INTERPRETATION OF THE SEISMIC STRATIGRAPHY OF THE PHOSPHATIC MIDDLE MIOCENE ON THE GEORGIA CONTINENTAL SHELF

by

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GEOLOGIC ATLAS 4

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INTRODUCTION

Introduction

Mineral exploration in Georgia in the 1960's revealed the presence of extensive phosphorite deposits under the marshland and barrier islands in Chatham County, Georgia. This phosphorite, the Tybee Phosphorite Member of the Coosawhatchie Formation (Huddlestun, in press) also was noted in a local offshore boring, the Savannah Light Tower test hole located about 10 miles east of Tybee Island. The phosphate concentration in the Tybee Phosphorite Member, as high as 29.7% P_2O_5 (Zellars and Williams, 1978) and averaging 10% P_2O_5 (Furlow, 1969; Zellars and Williams, 1978), is roughly comparable to the phosphorite currently being mined in Florida and North Carolina. Studies during the 1960's demonstrated the economic feasibility of mining these phosphates from under the marshes (Cheatum, 1968). However, the marshes provide a unique ecological habitat and are important nutrient sources. They are economically more valuable in an unaltered state. For this reason, it was not deemed advisable to mine the marshes. Nevertheless, if the Tybee Phosphorite Member is present offshore in commercially exploitable deposits, the recents development of more environmentally amenable subsea mining techniques may establish the Tybee Phosphorite Member as a valuable resource for the future.

This atlas is prepared by the Georgia Geologic Survey with two objectives: (1) to delineate, through interpretation of seismic data, the stratigraphic framework of the phosphate-bearing strata, and 2) to evaluate the relationship of these strata to the underlying Principal Artesian Aquifer System, the major source of fresh water to coastal Georgia. The maps and cross sections produced were based on the compilation and integration of several earlier studies on the subsurface stratigraphy of the Georgia continental shelf. These previous studies relied heavily on interpretation of high resolution seismic reflection data and correlation of the seismic data with the few lithologic logs or cores available on the Georgia continental shelf.

Phosphorites

Phosphorite deposits generally consist of igneous apatites, guano, and the depositional products of marine environments. Presently, almost all the economic phosphorite deposits are of shallow marine origin (Bushinsky, 1964; McKelvey, 1967). The Tybee Phosphorite Member of the Miocene Coosawhatchie Formation is also believed to have been formed in a shallow marine environment (Huddlestun, in press).

The element phosphorus predominantly occurs in apatite, $Ca_3(PO_4)_2$, a common component of igneous rocks. After being weathered out, phosphorus is transported to the sea as phosphate (PO_4-3), or adsorbed on iron compounds, aluminum hydroxides and clays, or carried in dissolved organic compounds.

Phosphorus has a very low solubility in seawater (McKelvey, 1967). As a result it is a limiting nutrient for life in the ocean. Ocean water is generally almost saturated with phosphorus as a result of its low solubility, so that it is continuously inorganically precipitated. A large percentage of this phosphorus is utilized by planktonic organisms, and much of it is eventually deposited by settling of these organisms after their death. In shallow water, deposition can occur before the phosphate can be dissolved, through chemical reactions, or be utilized by other organisms (Bushinsky, 1964; Riggs, 1979a; Birch, 1980; Wallace, 1980; Riggs, 1984). Deposition also commonly occurs through direct precipitation of phosphorus in regions of upwelling. Upwelling brings cold, phosphate-rich bottom water into contact with warm surface water. In the higher temperature and pH of surface water phosphorus is less soluble and thus precipitates out of solution (Bushinsky, 1964; Riggs, 1979b, 1984). Direct mineral replacement from sea water is aided by the presence of limy sediments, as concretions on calcareous material, such as skeletal fragments or fecal pellets, and as a result of the replacement of calcium carbonate with calcium phosphate (Ames, 1959; Birch, 1980; Wallace, 1980). Concentration is also aided where clastic or carbonate sedimentation is slow enough that the phosphate is not "diluted" by non-phosphatic material and where subsequent transport is restricted enough to prevent dissipation (Riggs, 1979b; Odin and Letolle, 1980).

The principal uses for phosphates in the United States are as fertilizer or feed supplements. Most of the domestic production of phosphate (87-91%) and about 35% of the world's production comes from deposits in Florida and North Carolina (Zellars-Williams, 1978; Stowasser, 1983), from the upper Miocene/lower Pliocene Bone Valley Formation and the lower/middle Miocene Pungo River and Pliocene Yorktown Formations, respectively. The "total identified resources in recoverable product tons" (Zellars and Williams, 1978) for the Tybee Phosphorite Member was estimated to be 3125 million short tons, 34% of the total for the North Carolina to Florida coastal plain. It must be recognized that any definitive statement on total recoverable ore will require extensive additional investigation, on and off-shore.

Regional Geology

General statement

The Atlantic continental margin is described as a passive trailing edge of the continent and has been relatively stable tectonically from the Cretaceous to the present. Tectonic activity has occurred only as tilting, subtle warping, and minor faulting (See Figure 1). The Georgia continental shelf occupies a broad, shallow reentrant about 70-80 miles wide. Water depth at the shelf break is 150-200 feet. This contrasts with the usual shelf break of about 300-350 feet. (Figure 2). The Georgia shelf is bordered on the west by a series of Pleistocene to Holocene barrier islands and tidal inlets.

The Coastal Plain and continental shelf of Georgia consist of a series of seaward dipping and variably thickening sedimentary wedges of early Cretaceous to Holocene age. The "basement" consists of Precambrian and Paleozoic igneous and metamorphic rocks overlain by lower Mesozoic clastics. The Jurassic/Cretaceous contact is located at an approximate depth of 3,500 to 4,500 feet below sea level beneath the coastal area.

The major structural feature of the region is the Southeast Georgia Embayment, bounded by the Cape Fear Arch at the north and the Peninsular Arch to the south (see Figure 1). The embayment opens and deepens to the southeast. Beaufort Arch and "Middle Shelf High" (Idris, 1983) are northeast-to- southwest trending highs which have been interpreted as being depositional in origin and influenced by differential compaction over underlying structures (Foley, 1981; Popenoe, personal communication). Foley (1981) shows a "Mid Shelf Low" in the southern portion of the study area. He interprets it as a deep trough bounded by a Miocene scarp to the west and the "Outer Shelf High" to the east. This low shallows northward, and deepens and broadens to the south. This "Outer Shelf High" trends north-south with positive relief increasing northward in the study area. Foley (1981) interpreted the geometry of the upper Miocene sediments overlying the Outer Shelf High as indicating deposition on an inclined and uplifted surface of middle Miocene sediments.

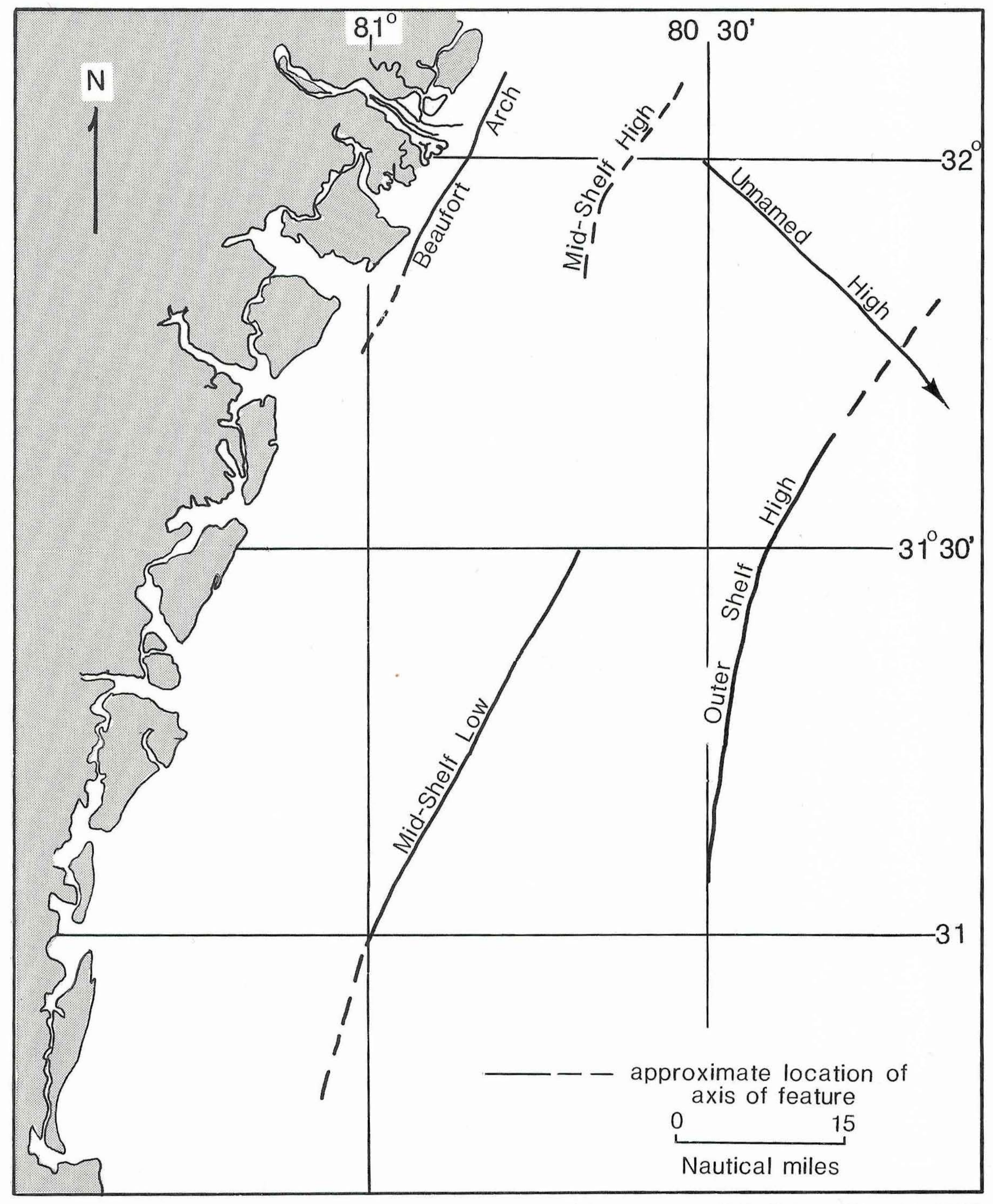
Stratigraphy

The Neogene stratigraphy of the Coastal Plain of Georgia has been the subject of extensive study since the 1950's, involving ground water and aquifer investigations, and the definition of stratigraphic units. For consistency the recent and comprehensive study by Huddlestun (in press) is used throughout this study. (See Table 1).

Although the Neogene of the Georgia Coastal Plain has received detailed study, little biostratigraphic control is available for the adjacent continental shelf. Borings and high resolution seismic data were obtained in the vicinity of the Savannah Light Tower (Porter and Associates, 1962; McCollum and Herrick, 1964). Deep drilling from the 1965 J.O.I.D.E.S. expedition was used to correlate on- and offshore stratigraphy east of Jacksonville, Florida (Bunce and others, 1965; Schlee and Gerard, 1965). Other core information concerning offshore stratigraphy was obtained from the AMCOR 6002 boring (Hathaway and others, 1976; Hathaway and others, 1979), COST GE-1 (Scholle, *ed.*, 1979), and the Georgia Geologic Survey core Cumberland Island 1 (GGS -3426).

Studies describing shallow high resolution seismic data obtained in the study area include Woosley (1977), Henry (1983), Henry and others (1978), Foley (1981), and Kellam (1981) on file with the Geology Department of Georgia State University. Seismic data obtained on the U.S. Geologic Survey R/V *Gillis* cruise of August 1979 (Popenoe, 1983), provided for direct correlation with the J.O.I.D.E.S and Cost GE-1 borings and were particularly useful in tying together the studies in the northern portion of the study area with those in the south. These data reveal a regional continuity of Coastal Plain and continental shelf stratigraphy and establish the basis for a generalized correlation of seismic stratigraphy of the study area to regional biostratigraphy.

FIGURE 1 STRUCTURE OF THE GEORGIA CONTINENTAL SHELF



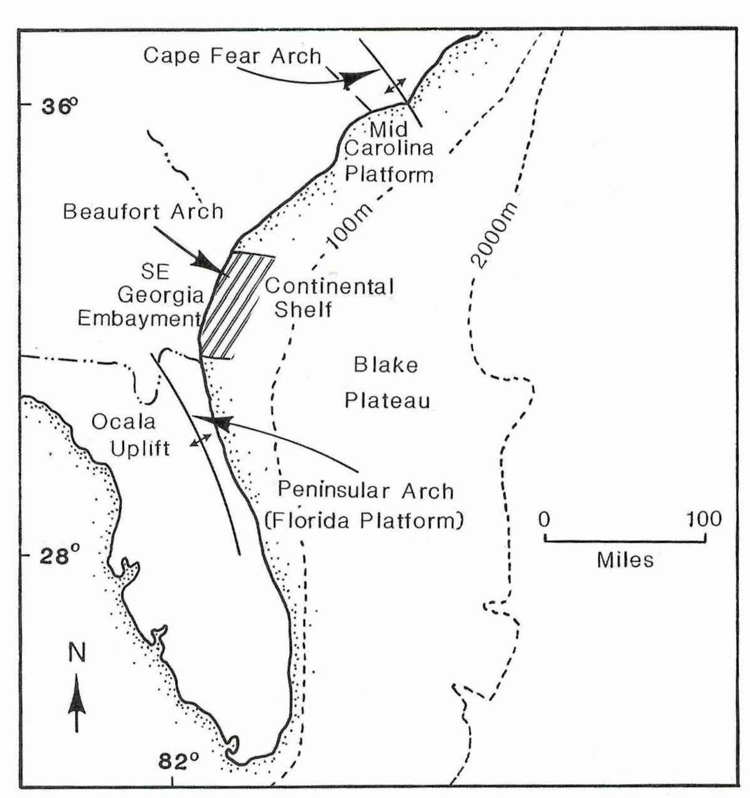
After Woolsey 1977; Foley 1981; Idris 1983

TABLE 1 GENERALIZED STRATIGRAPHIC NOMENCLATURE OF THE GEORGIA INNER CONTINENTAL SHELF

	NORTHERN				SOUTHERN		
QUATERNARY	undifferentiated				undifferentiated		
PLIOCENE	DUPLIN MARL				DUPLIN MARL EQUIVALENT		
MIOCENE upper							undifferentiated
middle	Hawthorne Group	Coosawhatchie Formation	West: Ebenezer Member	East: Charlton Member; Berryville Clay Member; Tybee Phosphorite Member	Hawthorne Group	West: Coosawhatchie Formation	East: Berryville Clay Member
lower	Hawthorne Group	Marks Head Formation			Hawthorne Group	?	
	Hawthorne Group	Parachucla Formation			Hawthorne Group	Parachucla Formation? Cooper Marl?	Cooper Marl
OLIGOCENE	Lazaretto Creek Formation						Cooper Marl
EOCENE	Ocala Formation Santee Formation				Ocala Formation & Equivalent		

From Huddlestun (in press)

FIGURE 2 LOCATION MAP



Modified from Riggs 1979a and Paull & Dillon 1980

As shown in Table 1, Tertiary stratigraphy in the study area can be divided into four seismic stratigraphic sequences: 1) the late Oligocene Lazaretto Creek Formation and the age equivalent portion of the Cooper Marl; 2) the lower Miocene, consisting of the Parachucla and Marks Head Formations; 3) middle Miocene, Coosawhatchie Formation; 4) post middle Miocene, consisting of undifferentiated upper Miocene, Pliocene (Duplin Formation equivalent, and younger undifferentiated sediments), and undifferentiated Quaternary sediments. The ages of the units and the hiatuses separating them, based on seismic reflector picks and correlation with cores, show good correlation with accepted Tertiary eustatic sea levels and changes proposed by Vail and others (1977).

The Tybee Phosphorite Member is the basal unit of the middle Miocene Coosawhatchie Formation. Due to its relative thinness and a paucity of core and boring information from the shelf, it is not possible to identify the Tybee Phosphorite Member as a unique reflector on the seismic records. Since it is the basal member of the Coosawhatchie Formation, its geographic extent is more or less represented by the structure-contour of the base of the middle Miocene (Plate 6).

The Principal Artesian Aquifer System is a complex of Eocene, Oligocene, and Miocene units. Facies changes occur within these units on the shelf, as seen in the available lithologic data. As a result, identification of the "top" of the aquifer and its seaward extent is generally conjectural. A clarification of the stratigraphic relationship between the phosphorite and the aquifer system is necessary before development of the mineral potential can begin. It is extremely important to protect this valuable aquifer and its aquitard. Breaching of the aquifer could result in contamination by seawater.

METHODS

This study utilized seismic stratigraphic cross-sections from several previous studies as presented on Plate 2.

First the various interpretations were reconciled to insure that the picks made for specific horizons, correlated across the study area. In order to provided a unified interpretation, additional information was obtained by examination of previously uninterpreted seismic records acquired from the U.S. Geological Survey. After all available data were reconciled, the prominent reflectors were transposed to stratigraphic cross-sections at a common scale.

Plates 3 and 4 are cross-sections chosen to provide a three-dimensional picture of the stratigraphic framework of the Georgia continental shelf. Isopach and structure-contour maps were prepared using the data from the cross-sections (Plates 5-9).

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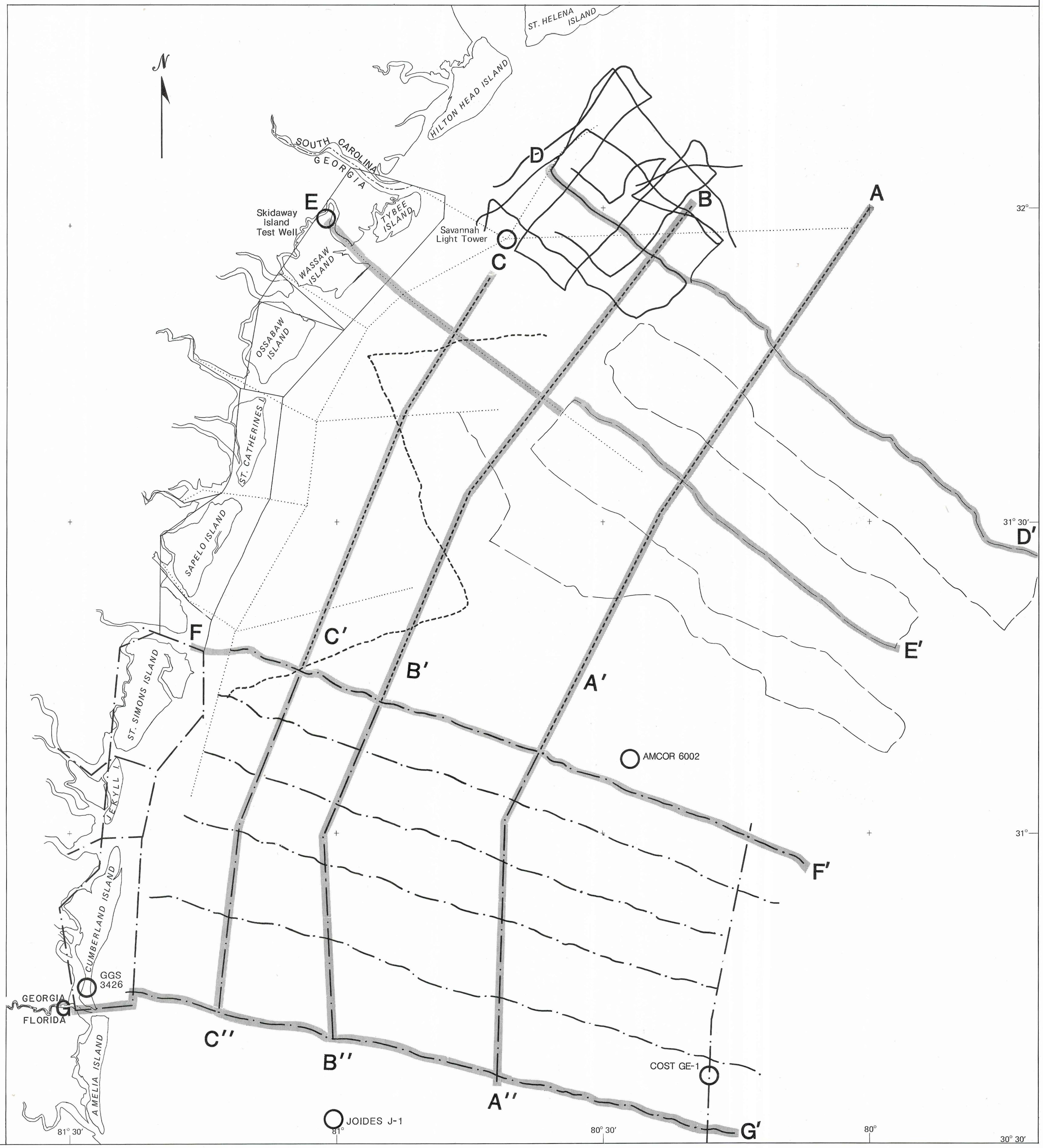
SEISMIC TRACKLINES and BORING LOCATIONS IN THE STUDY AREA

The data for this study consists of a compilation of information obtained from previous studies of the shallow stratigraphy of the continental shelf of Georgia. The high resolution seismic data used in these studies were gathered by a cooperative effort of the University of Georgia Marine Geology program at the Skidaway Institute of Oceanography, Savannah, Georgia, and the U.S. Geological Survey at Woods Hole, Massachusetts.

Seismic profiles from the studies were correlated, integrated, and compared with lithologic data from the six test holes or borings located in or adjacent to the study area. In areas where data from previous studies was not available, uninterpreted data were examined and correlated with existing produced showing structure-contour and isopach information pertaining to the phosphatic strata and aquifer system under the continental shelf of Georgia.



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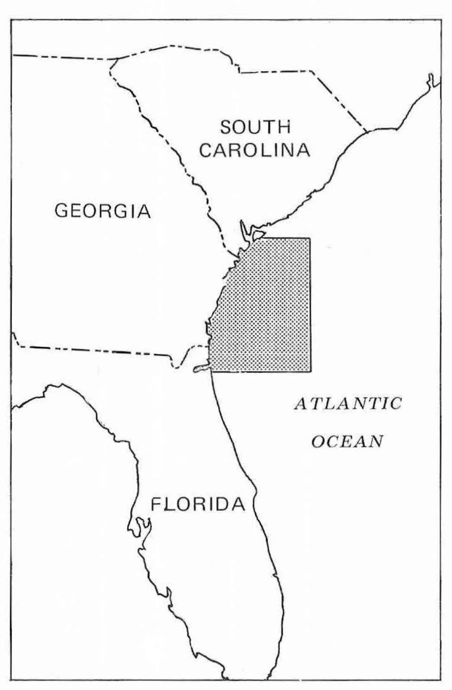
EXPLANATION

- Kellam 1981
- This study (Data from Popenoe, 1983)
- Foley 1981
- Henry 1983
- Woolsey 1977
- Henry and others 1978
- Used as cross section lines in this study
- Test hole, core or boring

SCALE 1:449,659

0 5 10 Nautical miles



STUDY AREA LOCATION

Base from National Oceanic and Atmospheric Administration Charleston Light to Cape Canaveral navigation map, 1984

CROSS SECTIONS FROM SEISMIC PROFILES

Plates 3 and 4 present a series of cross sections derived from high resolution seismic information. These cross sections were chosen to provide a representative grid of stratigraphic sections oriented roughly parallel and perpendicular to the coast and to the structural trend of the continental shelf of Georgia.

One of the few significant features on this portion of the shelf is that the north-south trending Beaufort Arch is seen as very subtle arching of Oligocene to middle Miocene strata in cross sections D-D' and E-E'. The major "structural" influences in the southern half of the mapped area are the shore-parallel "Mid Shelf Low" and "Outer Shelf High" (Foley, 1981), (see cross-sections F-F, G-G, Plate 4, this atlas). These features involve Oligocene to Middle Miocene strata, but may be both depositional and erosional rather than structural in origin.

Oligocene deposits consist of calcareous oozes deposited in a deep marine environment such as the outer shelf and slope. Generally where it is detectable with high resolution techniques, the Oligocene carbonates are represented on seismic records by a few discontinuous internal reflectors. This is due either to homogeneity of its constituents or to the attenuation of the acoustic signal, or both. The upper surface of the Oligocene is hummocky on the seismic records, as seen east of Tybee Island (Kellam, 1981) (see Plate 5, this atlas). The presence of this extensive erosion suggests subaerial exposure during late Oligocene time.

The lower Miocene strata consists of shallow marine, interbedded terrigenous clay and sand grading to the east and south into a calcareous argillaceous "ooze" like that found in the AMCOR 6002 boring (Hathaway and others, 1976). The clastic facies, on seismic records, shows a discontinuous internal banding indicating the interbedding of sand and clay which resulted from continual minor fluctuations of sea level. The surface of the lower Miocene also shows a hummocky surface, apparently the effect of subaerial erosion.

Middle Miocene strata consists of phosphatic, shallow marine, terrigenous clay and sand in the Savannah Light Tower boring, the GGS - 3426 core, and the J.O.I.D.E.S. J-1 boring, but grade in to a variably siliceous, clastic, calcareous clay in the AMCOR 6002 (Foley, 1981). The terrigenous facies exhibits a very characteristic banding on seismic records. This banding is strong, continuous, and laterally extensive, making the middle Miocene easily identifiable. The upper surface of the Middle Miocene strata is an extensive erosion surface. It is possible that winnowing and concentration of phosphatic material (in topographic lows such as stream channels or scour holes) are the result of the same processes that produced the erosion surface. This erosion is seen in the northern portion of the study area in the form of the Tybee Trough (cross section (D-D"). To the south erosion is manifested by the erosional scarp landward of the Mid Shelf Low and by the ancestral Altamaha River (Foley, 1981) (see Plate 7, this atlas).

The top of the middle Miocene generally dips to the east and south (Plate 7). Middle Miocene strata are much closer to the surface in the northern portion of the study area, and crop out in places. Additionally, much of the overburden has been removed from the crest of the Beaufort Arch. The middle Miocene has been removed from the nose of the arch (cross section D-D').

To the south and east, Pliocene sediments overlie the Miocene in an on-lapping depositional relationship (cross sections A-A', B-B', C-C', this plate). Upper Miocene sediments are considered to be present only as a wedge deposited on the landward flank of the "Outer Shelf High" (cross section F-F') and probably as wedges onlapping at the eastern extent of the mapped area, at the shelf break (cross sections D-D' and E-E').

The Tybee Phosphorite Member of the middle Miocene Coosawhatchie Formation is seen under Tybee Island, in the Savannah Light Tower boring, and in the G.G.S. 3426 core on Cumberland Island. It is not present in the three southern offshore borings. The phosphatic Middle Miocene sediments, in which the Tybee Phosphorite Member is contained, are most accessible in the northern portion of the study area, where they occur in relatively shallow water, under only a thin layer of overburden. Also, in this northern area the phosphorite zone and the aquifer system appears to be separated by a substantial aquiclude, the Marks Head Formation of early Miocene age. A final decision on the commercial and environmental feasibility for development of the phosphate resource will require the gathering of additional lithologic and stratigraphic information.

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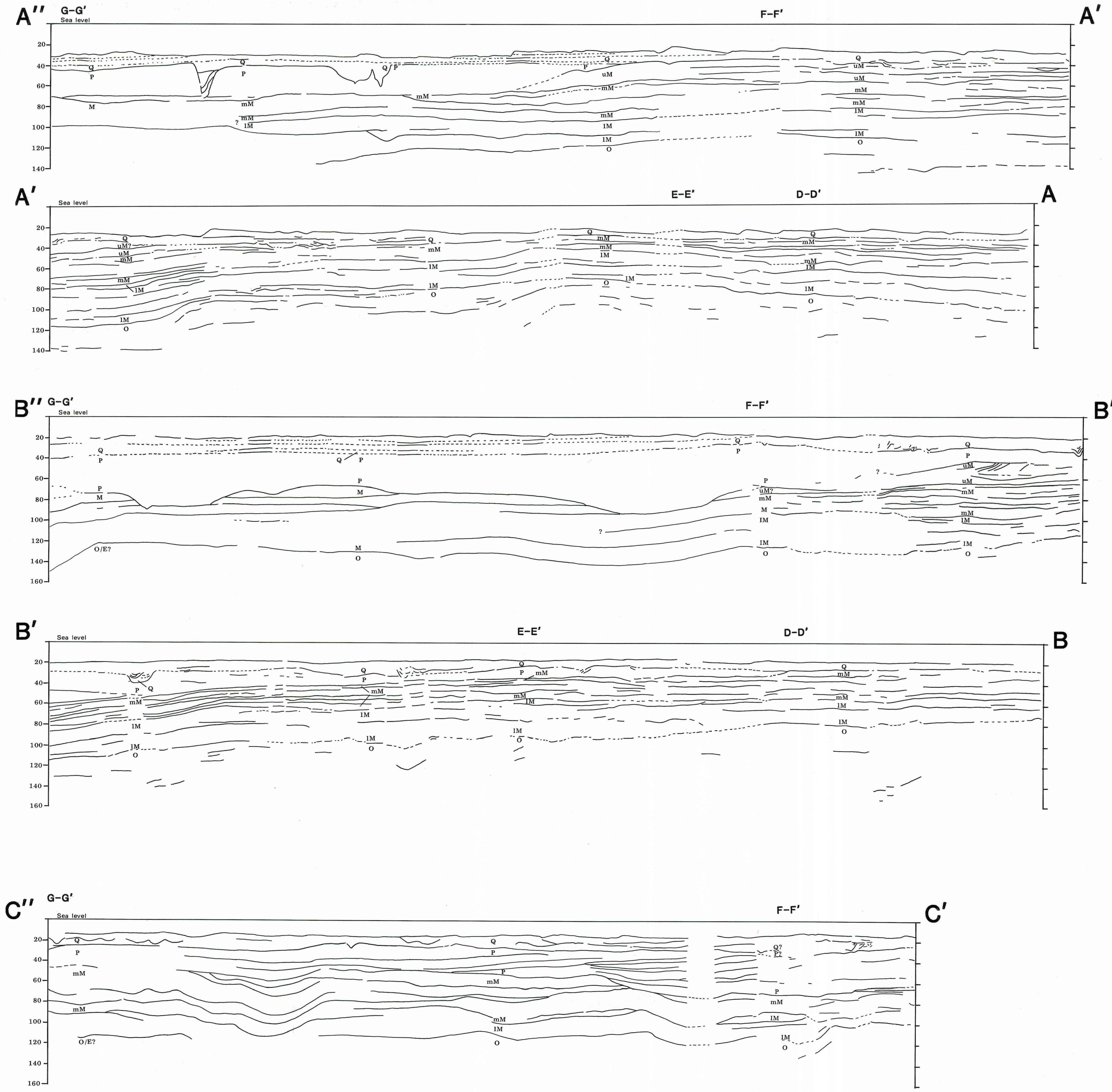
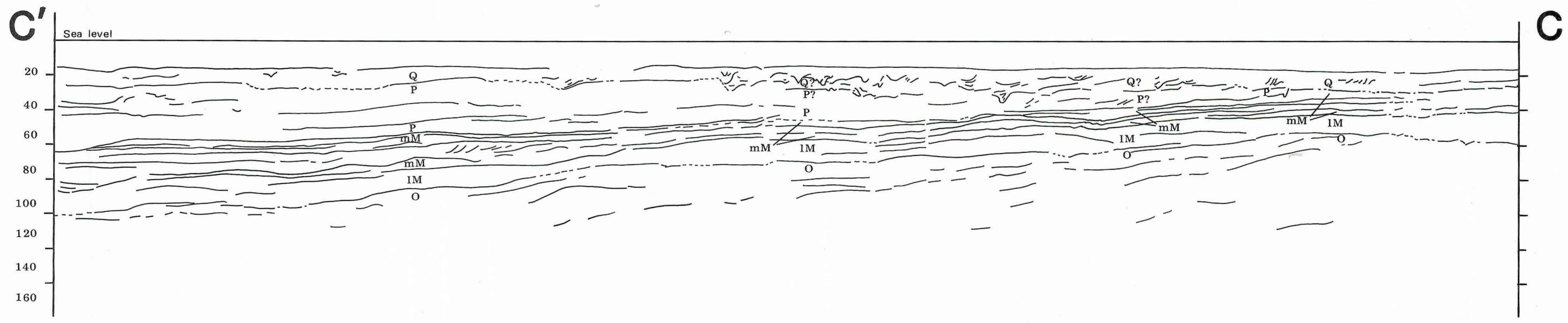
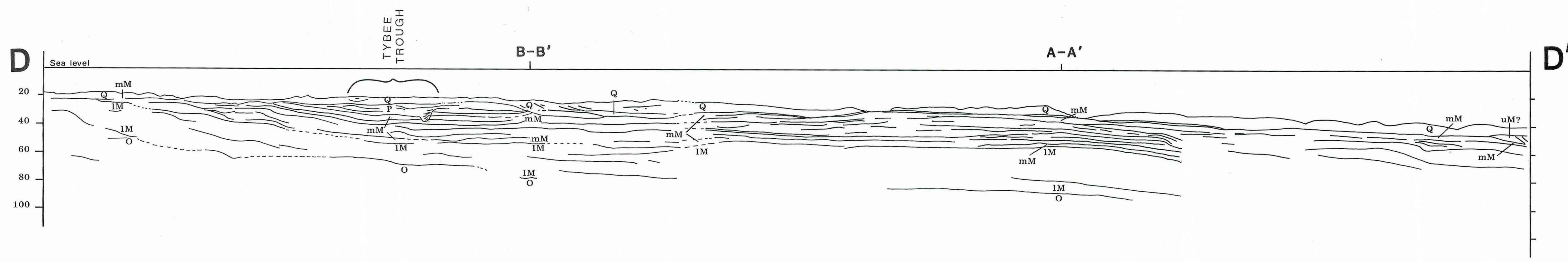
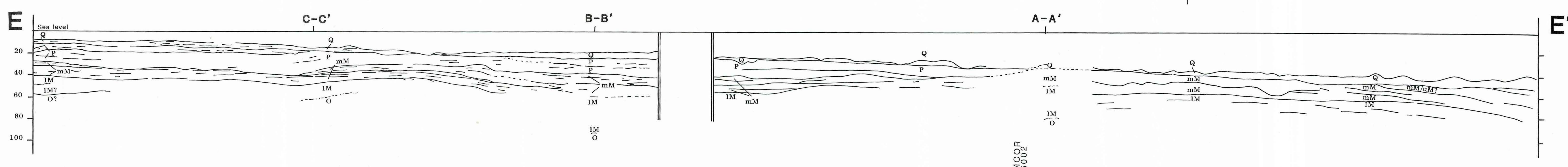


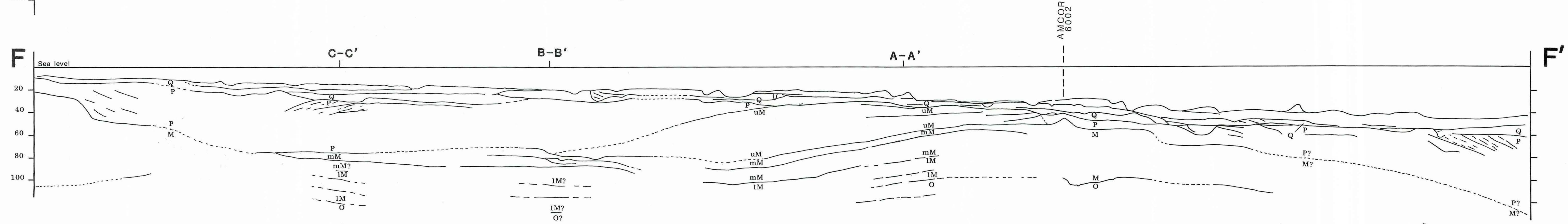
VERTICAL SCALE GREATLY EXAGGERATED
VERTICAL SCALE IN METERS

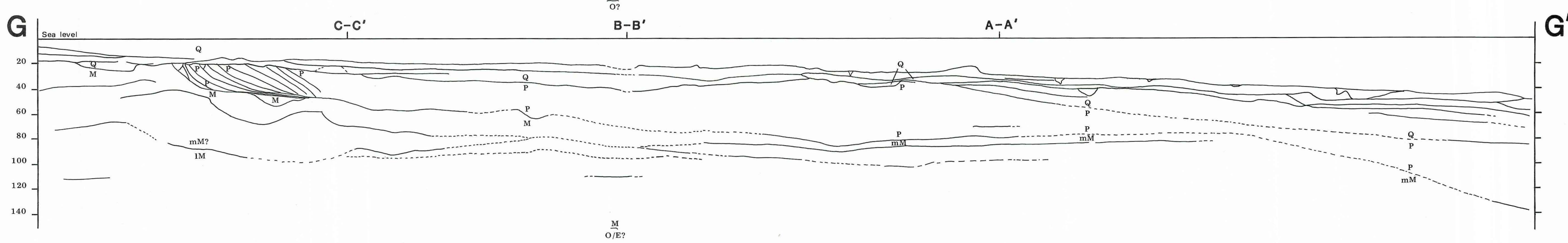
DATUM IS MEAN SEA LEVEL



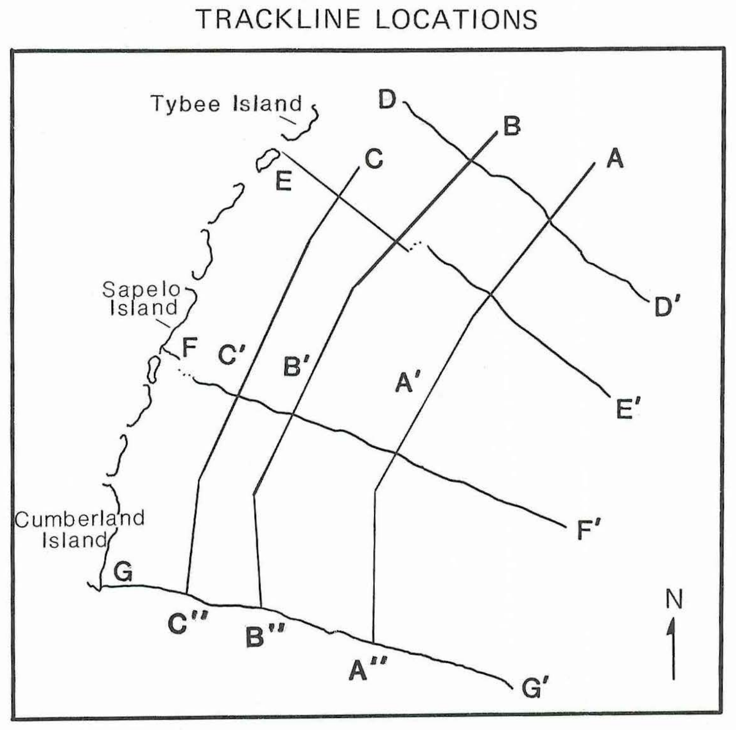




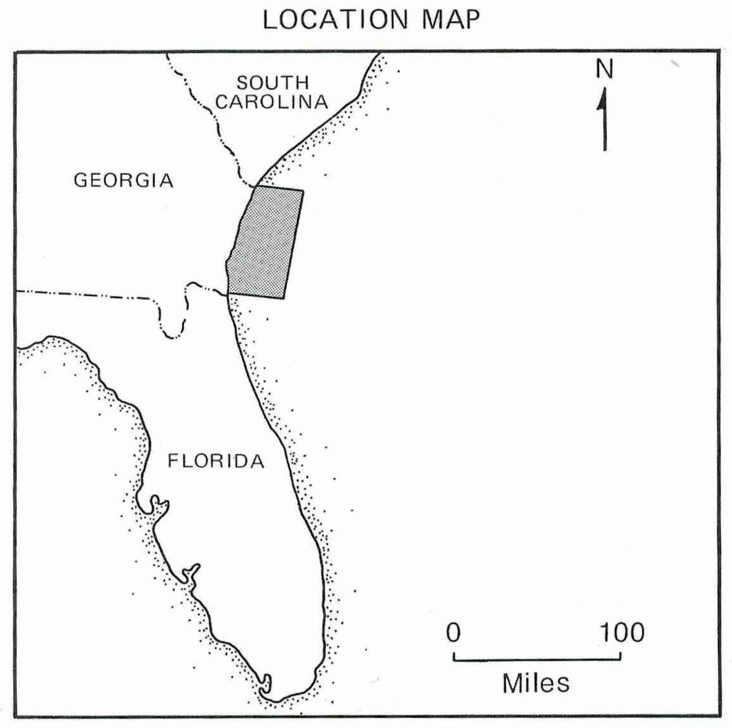




TRACKLINE LOCATIONS



LOCATION MAP



VERTICAL SCALE GREATLY EXAGGERATED
VERTICAL SCALE IN METERS

DATUM IS MEAN SEA LEVEL

STRUCTURE-CONTOUR MAP of the TOP OF THE OLIGOCENE-AGE SEDIMENTS

This plate presents structure-contours on the top of the Oligocene sediments on the continental shelf of Georgia. This surface is important in that it gives an indication of the top of the aquifer underlying the phosphoritic zone. It is recognized that the Principal Artesian Aquifer of the Coastal Plain is a complex system of sediments ranging in age from Eocene to Miocene. At this time, data are insufficient to precisely locate fresh water-bearing strata under the continental shelf. The elevation of the top of the Oligocene gives a reasonable indication of the relationship of the potential aquifer system to the Middle Miocene phosphorite-bearing zone.

In the northern portion of the study area, the top of the Oligocene reflector correlates with the top of the Lazaretto Creek Formation (Huddlestun, in press), a sandy limestone/calcareous sand identified in the Georgia Geologic Survey test well on Skidaway Island, and in the Savannah Light Tower test boring 10 miles east of Tybee Island. To the south, in the AMCOR 6002, J.O.I.D.E.S. J-1, and COST GE-1 test holes, Oligocene-aged sediment is an argillaceous, calcareous "ooze" which correlates with the Cooper Marl, with little potential as an aquifer. In the southwest portion of the study area, the Oligocene is absent. The Ocala Limestone is directly overlain by the lower Miocene Parachucla Formation. The base of the Parachucla Formation in this region is composed of interlayered terrigenous clay and limestone/marl.

The regional "structure" is reflected in the structure-contour map of the "top of the Oligocene", with the Beaufort Arch along the coast, the "Middle Shelf High" and the Mid Shelf Low and Outer Shelf High. The "Mid Shelf Low" and "Outer Shelf High" referred to by Foley (1981) appear to be components of the Eocene-age Suwannee Channel proposed by Pinet and Popenoe (1985). On this plate, the "Mid Shelf Low" represents Oligocene sediments overlying the inlet axis of the channel, while the "Outer Shelf High" represents those overlying the northern flank as described by Popenoe (1985). Some evidence of the erosional nature of the late Oligocene/early Miocene hiatus can be seen. On seismic sections (Plates 3 and 4), the erosion surface often shows a hummocky character of a scale too small to be defined on this map. Several depressions interpreted as being karstic in nature (Kellam, 1981) are seen in the northern portion of the study area.

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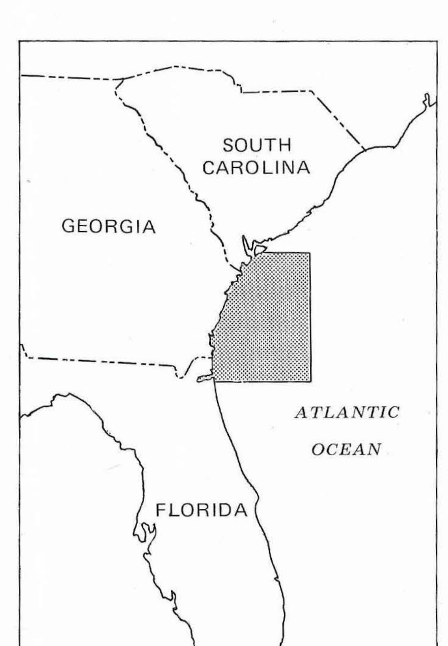
EXPLANATION

75 —— Structure Contour — Shows line of elevation below mean sea level of erosion surface of Oligocene-age sediments. Contour interval is 5 meters. Dashed where approximate. Datum is mean sea level.

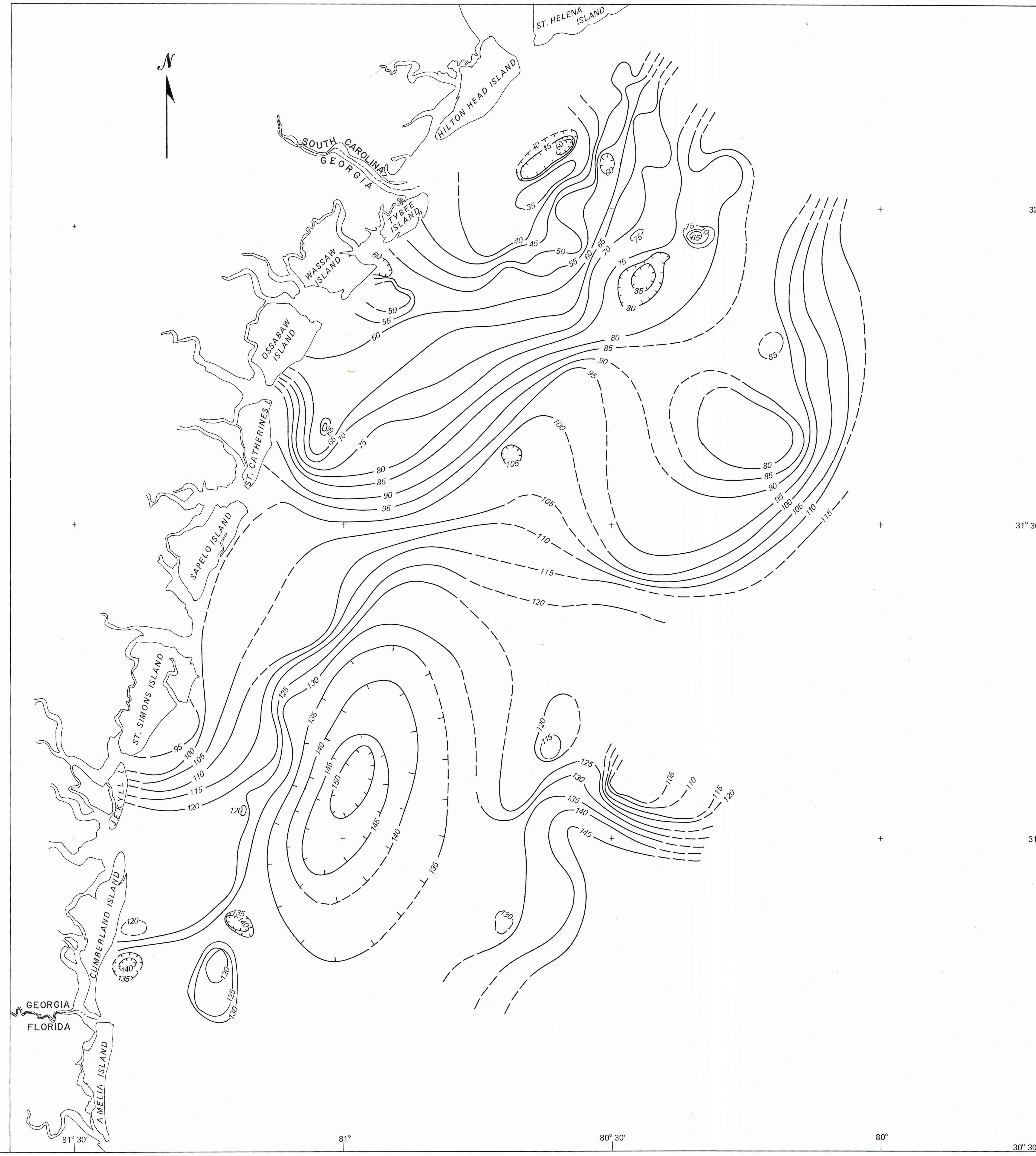
SCALE 1:449,659

0 5 10 Nautical miles



STUDY AREA LOCATION

Base from National Oceanic and Atmospheric Administration Charleston Light to Cape Canaveral navigation map, 1984



STRUCTURE–CONTOUR MAP of the BASE OF THE MIDDLE MIOCENE-AGE SEDIMENTS

This plate presents structure-contours of the base of the middle Miocene Coosawhatchie Formation on the continental shelf of Georgia. The basal unit of the Coosawhatchie Formation in the coastal area, recently given the name "Tybee Phosphorite Member" by Huddlestun (in press), contains considerable phosphorite. According to Huddlestun (in press), the Tybee Phosphorite Member averages 20 feet in thickness in coastal Chatham County with a thickness of 33 feet under southern Tybee Island. This unit thins to 1-2 feet in northwestern Chatham County. It is about 7.5 feet thick in coastal Bryan County and 9 feet thick in the G.G.S. 3426 core on Cumberland Island. The phosphorite has been reported, in a similar thickness (about 30 ft.) to that under Tybee Island, in the Savannah Light Tower test hole (McCollum and Herrick, 1964).

A subsurface feature of potential interest in the development of the phosphorite resource occurs east of the Savannah Light Tower. This feature is the Tybee Trough. Believed to be the buried remnant of a barrier island/tidal inlet complex, the Tybee Trough is manifested in the subsurface as a cluster of channels cutting middle Miocene sediments (Kellam, 1981). Seismic evidence of cut-and-fill and other complex fill structures could represent winnowing and concentration of phosphatic material. Some of these channels are as much as 120-130 feet deep. On the surface of the middle Miocene, this channeling is evident as a cluster of negative relief features (Plate 7). However, negative features on Plate 6 appear to be inherited from lows on the underlying surface.

As a general trend, the base of the middle Miocene can be seen to deepen southward from a minimum of less than 82 feet adjacent to Tybee Island to a maximum of more than 395 feet in the Mid Shelf Low in the southern portion of the study area.

In the northern portion of the study area, about 20 miles east of the northern end of Tybee Island, a previously unmapped high is defined. Unpublished data obtained from the Georgia State University Geology Program shows an apparently large scale high separated by a saddle from the outer shelf high. At present, a shortage of data in the area and to the north, on the South Carolina shelf, prohibits clarification of the genetic nature of this feature.

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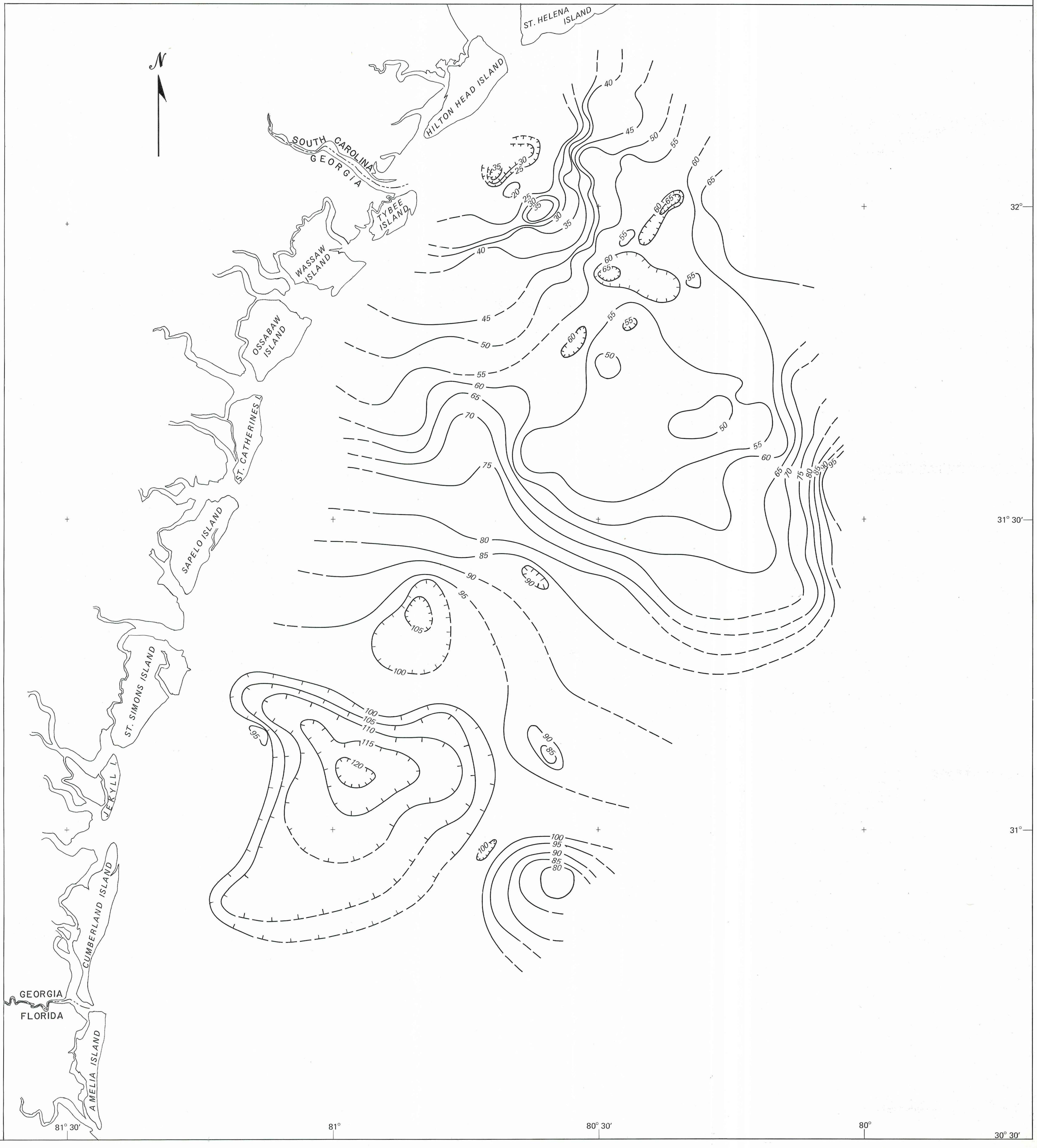
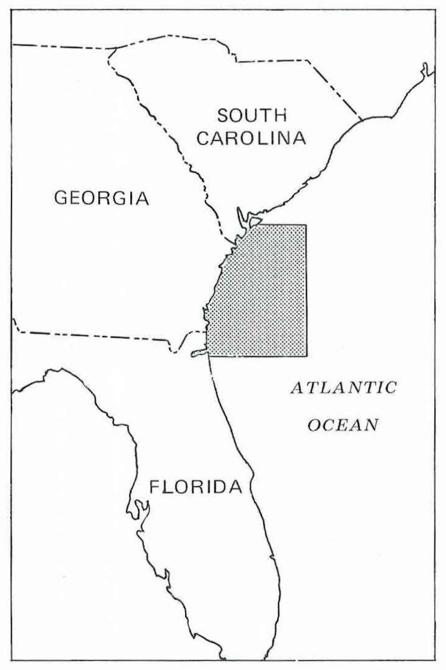


EXPLANATION

85 ▬ Structure Contour — Shows line of equal evaluation below msl of base of middle Miocene-age sediments. Contour interval is 5 meters. Dashed where approximate. Datum is mean sea level.

SCALE 1:449,659

0 5 10 Nautical miles



STUDY AREA LOCATION

Base from National Oceanic and Atmospheric Administration Charleston Light to Cape Canaveral navigation map, 1984

STRUCTURE–CONTOUR MAP of the TOP OF THE MIDDLE MIOCENE–AGE SEDIMENTS

This plate shows structure contours on the upper surface of the Middle Miocene sediments on the continental shelf of Georgia. The Middle Miocene is represented by the Coosawhatchie Formation onshore and on the continental shelf. It consists primarily of phosphatic clay and sand, with clay dominating in the offshore (the Berryville Clay Member), grading to sand landward (Ebenezer Member) (Huddlestun, in press). The formation is phosphatic to varying degrees, but in specific areas and strata, phosphate may be the dominant lithology. The Tybee Phosphorite Member (Huddlestun, in press) is a stratum containing economic grade phosphate, found under portions of the coastal counties and extending under the continental shelf of Georgia.

The Tybee Trough is a subsurface feature of potential interest in the development of the phosphorite resource. The Trough occurs east of the Savannah Light Tower boring. The Tybee Trough is believed to be the buried remnant of a barrier island tidal inlet complex, and is manifested in the subsurface as a cluster of channels cutting middle Miocene sediments (Kellam, 1981). Some of these channels are as much as 120 - 130 feet deep. Due to the spacing of tracklines it is not possible to trace the orientation of these channels. They are evident as a cluster of negative features on the surface of the middle Miocene-aged sediments.

In both Florida and South Carolina phosphorite deposits have been found to occur as concentrations of lag material in channels cut into phosphatic sediments (Riggs and Freas, 1965; Gibson, 1967). Seismic reflectors interpreted as showing cut-and-fill and other complex fill structures are seen in the Tybee Trough area seismic lines. These features could be composed of reworked concentrations of phosphatic material winnowed from older Miocene phosphatic sediments.

The extensive erosion occurring after the deposition of the Coosawhatchie Formation is evident as an irregular "hummocky" reflector, representing the top of the Middle Miocene. Additionally, evidence of erosion is seen in the truncation of internal reflectors. This erosion also is evidenced by the absence of Middle Miocene deposits on the nose of the Beaufort Arch in the northwestern corner of the study area. The southwestern portion of the mapped area contains an erosional scarp of relatively high relief cut into the middle Miocene-age strata (Foley, 1981). The scarp in turn is bisected by a large re-entrant east of St. Simons Island. This re-entrant, which connects with the Mid Shelf Low, is believed by Foley (1981) to be the channel of the ancestral Altamaha River.

In addition to the shore-parallel limb of the Beaufort Arch, a subtle high can be seen, passing through the Tybee Trough area. The other significant feature with positive relief seen on the structure-contours of the middle Miocene is the "Outer Shelf High", parallel to and seaward of the "Mid Shelf Low".

Following the trend of underlying Tertiary sediments, the middle Miocene sediments plunge to the east and southeast, with a rapid "break" in the southeastern corner of the mapped area. The top of the middle Miocene ranges in depth from less than 66 feet in the northwest, to 330 feet in the Mid Shelf Low, to greater than 510 feet in the extreme southeast. In approximately the northern third of the area mapped, the middle Miocene is directly overlain by a veneer of Quaternary sediments, but in isolated areas appears on seismic sections to crop out. South of a line running approximately east of Ossabaw Sound, middle Miocene strata plunge to the south and are onlapped by Pliocene-aged strata as much as 265 feet thick (in the Mid Shelf Low).

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EXPLANATION

70 —— Structure Contour — Shows line of equal elevation below mean sea level of erosion surface of middle Miocene-age sediments. Contour interval is 5 meters. Dashed where approximate. Datum is mean sea level.

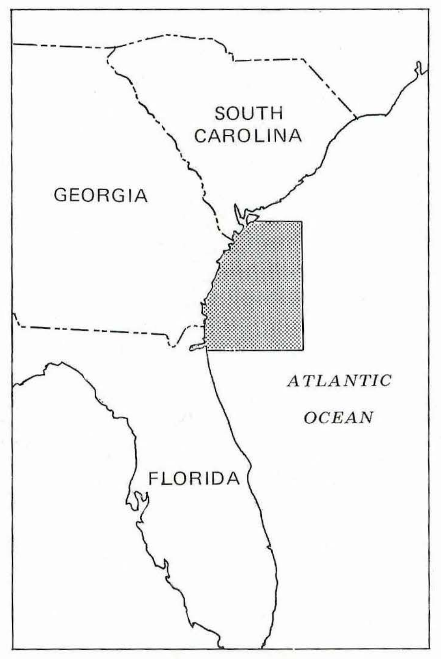
No middle Miocene present

Middle Miocene thickness reduced by channeling. Boundaries are approximate.

Outcrop — Seismic data indicates apparent outcrop on sea floor of middle Miocene.

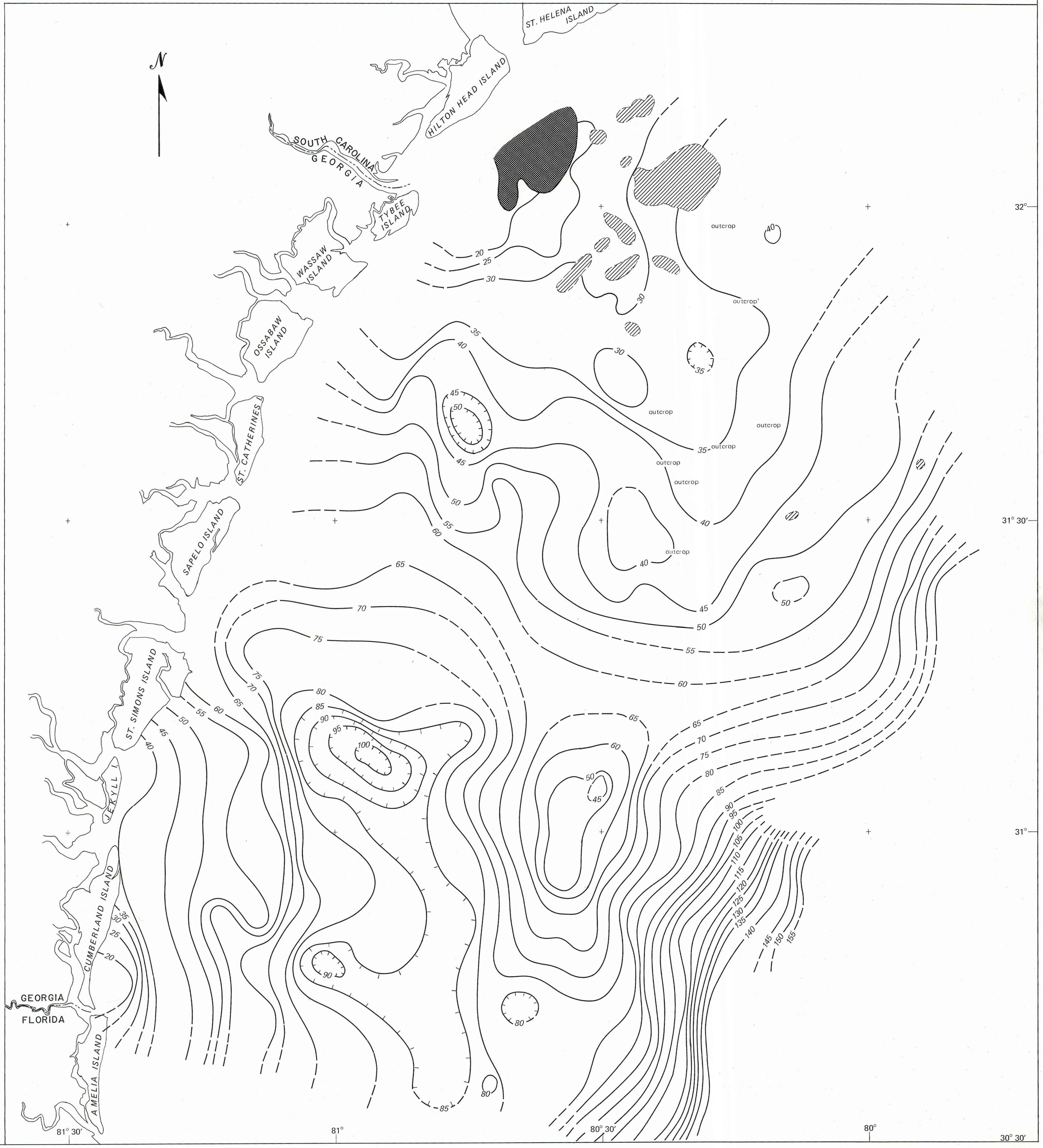
SCALE 1:449,659

0 5 10 Nautical miles



STUDY AREA LOCATION

Base from National Oceanic and Atmospheric Administration Charleston Light to Cape Canaveral navigation map, 1984



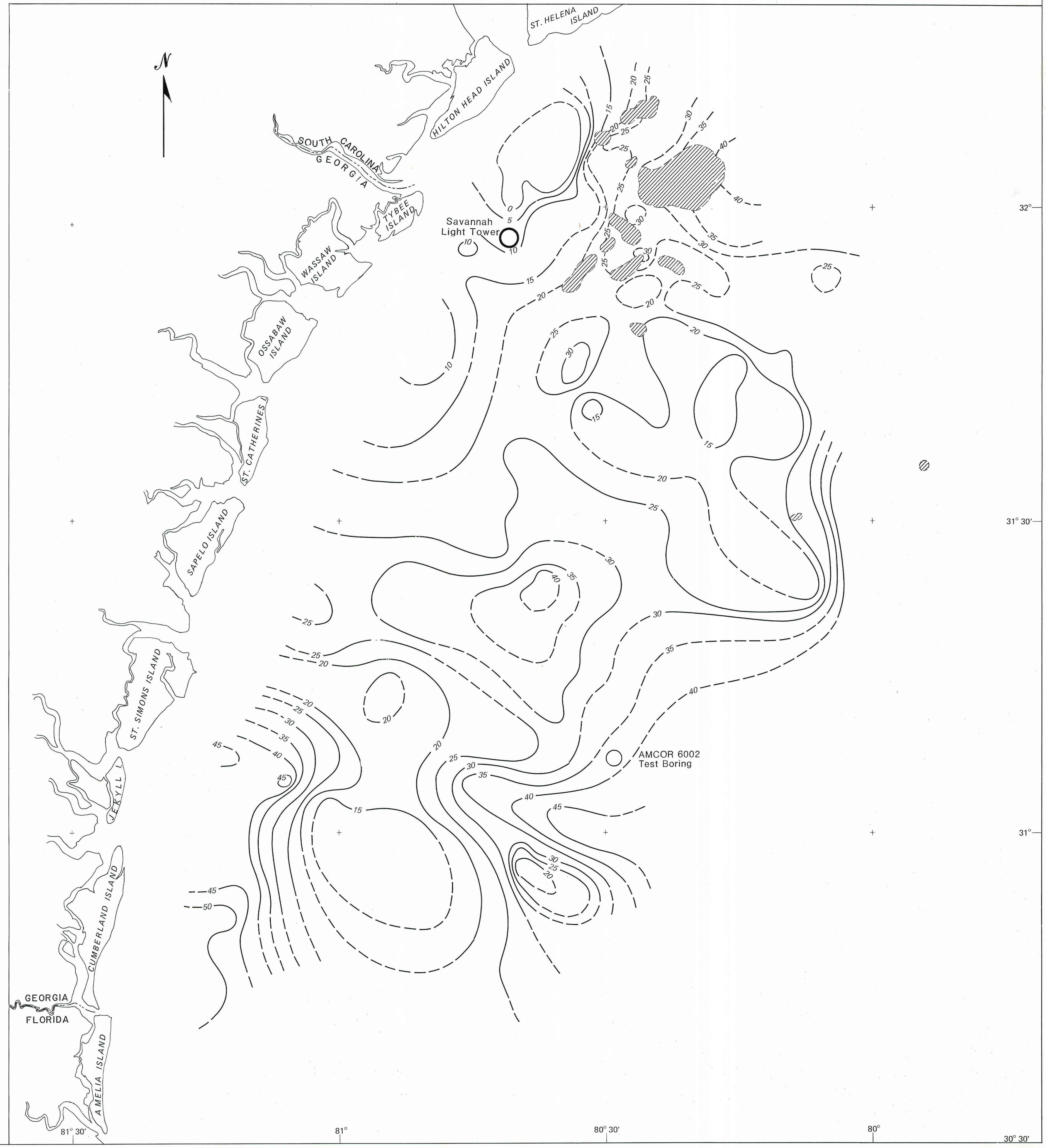
ISOPACH MAP
of the
MIDDLE MIOCENE-AGE SEDIMENTS

This plate represents the thickness of the middle Miocene (Coosawhatchie Formation) on the continental shelf of Georgia. The middle Miocene consists primarily of phosphatic sands and clays of the Coosawhatchie Formation with clay (Berryville Clay Member) dominating offshore and grading shoreward into the predominantly sandy Ebenezer Member (Huddlestun, in press). The overlying Berryville Clay Member averages about 50 feet under Tybee Island. The Tybee Phosphorite Member, the basal unit of the Middle Miocene in the coastal area, reaches a maximum thickness of 33 feet under Tybee Island. The Tybee Phosphorite Member averages 20 feet thick in eastern Chatham County and is present in varying amounts in borings along coastal Georgia, including 7.5 feet in Bryan County and 9 feet in the G.G.S. 3426 well on Cumberland Island. The Berryville and Tybee Phosphorite Members are present in thicknesses similar to eastern Chatham County in the Savannah Light Tower test hole 10 miles east of Tybee Island. At a correlative stratigraphic position in the three southern borings (J.O.I.D.E.S. J-1, COST GE-1, and AMCOR 6002) lithologies are described as phosphatic in varying amounts but no actual phosphorite zone is present.

The Tybee Phosphorite Member cannot be resolved as a definite series of reflectors on seismic sections, either as a result of its relative thinness or due to its compositional similarity to adjacent strata. Also, because of the scarcity of lithologic data on the continental shelf, it is not possible to estimate the areal extent or thickness of the phosphorite unit at present. Available lithologic evidence does suggest a limit of the possible extent to the north and west of a line between the J.O.I.D.E.S. J-1 and AMCOR 6002 borings.

The Middle Miocene sediments on the continental shelf range in thickness from 0 to greater than 175 feet. Discounting the effects of erosion, the middle Miocene thickens to the east and south. It is completely planed off the Beaufort Arch in the north and thins on the crest of the "Outer Shelf High". Effects of extensive erosion can be seen in the southwest portion of the study area, with the "Mid Shelf Low" bordered on the west by a prominent erosional scarp (Foley, 1981).

In the northern portion of the study area, east of Tybee Island, a cluster of negative structures can be seen which are channeled features in the Middle Miocene (cross section D-D′, Plate 4). These are interpreted by Kellam (1981) to represent the remnant of a barrier island/tidal inlet complex. These channels, some as much as 120-130 feet deep, are potential sites for the deposition of winnowed and concentrated phosphate material.



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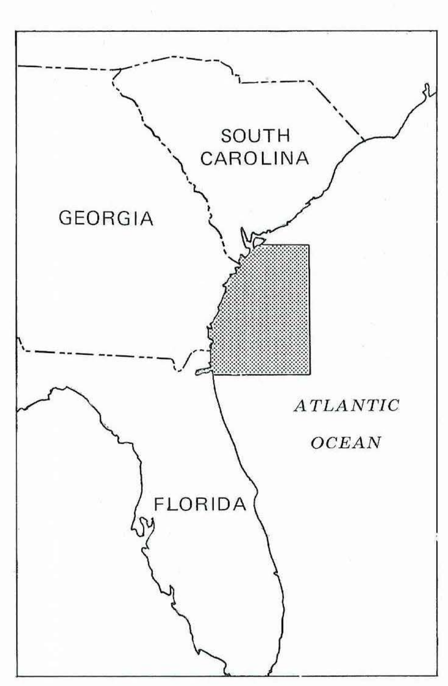
EXPLANATION

15 —— Line of Equal Thickness — Shows thickness of middle Miocene-age sediments. Contour interval 5 meters. Dashed where approximate.

Middle Miocene thickness reduced by channeling. Boundaries approximate.

SCALE 1:449,659

0 5 10 Nautical miles



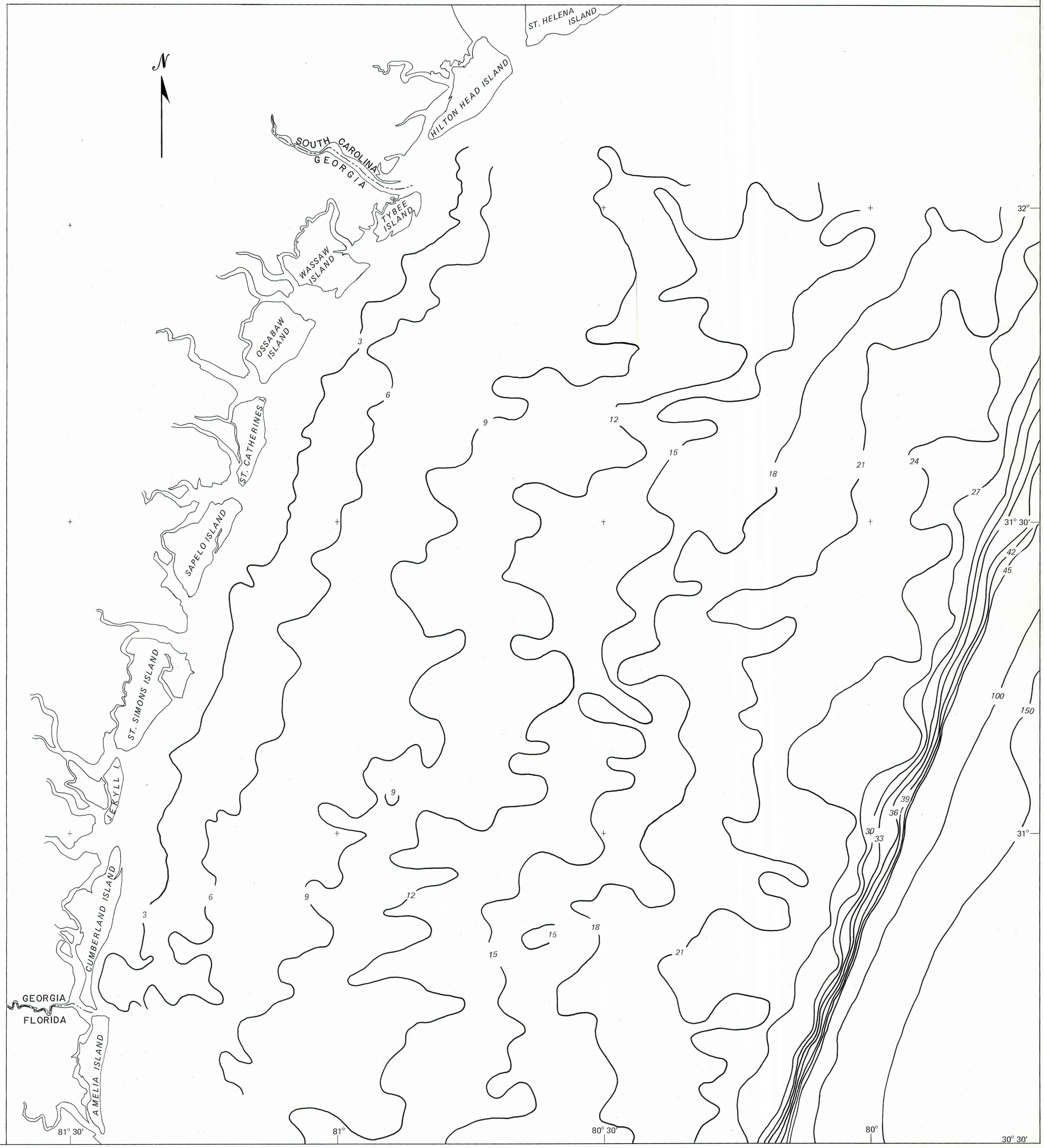
STUDY AREA LOCATION

Base from National Oceanic and Atmospheric Administration Charleston Light to Cape Canaveral navigation map, 1984

BATHYMETRIC SURFACE

The bathymetric surface of the continental shelf of Georgia is generally flat and featureless with a southeastward gradient of 2 ft/mi to the shelf break at about 33 fathoms (200 feet). Topography can best be described as gently undulatory. Low relief features, such as giant sand waves and a ridge and swale topography, are responsible for the sinuous character of the contour lines.

The lithology of the seafloor in the mapped area consists of a veneer of unconsolidated Pleistocene to Recent sediment. Only a few widely dispersed, low relief outcrops exist on the continental shelf of Georgia. These outcrops consist of lithified material of Pliocene and middle Miocene age.

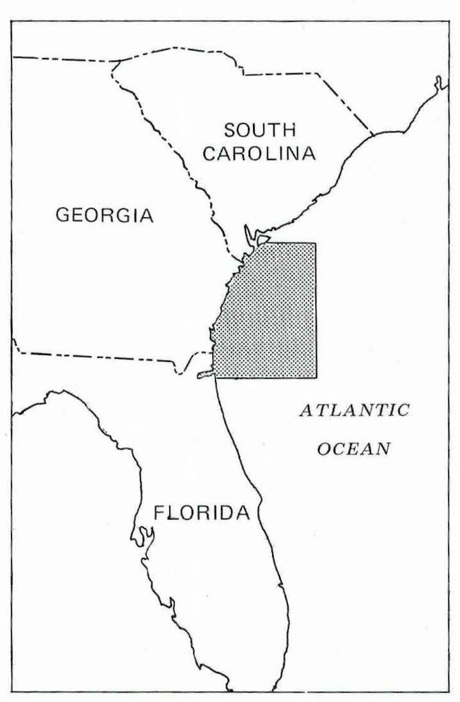


EXPLANATION

21 — Line of equal elevation in fathoms shows bathymetric surface below msl. Datum is mean sea level.

SCALE 1:449,659

0 5 10 Nautical miles



STUDY AREA LOCATION

SOURCE

National Oceanic and Atmospheric Administration, 1984, Charleston Light to Cape Canaveral navigation map, 25th edition, scale 1:449-659.

Base from National Oceanic and Atmospheric Administration Charleston Light to Cape Canaveral navigation map, 1984