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THE NORTHERN GULF COAST DURING THE FARMDALIAN SUBSTAGE: A SEARCH FOR EVIDENCE

by

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Considerable information has been published during the past decade supporting the concept of a relatively high sea level stand during the mid-Wisconsin Farmdalian substage; however, confirming evidence is absent in the voluminous literature on Gulf Coast geology. This paper discusses certain recently recognized evidence (?) in the form of buried weathered horizons and beach trends in the Pontchartrain Basin area of Louisiana and calls attention to

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additional overlooked and possibly relevant features from elsewhere along the Gulf Coast. Included in this category are apparent beach ridges in southwestern Louisiana, beach rock and related shoreline deposits in various coastal areas, discontinuities within entrenched valleys beneath coastal bays, an abandoned Mississippi River meander belt in south central Louisiana, and a Pascagoula River terrace in southeastern Mississippi.

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PREFACE

This paper was prepared several years ago upon the request of the editors of a proposed volume to commemorate a recently deceased distinguished scientist and professor under whom this writer had the privilege to serve as a graduate student and research assistant. Due to unfortunate circumstances, the volume could not be published as planned.

The data and hypotheses set forth in this paper were developed over a several year period as a partial consequence of geological investigations conducted and directed by the writer under sponsorship of the U. S. Army Engineer District, New Orleans, while assigned to the Geology Branch (now Engineering Geology and Rock Mechanics Division) of the Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station (WES). Although written several years ago, the paper calls attention to still unresolved problems that have direct bearing on the age and mode of origin of geological features and deposits which consequently influence the ability to predict and understand their engineering properties. Resolution of the problems highlighted herein and rejection or substantiation of the cited evidence could contribute measurably to improving the accuracy and effectiveness of geological interpretations pertaining to projects along most if not all of the Gulf and Atlantic Coastal Plain of the United States.

This paper was prepared under the direct supervision and guidance of Dr. C. R. Kolb, Chief of the Geology Branch (retired), WES, and the general supervision of Mr. J. P. Sale, Chief, Soils and Pavements Laboratory. The Director of WES during the preparation of this paper was BG Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

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PERSPECTIVE

As much as three decades ago, the pioneers of modern Gulf Coast and Mississippi Valley geomorphology, R. J. Russell and H. N. Fisk, argued convincingly that a thorough knowledge of eustatic sea level variations was a prerequisite to an understanding of virtually all aspects of coastal and deltaic processes, morphology, and Quaternary stratigraphy. Russell (1940, p. 1201) reintroduced the concept of defining the Recent as being the time during which sea level made its last general rise, a definition soon adopted by most Gulf Coast geologists and geographers.

In the hundreds of topical and regional investigations of Gulf Coast Quaternary geology conducted during the last 30 years or so, the validity of Russell's and Fisk's views on the importance of sea level variations has been established beyond question. However, it has been necessary in almost all cases to investigate and interpret evidence in terms of sea level variation curves and chronologies developed from evidence observed elsewhere. Because of the local and regional tectonic instability of the region (Bornhauser, 1958; Kolb and Van Lopik, 1958), even the most detailed investigations have been only partially successful in isolating true eustatic effects.

The inability to discern definitive local evidence of the magnitude and temporal aspects of sea level variations has been a long-term problem to Gulf Coast geoscientists. Local geologic evidence has had to be belatedly interpreted and reinterpreted in light of changing eustatic sea level chronological concepts developed largely from mid-continent glacial stratigraphic evidence. As would be expected, this has meant that even the most widely adopted chronological concepts (Fisk, 1944; Fisk and McFarlan, 1955) have been questioned and challenged regarding their appropriateness and accuracy (Trowbridge, 1954).

In the writer's opinion, Gulf Coast geology presently is at a point in time when existing concepts of Late Quaternary stratigraphy and certain aspects of coastal geomorphology still require reevaluation in light of a relatively new concept of Wisconsinan stage eustatic sea level variation (Shepard, 1963; Saucier, 1968). One intent of this paper is to point out that there are some previously unrecognized features and additional apparently misinterpreted evidence in the Gulf Coast region that could support the new concept. A second and perhaps more significant intent is to attract attention to certain areas and features that need to be investigated from a fresh viewpoint to establish the presence of either confirming or refuting evidence. It is anticipated that the readers of this paper, upon completion of that task, will have more rather than fewer unanswered questions in mind regarding this matter and will envision a variety of new projects or investigations.

THE CONCEPTS - OLD AND NEW

According to the widely accepted Gulf Coast chronological concept of Fisk (1944, Figure 75), the extensive Prairie-Beaumont terrace formation or coastal plain (Bernard and LeBlanc, 1965, p. 137) of Texas and Louisiana (Figure 1) was deposited during the last major interglacial stage. As recently as 15 years ago, the prevalent opinion was that this interglacial stage was the Bradyan (or Peorian) interglacial stage, which was thought to be at least 60,000 years old (Fisk and McFarlan, 1955) (Figure 2a). Following this interglacial stage, sea level fell in response to waxing Late Wisconsin glaciation. The maximum low stand of the sea was estimated to have been about 30,000 years ago. Waning of the Late Wisconsin glaciation resulted in the last major sea level rise, which ceased with the attainment of approximately present sea level at a time variously estimated to have been between about 3,000 years ago (Gould and McFarlan, 1959) and 5,000 years ago (Saucier, 1963).

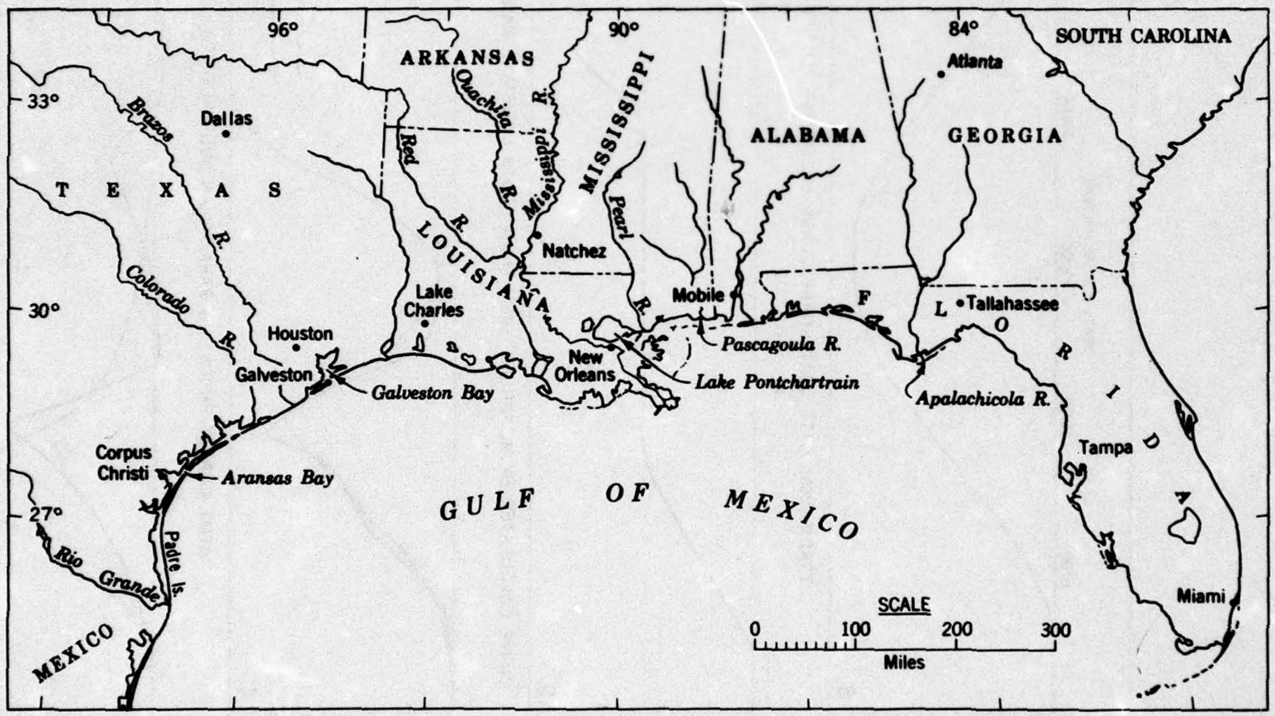

Fig. 1. The northern Gulf Coast

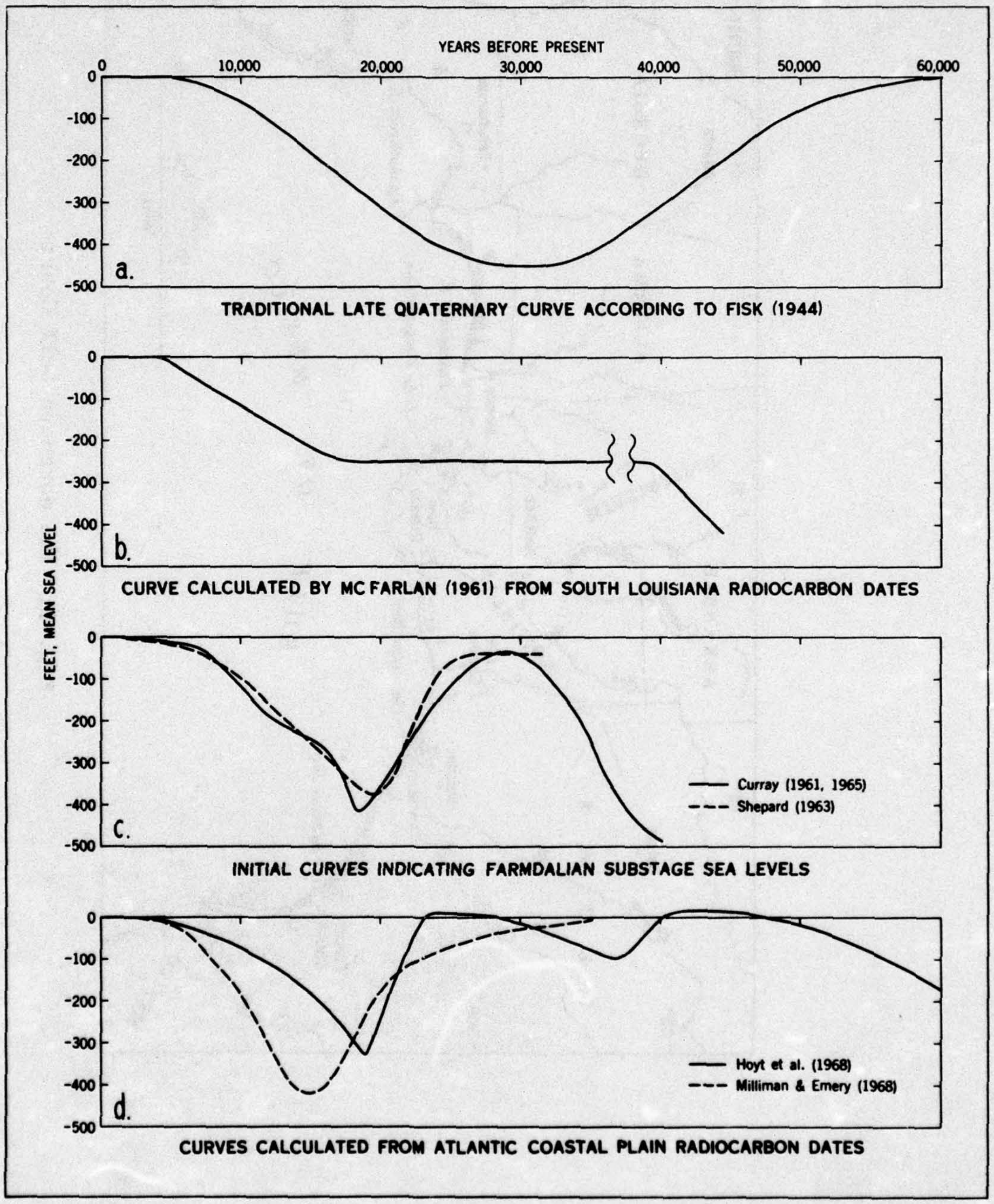

Fig. 2. Comparative sea level fluctuation curves

It is apropos at this point to emphasize that most if not all Gulf Coast geologists have failed to recognize any evidence whatsoever for a higher-than-present sea level stand during the last 6,000 years and frequently are adamantly opposed to such a concept (Russell, 1963, p. 14). Proponents of the concept, notably Fairbridge (1961), contend that sea level was as much as 10 feet higher than present during the Hypsithermal Interval 4,000 to 6,000 years ago. Discussions of the problem have been prepared by Jelgersma (1966) and Shepard and Curray (1967) who review evidence pro and con.

Probably the first significant modification to the Fiskian chronological concept was the realization that the last maximum low stand of the sea occurred about 18,000 years ago rather than 30,000 years ago (Russell, 1957). Shortly after this, McFarlan (1961) presented tenuous evidence from south Louisiana suggesting a long stillstand at a level about 250 feet below present from some date more than 35,000 years ago to about 18,000 years ago. As shown in Figure 2b, the stillstand was preceded by the maximum lowstand of the last glaciation and was followed by the last major sea level rise. Although McFarlan's concept drew immediate criticism (Broecker, 1961), it now appears he may have been the first to discern (but not accurately interpret) evidence from the Gulf Coast area suggesting a mid-Wisconsin interstadial and accompanying sea level rise. The third and latest Fiskian concept modification involves definite evidence supporting assignment of the Prairie-Beaumont formation (and the equivalent Pamlico formation of the eastern Gulf and south Atlantic coasts) to the Sangamon interglacial stage (Schnable, 1966; Hoyt et al., 1968; Saucier, 1968; Otvos, 1973). This would place the time of deposition of the formations earlier than 60,000 to 70,000 years ago and probably as much as 100,000 years ago according to current chronologies (Broecker et al., 1968; Mörner, 1971).

The question now arises - what happened in the way of eustatic sea level variations between at least 60,000 or 70,000 years ago and 18,000 years ago? Gulf Coast stratigraphy as commonly accepted appears to be devoid of evidence for more than one cycle of regression (coastal plain entrenchment and stream degradation) and subsequent transgression (stream aggradation and valley filling) following deposition of the Prairie-Beaumont formation. What then is the situation regarding the mid-Wisconsin Bradyan or Peorian interglacial stages as envisioned by Fisk?

Insofar as current North American glacial chronology is concerned, the Bradyan and Peorian stages no longer exist as significant interstadials or periods of glacial recession (Flint, 1963). However, as pointed out by Broecker (1961), there is substantial continental stratigraphic and paleoclimatic evidence for at least one pronounced interstadial in mid-Wisconsin time followed by a marked cooling of climate and glacial advance. The principal interstadial is now designated as the Paudorf interstadial in Europe and the Farmdalian substage in North America. But for many years, evidence of corresponding sea level variations as recorded in coastal sediments and stratigraphy was totally lacking.

During the last decade however, this situation has changed strikingly. Curray (1961), citing evidence opposed to the views of McFarlan (1961), was one of the first to point out definite evidence from a coastal area (Texas) for a relatively high stand of the sea during the Farmdalian substage. Shortly thereafter, Shepard (1963) presented additional evidence supporting the same concept. Their inferred sea level fluctuation curves are shown in Figure 2c.

Since 1961, considerable additional evidence, mostly in the form of radiocarbon dates on nearshore deposits, has been discerned in England (Donovan, 1962), at two separate localities in western Florida (Shumway et al., 1962; Schnable, 1966), at several localities in Georgia (Hoyt et al., 1968), on the east coast of Florida (Osmond et al., 1970), on the Atlantic continental shelf (Milliman and Emery, 1968), and in North Carolina (Whitehead and Doyle, 1969). Although there is appreciable variation in the interpretations (Figure 2d), all of these writers agree that the sea was near its present level at one or more times between 24,000 and 48,000 years before present. Most of the radiocarbon dates cluster between 25,000 and 35,000 years before present. While Hoyt and Schnable conclude that the sea rose above present level by as much as 15 feet, others like Curray and Shepard feel that the sea rose no higher than 30 to 35 feet below present level during this time. This view is supported by recent evidence from the Bering Sea area (Hopkins, 1973), and California (Birkeland, 1972). Still others, especially Mörner (1971), feel there was no major sea level rise at all during this time.

Assuming that the evidence for a reasonably high mid-Wisconsin sea level stand is valid and has been properly interpreted, what and where are the stratigraphic and morphologic evidence along the northern Gulf Coast, particularly Louisiana?

APPARENT EVIDENCE

A cursory but extensive review of available literature on Gulf Coast geology has revealed significant overlooked and/or misinterpreted evidence relevant to a post-Prairie or post-Sangamon but pre-Holocene transgression and high sea level stand. Considerable additional evidence, equally as indicative as that cited from coastal areas elsewhere, was discerned as part of an investigation of the subsurface Pleistocene formations in the greater New Orleans area (Figure 1) conducted by the U. S. Army Engineer Waterways Experiment Station. This evidence is of several types.

Weathered Horizons

Studies of the continental shelf of the northern Gulf of Mexico (Curray, 1960; Morgan, J. P., personal communication) indicate that Holocene sediments are quite thin or completely absent over extensive areas away from major river systems. Erosion rather than deposition must have been the dominant process during much of the last sea level rise (the Holocene transgression according to Curray (1965)), and it is inferred that a similar situation would have prevailed during a mid-Wisconsin transgression. However, in an area such as the Pontchartrain Basin (Figure 3) that is actively subsiding (Saucier, 1963) and that is marginal to a major source of sediments (The Mississippi River), it is logical to expect that deposition prevailed during stages of transgression. Since any sediments deposited during a mid-Wisconsin stage would have been subjected to subaerial weathering during the succeeding Late Wisconsin glaciation (because of regression of the sea), a weathered horizon overlying and younger than the Prairie formation weathered horizon should be present in the Pontchartrain Basin area.

Although the New Orleans area and much of the Pontchartrain Basin must rank as one of the world's most well-explored areas in terms of shallow sub-surface investigations, no evidence for more than one weathered horizon had been recognized as late as the mid-1960's. For example, over 100 core borings made in the mid-1950's for the Lake Pontchartrain Causeway (Figure 3) foundation investigation were used by Kolb and Van Lopik (1958, Plates 13-15) to construct a detailed 24-mile-long, north-south cross section across the basin. Only one weathered horizon, assumed to be the top of the Prairie formation, was apparent in these data.

In 1966, 45 additional core borings were made along the causeway route in connection with the design of a duplicate, parallel span. Although fewer in number, the newer borings were drilled more carefully, sampled more frequently, and logged in considerably more detail. These superior subsurface data have

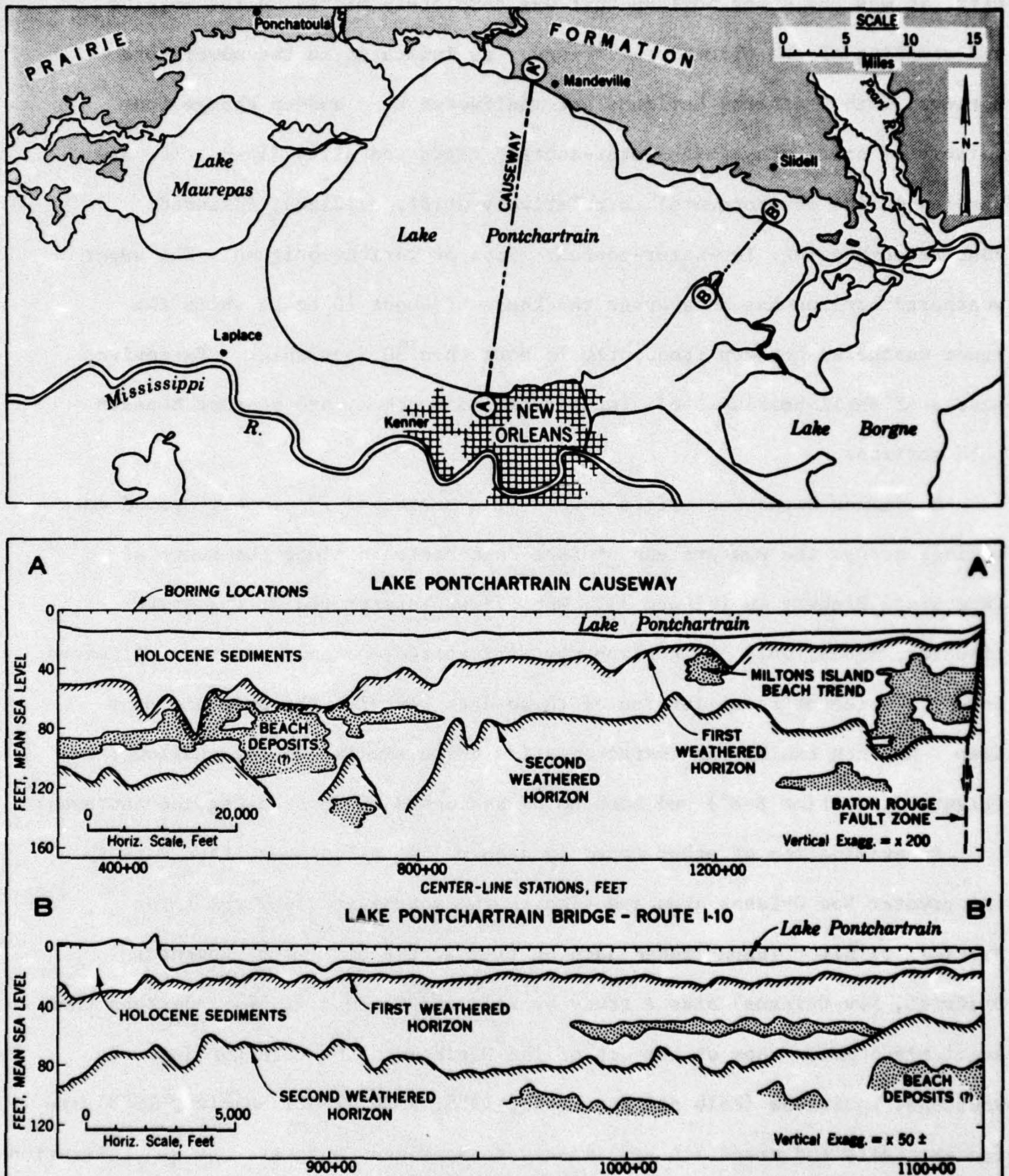

Fig. 3. Pontchartrain Basin area cross sections showing weathered horizons

yielded sound evidence for the presence of two weathered horizons rather than one as previously interpreted (Figure 3, section A-A'). For the most part, it was the upper horizon that was completely missed in the logging and sampling of the older core borings. As indicated in the newer core borings, both weathered horizons are manifested by a sudden change from relatively soft, gray, high-water-content clays and silts (lacustrine and shallow marine environments) to relatively stiff, oxidized, fissured, concretion-bearing, low-water-content clays of various origins. The upper weathered horizon has an average thickness of about 10 feet, while the lower weathered horizon frequently is more than 30 feet thick. Extensive masses of shell-bearing sand, interpreted as beaches, are present beneath both horizons.

A similar situation exists regarding a series of 70 closely-spaced core borings across the eastern end of Lake Pontchartrain along the route of Interstate Highway 10 (Figure 3). When first interpreted by the writer (Saucier, 1963), only one horizon was anticipated and only one was delineated. However, a recent reexamination of these data revealed the presence of a deeper horizon exhibiting characteristics quite similar to the shallower one (Figure 3, section B-B') and both being analogous to those along the causeway.

An examination of other recently acquired detailed subsurface data in the greater New Orleans area and also to the southeast along the lower Mississippi River (unpublished data on file at the U. S. Army Engineer District, New Orleans) plus a study by Kolb and Kaufman (1967) indicates that available contour maps on the top of the Pleistocene beneath portions of southeast Louisiana (Kolb and Van Lopik, 1958; Kolb, 1962; Saucier, 1963) are fundamentally incorrect. A preliminary reassessment suggests the generalization that north of the latitude of New Orleans, the contours delineate the upper horizon, whereas south of this latitude, the contours delineate the lower horizon; the relatively more detailed subsurface data near New Orleans are adequate to delineate the less well-developed upper horizon, while only the lower horizon is distinguishable in the poorer quality data available farther south.

Designation of the deposits below the upper horizon to the Farmdalian substage and those below the lower horizon as Prairie formation would appear reasonable just on the basis of stratigraphic position. However, additional evidence is available in the form of the relative amounts of displacement of the weathered horizons along the Baton Rouge fault zone (Figure 3, section A-A') (Saucier, 1963, p. 14) plus radiocarbon dates from the New Orleans area. Assays of marine shells from the deposits between the two weathered horizons include dates of 27,000 $\pm$ 1,200 and 29,300 $\pm$ 2,000 years before present (Kolb and Van Lopik, 1958, Plate 9B) plus at least one of >30,000 years before present (McFarlan, 1961, p. 158). Other similar dates are known to occur and are contained in articles being prepared for publication; however, as pointed out by Mörner (1971) and Stapor and Tanner (1973), there is reason to question the validity of any pre-Holocene radiocarbon date because of the effects of sample contamination. Numerous radiocarbon dates (Kolb and Van Lopik, 1958; McFarlan, 1961; Saucier, 1963) are available to indicate beyond question that the sediments overlying the upper horizon in the Pontchartrain Basin area were deposited during the Holocene transgression.

Beaches

As indicated in a comprehensive geomorphological investigation of the Pontchartrain Basin (Saucier, 1963), the maximum extent of the Holocene transgression in that area about 4,800 to 5,000 years ago resulted in the formation of the Pontchartrain embayment. The most conspicuous feature associated with the embayment was a 35-mile-long barrier spit (the Pine Island beach trend) that now underlies much of the city of New Orleans and trends northeast in the subsurface to near the mouth of the Pearl River (Figure 4). The mainland shoreline of the embayment was interpreted as being represented by a series of small beaches situated immediately south of the Prairie-Holocene contact north and west of Lakes Pontchartrain and Maurepas. These beaches, collectively designated as the Miltons Island beach trend (Saucier, 1963, p. 47) (Figure 4), almost everywhere have subsided to a point where they are now completely buried beneath 5 to 10 feet of Holocene paludal sediments. On the basis of core borings for the Lake Pontchartrain Causeway and bottom sediments and configuration, a narrow barrier spit apparently overlying the Prairie formation was recognized beneath the north central part of Lake Pontchartrain and was designated as part of the Miltons Island beach trend.

The beaches of the Miltons Island trend were observed to differ from others of unquestionable Holocene age in that they exhibited unusually well-developed soil profiles and a high degree of oxidation. Otherwise, stratigraphic position indicated assignment to the embayment stage was tenable. No radiocarbon dates are available even now to establish their absolute age; however, macrofaunal remains known to occur in the beaches could provide such information.

Interpretation of the newer Lake Pontchartrain Causeway borings (Figure 3, section A-A') indicates that the barrier spit segment of the Miltons Island trend lies beneath rather than above the upper weathered horizon; hence, assignment to the Holocene Pontchartrain embayment stage no longer appears tenable. This indication of possible association of the beach trend with a Farmdalian substage high sea level stand also provides an explanation for the thicker soil horizons and the more advanced oxidation, which themselves are indicators of greater antiquity (Price, 1962). A reassessment of all stratigraphic evidence relating to the beach trend revealed no conflicts would be generated by the proposed age reassignment.

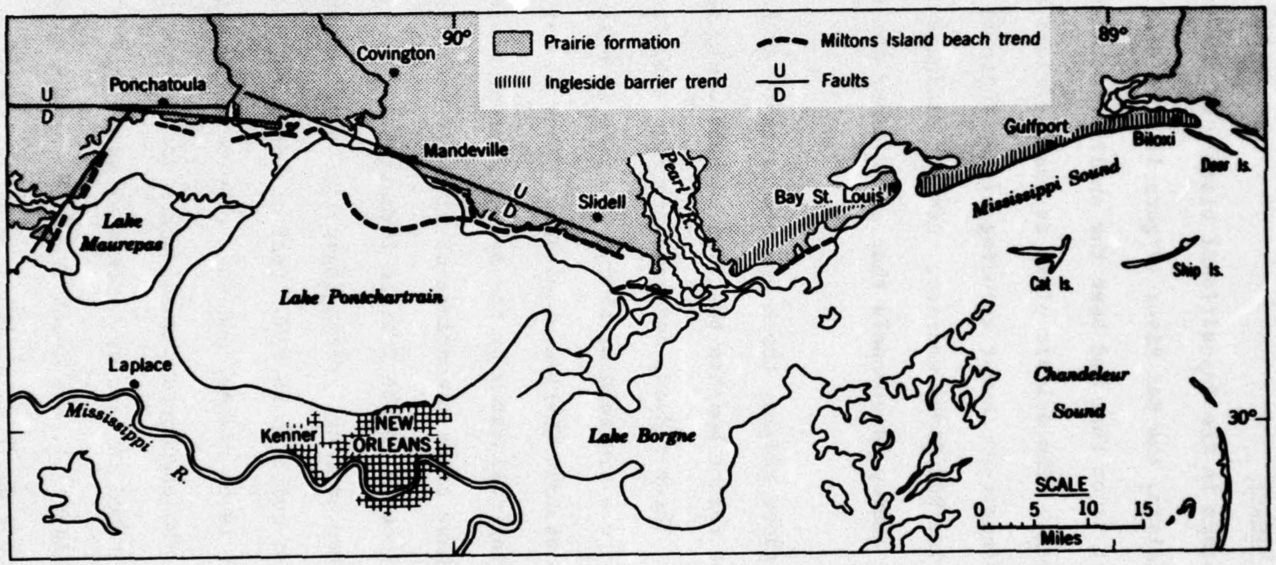

Fig. 4. The Miltons Island beach trend of the Pontchartrain Basin area

POSSIBLE EVIDENCE

Southwest Louisiana Ridges

During a late stage in the depositional history of the Prairie formation in southwestern Louisiana, the Red River (Figure 1) developed an extensive deltaic plain (Figure 5) on what had been the shallow continental shelf during an earlier stage. The deltaic plain is characterized by numerous low, narrow, sinuous, northeast-southwest trending ridges (natural levees) marking the locations of relict Red River courses. Present drainage frequently is controlled by relict abandoned channels that occur along the ridge crests (Fisk, 1948, p. 10).

In addition to these ridges, there are others that, although superficially similar, appear to be relict beaches that conceivably could date from the Farmdalian substage. These ridges, indicated in Figure 5, trend roughly east-west and extend to a distance of almost 20 miles on both sides of Calcasieu Lake south of Lake Charles, Louisiana. They appear prominently on topographic maps, being delineated by the 5- and 10-foot contours (above mean sea level) and have crest elevations of slightly over 15 feet. In all cases, they are located on the Prairie formation surface just north of the Prairie-Holocene contact. Morphologically they are narrower (about 2,000 to 3,000 feet as compared to 5,000 feet or more) and straighter than the Red River natural levee ridges, and they rise more abruptly from the surrounding surface. No abandoned channel scars are present along their crests. Where encountered in shallow borings along a highway south of Sulphur, Louisiana (Figure 5), the deposits of the ridges consist of well-oxidized sandy loam to a depth of at least 12 to 15 feet.

The overall association of present drainage with relict fluvial and marine landforms of the Prairie formation indicates that a major regression occurred shortly after the formation of the Red River deltaic plain. Consequently, it is not likely that the ridges south of Lake Charles could

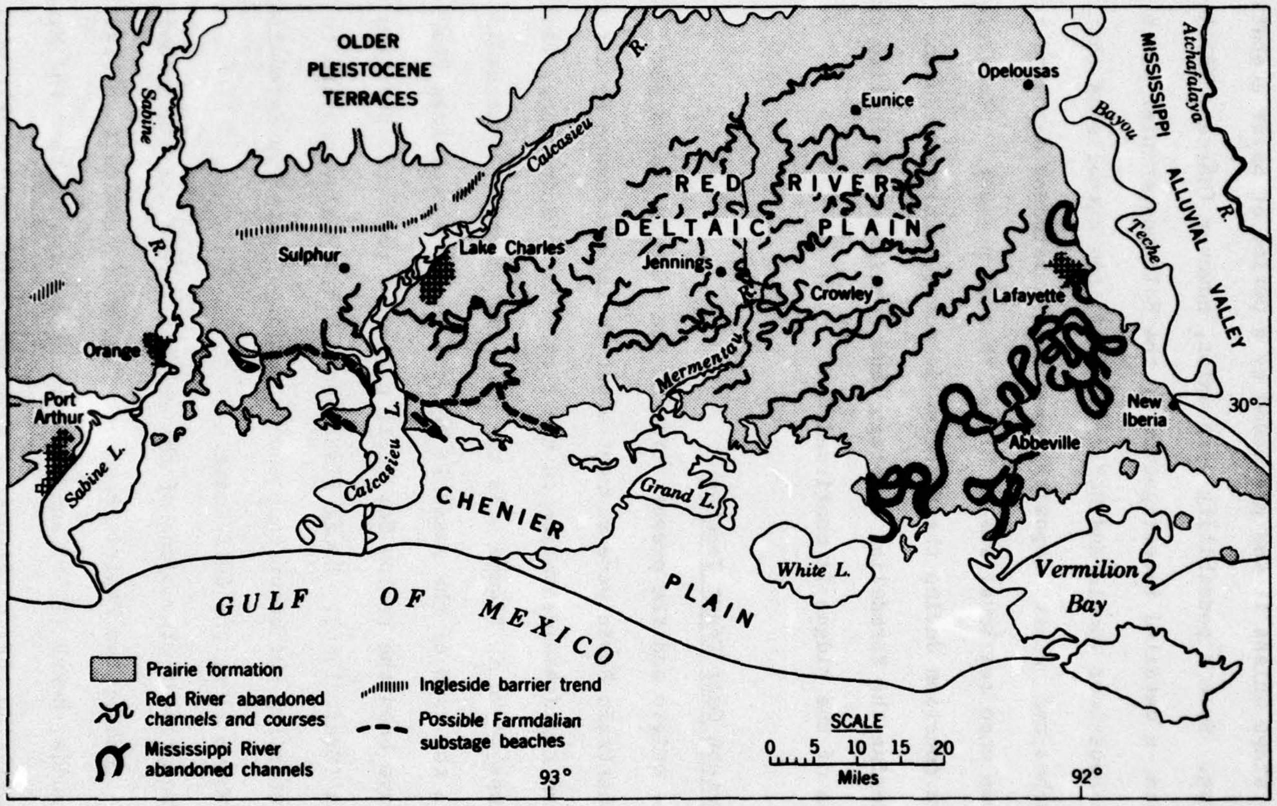

Fig. 5. Southwestern Louisiana beach trends and abandoned meander belts

have formed as a result of a minor transgression near the end of the Sangamon interglacial stage unless it was preceeded by a period of major eustatic sea level lowering. Such a possibility does exist, however (Mörner, 1971). On the other hand, a detailed investigation of the Holocene chenier plain of southwestern Louisiana (Gould and McFarlan, 1959) has established that all Holocene beaches and related deposits onlap the Pleistocene deposits and were laid down when sea level was no higher than at present. Deposition of the ridges in question during the Holocene is consequently precluded. Deposition during the Farmdalian substage thus remains a possibility provided marine origin of the ridges is confirmed.

Texas and Eastern Gulf Coast Beaches

Both the origin and the preservation of the Miltons Island beach trend in the Pontchartrain Basin were brought about in large measure by active subsidence and rapid sedimentation in the area. In this instance, faulting along the lines shown in Figure 4 is the principal subsidence mechanism involved. In the case of the possible related features near Lake Charles, uplift may have been the reason for their present topographic position and configuration (Graf, 1966). Local diastrophic history also appears to be a key to understanding the occurrence and detection of possible Farmdalian substage beaches elsewhere along the Gulf Coast.

Using the present elevations of the well-preserved and widespread Ingleside barrier trend of the Prairie-Beaumont-Pamlico formation (see Figures 4 and 5) as a guide, Henry (1956) and Graf (1966) determined that the Mississippi, Alabama, and Florida coasts (Figure 1) have been relatively stable while the Texas coast has subsided an average of 15 to 20 feet since Sangamon time. As indicated in Figure 4, the Ingleside barrier (averaging 2 miles in width and 25 to 30 feet in elevation) is coincident with the present mainland shoreline between Bay St. Louis and Biloxi, Mississippi (Otvos, 1973). Since this same situation or an analogous one exists along much of the eastern Gulf Coast (except in the Apalachicola River delta area, Figure 1), any Farmdalian substage beaches formed at or near present sea level possibly have been destroyed or, if preserved, are incorporated into and possibly indistinguishable from the Ingleside barrier. A similar coincidence of present mainland shoreline with Ingleside barrier exists along much of the Texas coast south of Galveston Bay (Figure 1), an area also characterized by prevailing subsidence and a low rate of Holocene sedimentation. It is quite probable that, because of these factors, any Farmdalian substage beaches that might have formed were destroyed during the latter part of the Holocene transgression or the early part of the Holocene stillstand.

Even in an absence of discernible beaches in these areas, some evidence for a Farmdalian substage transgression should be present. For example, a line of borings drilled across Padre Island just south of Corpus Christi, Texas (Figure 1), has indicated a thin zone of strand plain deposits (Fisk and McFarlan, 1955) immediately overlying the Beaumont formation (Dickinson, K. A., personal communication). Unpublished radiocarbon dates indicate the deposits were laid down between 27,000 and 30,000 years before present. The deposits are directly overlain by Holocene barrier island sands.

Elsewhere along the Gulf Coast, an analogous situation could be present and it should not be assumed that only Holocene strand plain deposits are present. How often have datable but undated materials from these deposits been discarded because of this assumption? Similarly, datable materials from in or near the Ingleside barriers should not be assumed to be beyond the range of dating by the radiocarbon method. At several localities along the eastern Gulf Coast, the writer has observed shell beds, peat horizons, and faunal-rich beach rock deposits along the seaward side of the barrier trend. These materials need documentation and dating, taking into consideration the problems pointed out by Stapor and Tanner (1973). Beach rock deposits from the seaward side of the Ingleside barrier along the lower Texas and upper Mexican coasts have yielded dates varying from 25,000 to >37,000 years before present; however, these have been questioned because of apparent carbonate replacement and/or recrystallization (Behrens, E. W., personal communication).

As pointed out by Schnable (1966), slow coastal progradation in the Apalachicola River area of Florida (Figure 1) because of deltaic sedimentation has provided a fortunate situation where possible Farmdalian substage beaches are preserved between and separated from the Holocene barriers of the present coast and the Ingleside barrier trend beaches farther inland. If analogous conditions occur elsewhere along the Gulf Coast, the Rio Grande and Colorado-Brazos River deltas of the Texas coast (Figure 1) would appear to be the logical places to look. Have the ages of all shoreline features in or immediately adjacent to these deltas been established?

Barrier Islands

The barrier islands, spits, and related phenomena forming much of the present coastline have been investigated in great detail at several localities, including Padre Island (Fisk, 1959), Galveston Island (Bernard and LeBlanc, 1965), Ship Island (Figure 4) (Rainwater, 1964), and the islands adjacent to the Apalachicola delta (Schnable, 1966). In each case, core borings revealed barrier island sands directly overlying a weathered Pleistocene horizon that could be traced beneath the full width of the island and the adjacent sound and the shallow offshore (Gulf) zone. Although the ages of the weathered horizons and the underlying sediments (i.e., Farmdalian substage or late Sangamon stage) were not determined at any location, dozens of radiocarbon dates are present to indicate that the barrier island sands are entirely of Holocene age.

Several of the writer's colleagues personally have expressed doubt about the assumed Holocene age of certain barrier islands or certain portions of particular barrier islands. Most concern has been centered around those portions of barrier islands exhibiting beach ridge (and/or dune ridge) series or complexes that trend in some direction appreciably different from that of the present shoreline. This condition is particularly evident on certain of the barrier islands of the Mississippi coast. Additional concern has been expressed regarding islands such as Deer Island (Figure 4) that occur outside the main barrier island trend.

No core borings or radiocarbon dates are known to be available specifically from within the beach ridge complexes; however, in view of the data obtained elsewhere on these islands, it appears unlikely that the areas would be of appreciably different age. The writer is of the opinion (but has no evidence to prove) that most of the beach ridges of the barrier islands of the present coast were formed during the early part of the Holocene stillstand. During this time, a sediment supply generally more abundant than at present should have been available as a result of the preceding transgression of the sea (Kwon, 1969). Subsequently, a diminishing sediment supply along certain segments of coastline has resulted not only in a cessation of beach ridge development, but also in island migration, erosion, and shoreline reorientation. Some of the islands along the Mississippi coast also have been affected by major changes in coastal current patterns resulting from the late Holocene seaward growth of the Mississippi River deltaic plain. In the case of Deer Island, borings are known to exist, but it is not known if they are available for examination.

Entrenched Valleys

Regardless of the absence or presence of shoreline features indicating a mid-Wisconsin high sea level stand, evidence in the form of buried entrenched river valleys should be present beneath the coastal bays and the shallow continental shelf. If the sea level variation curves shown in Figures 2c and 2d are basically correct, the sea fell to stands at least as low as 350 feet below present on two occasions following the Sangamon interglacial stage, i.e., during the Early Wisconsin and the Late Wisconsin glaciations. Thus, two distinct periods of stream entrenchment resulting from steepened stream gradients should be represented in the shallow stratigraphic sequence of the Gulf Coast.

Considering the number of factors such as topography, tectonic activity, and stream regime that could have influenced drainage basin configuration and stream alignment, it is impossible to predict without subsurface information the position or trend of either of the buried entrenched valleys for any river system. The two entrenchments may be coincident in some river systems, while in others they may be in entirely different locations. Even where perfect or near-perfect coincidence may be present, it is probable that the number of periods of entrenchment (i.e., one or two) would be decipherable. That all sediments filling the initial entrenchment would have been completely removed during the second entrenchment is highly improbable.

Outside of the Pontchartrain Basin area, there are probably very few locations along the Gulf Coast where core borings are of sufficient depth and detail (of logging or sampling) and are of sufficiently close spacing or density over a long enough distance to permit the recognition or delineation of more than one buried entrenchment. Nevertheless, huge volumes of detailed subsurface data in the form of seismic records obtained with acoustic subbottom profiling systems (continuous reflection seismic systems) are known to be available. Records have been obtained in and adjacent to virtually every navigable Gulf Coast bay, sound, or lake with systems such as the Sonoprobe and various types of pingers and sparkers (Saucier, 1970). Data of this type, representing thousands of miles of traverse, are known to have been acquired by and generally are available from literally dozens of Federal and state agencies, research corporations, universities, consultant engineering firms, and petroleum and geo-physical companies. The ability of the acoustic profiling systems to detect and delineate Pleistocene weathered horizons has been demonstrated on numerous occasions (e.g., McClure et al., 1958; Curray and Moore, 1963; Behrens, 1963).

A number of interesting and possibly relevant observations concerning weathered horizons already have been made using seismic records and are reported in the literature. For example, using seismic records plus data from core borings, Rehkemper (1969) recognized two and, in one case, three weathered horizons (and/or soil zones) beneath portions of Galveston Bay. The upper horizon, referred to as a disconformity, was estimated to be about 9,000 years old on the basis of radiocarbon dates from transgressive-stage deposits above the disconformity and on materials from within the soil zone. The disconformity lies wholly within and near the base of what is interpreted as a Trinity River channel entrenched in the Beaumont formation. This formation is interpreted as lying beneath the second weathered horizon, while the deposits lying beneath the third horizon are interpreted as pre-Sangamon in age (Montgomery terrace formation).

In this instance, even the presence of radiocarbon dates as young as about 9,000 years before present should not be presumed as precluding a considerably older age for the fluvial-deltaic deposits underlying the upper soil zone or disconformity. The dates were obtained from peat deposits lying within the soil zone, materials that could have accumulated at any time after the last regression of the sea up to the time of the Holocene transgression across the area. Thus, the dates can only be considered as minimum dates for the materials lying below the weathered horizon. Could they actually have accumulated during a time of relatively high sea level during the Farmdalian substage?

A somewhat analogous situation was observed beneath Aransas Bay (Figure 1) by Behrens (1963, p. 14) who, like Rehkemper, worked with seismic records and core borings. In this instance, the data were of poorer quality; nevertheless it was possible to discern within an entrenched valley an interval in which the sea regressed from the bay. No radiocarbon dates were available to establish the ages of any of the sediments in the area. Although Behrens (personal communication) equates the situation in Aransas Bay with the disconformity in Galveston Bay, he has no evidence to substantiate this.

In the writer's opinion, a minor regression of the sea (because of an interstadial) during the Holocene transgression would not have been of sufficient duration or magnitude to produce the effects observed in the Texas bays. As pointed out in an earlier publication (Saucier and Fleetwood, 1970, p. 886), adjustment of stream gradients, and particularly floodplain degradation, in response to falling sea level might be a relatively slow process even during major regressions.

Stream Terraces

Thus far in these discussions, attention has been devoted solely to possible evidence for a mid-Wisconsin high sea level stand in coastal and shallow offshore areas. However, if the sea attained an elevation reasonably close to that of the present, all streams discharging into the Gulf of Mexico probably experienced at least a minor shallowing of gradient in their lower reaches and some floodplain aggradation in a zone extending possibly a few tens of miles inland from the present coast. It is logical to expect, therefore, that fluvial terraces might be present along certain streams as evidence of this event. The amount of stream aggradation taking place and the consequent extent of terrace development would have been dependent in large measure on the sediment load of the stream. For this reason, it is necessary to consider the Mississippi River separately from all other Gulf Coast streams not just because of the much larger discharge but also because it was the only one that carried significant glacial outwash.

Recent studies of Mississippi alluvial valley geomorphology (Saucier, 1968; Saucier, 1974) have indicated that huge volumes of coarse glacial outwash were deposited in that valley during the time of the mid-Wisconsin transgression, i.e, because of waning Early Wisconsin glaciation. The Mississippi and Arkansas Rivers are known to have been braided streams building cones within the valley as far south as Natchez, Mississippi (Figure 1), during the latter part of the transgression. It is not known, however, if the Farmdalian substage lasted long enough or if glacial recession was sufficient to permit the Mississippi River to change from a braided to a meandering regime. If this did occur, it would have been only in the extreme lower part of the valley near the coast.

There exists in southwest Louisiana a series of abandoned channels of probable Mississippi River origin (Varvaro, 1957; Gould and Morgan, 1962, p. 320) but of unknown age that might represent deposition during the Farmdalian substage. As shown in Figure 5, the channels are part of a well-defined meander belt that trends southwestward from Lafayette, Louisiana, across what has been assumed to be the Prairie formation. On the basis of topography and relative position, they are known to be younger than the Red River deltaic plain to the west; however, there is no discernible evidence that unequivocally indicates they are of late Sangamon age as has been assumed. Daniels and Young (1968) have called attention to what they interpret as a thin blanket of loess overlying the Mississippi River meander belt, but the presence of this material is not indicative of age since loess has been identified as overlying deposits dating from the Farmdalian substage as well as the Sangamon interglacial stage (Saucier, 1968, p. 72.).

With no evidence present to indicate otherwise, it is conceivable that the channels represent development of a floodplain during the Farmdalian substage at approximately the same elevation as the Prairie formation. The Prairie formation would have been partially removed by lateral migration of the river at least across the width of the meander belt and replaced by point bar, abandoned channel, and related deposits. The discernible channels could have been situated within a deltaic plain or just upstream from a delta located just south of the present coastline.

Datable organic materials are likely to occur within the abandoned channels, but radiocarbon dates on them would only provide minimum ages for the features and consequently would not be definitive. Apparently only detailed studies of subsurface stratigraphy, with particular attention devoted to establishing the absence or presence of disconformities, will resolve the history of this meander belt.

During the past two decades, occasional attention has been focused on the Deweyville terrace, a fluvial terrace present on nearly every Gulf Coast stream except the Mississippi River (Bernard, 1950; Gagliano and Thom, 1967). This distinctive terrace is situated topographically between the Holocene floodplain and the Prairie-Beaumont-Pamlico terrace formation and is easily identified by characteristic meander scars several times larger than those of the present streams. Most geologists having cause to speculate on the origin of the terraces, including those mentioned above, have concluded that a significantly wetter climate (i.e., pluvial conditions) was probably present at the time of terrace formation. However, most have felt that a sea level change, particularly a rapid sea level rise, was the most important causal factor. Bernard (1950) felt that terrace formation took place during the Holocene transgression whereas Gagliano and Thom (1967), having radiocarbon dates of 17,000 to 30,000 years before present to work with, attempted to resolve an apparent age conflict and to show a correlation of the terrace with the Farmdalian substage. Such a correlation is certainly suggested by the relative stratigraphic position of the terrace and has been looked upon favorably (but informally) by a number of Gulf Coast geologists.

More recently, a study of the Deweyville terrace sequence along the Ouachita River (Figure 1) of Arkansas and Louisiana (Saucier and Fleetwood, 1970) has indicated strongly that terrace formation took place during waxing glaciation and a time of regression of the sea following the Farmdalian substage. This observation is supported by the fact that the Deweyville terrace has a slightly steeper gradient than the present streams and plunges beneath Holocene floodplain deposits along all Gulf Coast streams a short distance above their mouths. Thus being graded to a lower-than-present sea level, the Deweyville terrace obviously cannot be cited as direct evidence for a Farmdalian substage high sea level stand.

Eliminating the Deweyville terrace from consideration, only one known area remains in which evidence in the form of fluvial terraces might be present. This area is located adjacent to the coast in southeastern Mississippi between the mouth of the Pascagoula River and the Alabama state line (Figure 1). The Quaternary sequence in this locality consists of, from oldest to youngest, the Prairie terrace formation, a slightly lower and distinctly different terrace called the Pamlico terrace (Harvey and Nichols, 1960; Harvey et al., 1965), the Deweyville terrace, and the Holocene floodplain (Figure 6). The relative ages of the terraces are firmly established by both topographic position and the pattern of stream entrenchments and subsequent valley fills.

What has been separately (and confusingly) identified as the Pamlico terrace is of particular concern from the standpoint of Farmdalian substage evidence. Elevations on this terrace vary from about 10 to 20 feet, whereas the Prairie terrace is situated between elevations of 30 and 50 feet. A distinctive feature of the Pamlico terrace is a well-preserved relict meander belt of the Pascagoula River (Figure 6). At the time the abandoned course was active, the mouth of the river was at least 10 miles farther east than at present. The morphology of the meander belt indicates that the paleodischarge of the river was approximately the same as it is at the present.

Two explanations for the Pamlico terrace are tenable on the basis of discernible morphologic and stratigraphic evidence and in an absence of radiocarbon dates and subsurface information. The first explanation, suggested

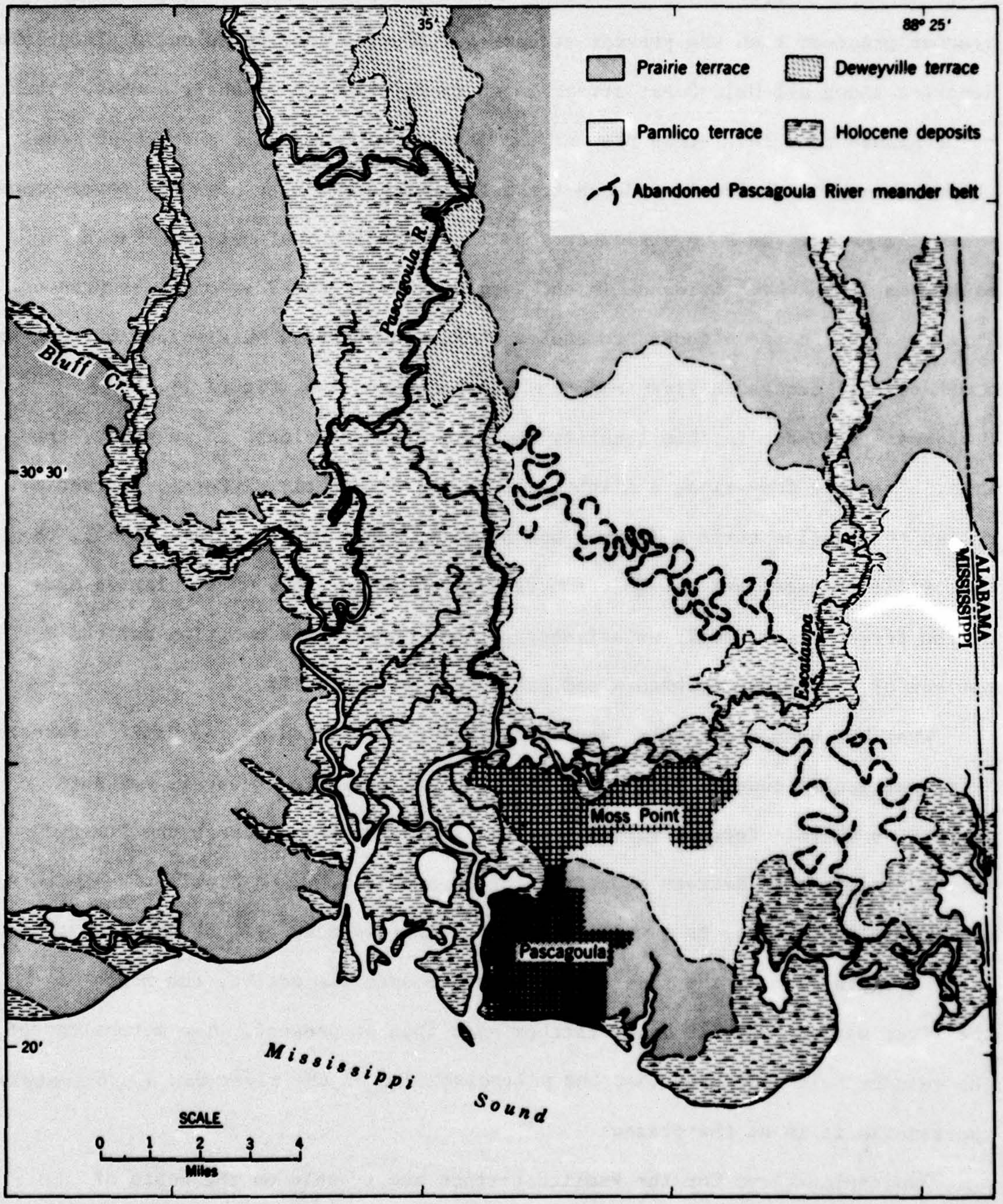

Fig. 6. Terraces of the Pascagoula River area

by Harvey et al. (1965), accounts for the difference in elevation between the Prairie and the Pamlico terraces by assuming the Pamlico level is a relict sea-floor plain (shallow offshore area) of Sangamon age while the Prairie level represents the higher (and coeval) beach and mainland deposits. If this explanation is valid, the implication is that the levels are merely physiographic or topographic terraces developed on a single formation of approximately one age. The abandoned Pascagoula River course could represent simply a short-lived diversion of the stream through a relatively low area at a slightly later date shortly after the sea had regressed from the area.

A second explanation, proposed by this writer as being equally as tenable, assumes the Prairie terrace to have been formed during the Sangamon interglacial stage and entrenched when the sea regressed during the subsequent Early Wisconsin glaciation. Whether more than one level was originally present on the Prairie formation is immaterial. During the mid-Wisconsin transgression, the Pascagoula River was forced to shallow its gradient and aggrade its floodplain. The maximum extent of aggradation took place during the Farmdalian substage and is evidenced by the Pamlico terrace and associated meander belt. The terrace formation, therefore, would likely consist of basal marine transgressive deposits overlain by estuarine and eventually fluvial deposits filling an entrenchment in the Prairie formation. By the onset of the Late Wisconsin glaciation, the Pascagoula River had diverted to its present course where it eventually became entrenched. During the period of entrenchment and regression of the sea, the Deweyville terrace was formed, largely as a result of adjustment to increased precipitation and/or discharge. Entrenchment to a level below that of the Deweyville terrace occurred about the time of maximum sea level lowering and was followed by valley filling and aggradation during the Holocene transgression.

A discovery of firm evidence supporting either explanation or an alternate one apparently requires only a desire on the part of an available, sciential individual to make even a moderately detailed geomorphological investigation of the area, something that has been proposed and initiated (Gagliano, 1962) but never completed. Large volumes of detailed subsurface data are available for study, including dozens of core borings to depths as great as 200 feet along an interstate highway route crossing the area. Carbonaceous materials suitable for radiocarbon dating are known to be present in the abandoned Pascagoula River meander belt and faunal remains abound in the Pamlico terrace formation.

IN RETROSPECT

Attention has been called to probable beach ridges, strand plain deposits, shoreline deposits, discontinuities within buried entrenchments, fluvial terraces, and relict meander belts as possible evidence in the Gulf Coast area for a Farmdalian substage high sea level stand. Certainly much of the discussions must be considered as speculation or conjecture. Nevertheless, enough evidence in the form of buried weathered horizons, beach trends, and radiocarbon dates from the Pontchartrain Basin area is present to suggest that the sea could have attained a level close to that of present at some time after the deposition of the Prairie-Beaumont-Pamlico formation which almost certainly was during the Sangamon stage. Could this high sea level stand have occurred during the Farmdalian substage? This concept would certainly be favorably received by some, but strongly rejected by others. Is there an alternative? To date, the only reasonably viable one is that proposed by Broecker et al (1968) and summarized by Mörner (1971, p. 140). According to their data, the high sea level stand could have occurred about 80,000 years ago during the brief Brörup Interstadial (of northern Europe) which is separated from the Sangamon high sea level stands (Eem I and II between 100,000 and 130,000 years ago) by a major regression. This possibility bears just as strong consideration as does that of a Farmdalian substage high sea level stand!

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