	Well Owner	Well Name	Sec	Town	Range	Latitude	Longitude	Elv.
16	J497	Christopher Gates	Test Well	13	6S	9W	30.51	-88.838000	40' GR
17	J512	Jackson Co. Utility Auth.	Test Well	2	6S	8W	30.549239	-88.750561	93' GR
3	K32	Vancleave High School		16	6S	7W	30.523611	-88.689167	21' GR
11	L183	Jackson Co. Utility Auth.	Surface Water Plant	13	6S	6W	30.529999	-88.543889	18' GR
18	M13	H. H., Hough	Home Well	17	6S	5W	30.530383	-88.503247	32' GR
19	M18	H. E. Furby	Home Well	14	6S	5W	30.523311	-88.454722	17' GR

Cross Section D to D'

Map No.	USGS No.	Well Owner	Well Name	Sec	Town	Range	Latitude	Longitude	Elv.
20	N996	West Jackson Co. Utility	Test Well	11	7S	9W	30.446389	-88.862222	20' GR
21	N81	City of Ocean Springs		16	7S	8W	30.428417	-88.791111	25' GR
22	N1048	City of Ocean Springs		23	7S	8W	30.417039	-88.764003	23' GR
23	O286	City of Gautier	Mall Well	35	7S	7W	30.3975	-88.6583	21' GR
8	P501	City of Pascagoula	Test Well Market Street	1	8S	6W	30.383056	-88.536667	10' GR
24	Q641	Miss. Off. Of Geology	Test Well	34	7S	5W	30.398403	-88.474967	8' GR

Cross Section E to E'

Map No.	USGS No.	Well Owner	Well Name	Sec	Town	Range	Latitude	Longitude	Elv.
25	N1035	Chuck Stone	Test Well	8	7S	8W	30.453611	-88.812222	43' GR
26	N1050	West Jackson Co. Utility	St. Martin School	16	7S	8W	30.440556	-88.796944	25' GR

GR Ground Level DF Derrick Floor

Table 3 Continued

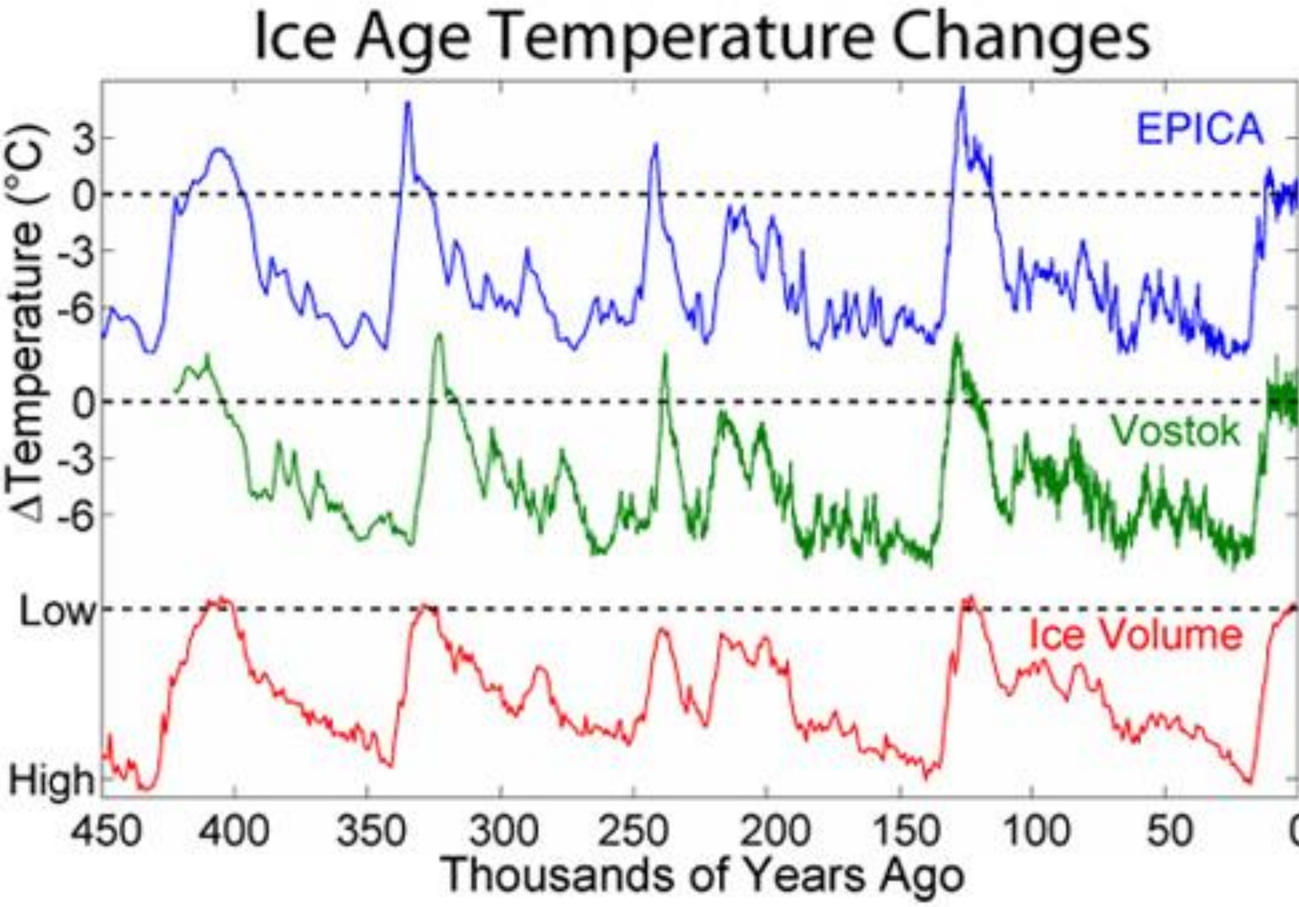


Table 4

Temperature and Ice Volume Graphs as derived from ice core studies in Anartica

EPICA - European Project for Ice Coring in Anartica

Vostok - Ice Core Study in East Anartica

Marine isotope stages and substages

The study of deep-sea cores, and specifically the study of oxygen isotope ratios in foraminifera in those cores, has revealed a consistent pattern representing changes in the ocean-atmosphere system through time. Cesar Emiliani, who published the first report of such isotopic data in 1955, designated the major swings in his data as numbered stages, which are now commonly known as "Marine Isotope Stages". Nicholas Shackleton, a prominent scholar of the history of the oceans and climate, explicitly subdivided Emiliani's Stage 5 into lettered substages in a 1969 paper. Thus Quaternary time came to be divided into marine isotope stages and substages.

As time passed, other researchers followed Shackleton's lead, if less explicitly, by designating other peaks and troughs in various isotopic time-series as substages. However, this was done with little attention to consistency, and eventually any one interval of the record had been assigned to as many as five different substages in different papers. In an effort to provide one consistent system, Railsback et al. (2015a) generated the scheme of marine isotope substages shown below.

The figure below is derived from Figure 3 of Railsback et al. (2015a), which extends back to MIS 28c at 1.0 mya. The oxygen isotope data are the LR04 stack of Lisiecki and Raymo (2005). The Mid-Brunhes Shift is from Berger and Wefer (2003), and the Early Brunhes Shift is from Railsback et al. (2015b).

Berger, W.H., Wefer, G., 2003. On the Dynamics of the Ice Ages: Stage-11 Paradox, Mid-Brunhes Climate Shift, and 100-ky Cycle. In: A.W. Droxler, R.Z. Poore and L.H. Burckle (eds.) Earth's Climate and Orbital Eccentricity: The Marine Isotope Stage 11 Question. AGU Geophysical Monograph 137, 41-59.

Emiliani, C., 1955. Pleistocene temperatures. Journal of Geology 63, 538–578.

Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic d¹⁸O records. Paleoceanography 20, doi:10.1029/2004PA001071.

Railsback, L.B., Gibbard, P.L., Head, M.J., Voarintsoa, N.R.G., and Toucanne, S., 2015a. An optimized scheme of lettered marine isotope substages for the last 1.0 million years, and the climatostratigraphic nature of isotope stages and substages. Quaternary Science Reviews 111, 94-106.

Railsback, L.B., Brook, G.A., Ellwood, B.B., Liang, F., Cheng, H., Edwards, R.L., 2015b. A record of wet glacial stages and dry interglacial stages over the last 560 kyr from a massive stalagmite in Carlsbad Cavern, New Mexico, USA (in prep).

Shackleton, N.J., 1969. The last interglacial in the marine and terrestrial record. Proceedings of the Royal Society of London, B. 174, 135–154.

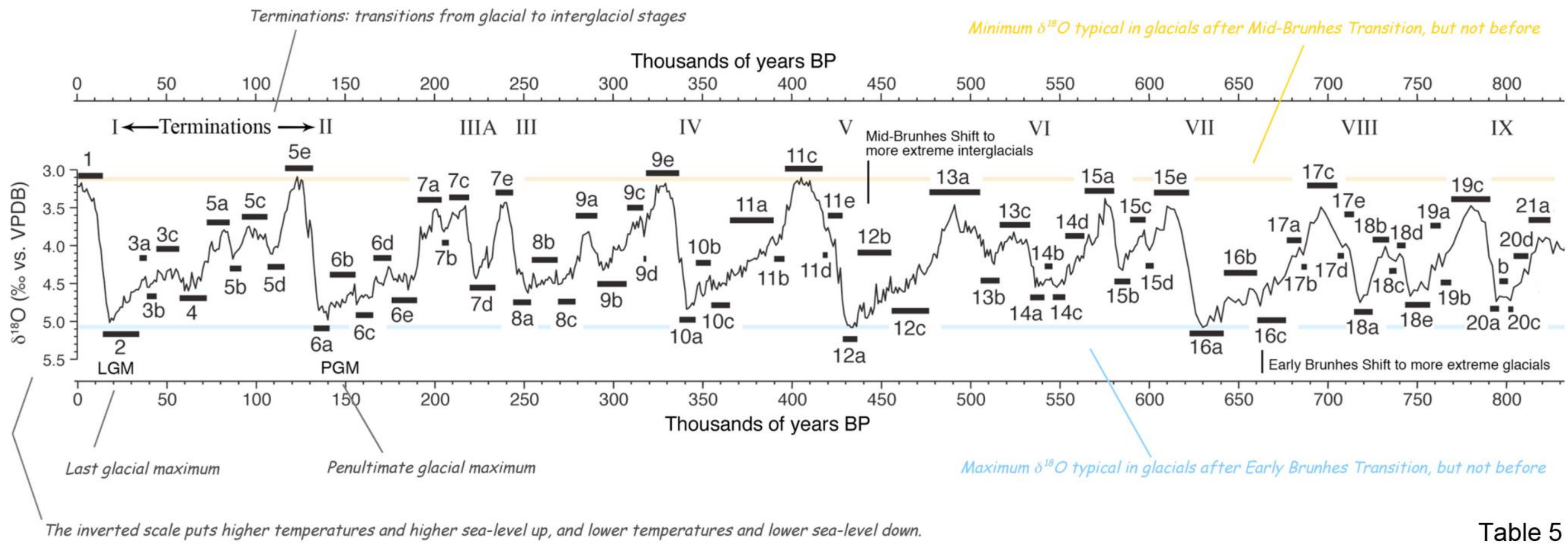


Table 5

Section III

Figures

Pascagoula River Basin as viewed from bridge on U.S. Interstate 10 looking north, Latitude 30 26’ 16.17” N - Longitude 88 36’ 13.87’’ W

Figure 1

Wade terrace (elevation 37 feet) located on the east side of HWY 63 north of Mississippi Power (Plant Daniel) in Sec. 2, T6S, R6W, Latitude 30 33’ 24.00’’ N - Longitude 88 33’ 42.48’’ W

Figure 2

Big Point terrace (elevation 80 feet) located Southeast of Hurley south of Government Road on Baria Road in Sec. 3, T5S, R5W, Latitude 30 38’ 28.00’’ N - Longitude 88 28’ 16.30’’ W

Figure 3

Hurley terrace (elevation 95 feet) located to the north of Hurley and to the east of HWY 613 in Sec. 28, T4S, R5W, Latitude 30 40’ 14.00’’ N - Longitude 88 29’ 45.59’’ W

Figure 4

Harleston terrace (elevation 122 feet) located to the Southeast of Harleston & south of Tanner-Williams Road on Rame-Farm Road in Sec. 8, T4S, R5W, Latitude 30 42’ 39.00” N - Longitude 88 29’ 45.81’’ W

Figure 5

Movella terrace (elevation 174 feet) located in the northeastern corner of Jackson County north of Tanner-Williams Road in Section 6, T4S, R4W, Latitude 30 43’ 19’’ N - Longitude 88 24’ 42.25’’ W

Figure 6

Pamlico terrace (elevation 21 feet) located east of Ocean Springs looking east along HWY 90 in Sec. 33, T7S, R7W, Latitude 30 23’ 54.54’’ N - Longitude 88 41’ 37.39’ W’

Figure 7

Big Ridge terrace (elevaton 54 feet) located to the north of Ocean Springs in Sec. 28, T6S, R8W, along the southeast side of Seaman Road Latitude 30 29’ 45.24” N - Longitude 88 47’ 56.81’’ W

Figure 8

Good Hope terrace (elevation 92 feet) located to the northwest of Vancleave along Jim Ramsey Road at Good Hope Church in Section 2, T6S, R8W, Latitude 30 32’ 43.54” N - Longitude 88 45’ 51.24’’ W

Figure 9

Type locality of the Graham Ferry Formation located on the west bank of the Pascagoula River north of Wade-Vancleave Road in Sec. 38, T5S, R7W, Latitude 30 36’ 41.09’’ N - Longitude 88 38’ 33.97’’ W

Figure 10

Light grey clay at the base of scarp going down to the Pascagoula River at the Graham Ferry type locality located in Sec. 38, T5S, R7W, Latitude 30 36’ 41.09” N - Longitude 88 38’ 33.97’’ W

Figure 11

Hurley terrace unconformably overlying Graham Ferry clay in road cut at Ward Bayou located in Sec. 40, T5S, R6W, Latitude 30 33’ 56.85’’ N - Longitude 88 37’ 40.27’’ W

Figure 12

Good Hope terrace unconformably overlying Graham Ferry sand located approximately two miles north of Vancleave along HWY 57 in Sec. 31, T5S, R7W, Latitude 30 34’ 04.24’’ N - Longitude 88 43’ 23.59’’ W

Figure 13

Good Hope terrace overlying cross-bedded sands in the Graham Ferry Formation located in a sand pit northwest of Vancleave off of Jim Ramsey Road in Section 6, T6S, R7W, Latitude 30 32’ 48.92” N - Longitude 88 43’ 58.81’’ W

Figure 14

Cross-bedded sand in the Graham Ferry Formation located approximately 5 miles northwest of Vancleave on Campground Road in Sec. 13, T5S, R8W, Latitude 30 36’ 16.01’’ N - Longitude 88 44’ 29.28’’ W

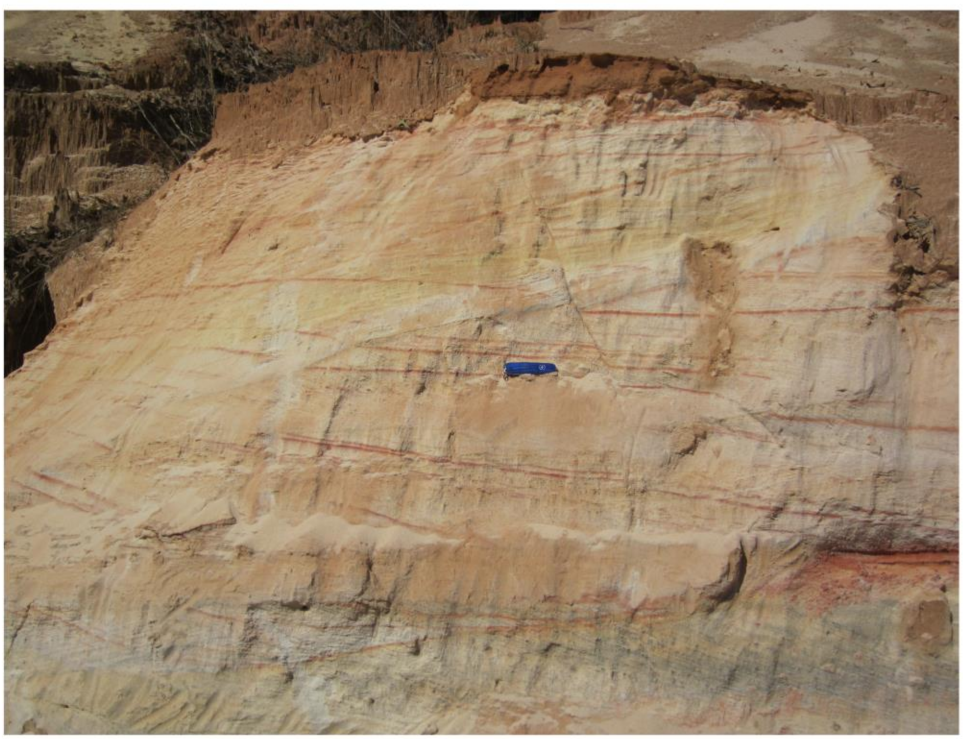
Figure 15

Silty sand in the Graham Ferry Formation located on east side of Escatawpa River close to the State Line along Government Road in Sec. 7, T5S, R4W, Latitude 30 37’ 44.21” N - Longitude 88 25’ 40.38’’ W

Figure 16

Light grey clay at the type locality for the Graham Ferry Formation located on the west bank of the Pascagoula River north of Wade-Vancleave Road in Sec. 38, T5S, R7W, Latitude 30 36’ 41.09’’ N - Longitude 88 38’ 33.97’’ W

Figure 17



Cross-bedded sand in the Graham Ferry Formation located northwest of Vancleave off of Jim Ramsey Road in Sec. 6, T6S, R7W; dark streaks at the bottom of the photo indicate the presence of heavy minerals, Latitude 30 32’ 48.92” N - Longitude 88 43’ 58.81’’ W

Figure 18

Weathered Pascagoula clay located along a gravel road at the county line between George and Jackson Counties off of Popetown Road in Sec. 2, T4S, R6W, Latitude 30 44’ 05.80” N - Longitude 88 32’ 57.52’’ W

Figure 19

Pascagoula clay exposed on the east bank of the Escatawpa River located on the northside of bridge along Tanner-Wiliams Road in Sec. 2, T4S, R5W, Latitude 30 43’ 28.50’’ N - Longitude 88 27’ 14.29’’ W

Figure 20

Cross-bedded sand of the Pascagoula Formation located along county line between Jackson and George Counties on Cowart Road in Sec. 31, T3S, R5W, Latitude 30 44’ 10.59” N - Longitude 88 31’ 24.34’’ W

Figure 21

Clayey sand of the Citronelle terrace located about a mile west of the town of Citronelle, Alabama north of Roussert Road in Section 34, T2S, R3W, Latitude 30 05' 08.98" N - Longitude 88 16' 20.38'' W

Figure 22

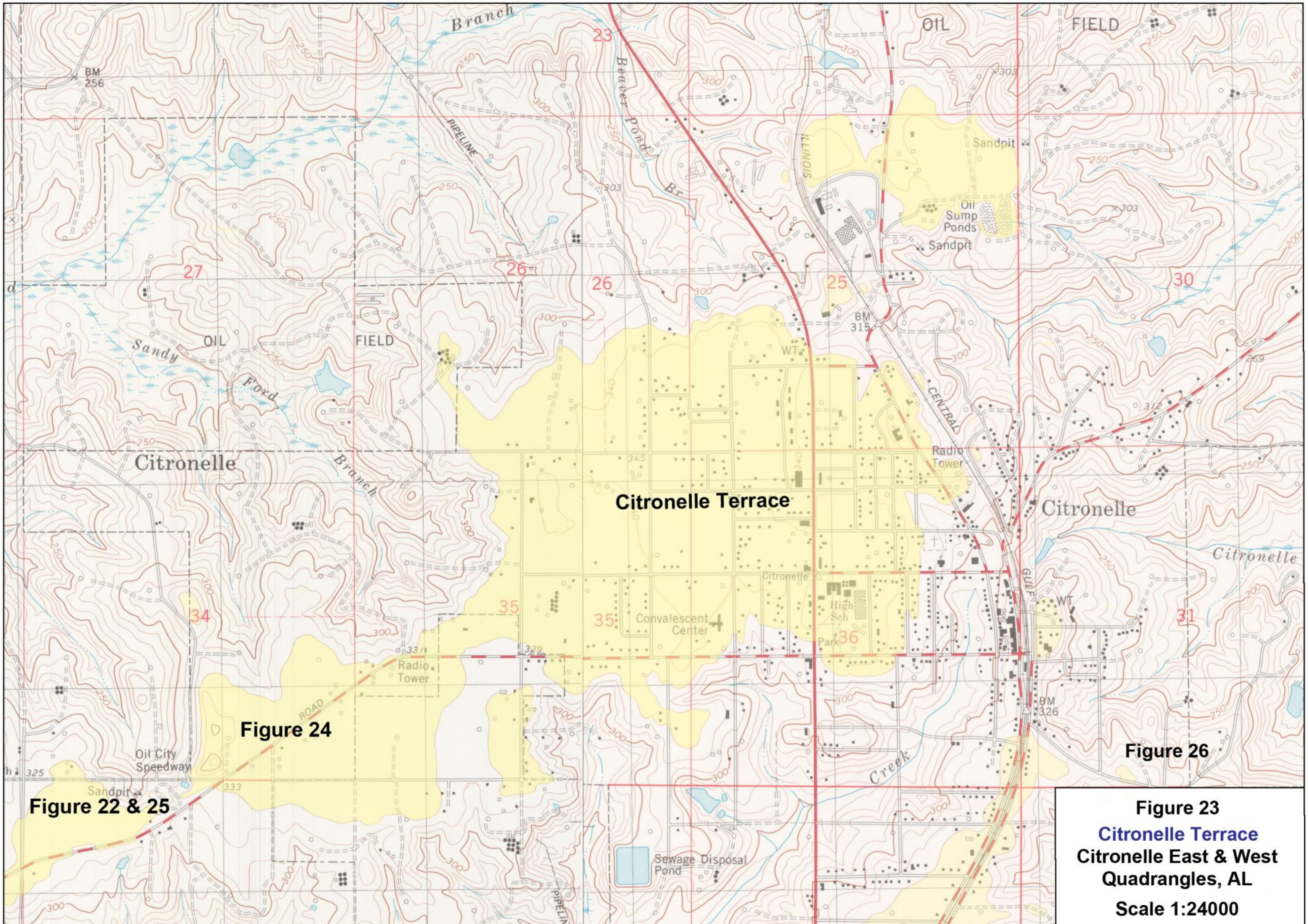


Figure 23
Citronelle Terrace
Citronelle East & West Quadrangles, AL
Scale 1:24000

Citronelle terrace (elevation 337 feet) located to the west of the town of Citronelle, Alabama along Prine Road (HWY 96) in Section 34, T2N, R3W, Latitude 30 05’ 19.23” N - Longitude 88 15’ 49.91’’ W

Figure 24

Cross-bedded sand (probably Pascagoula) that underlies the red clayey sand of the Citronelle located about a mile west of the town of Citronelle, Alabama north of Roussert Road in Section 34, T2S, R3W, Latitude 30 05' 08.98" N - Longitude 88 16' 20.38" W

Figure 25

Contact between the clayey sand of the Citronelle terrace and the underlying cross bedded sands (probably Pascagoula Formation) located east of the town of Citronelle, Alabama north of Irwin Street in Section 31, T2S, R2W, Latitude 30 05’ 11.93” N - Longitude 88 13’ 19.60’’ W

Figure 26

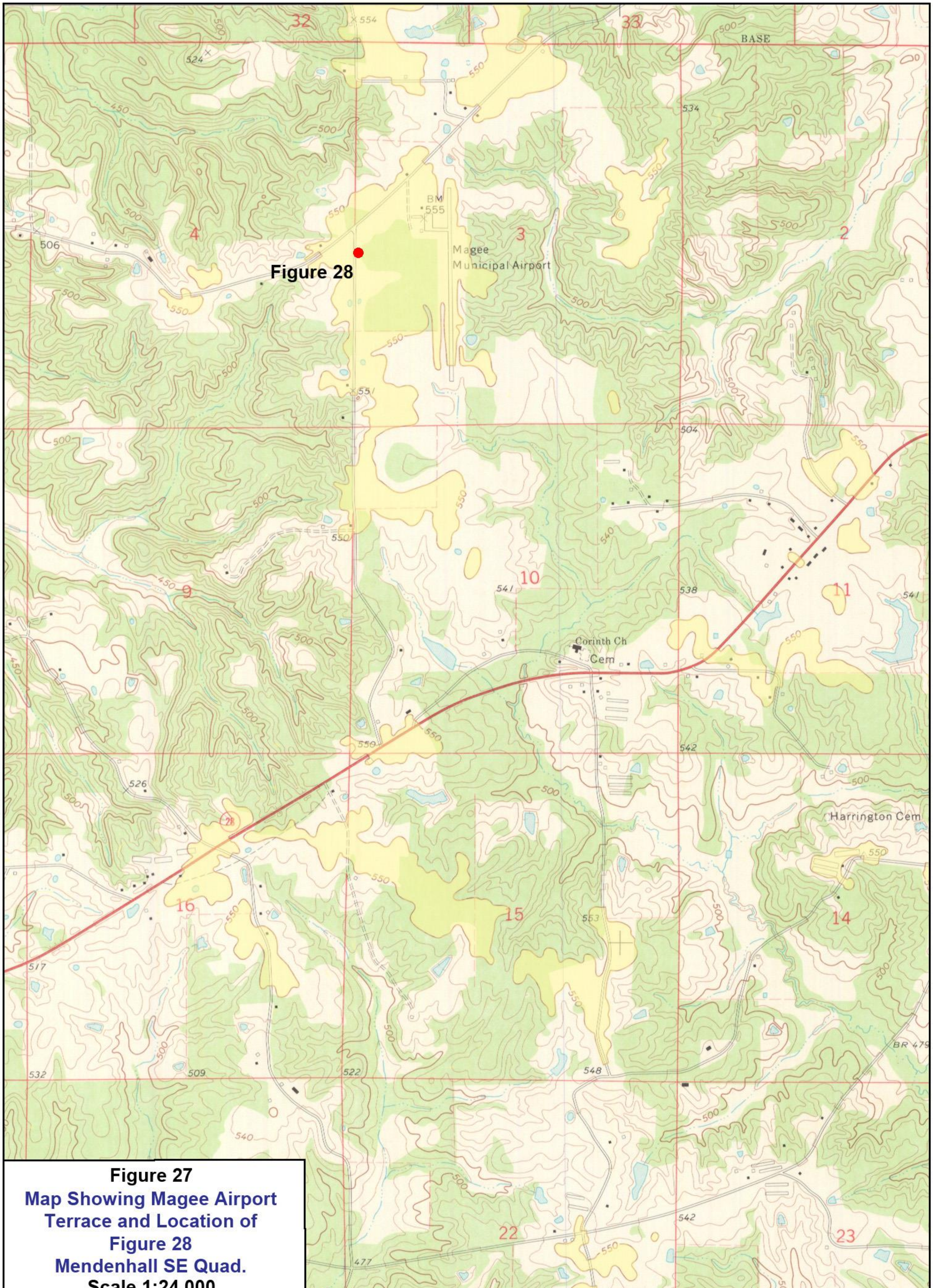


Figure 27
Map Showing Magee Airport Terrace and Location of Figure 28
Mendenhall SE Quad.
Scale 1:24,000

Magee Airport terrace (elevation 550 feet) located east of Magee off of Airport Road in Sec. 3, T10N, R5E, Latitude 31 51’ 50.19’’ N - Longitude 89 48’ 19’’ W

Figure 28

Highwall in gravel pit showing sand and gravel associated with the Magee Airport terrace located southeast of Mendenhall & east of HWY 49 in Sec. 17, T1N, R5E, Latitude 31 55’ 36.85’’ N - Longitude 89 48’ 47.95’’ W

Figure 29

Weathered gravel of the Magee Airport terrace located southeast of Mendenhall and east of HWY 49 in Section 8, T1N, R5E, Latitude 31 55’ 50.08” N - Longitude 89 48’ 54.73’’ W

Figure 30

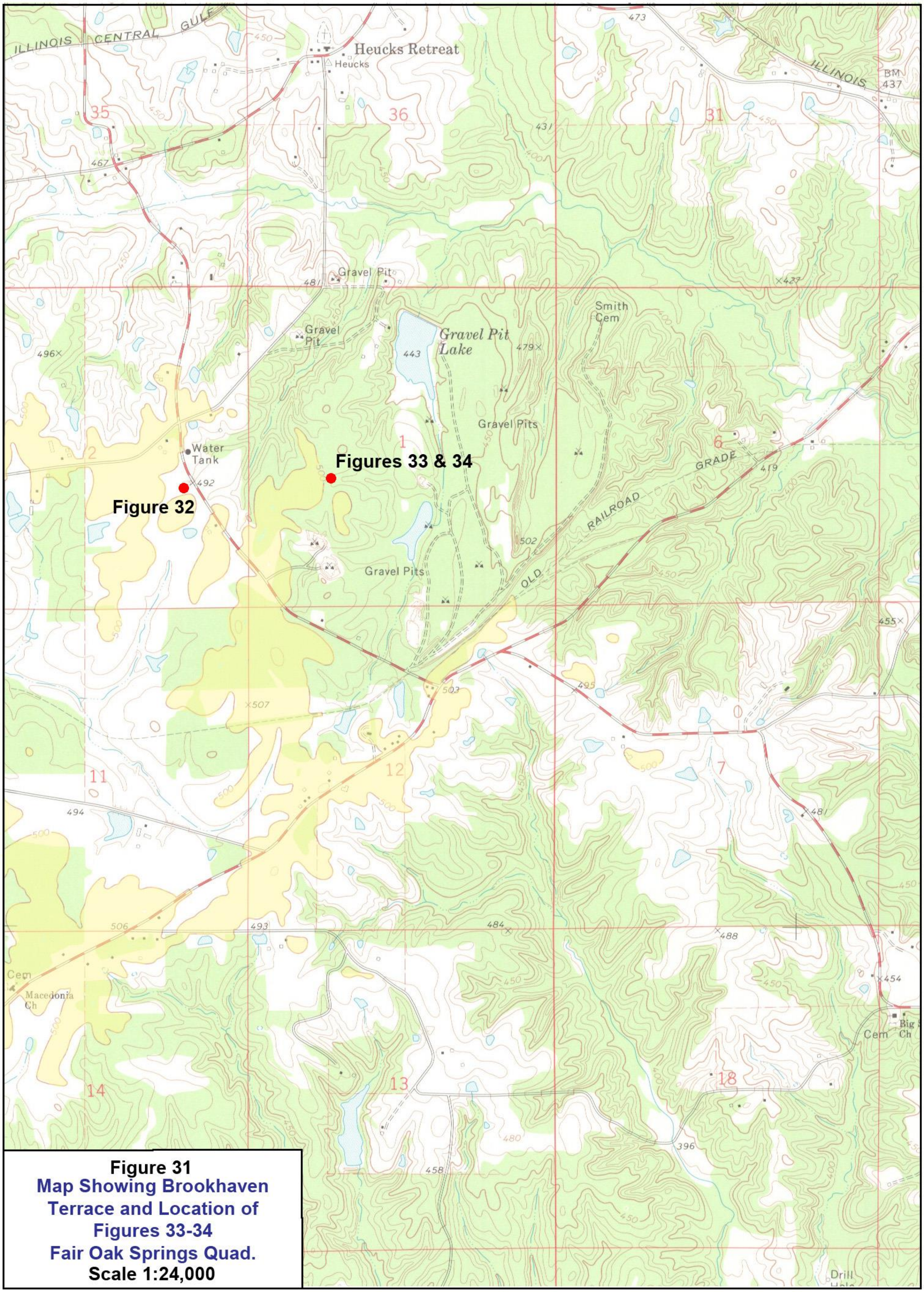


Figure 31
Map Showing Brookhaven Terrace and Location of Figures 33-34
Fair Oak Springs Quad.
Scale 1:24,000

Brookhaven terrace (elevation 500 feet) located northeast of Brookhaven off of Beason Dr. NE in Sec. 2, T7N, R8E, Latitude 31 36' 10.85'' N - Longitude 90 21' 53.66'' W

Figure 32

High wall in gravel pit showing sand and gravel associated with the Brookhaven terrace located northeast of Brookhaven and northwest of Nola Road in Sec. 1, T7N, R8E, Latitude 31 36' 14.18'' N - Longitude 90 21' 26.04'' W

Figure 33

Sand and Gravel of the Brookhaven terrace located northeast of Brookhaven and northwest of Nola Road in Section 1, T7N, R8E, Latitude 31 36’ 14.18” N - Longitude 90 21’ 26.04’’ W

Figure 34

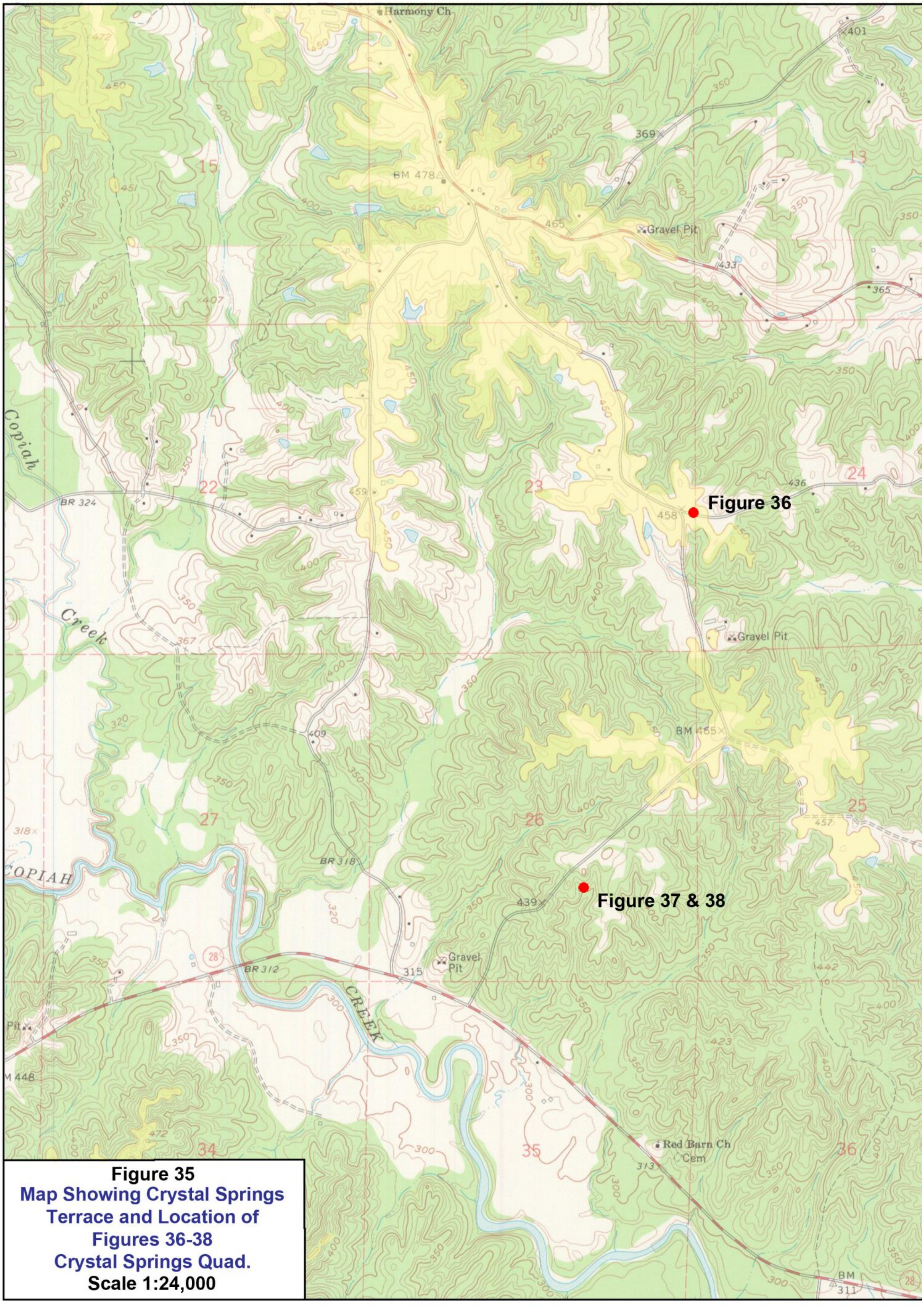


Figure 35
Map Showing Crystal Springs Terrace and Location of Figures 36-38
Crystal Springs Quad.
Scale 1:24,000

Crystal Springs terrace (elevation 458 feet) located south of Crystal Springs on Sandy Yarn Road in Sec. 23, T1N, R1W, Latitude 31 54’ 35.68’’ N - Longitude 90 15’ 44.40’’ W

Figure 36

High wall in gravel pit showing sand and gravel associated with the Crystal Springs terrace located south of Crystal Springs along Bailey Road in Sec. 26, T1N, R1W, Latitude 31 53’ 34.31’’ N - Longitude 90 15’ 59.83’’ W

Figure 37

Sand and gravel of the Crystal Springs terrace located south of Crystal Springs along Bailey Road in Section 26, T1N, R1W, Latitude 31 53’ 34.31’’ N - Longitude 90 15’ 59.83’’ W

Figure 38

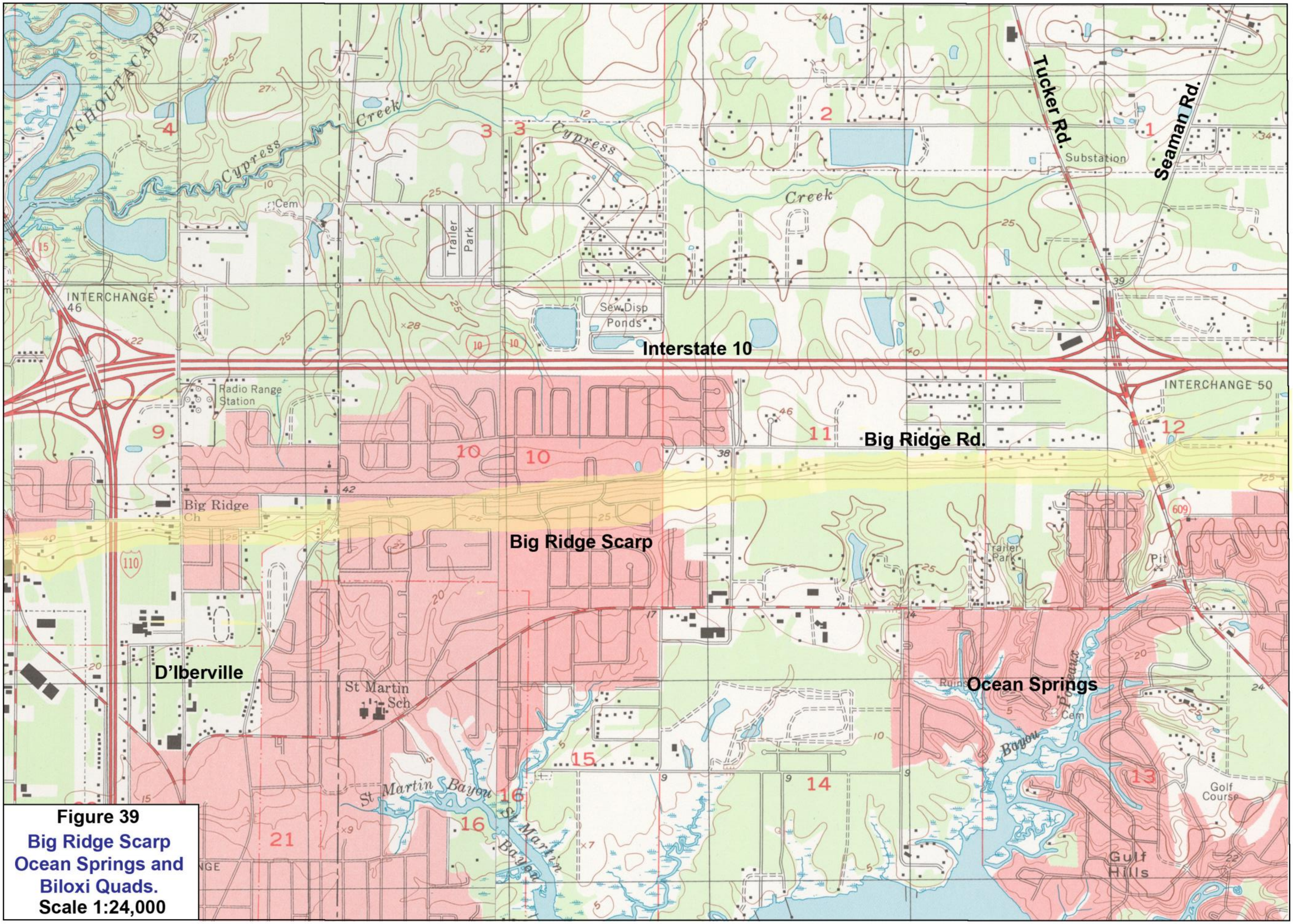


Figure 39

Big Ridge Scarp Ocean Springs and Biloxi Quads.

Scale 1:24,000

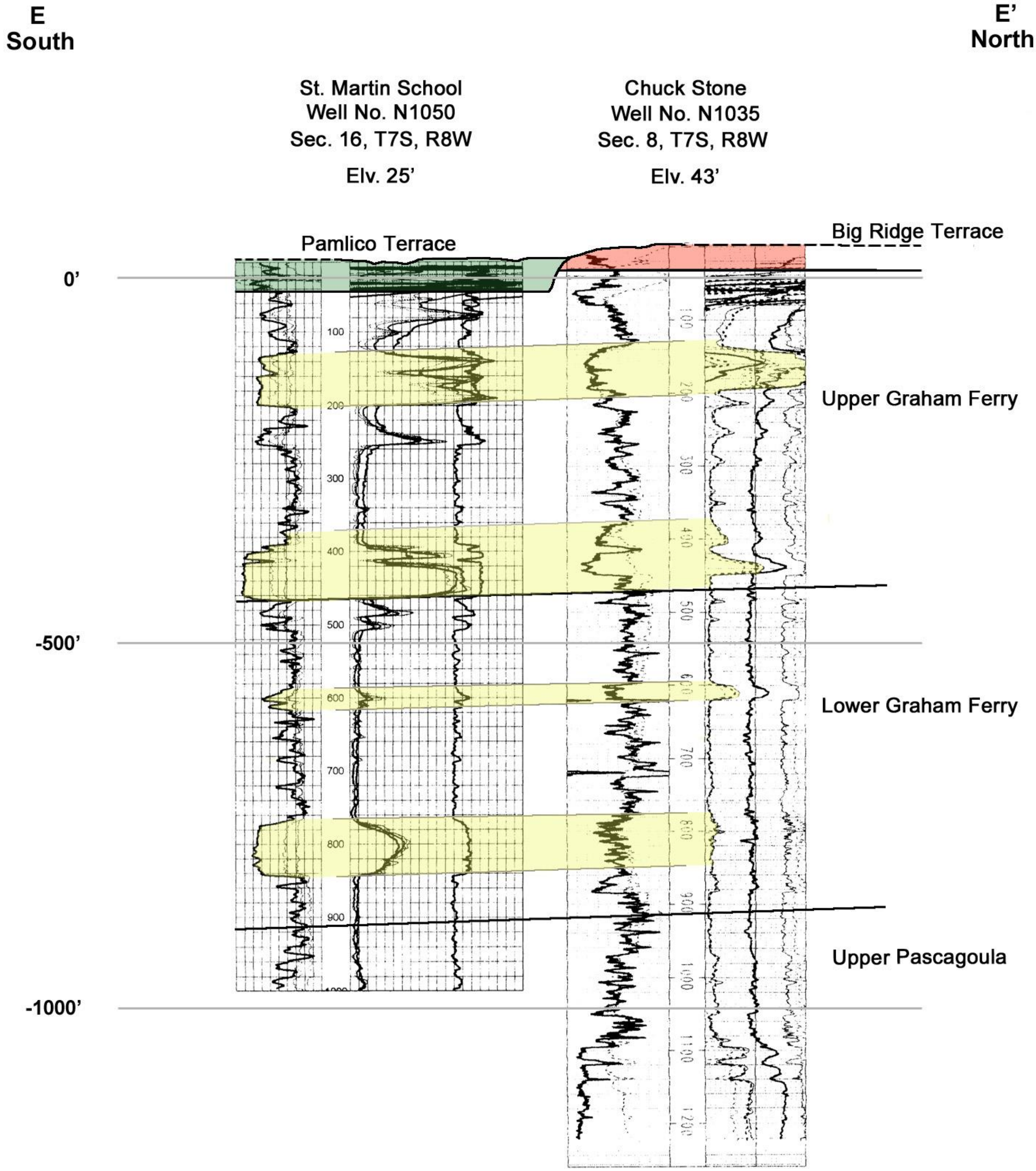


Figure 40
Structural Cross Section E-E'
Jackson County, Mississippi

Vertical Scale 1 inch = 200 feet
Horizontal Scale 1 inch = 1/2 mile

Location of Cross Section is Shown on Figure 41

August, 2017

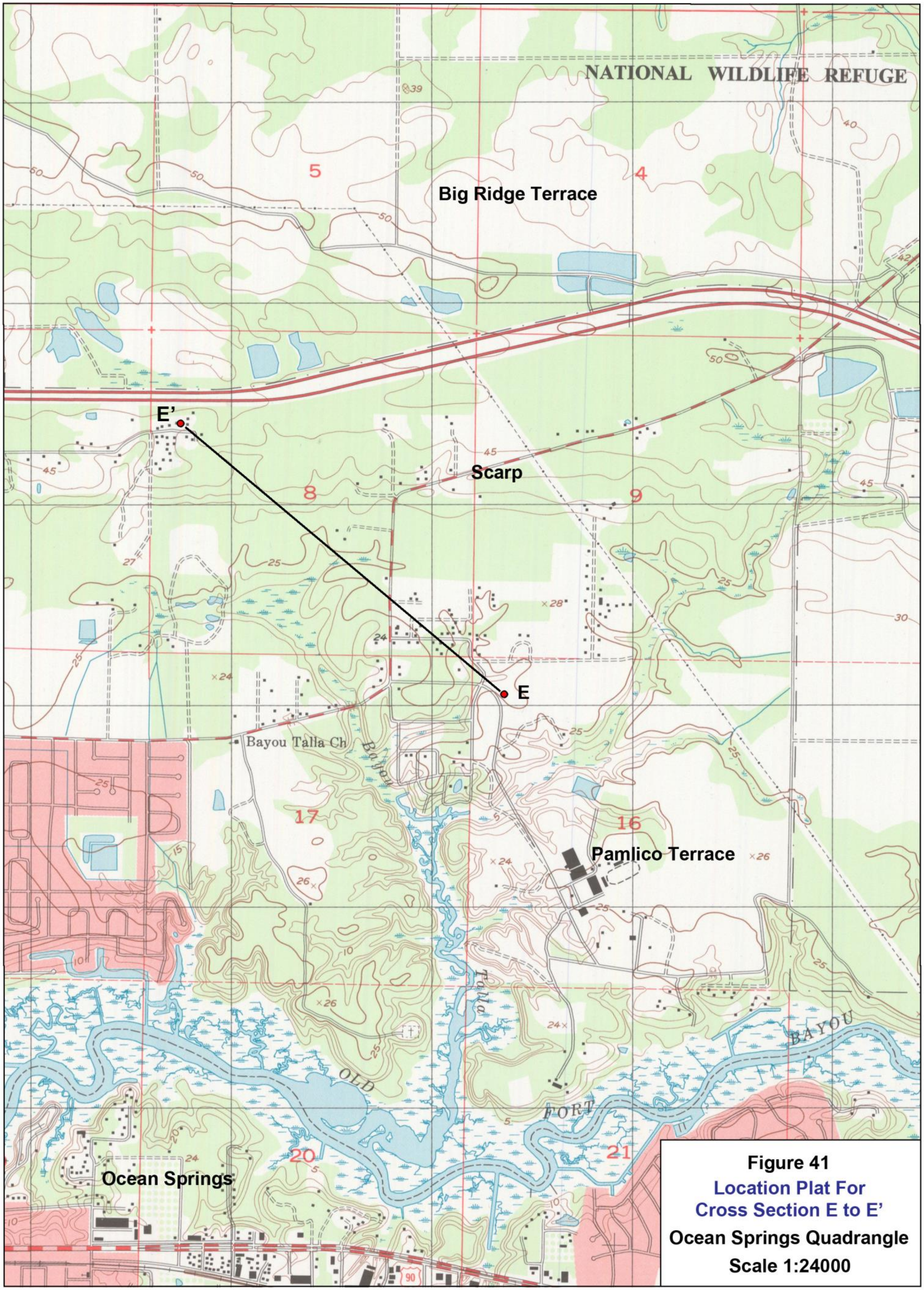


Figure 41
Location Plat For Cross Section E to E'
Ocean Springs Quadrangle
Scale 1:24000

West view of wave cut scarp on Pamlico surface, top of scarp is near 20 feet in elevation and the base of the scarp is close to sea level, located on Davis Point, east of Ocean Springs in Sec. 3, T8S, R8W, Latitude 30 22’ 18.88’’ N - Longitude 88 46’ 54.73’ W’

Figure 42

East view of wave cut scarp on Pamlico surface, top of scarp is near 20 feet in elevation and the base of the scarp is close to sea level, located on Davis Point, east of Ocean Springs in Sec. 3, T8S, R8W, Latitude 30 22’ 18.88’’ N - Longitude 88 46’ 54.73’ W’

Figure 43

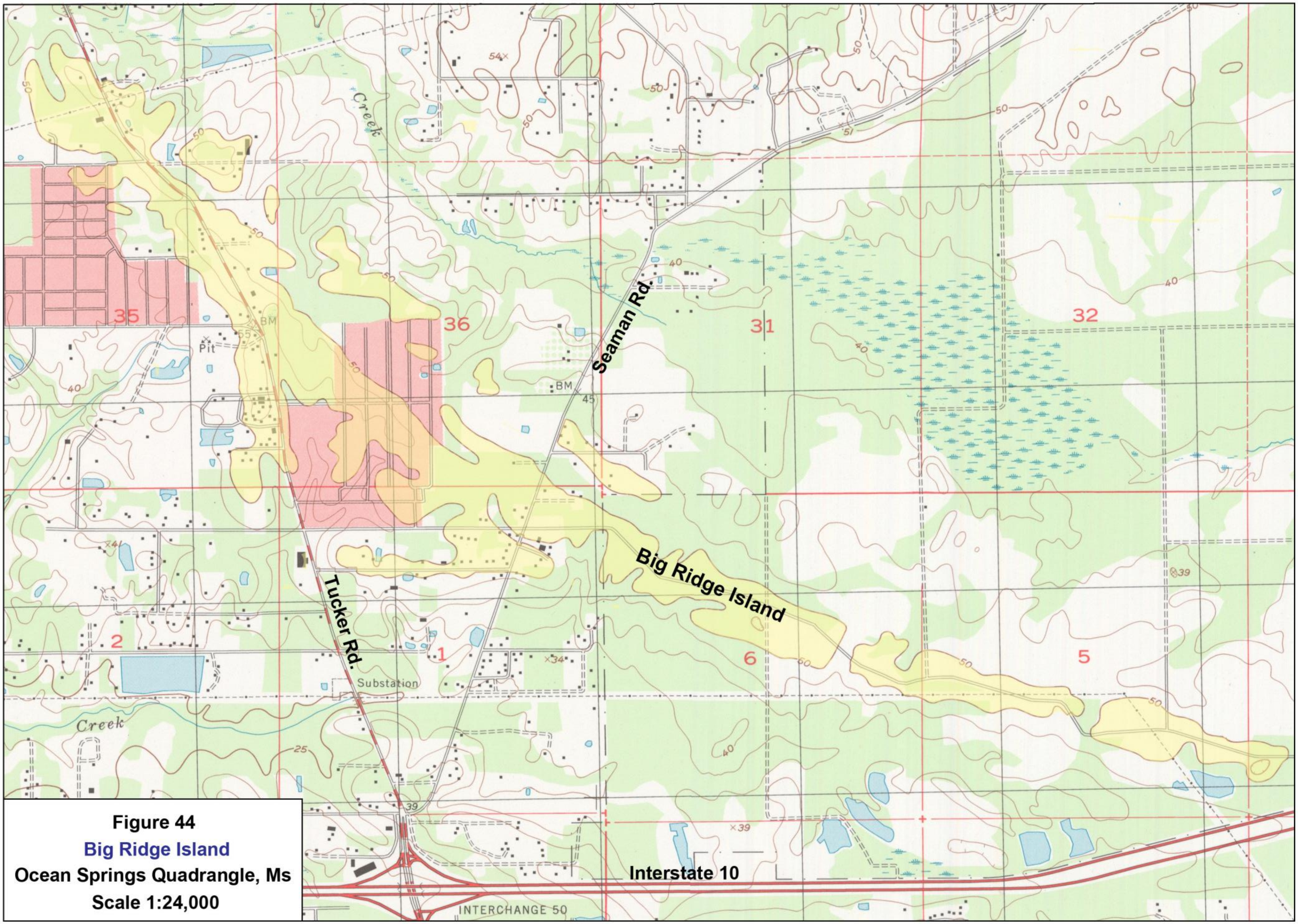


Figure 44

Big Ridge Island

Ocean Springs Quadrangle, Ms

Scale 1:24,000

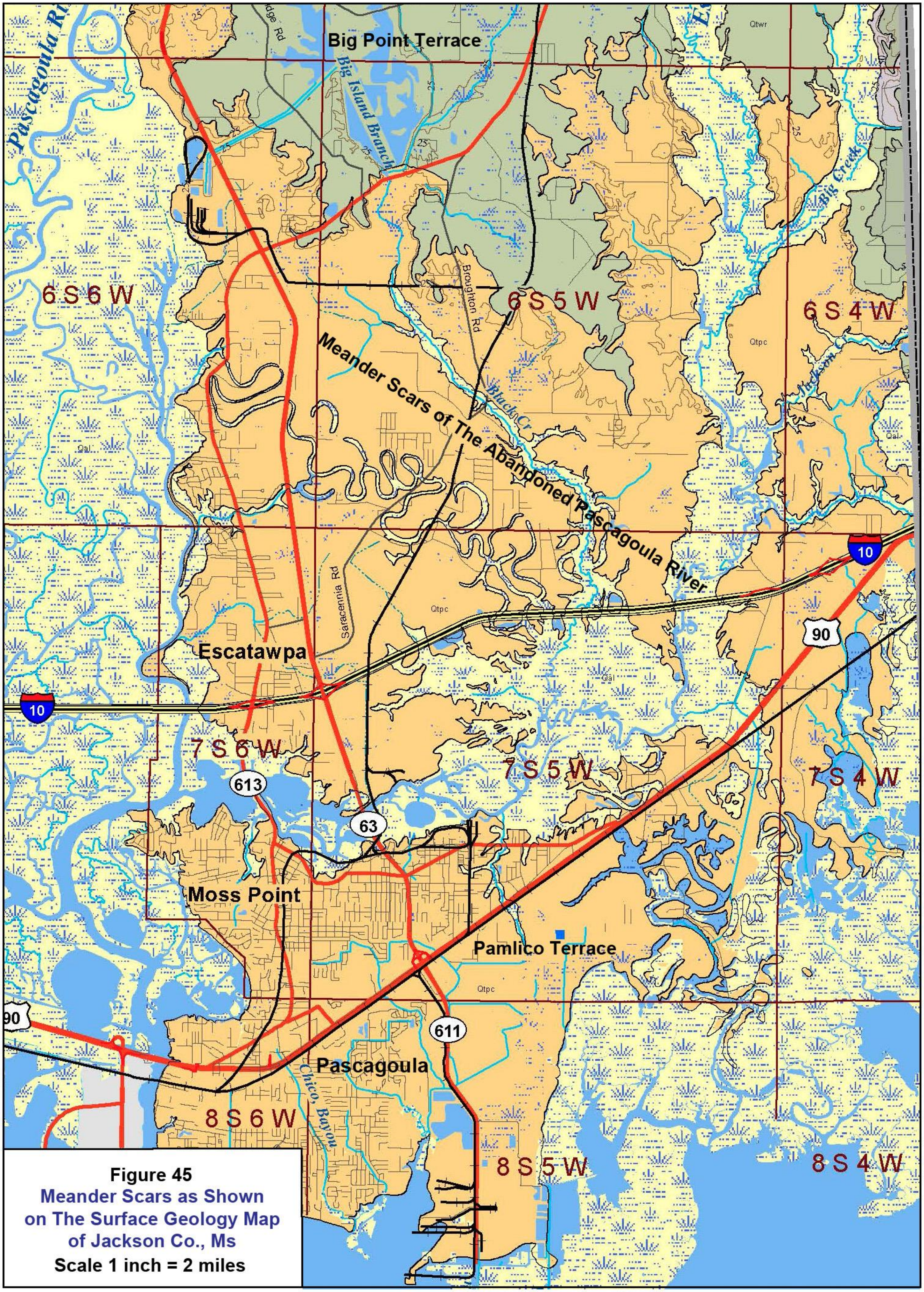


Figure 45
Meander Scars as Shown on The Surface Geology Map of Jackson Co., Ms
Scale 1 inch = 2 miles

Present day view of the abandoned course of the Pascagoula and Escatawpa Rivers at Bayou Cumbest located south of Orange Grove in Section 36, T7S, R5W, Latitude 30 23’ 06.72” N - Longitude 88 26’ 21.02’’ W

Figure 46

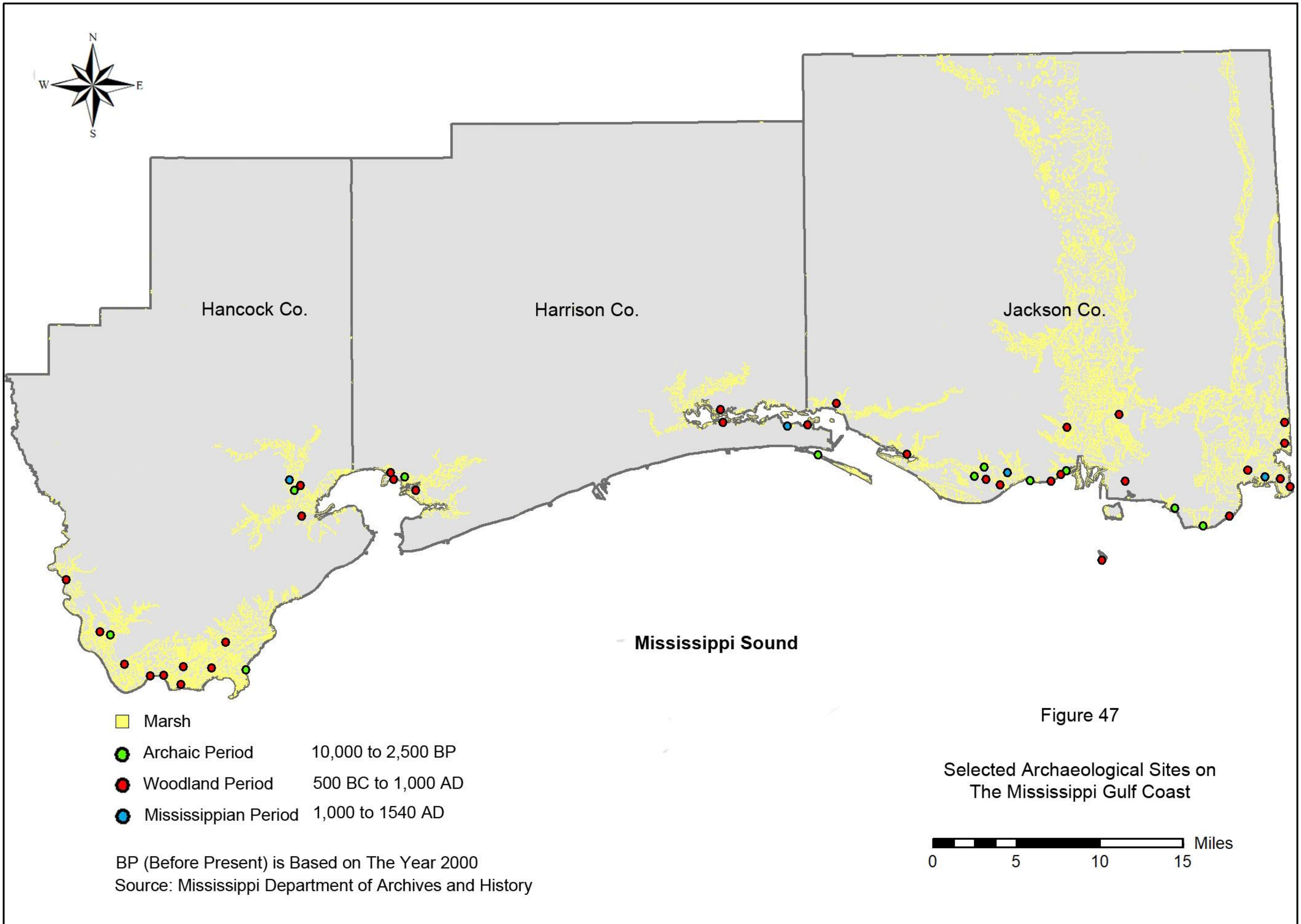
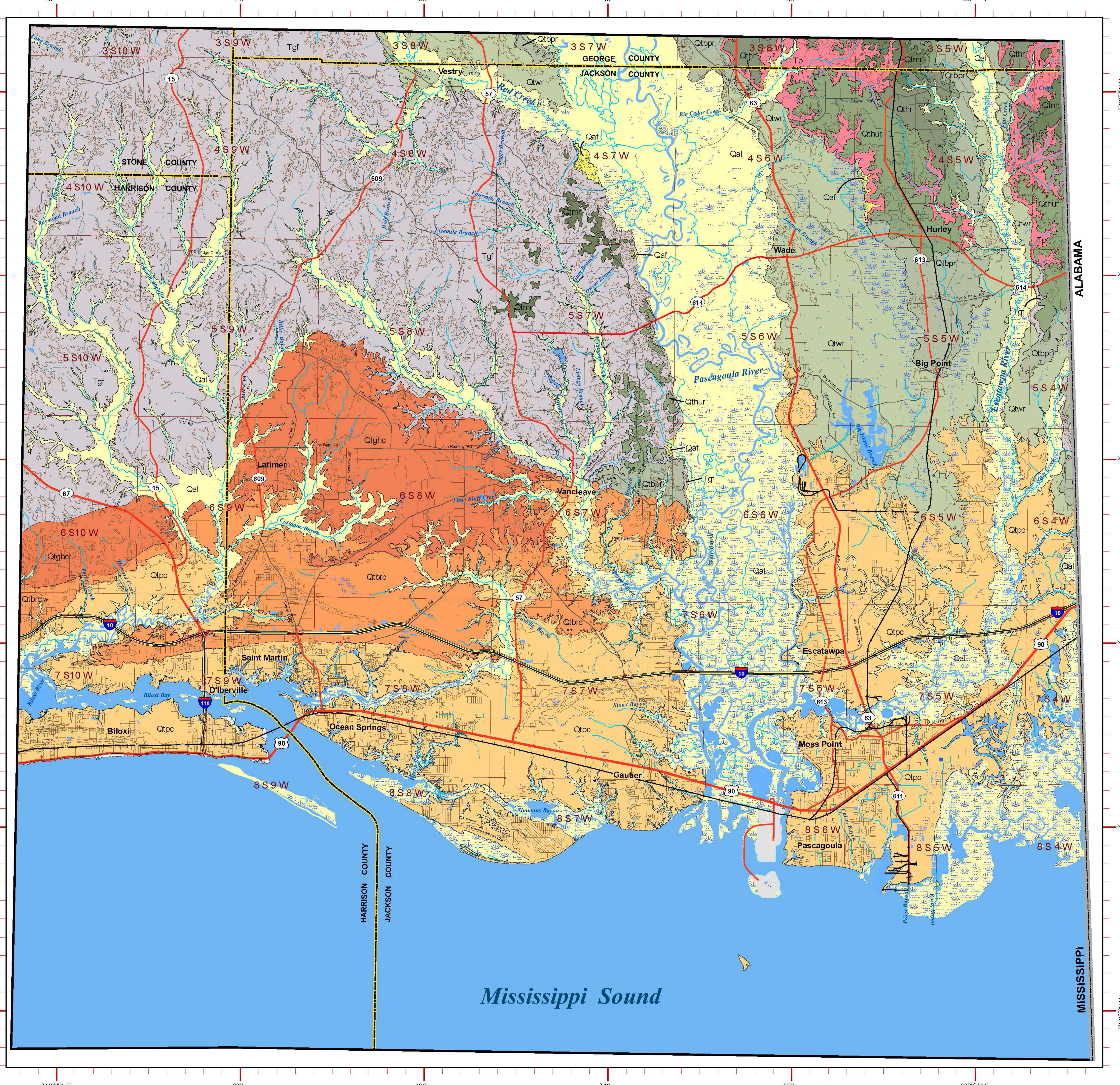


Figure 47

Selected Archaeological Sites on
The Mississippi Gulf Coast



MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

OFFICE OF GEOLOGY

In Cooperation With the Office of Land and Water Resources

OPEN-FILE REPORT 285

GEOLOGIC MAP of JACKSON COUNTY

Jackson, Harrison, George, and Stone Counties, Mississippi

Geology by Lindsey Stewart and James E. Starnes, RPG

2017

MAPPING UNITS

QUATERNARY

HOLOCENE

Fill — RECENT FILL

Qaf — ALLUVIAL FAN

Alternating silts, sands. Coarsest at the apex of the fan, fining laterally (radially) from the apex of the fan.

Qal — ALLUVIUM

Flood plain sands, silts, gravels, and clays. Lower-most reaches of stream alluvium may grade into tidally-influenced, brackish water marshes and muddy coastal deposits.

PLEISTOCENE

COASTAL TERRACES

Qtpc — PAMLICO COASTAL TERRACE

Interval: 0 to 30 feet; Terrace: 25 feet

Qtbrc — BIG RIDGE

Interval: 30 to 50 feet; Terrace: 50 feet

Qtghc — GOOD HOPE

Interval: 50 to 110 feet; Terrace: 100 feet

RIVER TERRACES

Qtwr — WADE TERRACE

Interval: 30 to 50 feet; Terrace: 50 feet

Qtbpr — BIG POINT TERRACE

Interval: 50 to 80 feet; Terrace: 70 feet

Qthur — HURLEY TERRACE

Interval: 80 to 110 feet; Terrace: 100 feet

Qthr — HARLESTON TERRACE

Interval: 110 to 130 feet; Terrace: 130 feet

Qtmr — MOVELLA TERRACE

Interval: 130 to 180 feet; Terrace: 150 feet

TERTIARY

PLIOCENE

Tgf — GRAHAM FERRY FORMATION

Sand, dark greenish-gray, yellow to tan, micaceous and glauconitic (exclusively in the fine-grained sands), fine- to coarse-grained, predominantly quartzose, cross-bedded to massive; Laminar to thinly-bedded quartz pea gravels in coarser fraction. Weathers to orange, purple, red, pink with reddish-brown colored pebbly ironstone residuum. Clay, green, gray, brown, weathers mottled purple to pink and white to reddish-brown, silty to sandy, locally lignitic.

MIOCENE

Tp — PASCAGOULA FORMATION

Shallow marine to intertidal deposits, contains the marker fossil, *Rangia johnsoni*. Clay, green, gray, brown, and white; locally lignitic, locally calcareous and fossiliferous. Weathers mottled purple to pink and white to reddish-brown, silty to fine-sandy. Sand, dark greenish-gray and glauconitic, micaceous, locally lignitic, fine- to coarse-grained, predominantly quartzose, silicified wood common.

Scale 1:125,000

1 in = 2 miles

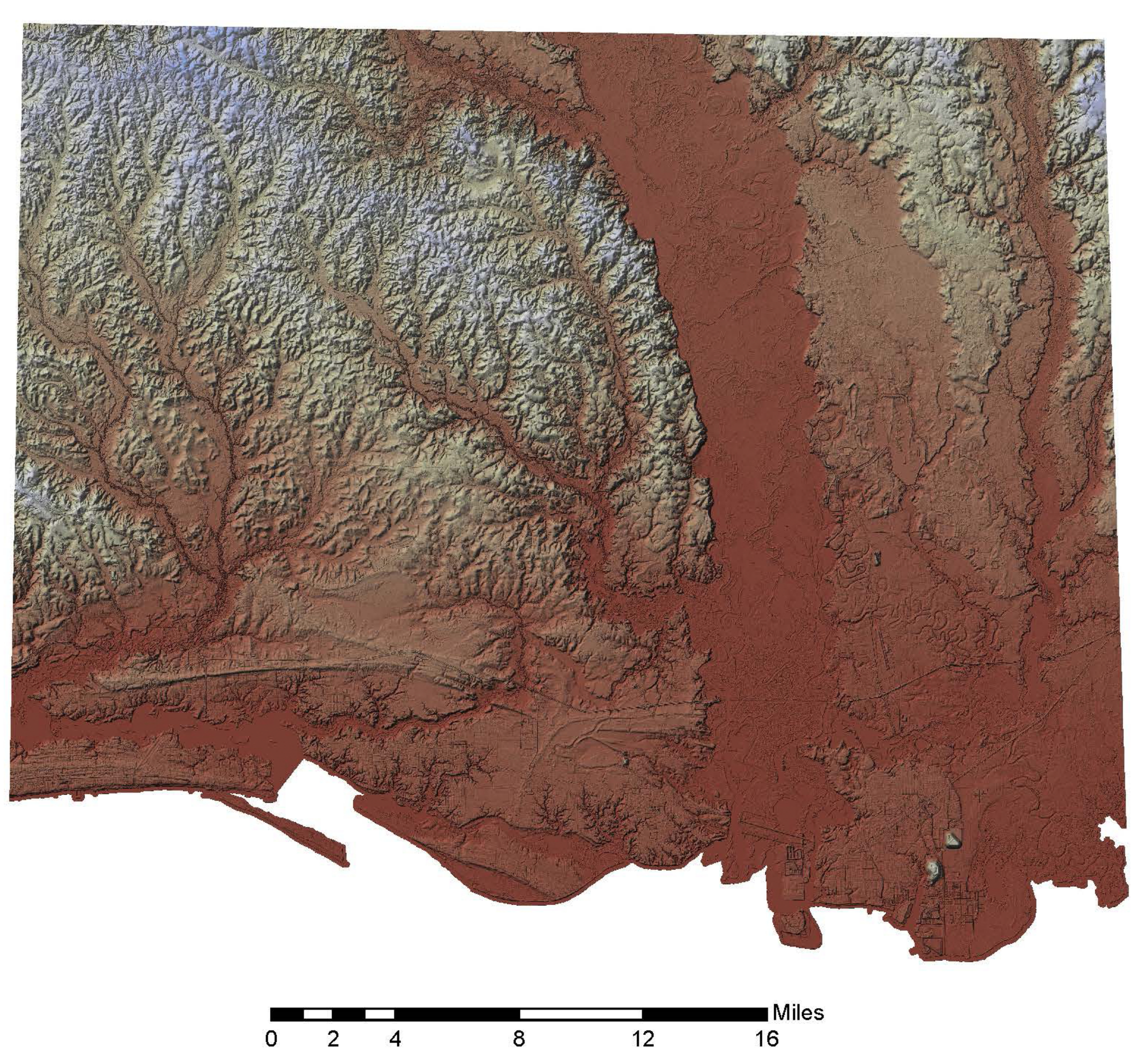
contour interval 25 feet — 50 —

Geology field checked in 2016 and 2017 using U.S. Geological Survey 7.5-minute topographic quadrangles and LIDAR in the studied area, Universal Transverse Mercator projection, 1983 North American datum, 1000-meter Universal Transverse Mercator 1983 datum grid ticks, zone 16, shown in red. January 2017, magnetic north declination in county center is 1°26' west of true north, 0°20' uncertainty, changing by 0°7' west per year.

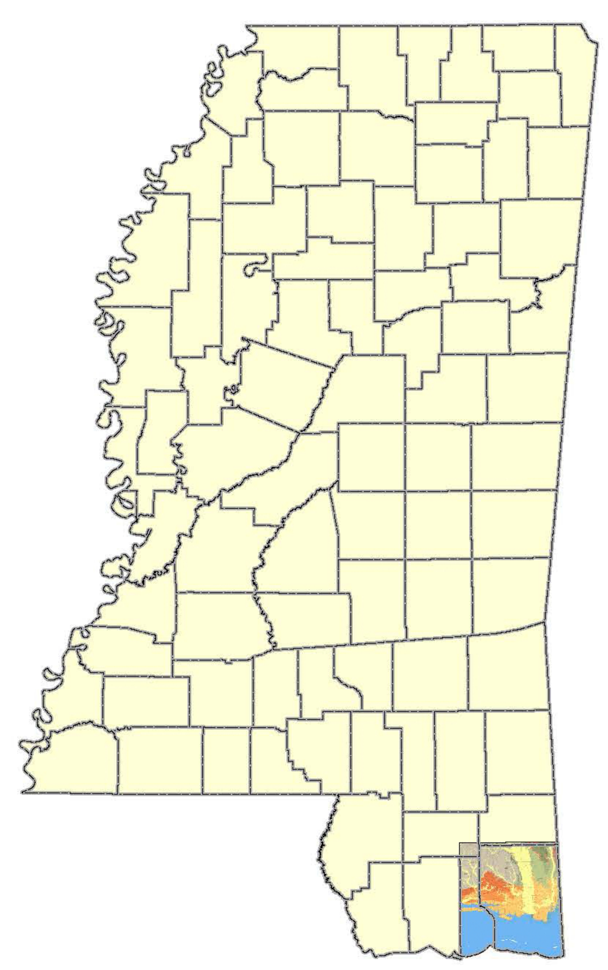
Sources: Contours derived from Mississippi Automated Resource Information System (MARIS) vectorizing the mylar separate of the USGS topographic quadrangles; Public Land Survey System, 1:24,000 scale, from MARIS; fresh water and salt marsh from Mississippi Digital Earth Model (MDEM); railroad features from Federal Railroad administration (FRA), edition 2002, 1:100,000 scale; road features derived from the Mississippi Department of Transportation (MDOT) road centerlines and (MDEM); Declination, National Oceanic and Atmospheric Administration (NOAA). We thank the US Forest Service for their cooperation and for facilitating the data collection and field work necessary for this mapping project. Light Detection and Ranging (LIDAR) 2015 (0.7 meter nominal point spacing) project from the Mississippi Department of Environmental Quality (MDEQ), (NOAA), (USGS), Natural Resources Conservation Service (NRCS), and Mississippi State University (MSU).

Geographic Information System by Daniel W. Morse. MDEQ does not warrant the accuracy or completeness of the source data for any particular purpose. Geologic maps are only a guide to current understanding and do not eliminate the need for detailed investigations of specific sites for specific purposes.

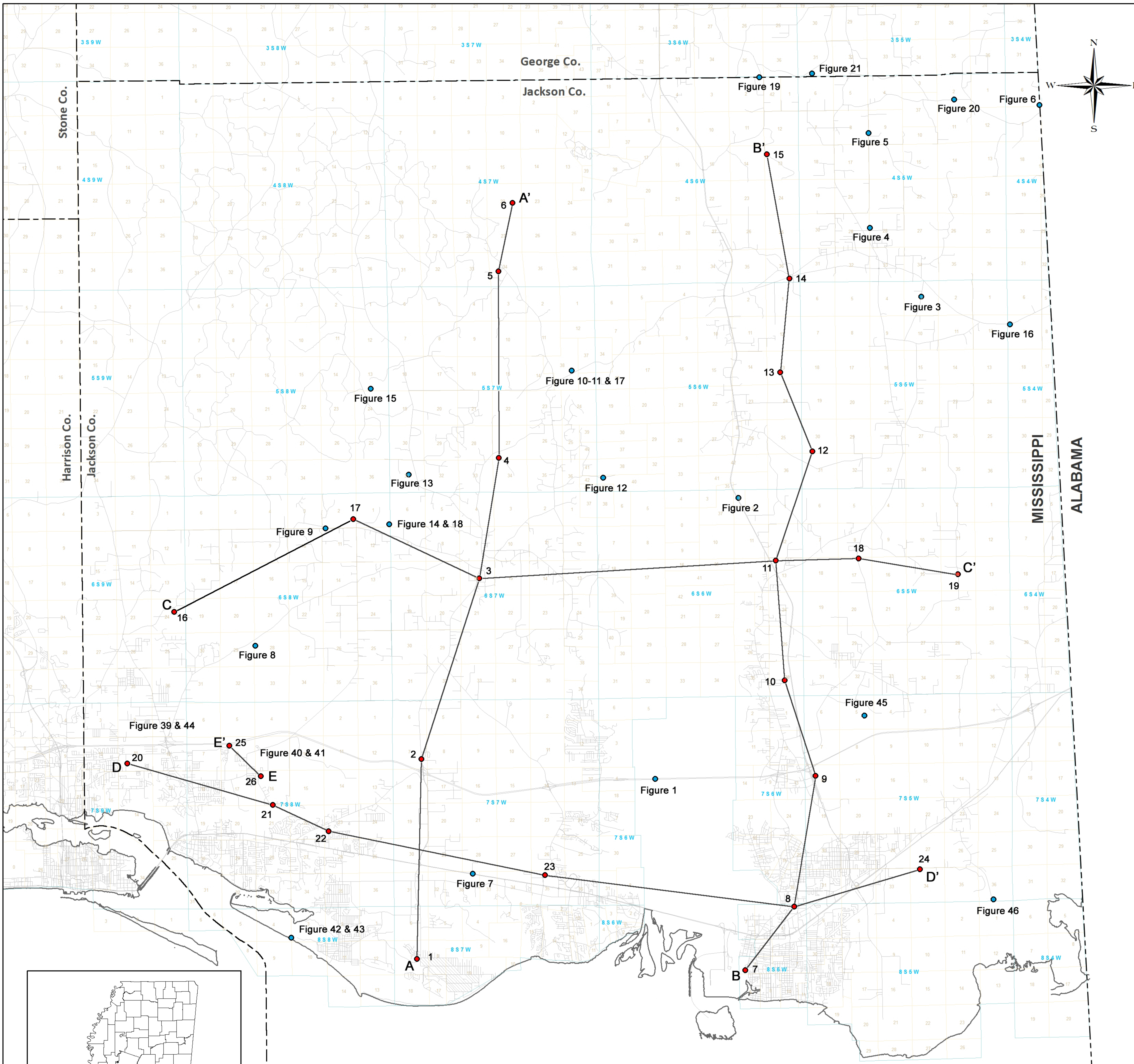
This map was produced by the Mississippi Office of Geology in cooperation with the Office of Land and Water Resources.

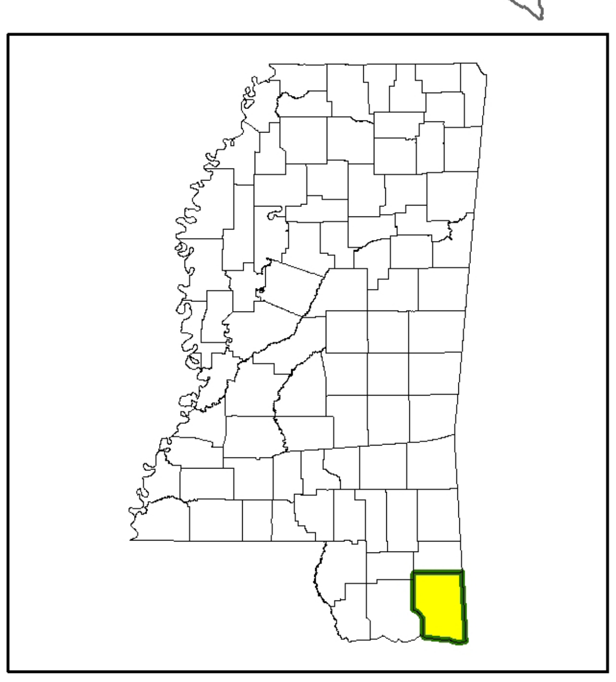


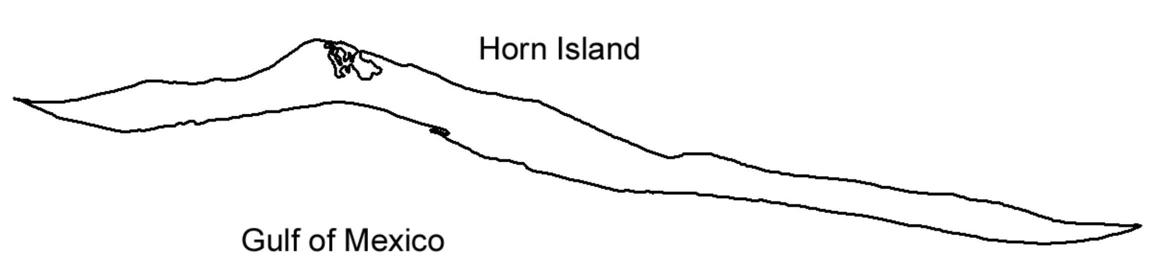
Bare Earth LIDAR Hillshade of the Jackson County Study Area



Location of Study Area







Gulf of Mexico

This map was produced by the Mississippi Department of Environmental Quality, Office of Geology, in cooperation with the Office of Land and Water Resources on December 16, 2016.

All map data is from the Mississippi Automated Resource Information System (MARIS), and MDEQ.

Map Projection: Mississippi Transverse Mercator

The Mississippi Department of Environmental Quality makes no warranties, expressed or implied, as to the accuracy, completeness, currentness, reliability, or suitability for any particular purpose, of the data contained on this map.

- Location of Figures
- Location of Wells in Cross Sections

Well information shown in Table 3

Location of Figures 22-41 & 47 are not shown on plate

Mississippi Department of Environmental Quality
Office of Geology
In Cooperation With the Office of Land and Water Resources

Open-File Report 285

Michael B. E. Bograd
State Geologist

Plate 2
Location Plat for Cross Sections & Figures

by Lindsey Stewart & James Starnes

August, 2017

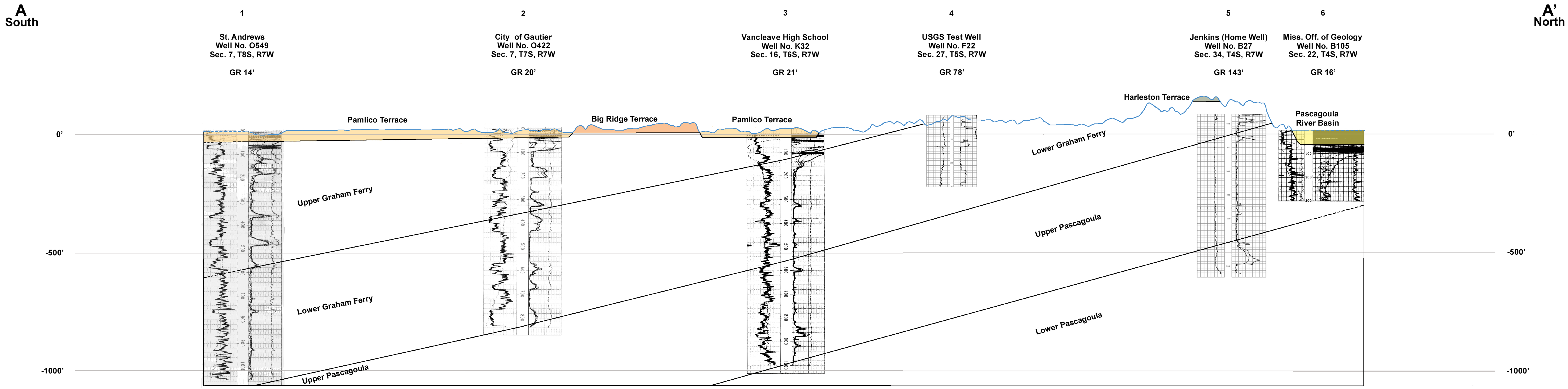
Scale 1 inch = 2 miles

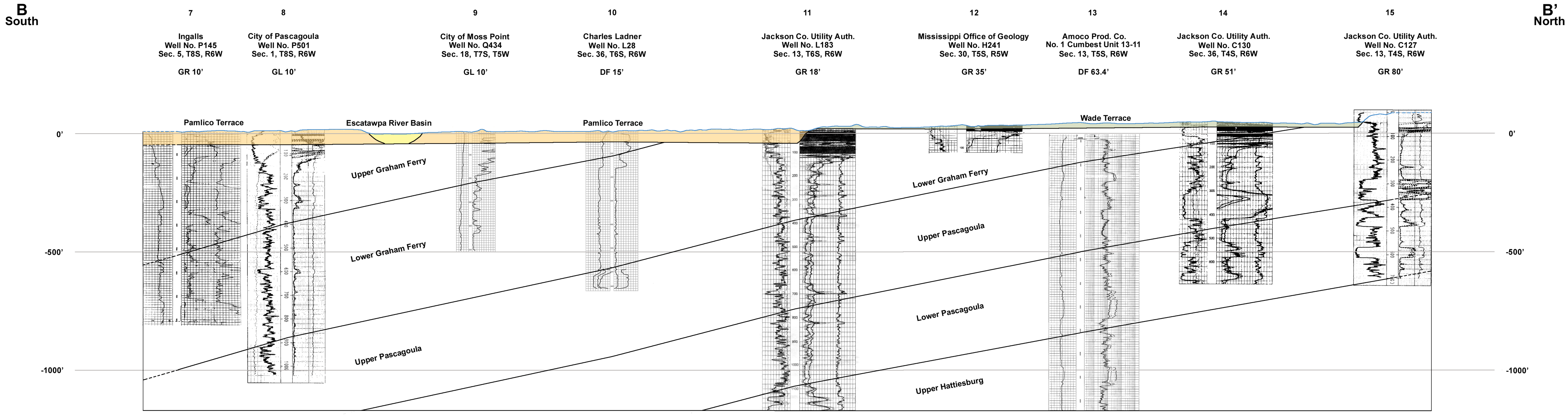
0 1 2 3 4 miles

REGISTERED PROFESSIONAL GEOLOGIST
MS 0791
JAMES E. STARNES

This map prepared under the supervision of
James E. Starnes, RPG

James E. Starnes, RPG
August, 2017





This map prepared under the supervision of
James E. Starnes, RPG

James E. Starnes, RPG
August, 2017

Location of Cross Sections Shown on Plate 2

Mississippi Department of Environmental Quality
Office of Geology
In Cooperation with the Office of Land and Water Resources

Open - File Report 285

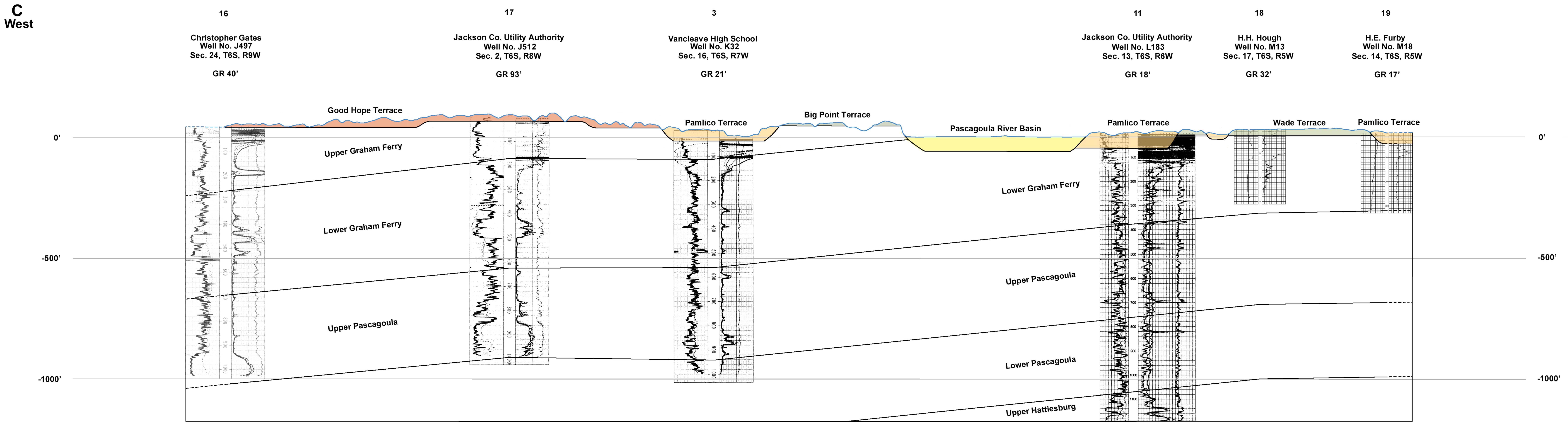
Michael B. E. Bograd
State Geologist

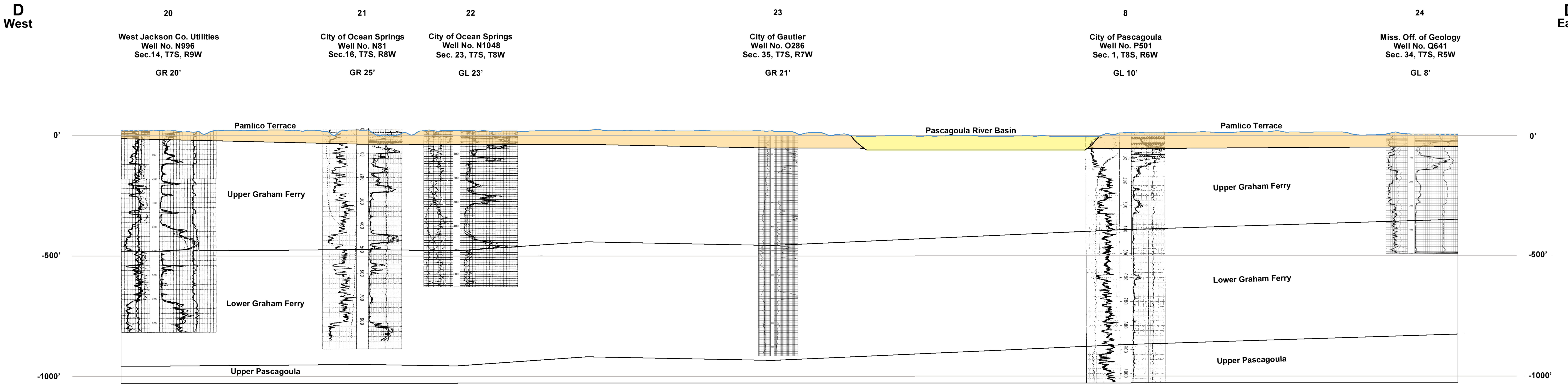
Plate 3
Structural Cross Sections A-A' & B-B' Of the Graham Ferry & Pascagoula Formations Jackson Co., Mississippi

by Lindsey Stewart & James Starnes

August, 2017

Horizontal Scale 1 inch = 1 mile
Vertical Scale 1 inch = 200 feet





These Cross-sections prepared under the supervision of James E. Starns, RPG

James E. Starnes, RPG
August, 2017

Location of Cross Sections Shown on Plate 2

Mississippi Department of Environmental Quality
Office of Geology
In Cooperation with the Office of Land and Water Resources

Open - File Report 285

Michael B. E. Bograd
State Geologist

Plate 4
Structural Cross Sections C-C' & D-D' Of the Graham Ferry & Pascagoula Formations Jackson Co., Mississippi

by Lindsey Stewart & James Starnes

August, 2017

Horizontal Scale 1 inch = 1 mile
Vertical Scale 1 inch = 200 feet