MIOCENE SEISMIC STRATIGRAPHY, STRUCTURAL FRAMEWORK, AND SEA-LEVEL CYCLICITY: NORTH CAROLINA CONTINENTAL SHELF

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ABSTRACT

Preliminary interpretations of over 1000 km of high-resolution seismic reflection data, supplemented by over 100 9-m vibracores, have delineated the shallow stratigraphic and structural framework for several Miocene depositional sequences overlying the Carolina Platform in the area of Onslow Bay, North Carolina. Comparison of the observed stratigraphy with published seismic, gravity, magnetic, and core hole data indicates that the distribution, thickness and depositional pattern of each sequence has been controlled by: 1) the regional tectonic framework; 2) several, local structural features; and 3) numerous, relative, sea-level fluctuations.

A broad zone of phosphate-rich, Miocene sediments and rocks crops out at mid-shelf across the northern segment of the Carolina Platform. This outcrop belt trends northeast-southwest, and extends from Frying Pan Shoals off Cape Fear to the middle shelf off Bogue Banks. Older Tertiary and Cretaceous sequences crop out southwest of Frying Pan Shoals owing to the presence of the Cape Fear Arch, a mid-Carolina Platform high. In the vicinity of Bogue Banks, the Miocene sequences abruptly change strike and run parallel to the north-south oriented White Oak Lineament. North of Bogue Banks, the Miocene depositional sequences thin and/or pinch out over the Cape Lookout High, which is presently thought to be a pre-Miocene, erosion-originated paleotopographic feature. In southwestern Onslow Bay the Miocene sequences change strike and thicken along a third local structure, herein referred to as the Cape Fear Monocline. Several shallow Miocene outliers, which are the surficial expression of subbottom "flexures," were also identified in this area. These structures are deformational in origin, and may be a consequence of differential movement along deep-seated structures within the Carolina Platform.

The Miocene depositional sequences and associated unconformities indicate several cycles of relative sea-level change. Comparison of the Miocene relative sea-level cyclicity with the proposed global eustatic sea-level curve of Vail and others (1977) depicts a potentially strong correlation. However, the present lack of high-resolution biostratigraphic data precludes exact correlations.

INTRODUCTION

This paper presents a brief sketch of the Miocene structural and stratigraphic framework for the Onslow Bay Embayment of the North Carolina continental shelf (Fig. 1) as defined by the preliminary results of an ongoing high-resolution seismic survey. We have identified several local structures which separate this portion of the Carolina Platform into a series of Neogene depositional basins. Basin geometries, infilling histories, as well as regional and local deformation events, have been defined by correlating the seismic data to vibracore (Meisburger, 1979; Lewis and others, this issue) and existing drill hole data on the lower North Carolina Coastal Plain.

Seismic sequence analyses (Mitchum and others, 1977) was used to identify several distinct depositional sequences within the study area. Each depositional sequence is a package of concordant reflectors and represents a given interval of geologic time as defined by the sequence boundaries (Vail and others, 1977). The boundaries in this case are basin-wide unconformities that can be readily identified by onlap, toplap, and downlap relationships. The majority of these depositional sequences were found to be Miocene in age.

Comparison of the observed stratigraphy with published seismic, magnetic, gravity, and drill hole data suggests the distribution, thickness and depositional patterns for each Miocene sequence have been dictated by: 1) the regional tectonic framework; 2) several, local structural elements; and 3) numerous, relative, sea-level fluctuations.

METHODS

The interpretations presented here are the preliminary results of a comprehensive, single-channel, high frequency, high-resolution seismic survey of Onslow Bay, North Carolina (Fig. 1). This survey includes approximately 1200 km of sparker profiles (200 Hz -5 kHz), over 1000 km of uniboom profiles (300 Hz -15 kHz), and over 2500 km of 3.5 kHz profiles. Most of the seismic data were collected on the inner and middle shelf between Cape Fear and Cape Lookout. However, a number of seismic

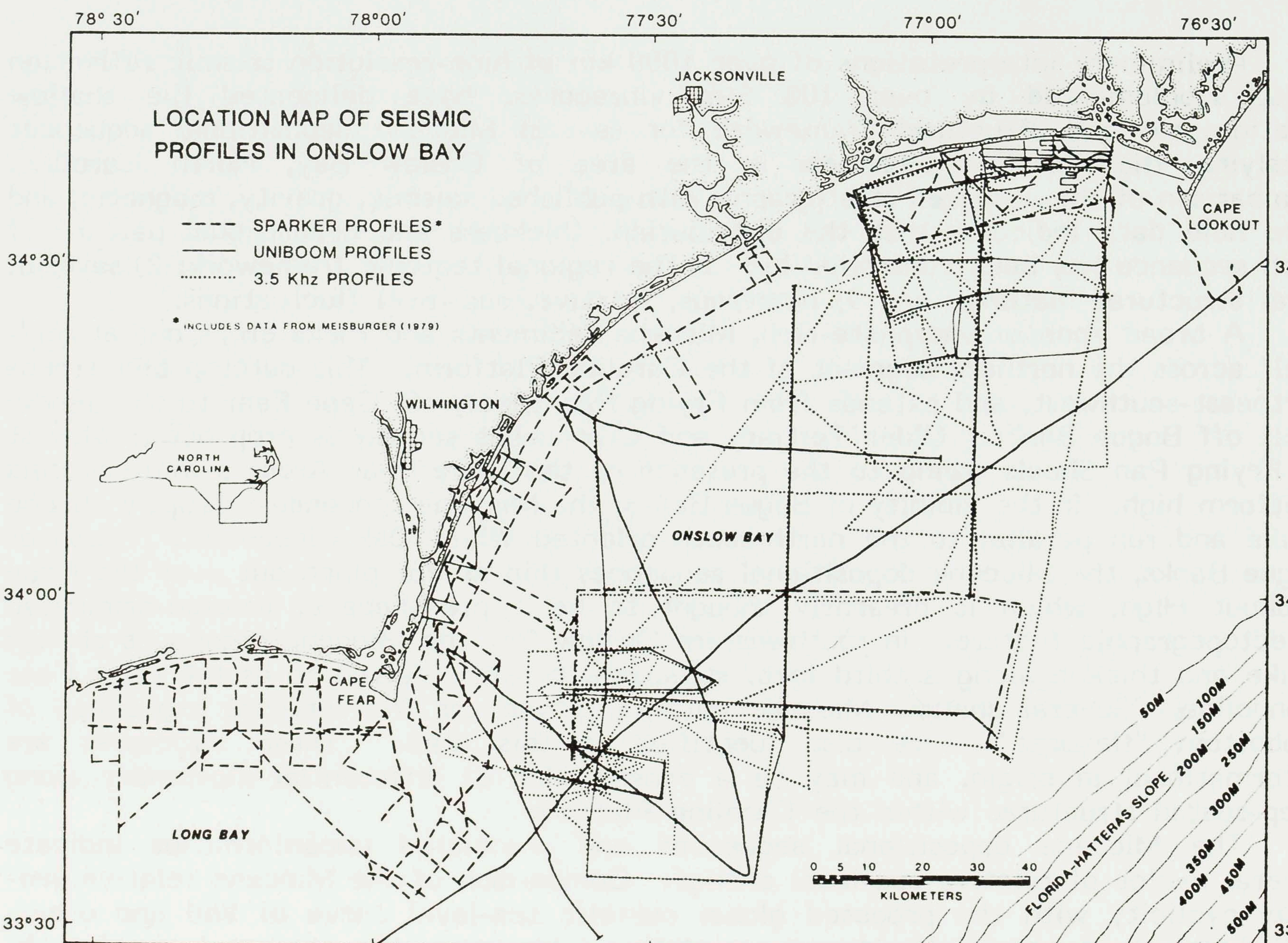

Figure 1. Location of high-resolution seismic reflection profile tracks.

lines were run through the back-barrier lagoons and estuaries in the vicinity of Cape Lookout, where an abundance of drill and core hold data were available for stratigraphic control. These seismic lines were carried out onto the shelf for chronostratigraphic correlations. Over 100 vibracores (Lewis and others, 1982) have provided a check for our stratigraphic correlations as well as determination of lithologic facies.

Most profiles have been graphically reduced to stratigraphic sections (line-drawings) with a vertical exaggeration of 90:1 or 100:1. The approximate vertical scale for each section was determined using a seismic velocity of 1500 m/sec in water and 1695 m/sec in the subsurface (13 percent increase).

REGIONAL TECTONIC FRAMEWORK

Carolina Platform

Onslow Bay is located on the Carolina Platform, which is a major tectonic component of the trailing-edge continental margin of North America (Fig. 2). The platform proper is a broad region of shallow pre-Jurassic continental crust, which extends from the Florida Platform to the Baltimore Canyon Trough (Klitgord and Behrendt, 1979; Fig. 2). The Brunswick Magnetic Anomaly (Taylor and others, 1968) marks the seaward limit of the platform where the overlying wedge of Mesozoic and Cenozoic sediments thicken abruptly from generally less than 2 km to over 10 km in the Carolina Trough (Sheridan, 1974a; Grow and Markl, 1977; Paull and Dillon, 1980; Klitgord and Behrendt, 1979).

The Carolina Platform is the dominant structural feature governing the post-rift evolution of this part of the margin (Klitgord and Behrendt, 1979). A southwest to northeast transect across the present inner shelf of the Carolina Platform (Fig. 2) depicts three regional segments separated by the Cape Fear Arch, a mid-platform topographic high. Each regional segment displays relatively distinct Mesozoic-Cenozoic depositional histories.

Southern Carolina Platform

The Carolina Platform descends south of Cape Romain, South Carolina, forming the northeastern limb of the Southeast Georgia Embayment. Here, the platform is broken into a series of basins of probable Triassic age (Fig. 2; Marine and Siple, 1974; Popenoe and Zietz, 1977; Popenoe, 1977; Dillon and others, 1979; Buffler and others, 1979). A prominent seismic reflector, previously thought to be the top of the crystalline basement (Antoine and Henry, 1965; Sheridan and others, 1966; Dowling and others, 1968; Emery and others, 1970; Sheridan, 1974a), has recently been interpreted as an extensive Late Triassic (?) or Early Jurassic (?) volcanic layer overlying both the crystalline crust and Triassic rift-basins (Fig. 2; Dillon and others, 1979). The top of this reflector forms a relatively smooth, erosional topographic surface, and underlies the Southeast Georgia Embayment which has been filled with over 2.5 km of Mesozoic-Cenozoic sediments (Shipley and others, 1978; Poag and Hall, 1979; Dillon and others, 1979; Paull and Dillon, 1980).

Northern Carolina Platform

East of Cape Lookout, North Carolina, the overlying wedge of post-Triassic sedimentary sequences thickens abruptly as the Carolina Platform descends into the marginal Mesozoic basin of the Carolina Trough (Fig. 2). Here, the Carolina Platform is thought to consist of a series of fault blocks bound by rift-originated, normal faults (Sheridan, 1974a). Over 3 km of coastal plain sediments were drilled at Cape Hatteras (Maher, 1965; Brown and others, 1972) where the coastline is proximal to the seaward edge of the Carolina Platform.

Central Carolina Platform

As illustrated in Figure 2, the Central Carolina Platform is relatively flat and

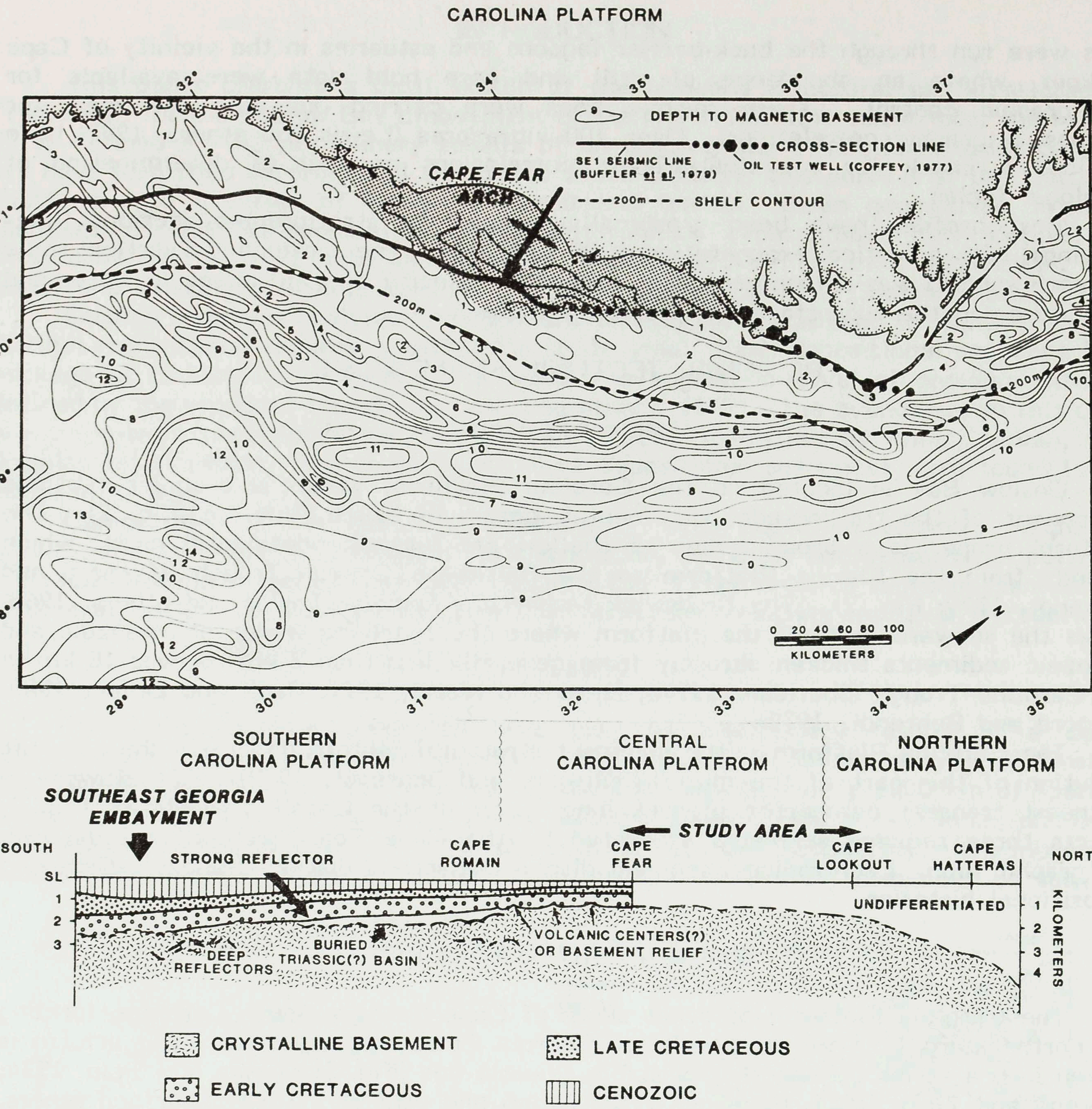

Figure 2. Regional subdivision of the Carolina Platform. Magnetic basement map from Klitgord and Behrendt (1979); SE-1 seismic line and interpretations from Buffler and others (1979).

shallow (< 1 km). The shallowest segment of the Platform is located in the vicinity of Cape Fear, North Carolina, and has been traditionally recognized as the Cape Fear Arch (Stephenson, 1923; McCarthy, 1936; Mansfield, 1937; Richards, 1945, 1974; Straley and Richards, 1950; Maher, 1965; Baum and others, 1978). It is becoming clear from magnetic depth analyses (Klitgord and Behrendt, 1979), CDP seismic analyses (Dillon and others, 1979) and mapping of the basement surface from well data onshore (Brown and others, 1972; Popenoe and Zietz, 1977) that the Cape Fear Arch is not a discrete anticlinal structure as first described by Stephenson (1923), but rather a broad mid-platform high consisting of very shallow continental crust extending from Cape Romain, South Carolina, to Cape Lookout, North Carolina (Fig. 2).

No known major fracture zones or Triassic basins exist within this segment of the Carolina Platform. However, recent seismic investigations by Dillon and others (1979) and Buffler and others (1979) have identified several low-relief basement topographic features between Cape Romain, South Carolina, and Cape Fear, North Carolina (Fig. 2). These features coincide with several concentric magnetic anomalies, and are presently thought to be the volcanic centers for the extensive Early Jurassic (?) volcanic layer covering the southern segment of the Carolina Platform.

Our seismic survey was conducted on the shallow central portion of the Carolina

Platform, overlying the northeast limb of the mid-platform high of the Cape Fear Arch (Fig. 2). Unlike the adjacent northern and southern segments, this portion of the Platform is overlain by a relatively thin (<1 km) cover of Mesozoic-Cenozoic sediments. Interpretations of the seismic data, supplemented by the magnetic survey and magnetic depth analyses of Klitgord and Behrendt (1979), suggest that recurrent movement along subtle, local basement structures has been translated through the relatively thin overlying stratigraphic sequences. These tectonic events have, in part, regulated the depositional patterns and infilling histories of the basins that formed, particularly in the Miocene.

STRATIGRAPHIC AND STRUCTURAL FRAMEWORK

Analysis of the seismic data from Onslow Bay depicts several, discrete depositional sequences. Each sequence and its associated unconformities were correlated with existing drill and core hole data on the adjacent emerged lower North Carolina Coastal Plain for stratigraphic control. Chronostratigraphic correlations were subsequently checked by a series of vibracores collected along the seismic lines (Lewis and others, 1982). The stratigraphic correlations and subdivision of the Onslow Bay depositional sequences are illustrated in Table 1.

The general distribution of the southeastern North Carolina depositional sequences has been controlled by the morphology of the Carolina Platform. These sequences form a northeast-southwest band of successively younger, onlapping stratigraphic units which closely parallel the regional strike of the basement. However, several local structures identified via seismic profiling have strongly influenced the local distribution and thickness of the Onslow Bay sequences, particularly in the Miocene. Three of these structures form the boundaries for three Miocene depocenters (Fig. 3), herein referred to as: 1) the Aurora Embayment; 2) the Northeast Onslow Bay Embayment; and 3) the Frying Pan Shoals Embayment.

Table 1. Stratigraphic and subdivision of Onslow Bay depositional sequences and correlations with lower North Carolina Coastal Plain Tertiary formations.

UNCONFORMITY	DEPOSITIONAL SEQUENCE	PROBABLE CORRELATIVE FORMATION
	Q_u	QUATERNARY SEQUENCES UNDIFFERENTIATED
δ_1		
	P_y-B	PLIOCENE YORKTOWN FM
γ_2		
	P_y-A	
γ_1		
	M_{pr}-E	MIOCENE PUNGO RIVER FM
β_6		
	M_{pr}-D	
β_5		
	M_{pr}-C	
β_4		
	M_{pr}-B	
β_3		
	M_{pr}-A	
β_2		
	M_s	LOWER MIOCENE SILVERDALE FM
β_1		
	O_b	UPPER OLIGOCENE BELGRADE FM

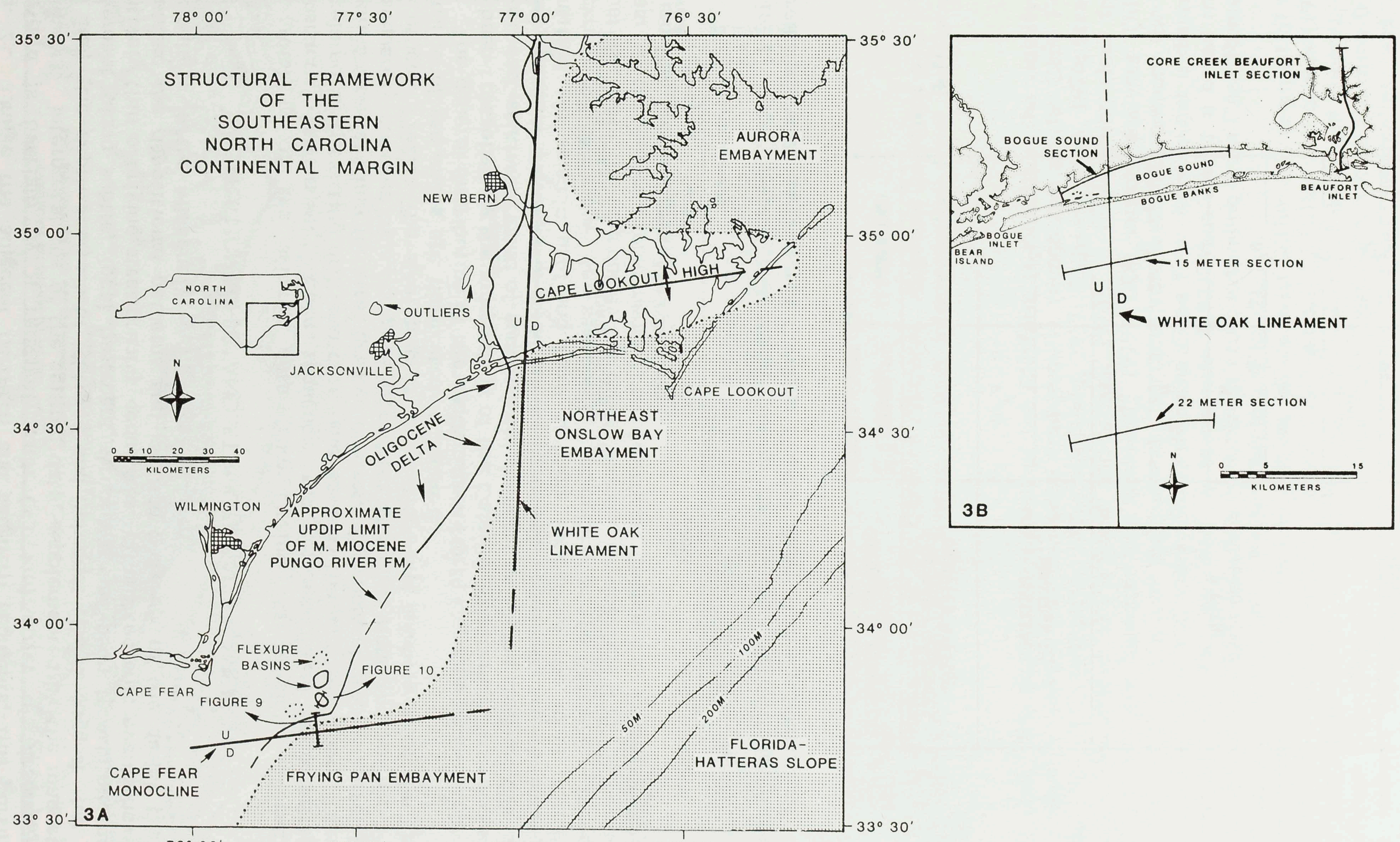

Figure 3. *A) Structural framework of the upper southeastern North Carolina continental margin. B) Location of interpreted seismic profiles discussed in text (Figures 5, 6, 7, and 8).*

Oligocene Delta

Vibracore and seismic data depict a broad outcrop belt of phosphate-rich Miocene rocks and sediments on the middle to inner shelf of Onslow Bay. The updip limit of these Miocene sequences parallels the seaward limit of an Oligocene depositional package characterized by a series of prograding clinoforms (Fig. 3). Vibracores have identified this depositional unit as a fine quartz arenite to calcarenite (Meisburger, 1979; Lewis and others, 1982). Faunal analysis suggests this unit is Oligocene in age (Meisburger, 1979). Seismic data depict a series of clinoforms prograding out in a radial fashion from a central point located in the vicinity of New River, North Carolina (see Meisburger, 1979). The distribution, lithology, internal structure, and overall geometries suggest this depositional unit is deltaic in origin. This interpretation agrees with the earlier work of Lawrence (1975) who recognized the existence of a late Oligocene-deltaic system in the adjacent emerged coastal plain from paleoecological and paleoenvironmental investigations of *Crassostrea gigantissima*. This depositional structure has, in part, controlled the local outcrop pattern of the Miocene sequences in central Onslow Bay as illustrated in Figure 3.

White Oak Lineament

The Miocene sequences of the Pungo River Formation thicken abruptly across a generally north-south striking lineament in northeastern Onslow Bay. This structural lineament has been referred to as the White Oak Lineament. Through a series of seismic profiles, we have traced the White Oak Lineament across the shelf from the outermost profile at approximately 76° 50' longitude / 34° 08' latitude to the shallow lagoon behind Bogue Banks (Fig. 3). On the emerged coastal plain north of Bogue Banks, the White Oak Lineament marks the updip outcrop limit of the Pungo River Formation (Fig. 4).

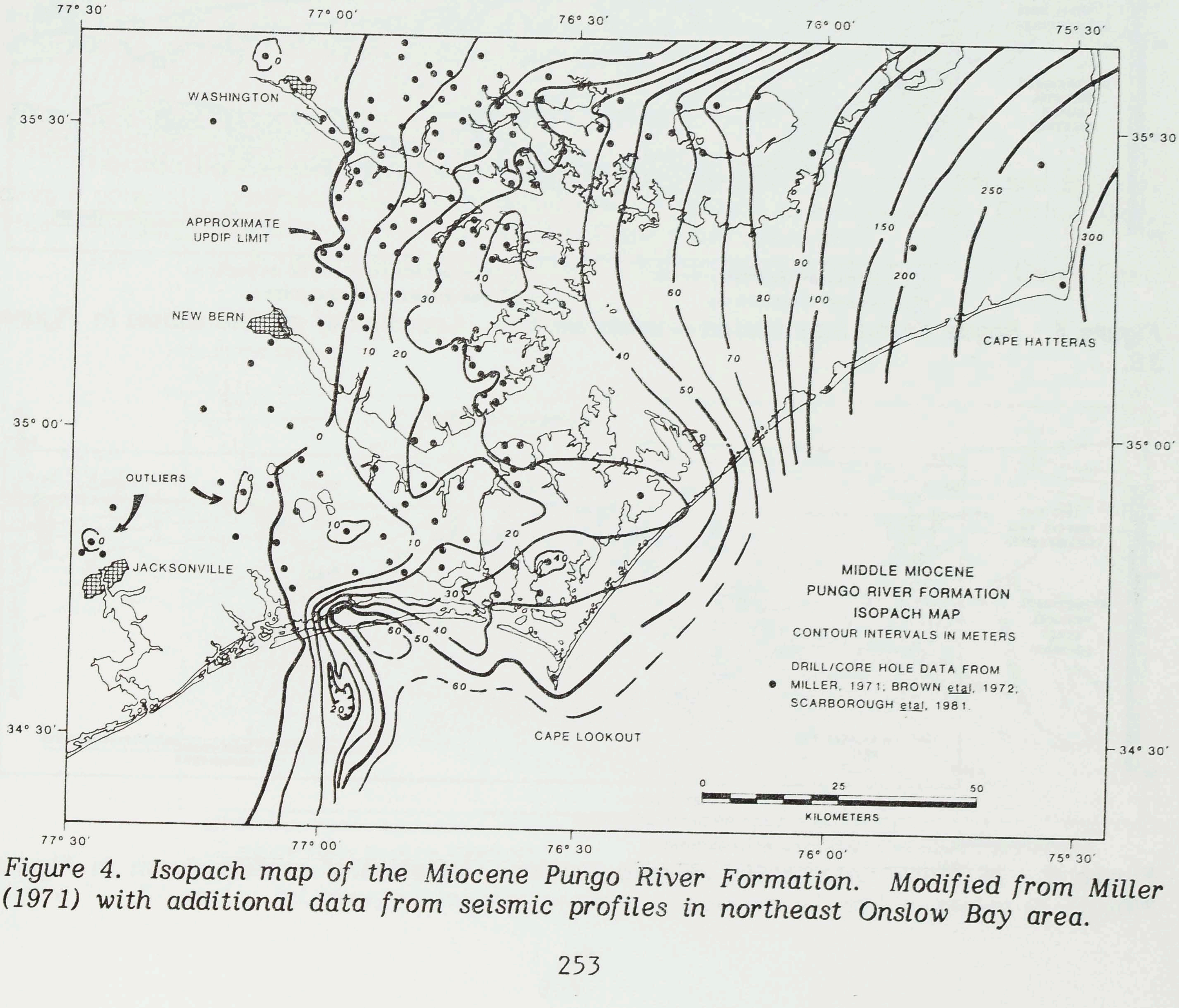

Figure 4. Isopach map of the Miocene Pungo River Formation. Modified from Miller (1971) with additional data from seismic profiles in northeast Onslow Bay area.

This lineament is a broad monoclinal structure in Bogue Sound. Here, the Pungo River Formation thickens from its western updip limit to over 50 meters in less than 6 km of horizontal distance (Fig. 5). This same abrupt eastward thickening of the Pungo River Formation was observed on every profile south of Bogue Banks (i.e., Figs. 6 and 7), and possibly continues south to the shelf-slope break. Figure 7 is a seismic section from the middle shelf where the White Oak Lineament is more dramatically represented by a subbottom scarp with over 25 meters of relief. A series of middle Miocene prograding clinoforms extends eastward from the scarp, and are characteristic of most of the mid-shelf profiles crossing this feature.

The White Oak Lineament closely approximates the orientation and position of several structural elements previously reported in the literature (Spangler, 1950; Miller, 1971; Brown and others, 1972). These structures are described as flexure zones and/or fault zones related to basement tectonics. The White Oak Lineament also coincides with the position of increased basement declivity (Klitgord and Behrendt, 1979; Brown and others, 1972: Plate 5), where the northern segment of the Carolina Platform starts a rapid descent into the Carolina Trough to the east. Sheridan (1974a; 1974b) suggests this segment of the Carolina Platform contains a series of normal faults which originated through a sequence of rift/drift processes (Schneider, 1972; Kinsman, 1975) during the late Triassic-early Jurassic rifting of North America from Africa.

The apparent relative movement, regional extent, local vertical relief, and proximity to a major change in basement slope suggests the White Oak Lineament may be a consequence of recurrent movement along an older, rift-originated (?), normal fault zone. This lineament may be the surficial expression of one in the series of tensional fault systems thought to comprise the northern segment of the Carolina

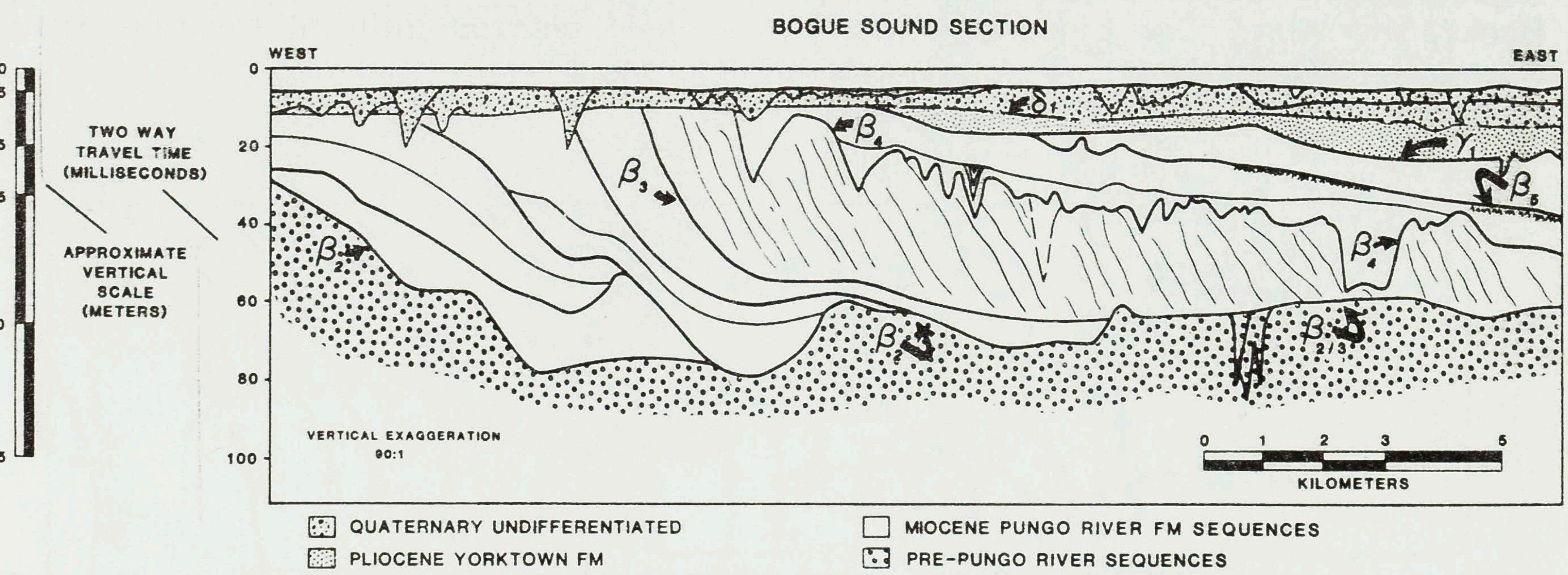

Figure 5. Bogue Sound interpreted seismic section. Location of profile shown in Figure 3B.

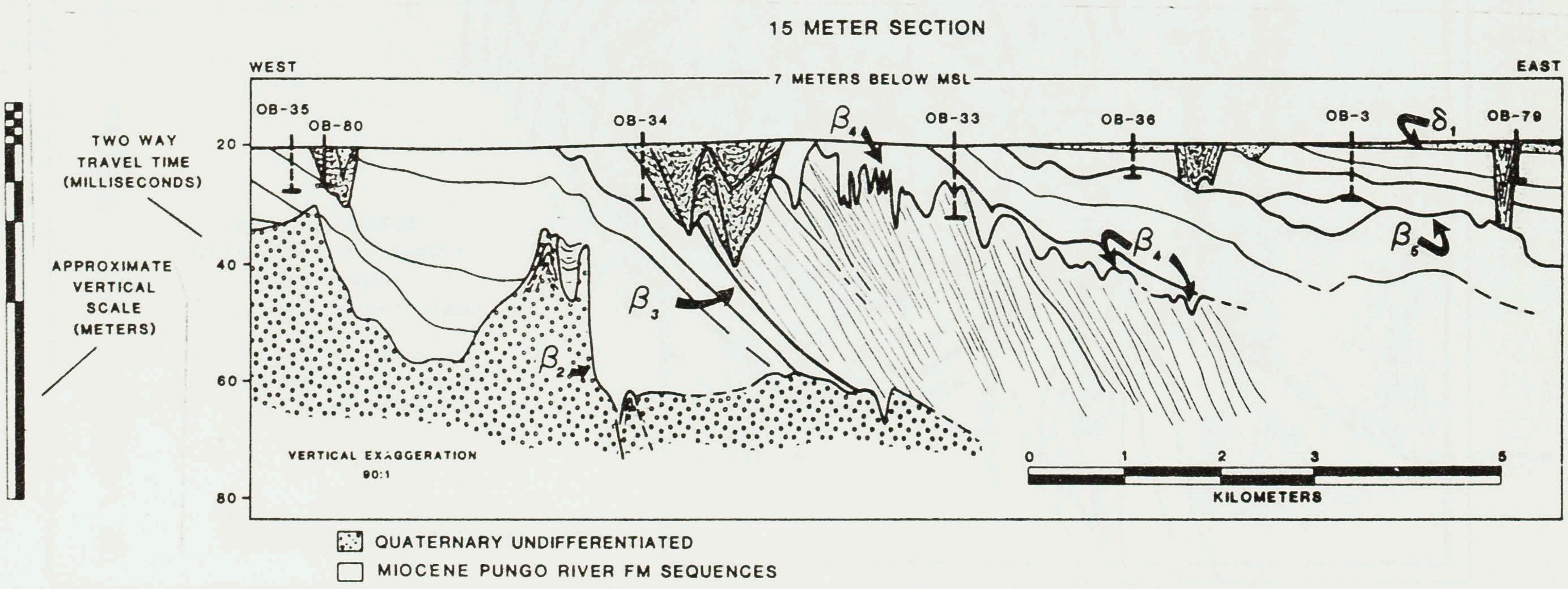

Figure 6. 15 meter interpreted seismic section. Location of profile shown in Figure 3B.

Platform. Down-faulting to the east of the lineament created a large Neogene basin, which is locally broken by the generally east-west striking Cape Lookout High.

Cape Lookout High

A relatively thick sequence of Miocene Pungo River sediments lies beneath Bogue Banks. Figure 8 depicts a northward thinning of this sediment package (bounded by reflectors β_2 and γ_1) from approximately 35 m near Beaufort Inlet to less than 15 m on the emerged coastal plain. This relatively abrupt thinning to the north is the product of an antecedent topographic feature referred to as the Cape Lookout High (Snyder and others, 1980). The axis of this pre-Miocene topographic high lies north of the northern limit of our seismic data. A middle Miocene isopach map (Fig. 4) delineates the general orientation and areal extent of this structure.

Regional stratigraphic studies by Gibson (1967; 1970), Miller (1971) and Riggs (1979) have denoted a similar structural element in this area. Although the location and orientation of their respective structures differ, each investigator demonstrates that a discrete positive structure has controlled the depositional patterns of the Miocene Pungo River Formation. Comparison of a series of Neogene isopach and structural maps (Miller, 1971; Brown and others, 1972), supplemented with our seismic data, suggests this structure was a positive topographic feature preceeding, during and immediately following deposition of the Pungo River Formation, and may be the result of pre-Pungo River differential erosion. This interpretation conforms with the paleoenvironmental interpretations from several detailed lithostratigraphic and biostratigraphic studies of the Pungo River Formation along the Cape Lookout High (Scarborough and others, this issue; Katrosh and Snyder, this issue; Riggs and others, this issue).

The Cape Lookout High separates the large Neogene Basin east of the White Oak Lineament into two distinct Miocene depocenters (Fig. 3). The basin north of this structural element is known as the Aurora Embayment (Riggs and others, 1981; Snyder and others, 1981); and the depositional basin south of the Cape Lookout High is herein referred to as the Northeast Onslow Bay Embayment.

Cape Fear Monocline

The Miocene sequences of the Pungo River Formation change strike and thicken over a generally northeast-southwest structural lineament in southwestern Onslow Bay. This structure is herein referred to as the Cape Fear Monocline (Fig. 3).

Figure 9 is a north-south interpreted seismic section crossing the Cape Fear

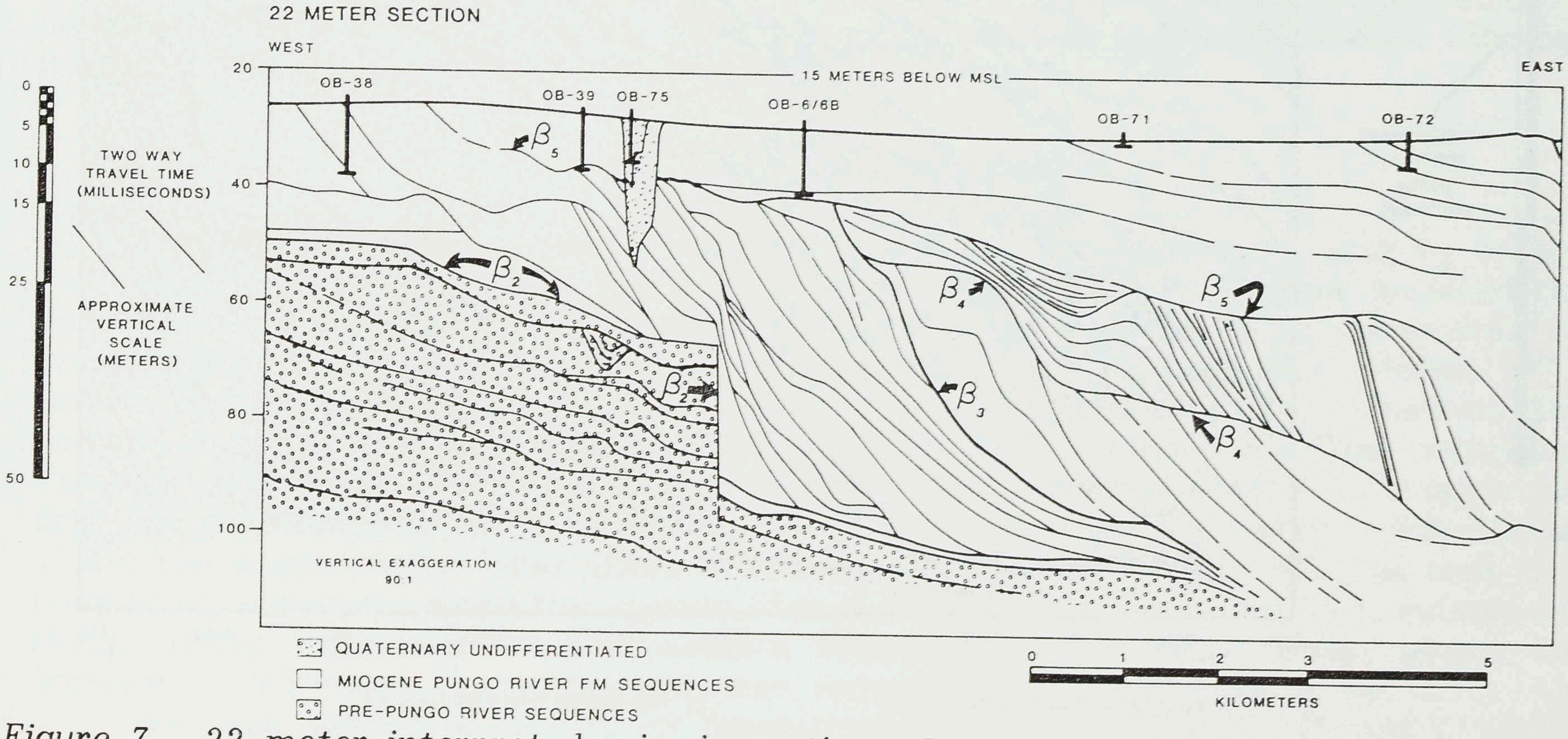

Figure 7. 22 meter interpreted seismic section. Location of profile shown in Figure 3B.

Monocline. Note that the Pungo River sequences thin from greater than 60 m to their updip outcrop limit in less than 8 km horizontal distance. This abrupt northward thinning is a consequence of relative subsidence to the south along the Cape Fear Monocline, as evidenced by the uniformly folded, pre-Pungo River sequences. The sigmoidal to divergent clinoforms characterizing the Miocene Pungo River sequences (bound by β_2 and δ_1) suggest these sequences were deposited in an actively subsiding basin (Vail and others, 1977).

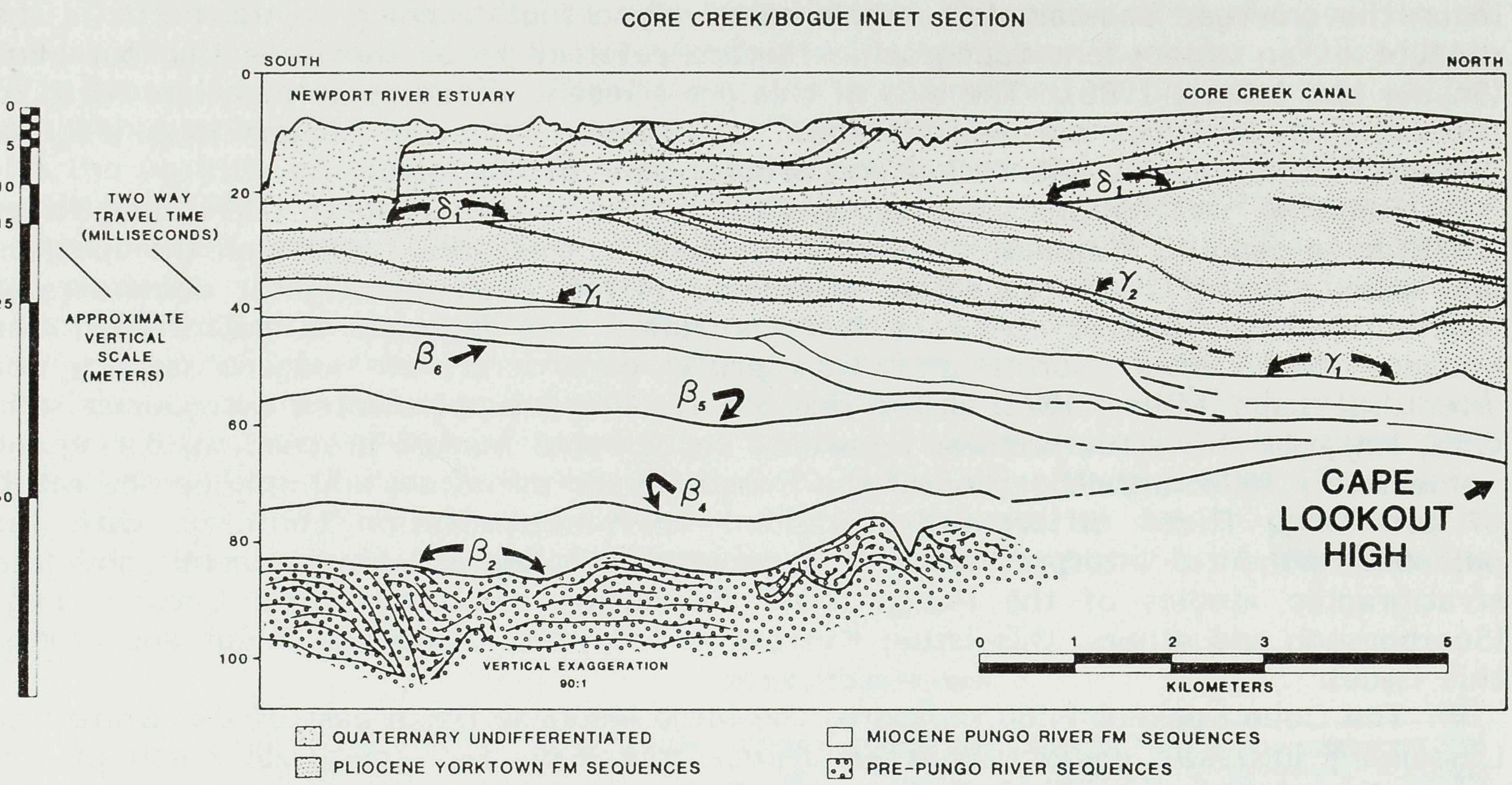

Figure 8. Core Creek/Beaufort Inlet interpreted seismic section. Location of profile shown in Figure 3B.

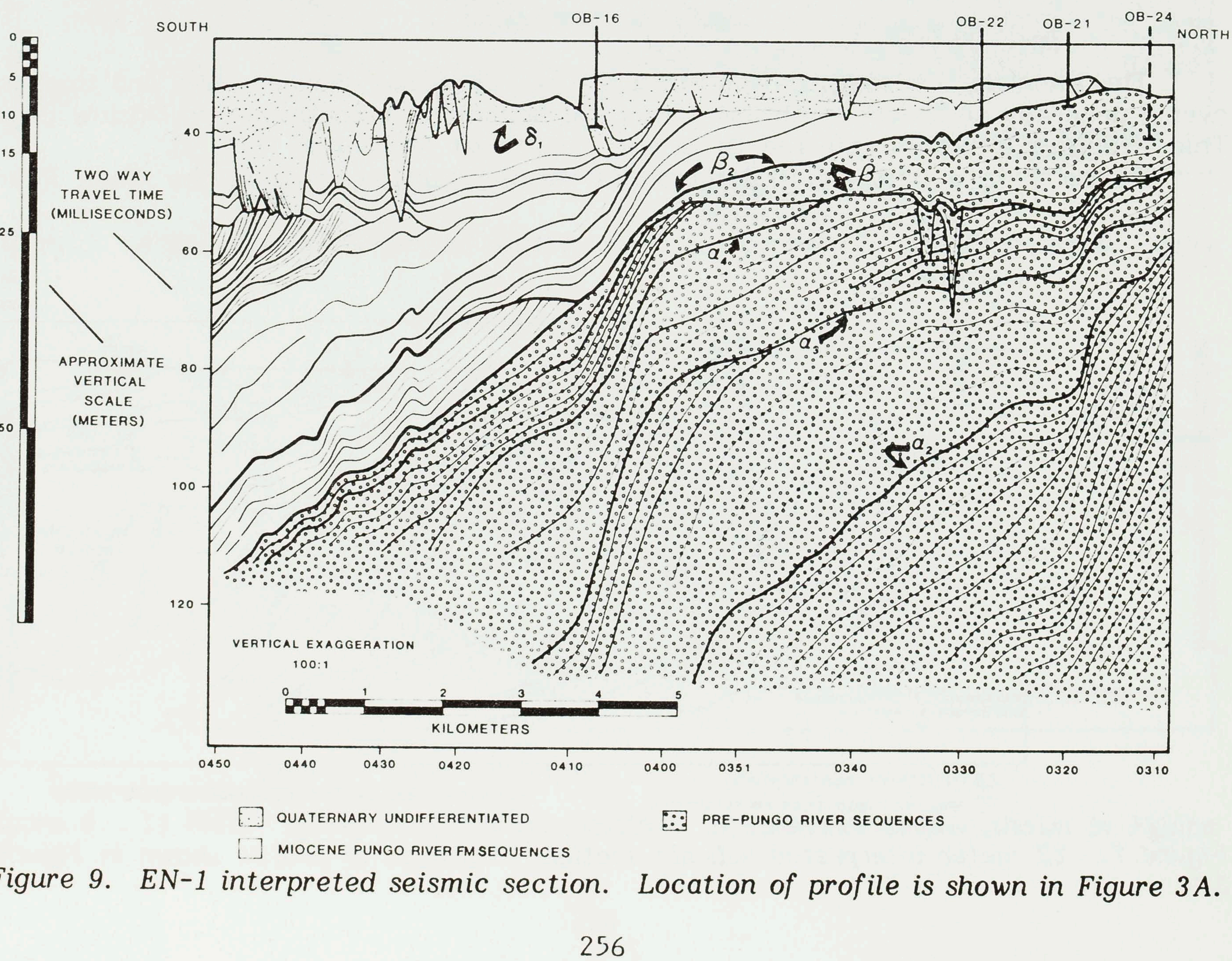

Figure 9. EN-1 interpreted seismic section. Location of profile is shown in Figure 3A.

The relative thickening of the Pungo River sequences to the south and southeast as illustrated in Figure 9 was found on all the profiles crossing the Cape Fear Monocline. However, this structure becomes more of a broad homoclinal feature to the east.

Flexure Basins

Several Miocene outliers of the Pungo River Formation were identified via seismic and vibracore data (Lewis and others, 1982) in the area of the Cape Fear Monocline (Fig. 3). These outliers are relatively thin (<15 m) and limited in areal extent (<20 km^2). Seismic data crossing the outliers depict multiple flexures in the underlying strata (Fig. 10), which suggests they are structurally controlled. Furthermore, the sigmoidal-progradational to divergent fill geometries of the Pungo River sediments within the flexure basins indicate the flexures were active penecontemporaneous with Miocene deposition.

As illustrated in Figure 10, the phosphatic Miocene sequences of the Pungo River Formation are restricted to the troughs of the flexures. This relationship between the troughs of the flexures and the occurrence of Pungo River outliers is relatively consistent throughout the Frying Pan Shoals area.

MIOCENE SEISMIC STRATIGRAPHY

As discussed earlier, seismic sequence analysis (Vail and others, 1977) has defined several depositional sequences which can be traced throughout the depositional basins. In the Northeast Onslow Bay Embayment, where we have the greatest seismic and stratigraphic control, four major unconformities mark the boundaries between 5 depositional epochs:

1) β_1 - Upper Oligocene Belgrade Formation/Lower Miocene Silverdale Formation
2) β_2 - Lower Miocene Silverdale Formation/Miocene Pungo River Formation
3) γ_1 - Miocene Pungo River Formation/Pliocene Yorktown Formation
4) δ_1 - Pliocene Yorktown Formation/Undifferentiated Quaternary Sequences

Lower Miocene Silverdale Formation

Reflector β_2 in Figures 5, 6, 7 and 8 represents a major unconformity between the lower Miocene Silverdale Formation and the Miocene Pungo River Formation. This reflector was traced via seismic profiling to western Bogue Banks where Steele (1980) drilled a thick sequence of unconsolidated, poorly sorted, calcareous, clayey quartz sands intercalated with occasional coarse horizons where shells constitute up to 50 percent of the sediment. Faunal analyses indicate this unit is part of the lower Miocene Silverdale Formation of Baum and others (1978). A vibracore (#OB-37) penetrating reflector β_2 along the 15 meter seismic section obtained a similar lithology (Lewis, 1981).

Miocene Pungo River Formation

The Miocene Pungo River Formation is bound by reflectors β_2 and γ_1 or δ_1. Reflector γ_1 (Figs. 6 and 9) represents a major erosional unconformity between the Pungo River Formation and the Pliocene Yorktown Formation as demonstrated by correlations to several drill and core holes in the lower coastal plain (Miller, 1971; Brown and others, 1972; Mixon and Pilkey, 1976). Reflector δ_1 represents the velocity/density contrasts between basal Quaternary sediments and the underlying Tertiary sequences. This relationship has been verified by correlations to numerous drill and core holes on Bogue and Shackleford Banks (Susman and Heron, 1979; Steele, 1980), the lower coastal plain (Daniels and others, 1972; Berelson, 1979), as well as a number of vibracores along the seismic lines (Lewis, 1981). Reflector δ_1 truncates the Pungo River Formation in the western segment of the Bogue Basin where the intervening Yorktown Formation has been removed by erosion (Figs. 6 and 7).

We have delineated five major depositional sequences (A, B, C, D, and E) within the Pungo River Formation. Each depositional sequence is a package of generally

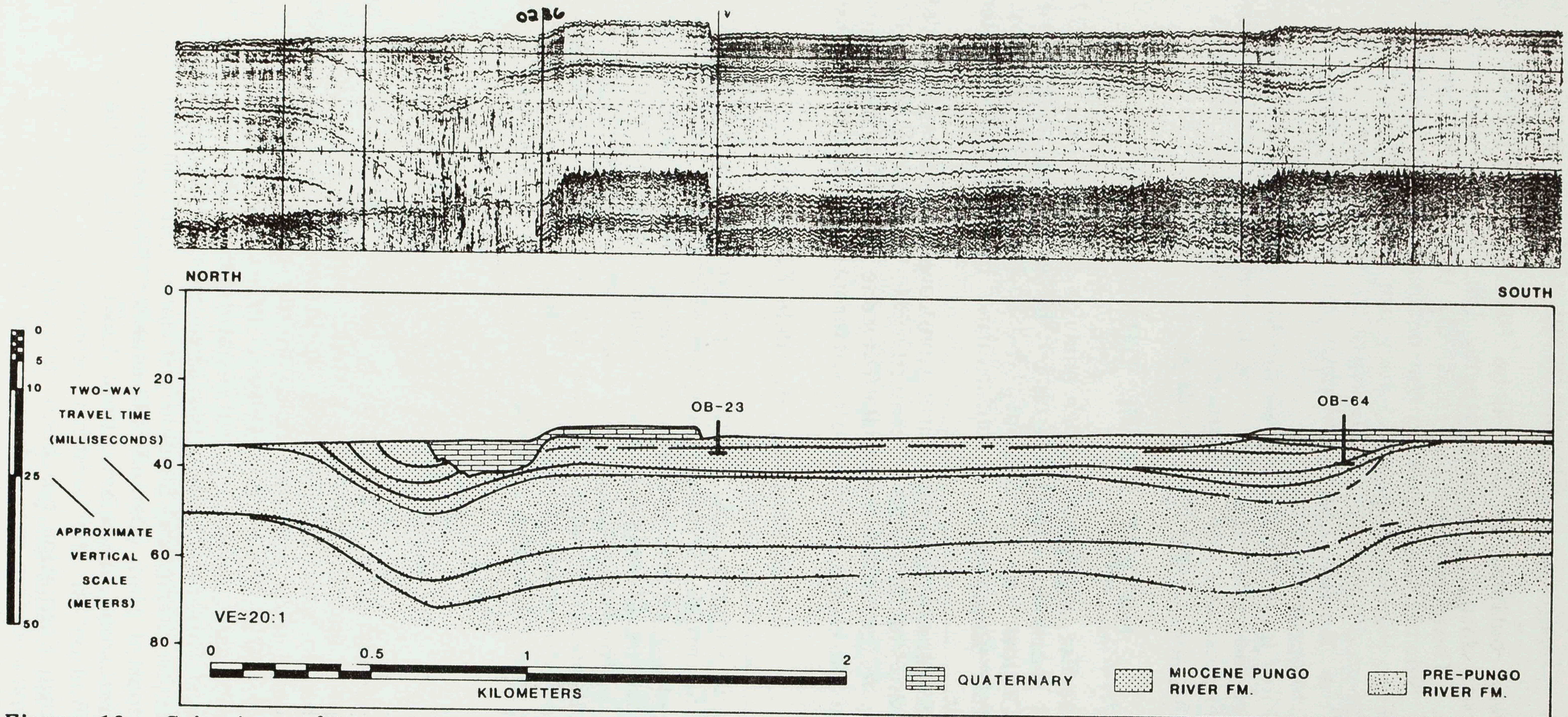

Figure 10. Seismic profile and interpretations of a flexure basin from southwestern Onslow Bay. Location of profile is shown in Figure 3A.

concordant reflectors consisting of genetically related strata bound at their top and base by unconformities as illustrated in the seismic sections (Figs. 6, 7, 8, and 9).

Sequence A--Pungo River Formation: Sequence A is bound by reflectors β_2 and β_3 (Figs. 6, 7, and 8), and represents the oldest depositional sequence of the Pungo River Formation. The sequence reflectors exhibit both onlap and downlap terminations on reflector β_2 which marks the top of the Silverdale Formation. In Figures 6, 7, and 8 the reflectors within the overlying sequence (sequence B) consistently terminate in a downlap fashion on reflector β_3 illustrating the unconformable relationship between these two sequences.

Correlations with several drill holes on Bogue Banks (Steele, 1980), as well as a number of vibracores penetrating sequence A (Figures 6 and 7), indicate this lower depositional unit consists of highly desiccated quartz-bearing, silty clay to clayey silt with occasional interbeds of fine calcareous sands. The silt fraction is predominantly rhombohedral dolomite. Several chert nodules were also recovered from this sequence (Lewis, 1981).

Sequence B--Pungo River Formation: The velocity/density contrast between sequence B and the overlying section is defined by reflector β_4, which forms a highly dissected, erosional unconformity truncating reflectors within the B sequence (Figures 6 and 7). The base of this sequence is marked by reflector β_3.

Correlations to drill hole data on Bogue Banks (Steele, 1980) indicate sequence B consists of a clayey, coarse barnacle shell hash to fossiliferous, clayey, fine-medium quartz sand. The uppermost section of sequence B is a tightly bound fossiliferous clay to indurated barnacle biomicrudite, and forms the karst-like topography illustrated by reflector β_4 in Figures 5 and 6.

Sequence C--Pungo River Formation: Sequence C is bound by reflectors β_4 and β_5 (Figs. 5, 6, 7 and 8). Reflector β_5 is an erosional unconformity between sequences C and D, as illustrated by the truncation of the reflectors within the C sequence in Figure 7.

Vibracores obtained from sequence C (OB-33 and OB-36 in Fig. 6) depict a similar lithology to sequence B except the quartz sand fraction comprises generally less than 5 percent of the sediment. In a series of correlative holes drilled on Bogue Banks, Steele (1980) encountered a similar trend. The uppermost section of sequence C is a lithified biomicrite (Steele, 1980) which has apparently impeded the vertical excavation of several Pleistocene channels (Fig. 7).

Sequence D--Pungo River Formation: The top of sequence D is defined by reflector β_6, where the youngest sequence (E) of the Pungo River Formation has not been removed by subsequent transgressions (Fig. 9). In Figure 5 the top of this sequence is marked by reflector Υ_1, which is the erosional base of the Pliocene Yorktown Formation. In Figure 6 the top of sequence D is defined by reflector δ_1, which represents the base of an early Quaternary transgression. This sequence outcrops on the middle shelf (Fig. 7), and is currently being eroded by the Holocene transgression. A number of vibracores penetrating sequence D (Figs. 6 and 7; Lewis, 1981) indicate this sequence consists of a clayey, fine to medium, phosphorite sand to phosphatic quartz sand.

Sequence E--Pungo River Formation: Sequence E is the youngest sequence of the Pungo River Formation, and is limited to the eastern segment of the Bogue Basin due to the erosion by Pliocene and younger transgressions. This sequence is bound by reflectors β_6 and Υ_1 in Figure 8. Reflector Υ_1 truncates the reflectors within sequence E (Fig. 8) illustrating a major unconformity between sequence E and the Yorktown Formation. A vibracore (OB-5) off Beaufort Inlet has identified this sequence as a clayey, fossiliferous, fine calcareous quartz sand (Lewis and others, 1982).

Pliocene Yorktown Formation

The Pliocene Yorktown Formation is limited to the eastern segment of the Bogue Basin due to the erosional truncation by subsequent Pleistocene transgressions. Where present, the Yorktown Formation is bound by reflectors γ_1 and δ_1. An unconformity within the Yorktown Formation (reflector γ_2 in Fig. 8) separates this formation into two distinct depositional sequences. Reflectors γ_1 and γ_2 bound the lower Yorktown member, and reflectors γ_2 and δ_1 define the upper Yorktown member. These two sequences are similar to those defined in the Aurora Basin by Riggs and others (1980; 1981) and Snyder and others (in press).

DISCUSSION

Origin of Structures

Recent interpretations of magnetic surveys, supplemented by multi-channel and single-channel seismic data, depict the Carolina Platform as a relatively smooth topographic surface containing several, small, topographic features (Klitgord and Behrendt, 1979; Dillon and others, 1979; Buffler and others, 1979; Klitgord and Grow, 1980; Paull and Dillon, 1980). Many of these basement features have been mapped and interpreted as basement faults which originated during the Early Mesozoic rifting of North America from Africa (Sheridan, 1974a; 1974b). Recurrent movement along these fault zones has produced numerous small shallow sedimentary basins within this trailing-edge margin (Dillon and others, 1979; Paull and Dillon; 1980). The infilling history of each basin has been regulated by the timing, relative direction and magnitude of movement along these basement faults.

Most of the local structures we have identified within Onslow Bay appear to be coincident with mapped gravity anomalies, magnetic anomalies and/or sharp magnetic gradients. Some of the magnetic features have been interpreted as basement-rooted structures having subtle topographic relief (Klitgord and Behrendt, 1979), while the large (-60 mgal) Bouguer gravity anomaly in the Frying Pan Shoals area is thought to be, in part, a product of a syn-rift basin (Grim and others, 1980).
The local deformation, depositional infilling patterns and coincidence with mapped geophysical anomalies suggests the Onslow Bay structures may be the surficial expression of recurrent movement along older, rift-originated or pre-rift faults within the Carolina Platform.

Miocene Stratigraphy and Sea-Level Cyclicity

The Miocene depositional sequences and associated unconformities indicate several cycles of relative sea-level change. These relative sea-level fluctuations can be attributed to: 1) global sea-level events produced by geoeustatic and/or glacio-eustatic fluctuations; 2) local, relative sea-level fluctuations produced by changes within the depositional basin from sedimentary infilling and/or local tectonism; or 3) a combination of both eustatic and local relative sea-level events.

Comparison of the Miocene relative sea-level cyclicity identified in the depositional sequences of Onslow Bay with the global eustatic sea-level curve proposed by Vail and others (1977) depicts a potentially strong correlation. The late Paleogene through Neogene segment of Vail's curve consists of four second-order supercycles (Td, Te, Tf, and Q in Fig. 11). Three major unconformities identified in Onslow Bay (Reflectors β_1, γ_1, and δ_1) may be correlative to the maximum regressions separating these four second-order cycles. Vail and others (1977) depict the maximum transgressions of eight Neogene third-order cycles at or above present-day sea level. We have tentatively correlated the depositional sequences and associated unconformities found in Onslow Bay to these third-order cycles of eustatic sea level change. These *preliminary* correlations are shown in Figure 11.

Our tentative correlations between the observed Miocene relative sea-level cyclicity and the global eustatic cycles of sea-level change of Vail and others (1977) are speculative at best. We currently lack the high-resolution biostratigraphic data needed to justify these correlations. Also, the magnitudes (maximum trans-

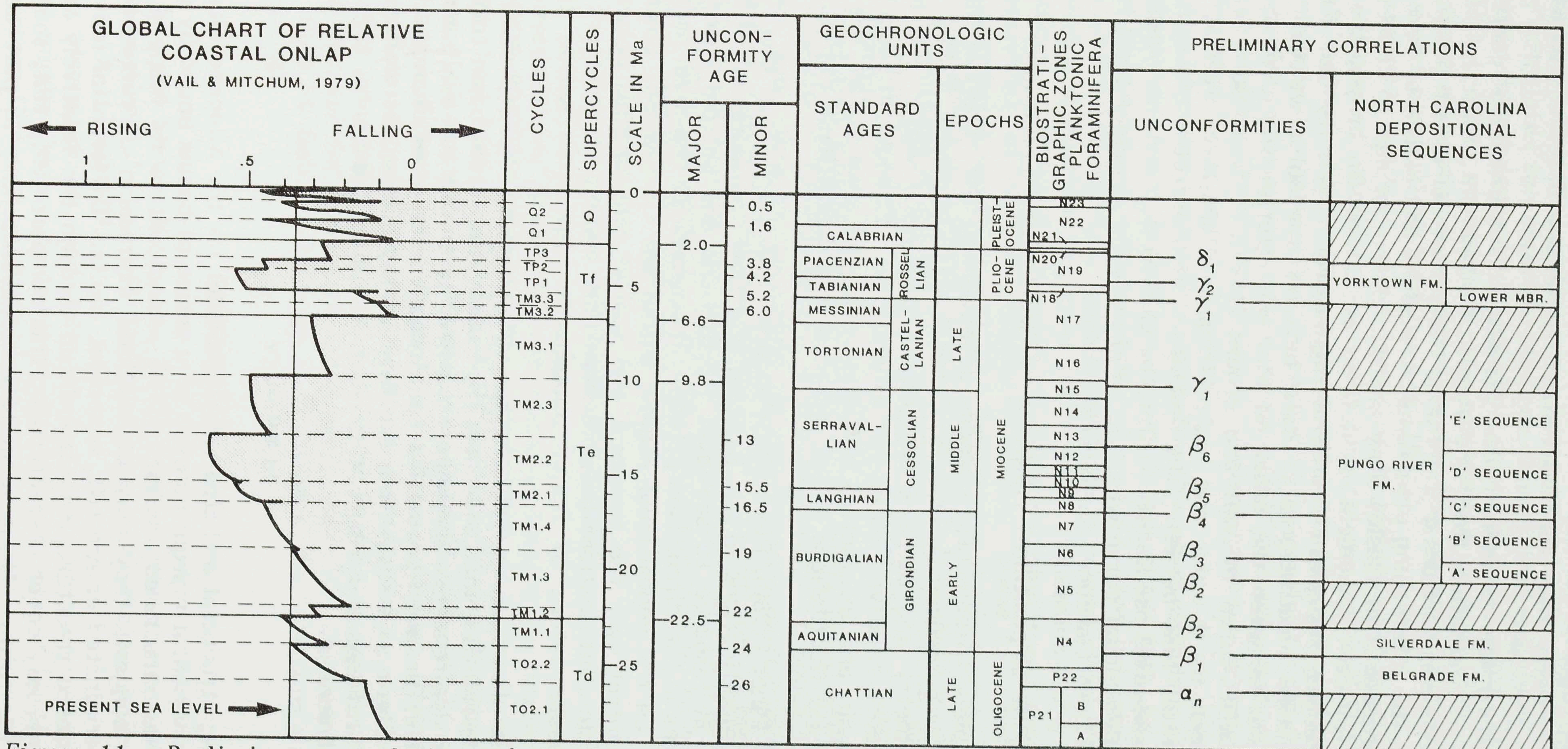

Figure 11. Preliminary correlations of the Onslow Bay depositional sequences and associated unconformities with the proposed eustatic sea-level curve of Vail and Mitchum (1979).

gressions/regressions) of the cycles within the relative sea-level curve for the North Carolina margin may deviate significantly from the eustatic curve of Vail and others due to local and/or regional tectonic overprint. Furthermore, the observed Miocene relative sea-level cyclicity may represent fourth or higher-order cycles of sea-level change.

Gibson (in press) has examined the planktonic Foraminifera content of the Miocene Pungo River Formation from the Aurora Embayment, directly north of our study area. He correlates portions of the Pungo River Formation with planktonic zones N 8 and N 11, with the intervening planktonic zones N 9 and N 10 not recognized. If the Pungo River sequences of Onslow Bay are correlative in age to the Pungo River Formation of the Aurora Embayment as defined by Gibson (in press), then many of these sequences probably represent fourth or higher-order cyclicity (see Fig. 11).

As high-resolution biostratigraphic data become available, we will refine our tentative correlations between the observed Miocene *relative* sea-level cyclicity and the proposed, eustatic curve of Vail and others (1977). These data will help to differentiate between third order and higher-frequency sea-level events, as well as evaluate the potential link between the initiation of Antarctic glaciation and the observed Miocene sea-level oscillations within the Onslow Bay system. Also, anomalous departures from Vail's global curve will help to identify the regional and local tectonic overprint for the North Carolina continental margin.

Miocene Depositional Response to Sea-Level Fluctuations

Significant paleoenvironmental changes accompanied the observed Miocene sea-level fluctuations, as evidenced by vibracore data (Lewis and others, 1982). Alterations in the paleobathymetry and paleo-oceanographic conditions within the basins were concomitant with each relative rise or fall in sea level. Changes in basin circulation, both within the basin and interaction between basin and open ocean, are thought to have controlled major fluctuations in the chemical and depositional climate within the basins.

Popenoe and Pinet (1980), Pinet and Popenoe (1980), and Paull and Dillon (1980) have documented modifications in the position and flow configuration of the Western Boundary Current in response to sea-level fluctuations and bottom topography. We believe that changes in the circulation patterns in response to sea-level oscillations had a major influence on the depositional regime within the Onslow Bay basins, and may be the primary control over the temporal and spatial relationships between sites of deposition and erosion, alternations between carbonate and clastic sediment regimes, as well as the episodic nature of major phosphorite deposition within the Miocene sequences.

The vibracore data (Lewis and others, 1982) suggests the depositional response accompanying each relative change in sea level has varied from basin to basin due to the new set of physical/chemical/biological constraints unique to each basin. Although the lithologies differ between basins for each relative sea-level change, the sea-level cyclicity seems to be consistent within the Onslow Bay system, as well as throughout the southeast U. S. (Riggs and others, this issue; Missimer and Banks, 1981), indicating regional or global control.

SUMMARY

The emerging structural and stratigraphic model for the Miocene along the upper North Carolina continental margin consists of a series of basins bound by several local structures. These structures appear to be coincident with mapped geophysical anomalies, which suggests they may be surficial expression of recurrent movement along older, rift-originated or pre-rift, basement faults. Differential movement along these basement-rooted structures was translated through the relatively thin Mesozoic to Cenozoic sedimentary cover characterizing this comparatively flat, shallow segment of the Carolina Platform. These local tectonic events have in part controlled the position of basin centers, as well as basin geometries through time, and have had a significant role in manipulating the local distribution, thickness and overall depositional pattern of the Miocene stratigraphic sequences.

The basin infilling histories have been dominated by several cycles of relative sea-level change. Six Miocene depositional sequences were identified in the Northeast Onslow Bay Embayment via high-resolution seismic profiling, vibracore analysis and correlations to existing drill and core hole data on the emerged coastal plain. We have tentatively correlated the observed Miocene depositional sequences and their associated unconformities to the proposed third-order global eustatic sea-level cycles of Vail and others (1977). These correlations are speculative at best since we lack the high-resolution biostratigraphic data needed to tie the observed Miocene cyclicity to the global sea-level curve of Vail and others (1977).

Each relative sea-level event identified in the Miocene depositional sequences of Onslow Bay produced modifications in the physical parameters within the basins. The depositional response to these paleoenvironmental changes differed for each basin, resulting in dissimilar lithologies for each change in relative sea level. Although the lithologic sequences for each sea-level event differ, the sea-level cyclicity seems to be consistent throughout Onslow Bay system. This suggests a regional or global eustatic factor rather than local tectonic control.

Both the Neogene tectonism controlling the structures delineated in Onslow Bay and the observed Miocene relative sea-level cyclicity may be related to major fluctuations in the rate of plate motion. Rona (1973) has indicated that the Miocene was a time of greater sea-floor spreading rates. Increased plate motion may result in an incipient rise in eustatic sea level and greater subsidence along the North Carolina Margin (Pittman, 1978). Differential subsidence within the Carolina Platform may initiate reactivation of basement-rooted structures. These local tectonic events would produce local relative sea-level changes. Subsidence of the faulted basement platform as a whole may result in regional, relative sea-level fluctuations. Both of these would modify the magnitudes of second and third order eustatic cycles of sea-level change, generating a *relative* curve unique to this portion of the upper North Carolina continental margin.

High-resolution biostratigraphic analysis, currently being done at East Carolina University (planktonic foraminifera) and the University of South Florida (calcareous nannofossils), will allow us to refine our preliminary correlations with the global eustatic sea-level curve of Vail and others (1977). Departures of the observed Miocene sea-level cyclicity in Onslow Bay from the global curve will help to differentiate local and regional relative sea-level fluctuations genetically related to tectonism from the proposed global eustatic sea-level oscillations.

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