Seismic stratigraphy of the Baltimore Canyon trough

by

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U. S. Geological Survey
Open-File Report 80-1079

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

1980

ABSTRACT

Examination of approximately 3,000 km of multichannel seismic-reflection profiles collected over the U. S. Middle Atlantic shelf (Cape Hatteras to Long Island) shows that the margin was rifted prior to the separation of Africa and North America and that it broadly subsided after the separation. Major accumulation of sediment is centered in the Baltimore Canyon trough, where in excess of 15 km of Triassic (?) and younger sedimentary rocks have been deposited. The trough is asymmetrical in that the thickest sedimentary section is beneath the outer part of the shelf seaward of a hinge zone; further, the trough is wider to the north off New Jersey than it is seaward of Virginia. Flanking the trough are two block-fault platforms (Long Island and Carolina) where thickness of the sedimentary cover is 1-4 km.

Eight depositional sequences have been delineated in analysis of the profiles by use of the techniques Vail and others as set forth in AAPG Memoir 26. Marked changes in reflector characteristics and unconformities are used to bound the sequences. The oldest sequence (Late Triassic-Early Jurassic) is thought to be nonmarine and restricted marine sediments associated with a complexly faulted crust. The changing seismic facies of younger sequences chronicle the transition to more open marine shelf and slope paleoenvironments during the Cretaceous and Tertiary. The thickest units accumulated during a phase of rapid basin subsidence in the Jurassic; sediment accumulation decreased substantially during the late Cretaceous and Cenozoic so that the sequences are thinner and unconformities are more evident. The most conspicuous unconformities seismically are correlated with the Albian, Turonian-Coniacian, Late Cretaceous-Paleocene, Oligocene, and Late Miocene-Early Pliocene, as

tied to COST (Continental Offshore Stratigraphic Test) and coastline wells. Several of these breaks coincide with pronounced fluctuations in the Vail curve of relative sea-level fluctuation, particularly during the Tertiary, when a broad trend toward falling sea level existed. Lastly, the records confirm the existence of a carbonate platform along the seaward edge of the trough during the Jurassic and Early Cretaceous. The stages of formation of the continental margin here are similar to those of the margin off the Canadian Maritime Provinces.

INTRODUCTION

Since 1973, the U. S. Geological Survey (U.S.G.S.) has contracted for approximately 20,000 km of multichannel common-depth-point (CDP) seismic-reflection profiles on the Atlantic continental margin (Schlee and others, 1976, 1977, 1979; Dillon and others, 1979a, b; Grow and others 1979). Approximately 3,000 km of these profiles were analyzed for the middle Atlantic shelf between Cape Hatteras and Long Island (Fig. 1). My purpose is to describe the seismic units delineated on these records and to interpret the depositional environments in which rocks they represent were formed. To check the seismic interpretations, I used data from coastal wells (Brown and others, 1972; Poag, 1978: Poag and Hall, 1979), a few shallow shelf holes (Atlantic Margin Coring Project-Hathaway and others, 1979), and the Continental Offshore Stratigraphic Test (COST) B-2 and B-3 wells (Scholle, 1977; Amato and Simonis, 1979) off northern New Jersey (Fig. 1).

Figure 1 near here

All the profiles were collected by Digicon, Inc., Teledyne, and Geophysical Services, Inc., from 1973 to 1978. Digicon processed lines 2, and 3; Geophysical Services, Inc., processed lines 6, 9, 10, 23 to 29, 36, and 37; Teledyne processed line 15; and the U.S.G.S. processed lines 11, 12, and 14 on the Phoenix 'I' system in Denver. Lines 2 and 3 were collected in 1973 from the M/V <u>Gulf Seal</u> (a 50 m offshore supply vessel) using a 20 airgun array (total volume 20,650 cc or 1,260 cu. in.); guns were operated at a pressure of 1,800-2,000 psi and were towed 17 m behind the vessel and 9 m below the the sea surface. The airguns were fired once every 50 m (approximately) once every 20 seconds at a speed of 5 knots). Returning signals were received by a 24-group (100 m) hydrophone array 2.4 km long and towed 356 m

Figure 1. Map of the Middle Atlantic offshore area showing the locations of multichannel lines and offshore holes. The letter-number designations of land wells are taken from Brown and others (1972). The four-digit well designations are from the AMCOR drilling project (Hathaway and others, 1979).

behind the ship at a depth of approximately 12 m below the sea surface. The returning signals were recorded on one of two 48-channel recorders (Texas Instrument DFS-III system)[1] and a single-channel analog recorder. Later, tapes were processed to include a common-depth-point gather, velocity analysis, normal move out correction, vertical summation of 2 on 1, horizontal stack, and time-variant filtering. Twelvefold processing was done on data collected from where water depth was less than 1,000 m. In addition, to enable better delineation of deeply buried reflectors, 24-fold processing was done on data collected along the outer shelf and upper slope parts of line 2.

Profile 6 taken in 1974 was collected by means of the same system as that used in the previous year except that 23 airguns were used (27,850 cc or 1,700 cu. in. total volume), and the returning signals were received by a 48-group (50-100 m) hydrophone array 3.6 km long; 36-fold processing was done on data collected along line 6. The 1975 data were collected by essentially the same system as that used in 1974. Processing of data collected along lines 9 and 10 was similar to that of data collected earlier (for a detailed description, see Grow and others, 1979). The processing sequence included demultiplexing and resampling, geometry and common-depth-definition, velocity analysis, noise muting, band-pass filtering, 48-fold horizontal stack, time-variant filtering, time-variant deconvolution, and automatic gain control (AGC) scaling, before the final profile playout.

1) Any trade names in this publication are used for descriptive purposes only and do not constitute endorsement by the U. S. Geological Survey.

SEQUENCE DELINEATION

Objectives

The three main objectives of the study are: 1) delineation of chronostratigraphic units on the profiles, 2) analysis of these units to infer the environment of deposition for the rocks they represent, and 3) comparison of acoustic information with drill-hole information. In addition, the broad trend of the stratigraphy is compared with that of other sequences on Atlantic-type continental margins to see if the response to crustal separation has been similar.

Geologists interpreting geophysical records have long attempted to correlate distinctive horizons and to give them chronostratigraphic significance (to assign them the same age everywhere the horizons are detected). Horizon A (lower Eocene), in the deep ocean basins, is one of the first of the reflectors to be so correlated (Ewing and others, 1966; Ewing and others, 1970); other reflectors (B, B*, A*, AII) have been used to correlate packages of reflectors over wide areas of sea floor (Emery and others, 1970; Emery and others, 1975) in an attempt to put together the geologic history of the oceanic basins. On the continental margin, similar attempts have been made to correlate distinctive reflectors, but the results have been limited mainly to the upper second of record because of the problem of multiples on single-channel reflection profiles. On the first multichannel profiles collected off the U. S. Atlantic margin, correlation of Cenozoic, Cretaceous, and pre-Cretaceous sequences was based on changes in the seismic character of the reflectors; horizons (K, Z, X) were drawn in to bound these distinctive groups (Schlee and others, 1976). Implicit was the assumption that these horizons approximated time lines. On the Canadian margin, the correlation of acoustic reflectors and drill-hole stratigraphy has achieved a high degree of certainty (Jansa and Wade, 1975a, b; Parsons, 1975; Given, 1977).

Approach

In this paper, I have attempted to apply the techniques of P. R. Vail and his associates to the Atlantic margin. Their methods are well explained in AAPG Memoir 26; on the basis of their analysis of seismic-reflection profiles in areas where drill holes are numerous, they find that seismic reflections are returned primarily 1) from stratal surfaces and 2) from unconformities that have sufficient velocity-density contrasts (Vail and others, 1977, pt. 5) to cause a coherent return of acoustic energy. The stratal surfaces are bedding surfaces; hence, they approximate ancient surfaces of deposition that existed over a wide area and are time-synchronous surfaces. Unconformities bound groups of reflectors into depositional sequences that have chronostratigraphic significance (Fig. 2). To identify the unconformities, evidence for downlap, toplap, onlap, and erosional truncation are looked for in the arrangement of the reflectors on a seismic profile.

Figure 2 near here

The time significance of the unconformity is that all the rocks below the unconformity are older than the rocks above it (Fig. 2). More important, the depositional sequences between major unconformities have been analyzed for coastal onlap, downlap, and toplap to identify geochronologic cycles of relative change of sea level. Some of these unconformities proved to be caused by small relative shifts of sea level, but certain major unconformities are apparently worldwide in their times of formation and appear to correlate over wide areas; thus, they indicate a major relative drop of sea level. Vail and his coworkers (1977, pt. 4) mapped the depositional sequences at 47 localities throughout the world, found the interregional hiatuses, noted the location of the key depositional sequences on the continental margin (which are mainly under the present inner shelf or under the present continental slope), and from their positions, constructed a curve showing relative changes

Figure 2. Schematic diagram of a depositional sequence to show the different arrangement of reflectors (onlap, truncation, downlap) that can exist along the same unconformity. Below, chronostratigraphic section indicates where sedimentary record is most complete and the lateral change in the amount of time represented by a particular hiatus (from Mitchum and others, 1977).

of sea level (Fig. 3) with time. The curve indicates major relative shifts in

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sea level during the late Miocene, late to middle Oligocene, latest early Eocene, middle Paleocene, middle Cenomanian, Valanginian, and Sinemurian (Early Jurassic), and it indicates several older hiatuses that are earlier than the formation of the Baltimore Canyon trough. Numerous lesser shifts also took place, and they have caused the unconformities that bound minor depositional sequences.

A section based on data gathered from wells drilled on the Atlantic Coastal Plain (Fig. 4) reveals conspicuous unconformities in the Oligocene and near the base of the Tertiary. Local unconformities also are evident in the upper

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part of the Cretaceous of New Jersey.

Offshore, the CDP profiles show several unconformities (arrows - Fig. 5A),

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particularly in the upper part of the section. To check the ages of these unconformities, the sequences they enclose were traced back to the COST No. B-2 and COST No. B-3 wells (Scholle, 1977; Smith and others, 1976; Amato and Simonis, 1979), where the ages had been determined (Fig. 5B). An examination of well cuttings from both the COST wells by Poag (1980b) has delineated unconformities between the Hauterivian and Barremian (B-3 only), the Turonian and late Cenomanian (B-3 only), the Turonian and Coniacian, the Maestrichtian and Paleocene, the late Eocene and late Oligocene, and the middle Miocene and the

Figure 3 Global cycles of relative change of sea level, Late Triassic to Tertiary (Vail and others, 1977, pt. 4, fig. 2). Hachured area shows part of curve where information on cycles has not been fully released for publication.

Figure 4. A stratigraphic section based on cores from 13 holes drilled near the seaward edge of the Atlantic Coastal Plain, from New York to North Carolina, and on well data of Brown, Miller, and Swain (1972). A, Generalized lithologic section, showing major hiatuses and units designated by letters as shown in Table 1. Letter - number designation of wells taken from Brown, Miller, and Swain (1972). B, Environments of deposition (Interpretation by C. Wylie Poag, U. S. Geological Survey, Woods Hole, MA.).

Figure 5. A. A part of profile 6 off southern New Jersey (see Fig. 1 for location). Arrows indicate conspicuous reflector terminations.

B. Paleoenvironmental interpretation of part of profile 6 made by adapting the criteria of Sangree and Widmier (1977). Letter designations at side indicate the seismic units present on the profile (see Table 1).

late Oligocene (B-2) or early Miocene (B-3). I have used the results from the COST wells and the major relative shifts of sea level of Vail's curve to date the unconformities traced on the seismic-reflection profiles. Unconformities are inferred in the Middle Miocene, Oligocene, and early Paleocene. Other unconformities are inferred in the Coniacian, the Albian, and near the Jurassic-Cretaceous boundary; the boundary between the two oldest units (Table 1) is marked by a strong group of continuous parallel reflectors rather than an obvious unconformity. The change in acoustic character and the increased interval velocity (4.7 - 5.5 km/s) suggest that the top of the oldest sequence may be marked by a group of interbedded evaporitic and carbonate rocks (see discussion of unit A). Similar strong reflectors occur just above acoustic basement on the Scotian Shelf where a sequence of halite and dolomite - - part of the Argo, Iroquois, and Mohican Formations of Early to Middle Jurassic age (Given, 1977) - - was drilled.

The seismic units are shown on a profile (Fig. 6) across the northern part of the Baltimore Canyon trough in the vicinity of the COST No. B-3 well (Schlee and Grow, 1980). Also shown on Figure 6 is the presence of an ancient shelf edge seaward of the COST well and present shelf edge. Rocks as old as Middle Jurassic (Callovian?) were recovered from the well site (Poag, 1080b), and the area changed from a coastal swamp-delta-backreef

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milieu in the Jurassic to a shallow marine shelf in the Early Cretaceous. The profile (Fig. 6) and its interpretation show what a dominant feature the Early Cretaceous - Jurassic shelf-edge buildup was; it created a broad anticline beneath the slope similar to the one off the West African Aaiun

Table 1 - Depositional units delineated in the Baltimore Canyon trough

Unit designation	Inferred age	External lower Boundary	Internal Properties: Configuration	Internal Properties: Continuity	Internal Properties: Intensity	Range of interval velocities	Paleoenvironmental interpretation of seismic facies
H	Late Miocene and younger	onlap - conformable - downlap	parallel to low-angle divergence	low to high	moderate to high	1.51-2.09 km/s	open shelf marine, contrasting high energy-low energy to low energy
G	Middle Miocene to late Oligocene	onlap - conformable - downlap	parallel to sigmoid	low to moderate	low to high	1.74-2.47 km/s	open shelf marine, contrasting high and low energy; progradation shelf-edge wedges
F	Oligocene to early Paleocene	onlap - conformable - downlap	parallel and sigmoid	lot to high	moderate to low and high	1.90-2.87 km/s	open shelf marine of varying energy conditions, with a delta built off Delaware
E	Late Cretaceous (to Coniacian	conformable; some onlap and downlap	parallel to 1wo angle divergence	moderate and high	low to high	2.05-3.15 km/s	open shelf marine of low to modest energy conditions
D	Early Cretaceous (to Albian)	onlap - conformable - downlap	parallel, low angle divergent complex oblique sigmoid	low to moderate	low to moderate	2.45-3.63 km/s	nonmarine to open shelf marine with low energy conditions
C	Early Cretaceous	conformable - onlap	parallel to low angle divergence	low to moderate	variable; low to high	2.78-4.65 km/s	mostly nonmarine to littoral marine
B	Late Jurassic to near the base of Jurassic System	onlap - conformable	parallel and divergent	low to moderate	variable; low to high	3.25-5.94 km/s	mixed nonmarine and evaporitic restricted marine; sand prone
A	Earliest Jurassic and Trassic (?)	onlap; fault boundary	divergent to parallel	low to high	high to low	3.84-6.49 km.s	mixed nonmarine and restricted marine

Figure 6. Depth section of profile 25 (see fig. 1 for location). Letters designate the depositional sequences (Table 1) distinguished on the profile. Note the broad anticline beneath the slope reflecting presence of a buried shelf-edge carbonate buildup.

basin described by Von Rad and Einsele (1980).

A close up of Line 6 (Figs. 5A, 5B) reveals some of reflector arrangements that help to delineate unconformities; line 6 is over the middle part of the shelf south of line 25 (Fig. 1), and upper part of the record is marked by downlap of a unit showing oblique progradation (at 1 second,two-way travel time-left side) and by truncation of unit G (Fig.5A, uppermost arrow). Figures 5A and B also show that unit G is a composite of two major episodes of sediment accumulation; the earlier progradational outbuilding is marked by downlap and a later onlapping sequence of sediment buried the front of the older one. The progradational arrangement of reflectors of unit G is restricted mainly to the northern part of the Baltimore Canyon trough (Fig. 14). The ages inferred for the units seen in Figures 5 A and B of Line 6, range from Plio-Pleistocene to Early Cretaceous (Table 1) and paleodepositional environments inferred for the units are deltaic (oblique progradation), nonmarine, and marine shelf.

The seismic facies described in Table 2 and distinguished in Figure 5B

Table 2 near here

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are based mainly on the continuity of reflectors, their intensity (amplitude), and their breadth; in addition, the geometry (shape) of the entire unit (Table 1) is used along with the internal arrangement of reflectors. The criteria are those of Sangree and Widmier (1977). They based their environmental inferences on drill-hole data keyed to multichannel seismic-reflection profiles collected in the same area.

The internal arrangement of reflectors is also an important guide in distinguishing environmental types. Most of those units associated with the shelf or Coastal Plain show a parallel to low-angle divergent arrangement of

Table 2 - Seismic facies present in the Baltimore Canyon trough

Seismic facies unit	Paleoenvironmental facies interpretation	External form	Internal configuration	Reflection geometry at boundaries
Parallel Low continuity and variable-amplitude	Nonmarine - river and associated marginal marine transport processes	Sheet or wedge	Parallel to divergent	Concordant at the top and concordant to gentle onlap and downlop at base
Parallel High continuity and high amplitude	Shallow open marine shelf with wave transport; high and low energy conditions; possible fluvial deposits interbedded with swamp and coastal deposits	Sheet or wedge	Parallel to divergent	Concordant at top and concordant to gentle onlap and downlap at base
Parallel Low amplitude and low continuity	Sand: Fluvial and nearshore littoral processes Shale: Marine shelf sediments deposited under low energy regime from turbidity currents and by wave transport	Sheet or wedge	Parallel to divergent	Discordant at top with concordant to gently downlap or onlap at base
Parallel Moderate continuity and low to moderate amplitude	Mixed inshore shelf deposits formed in low to modest energy conditions and non-marine coastal deposits	Sheet or wedge	Parallel to divergent	Concordant or low-angle truncation at top; concordant or onlap at base
Sigmoid - low relief mound	Shelf edge progradation	Low broad mound	Sigmoid along deposit-ional dip; onlap and lens-shaped parallel to depositional strike	Concordant at top with downlap and onlap at base

Table 2 Seismic facies present in the Baltimore Canyon trough -- continued.

Seismic facies unit	Paleoenvironmental facies interpretation	External form	Internal configuration	Reflection geometry at boundaries
Oblique-Progradational	Deltaic outbuilding variable energy conditions from high in toplap truncated area to low energy in clinoform and fondoform (prodelta zones)	Fan-shaped	Parallel in upper part oblique along depositional dip and parallel or gently oblique to sigmoid parallel to depositional strike	Toplap truncation to downlap at base

reflectors. However, where the sediments are deposited at the shelf edge or as a delta, then a sigmoid progradation pattern of reflectors (perpendicular strike) is possible. If high-energy conditions have impinged on a part of the delta, the shallow water part may be the site of sediment bypass and some erosion, to result in a oblique progradational pattern of reflectors (Fig. 5A). Parallel to the depositional strike, the delta might show a mounded arrangement of reflectors.

The broad progradational arrangement of reflectors is also present in shelf-edge deposits. Normal to depositional strike, the reflectors can show the same sigmoid or oblique progradational arrangement found in deltas, depending on energy conditions at the shelf; obviously, sediment bypassing of the shelf (because of vigorous erosion) could create an oblique progradational pattern of reflectors. Laterally along the shelf edge, these deposits could be expected to grade into other shelf or upper slope deposits. Landward of the shelf edge, they could grade into normal marine-shelf deposits (parallel; high continuity; high amplitude to low amplitude), or in a seaward direction, they could grade into hemipelagic or mass-movement deposits of the continental slope.

The high continuity of reflectors is interpreted to be caused by strata deposited in relatively widespread and uniform depositional energy conditions, perhaps on a broad marine shelf; agents of active sediment transport would probably be waves and currents. Sangree and Widmier (1977) also noted that a high continuity can also characterize broad swampy coastal plain areas in which fluvial sands are interbedded with widespread coal and marsh clays. Conversely, low-continuity reflectors indicate the presence of lithologic units of limited areal extent, such as discontinuous channel sands interbedded with flood-plain clays in an alluvial plain. This type of environment can be recognized by variable seismic intensity coupled with the low continuity.

Seismic intensity (high-low-variable) provides a qualitative guide to the velocity-density contrast of vertically adjacent reflectors. High intensity of reflectors implies beds "with relatively moderate reflection coefficients whose thicknesses give rise to strong constructive addition" (Sangree and Widmier, 1979, p. 134-135). Low intensity (amplitude) suggests sedimentary rocks of a uniform lithology - - commonly sandstone and shale. Variable intensity may indicate a nonmarine paleoenvironment; sequences of channel sandstone of limited areal extent could contrast strongly in density with adjacent flood-plain clays so that discontinuous high-intensity reflections could result.

In a depositional basin, the normal progression of environments that might be expected is from alluvial plain - coastal marsh (parallel, low continuity, variable amplitude) through a sandy littoral zone (parallel, low continuity, low amplitude), across a marine shelf (parallel, moderate to high continuity, high amplitude) into deeper parts of the basin, where uniformly low energy conditions prevailed (shale prone, parallel, low continuity, low amplitude). Obviously, mapping these facies on a grid of seismic-reflection profiles is important to establish the paleogeography. Then potentially confusing facies can be sorted out. A sand-prone low-amplitude facies (a thick sequence of sandstone originating in a littoral environment) could be expected to change laterally offshore into high-continuity and high -moderate-amplitude shelf facies and onshore to a low-continuity and variable-intensity nonmarine facies.

A similar appearing low-continuity, low-amplitude, shale-prone facies originating in an offshore shelf basin could be expected to grade laterally into the high-continuity, high-amplitude facies (shallow shelf) toward the basin edge and possibly into prograded slope deposits (chaotic fill; mounded onlapping fill, fan complex facies) in a deep basinward direction.

The cycle breadth of seismic reflections gives a general idea of the thickness of strata causing the return, and it is useful as an aid in observing probable facies changes in groups of reflectors. Optimum spacing for wavelet resolution is $\lambda = \frac{v}{f}$ (Sheriff, 1976) where v = interval velocity and f = frequency of seismic waves. Sangree and Widmier (1979, p. 135) noted that the "Optimum bed thickness for constructive addition corresponds to 1/4 a reflection cycle breadth on a seismic section (e.g. for 30-hz data, a 10,000-ft/sec bed has an optimum spacing of 82 feet)". They further noted that broad reflectors interspersed with narrow reflectors is an indication that the beds are unusually thick -- more than the optium thickness for wavelet resolution. The formula indicates that, for deeply buried strata, where interval velocity is high and the high frequencies are attenuated, the value for lambda (λ) will be greater; hence at depth, reflectors are the returns from thicker sequences of strata than those returns from shallowly buried sequences. Keeping in mind these relations, we can follow individual reflectors and observe their breadth narrow as the group of beds causing the reflection thins.

By use of the criteria of Sangree and Widmier (1977, 1979), part of profile 6 has been interpreted (Fig. 5B) to show the type of seismic facies present within six depositional sequences. The older sequences of Cretaceous age show a transition from a marine-shelf to a nonmarine environment. The younger sequences were deposited on a marine shelf, though unit G shows an obvious pattern of deltaic progradation following a major sea-level lowering. The shelf progradation is a widespread phenomenon over the northern part of the trough (see discussion of unit G).

SEISMIC FACIES AND DEPOSITIONAL SEQUENCES

The depositional sequences recognized in the Baltimore Canyon trough (table 1) vary widely in acoustic character and in boundary relations. The change in seismic character both laterally and with depth was noted by Schlee and others (1976); the change is mainly in the continuity of the reflectors and in their intensity (amplitude) (Fig. 5). The environments described in Table 2 are mainly shelf or coastal plain types. Two shelf-slope types (sigmoidal-mound seismic facies and oblique-progradational seismic facies) are associated with the other seismic facies. The main characteristic of most shelf seismic facies is a general parallelism of reflectors, although reflectors diverge in some areas because of differing rates of subsidence. However, continuity and intensity vary significantly, and these are the variations best indicators of changes of environment within the sequence.

Unit A

The oldest seismic unit (A) is inferred to include strata deposited during

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Figure 7 near here

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the Late Triassic and early part of the Jurassic (Fig. 7). The strata unconformably overlie an irregular basement, probably consisting of block-faulted continental crust rifted during the latest opening of the Atlantic Ocean. On most cross-shelf profiles, acoustic basement is easily discernible under the inner part of the continental shelf where it deepens abruptly to more than 10 km east of New Jersey.

The upper limit of seismic unit A is taken to include a group of high-amplitude continuous reflectors assumed to be a sequence of carbonate rocks and evaporite deposits. Averaged interval velocities within the unit are in the range of 3.8 - 6.5 km/s; highest interval velocities in this unit and in units above tend to be associated with rocks under the middle and outer parts

Figure 7. Unit A thickness, depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Contours are dashed where seismic data were sparse. Velocity values are the arithmetic mean of 3 to 5 shotpoints between the black lines. Italicized values are averages for profiles that parallel the coastline.

of the shelf. Within the unit on some profiles (Fig. 6) is a conspicuous unconformity (tilted reflectors below) which may represent the boundary between earliest rift deposits and later subsidence phase sediments -- the initial deposits of the trough, laid down during and after continental separation.

Given (1977) showed that a group of strong reflectors is present just above acoustic basement under the northern Scotian Margin; they originated in the Mohican Formation, a sequence of continental red beds, evaporite deposits, and dolomites of Early Jurassic age. The similar appearance of these reflectors, their position in the section, and the similarity in the range of velocity values dolomites and evaporite deposits range from 4.5 to 7.3 km/s in compressional velocity (Gardner and others, 1974) indicate that equivalent units may be present under both central Georges Bank and the Balitmore Canyon trough. As can be seen from Figure 8, unit A pinches out south of line 11 where basement is probably only

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Figure 8 near here

3.5 km below sea level. To the northeast it thickens to more than 5 km (Fig. 7) off central New Jersey. Not included in the isopach map (Fig. 7) is the area of pinchout over the Long Island platform, where the isopach pattern of this unit combined with unit B (Fig. 16A) is irregular because the two units are contained within several fault-bounded troughs.

Both nonmarine and restricted-marine conditions appear to have prevailed during deposition of unit A. Strong continuous reflectors (having high interval velocities) are above discontinuous reflectors of variable amplitude and breadth. No strata of this inferred age (Late Triassic and Early Jurassic) have been drilled in the Baltimore Canyon trough, though the COST wells on Georges Bank (Amato and Simonis, 1980; Amato and Bebout, 1980) did penetrate a sequence of carbonate deposits, evaporite deposits, and red beds of equivalent age; also Canadian

Figure 8. Depth section along line 12 (see Fig. 1 for location) parallel to the coast. The line traverses the shelf from Virginia to New York and shows deepening from southwest to northeast in the Baltimore Canyon trough; maximum depth is off New Jersey. Letters refer to the depositional sequences described in Table 1; cross-hatched areas represent basement rocks.

offshore holes (McIver, 1972; Given, 1977) penetrated similar lithologies. Interbedded evaporite deposits are probably present at depth because one exploratory hole drilled on the southern flank of the Great Stone dome ended in salt, and a diapir is present on line 14. Line 15 crosses two broad faulted arches, both which could be supported on salt pillows; these two structures have been leased and drilled as a part of exploratory drilling in the area.

Unit B

Unit B is thought to include both nonmarine and transitional rocks of Jurassic age, to be more than 5 km thick in the central part of the basin, and to have a range of interval velocities of 3.3 to 5.9 km/s (Fig. 9). It conformably overlies the oldest unit and broadly onlaps acoustic basement. The unit is in turn

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Figure 9 near here

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onlapped by the unit C toward the coast, as seen on the shoreward ends of the cross-shelf seismic profiles. Elsewhere, the top of unit B is in apparent conformity with the sequence above. Internal configuration of reflectors is parallel except for the inshore parts of cross-shelf profiles, which show a low-angle seaward divergence of reflectors.

Within the northern part of the Baltimore Canyon trough, unit B exceeds 5 km under the outer shelf off southern New Jersey (Fig. 9). It pinches out toward the Long Island platform and inner shelf adjacent to the coast, farther south. It thickens toward the east in a more even manner then does the unit A. This less convolute arrangement of the thickness contours suggests that as the post-rifting phase of margin formation continued, the trough broadened its pattern of subsidence away from the earlier pattern dominated mainly by subsidence in fault troughs of limited areal extent.

The low to moderate continuity of reflectors and their variable amplitude suggest a mainly nonmarine sequence along the periphery of the trough (Fig. 9).

Figure 9. Unit B thickness, depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Contours are dashed where seismic data were sparse. Velocity values are the arithmetic mean of 3 to 5 shotpoints between the black lines. Italicized values are averages for profiles that parallel the coastline.

Some continuous high-amplitude reflectors are interspersed with the main group of reflectors in the southern part of the trough and are interpreted to be interbedded dolomites and evaporite deposits. Continuous high-amplitude reflectors also occur toward the outer edge of the shelf in the upper part of the unit and merge with a lensoid mass under the slope, which has been interpreted to be carbonate buildup (Schlee and others, 1979, figure 7).

The upper part of unit B has been drilled in the COST No. B-2 and COST No. B-3 holes. The COST B-2 contains 1.2 km of variegated gray-brown shale interbedded with fine-to-medium-grained sandstone and lignite; the unit is of a mixed nonmarine and shallow-marine origin and interval velocities cluster around 4.5 km/s (Grow and others 1979). In the COST B-3 well, a sequence of interbedded calcareous shale and limestone (and zones of oolites) was drilled (3.8 - 4.8 km below K. B. [Kelly Bushing]); interval velocities range from 13,800 to 16,700 ft/s (4.2 - 5.1 km/s) (Lachance, 1979; Carlson, 1979). The rocks encountered in the hole are as old as Callovian (?) (Middle Jurassic) and appear to have been deposited in coastal marshes; the limestones were deposited on a shallow marine shelf as back reef facies (Poag, 1980b). Where the equivalent unit has been drilled in the Scotian basin (1,000 km to the northeast), Given (1977, p. 68) described "Early-Middle Jurassic section of halite, dolomite, and interbedded clastics" as part of the Argo, Iroquois, and Mohican Formations. The Mohican Formation grades into the Scatarie Member of the Abenaki Formation above a sequence of oolitic and pelletoidal limestone of Middle Jurassic age that Given interpreted as the first broad marine transgression into the northern Scotian basin. During the Middle to Late Jurassic, nonmarine (deltaic and fluvial clastic rocks) facies were deposited in the inner half of the Scotian Shelf (Mic Mac Formation and Mohawk

Formation), and carbonate rocks plus deeper marine shales and sands (Baccaro Member of Abenaki Formation) were deposited under the present outer shelf and upper slope (Eliuk, 1978); the carbonate banks were discontinuous features, in part because of the influx of terrigenous clastic sediments from a large delta near Sable Island.

Unit C

Unit C is inferred to be Early Cretaceous (mainly pre-Albian) and is mixed marine and nonmarine sediment as much as 2 km thick under the seaward part of the trough (Fig. 10). Within the unit, reflectors tend to be parallel or divergent at a low angle. At the base, reflectors can onlap older units, though on many profiles, the boundary is a disconformity between conformable

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Figure 10 near here

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reflections above and below. The upper boundary shows both onlap and downlap by the overlying unit, particularly on the Long Island platform. Over much of the rest of the trough, reflectors in the upper part of unit C are conformable with those in the unit above . The upper part of the unit is characterized by fairly continuous reflectors of high to moderate amplitude on the seaward ends of a few cross-shelf lines; these reflectors are interpreted to represent probable limestones (Schlee and others, 1976; Sheridan, 1976).

Unit C locally thickens to 1 1/2 km in the northern part of the trough. It appears to pinch out toward the New York Bight and to thin more gradually to the southwest (Virginia-Hatteras area); locally, it is thinned over an intrusive body off central New Jersey (the Great Stone dome, Fig. 1). The pattern of subsidence is broad, though not to the same extent as the pattern for unit B below, adjacent to the inner shelf east of the Chesapeake Bay.

Interval velocity (Fig. 10) is mainly between 2.8 and 4.7 km/s, and

Figure 10. Unit C thickness, depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Contours are dashed where seismic data were sparse. Velocity values are the arithmetic mean of 3 to 5 shotpoints between the black lines. Italicized values are averages for profiles that parallel the coastline.

the values tend to be higher offshore in the area where the unit is more deeply buried and is inferred to be composed of marine-shelf deposits. The offshore stratigraphic information for this interval comes from the COST No. B-2 and B-3 wells (Smith and others, 1976; Amato and Simonis, 1979); values from velocity analyses for this interval range from 3.7 to 4.5 km/s in the COST No. B -2 well, and from 3.2 to 4.2 km/s in the COST No. B-3 well. The rocks drilled in the COST No. B-2 well consisted mostly of interbedded sandstone. shale, siltstone, and scattered beds of limestone and lignite, deposited mainly in a coastal to inner shelf environment; the section in the COST B-3 well (Lachance, 1979) is interbedded medium-grained sandstone and gray-brown silty shale (and traces of coal and dolomite)deposited under shallow-marine to nonmarine conditions (Poag, 1980b).

Unit D

Unit D is inferred to represent the stratigraphic interval from the early Albian to the Coniacian Stage (Upper Cretaceous), and it shows a change to more widespread marine conditions in the Baltimore Canyon trough (Fig. 11). The upper boundary of unit D is tied to two ages. On the profiles (11, 3, 29)

Figure 11 near here

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southwest of line 10, the upper boundary is taken to be a conspicuous conformable reflector that is Cenomanian in age (COST wells). For the profiles northeast of line 10, a shallower conformable reflector is more obvious, and it is near the Coniacian-Turonian boundary. Therefore, southwest of line 10, the thickness values are measured to a stratigraphically lower horizon as are the interval velocities and the inferences of paleoenvironment. Reflectors adjacent to the lower boundary onlap toward the coast, but over most

Figure 11. Unit D thickness, depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Velocity values are the arithmetic mean of 3 to 5 shotpoints, between the black lines. Italicized values are averages for profiles that parallel the coastline. The dashed isopachs are based on using a conspicious horizon inferred to be Cenomanian in age as the upper boundary. The solid isopachs use a probable disconformity inferred to be Coniacian as the upper boundary; a heavy dashed line seaward of Maryland separates the two types of contours.

of the basin, they are conformable with those reflectors in unit C below. Some channeling is associated with basal reflectors to mark an unconformity at the base of unit D, but channeling is more evident at the upper boundary of this unit (Coniacian). Even at the upper part of the sequence, reflectors tend to be conformable with the overlying sequence except near the landward part of the trough and the Long Island platform (line 9), where reflectors are beveled at a low angle by the overlying onlapping sequence (E).

In an irregular manner, unit D thickens to a maximum of 1 km off Maryland and 0.8 km under the seaward part of the shelf off Delaware and New Jersey. It thins to less than 0.5 km under the Atlantic Coastal Plain, and thickness change of unit D under the inner Continental Shelf is seen mainly as a low-angle divergence of reflectors on cross-shelf profiles.

Continuity of reflectors is low to moderate, as is the seismic amplitude. The seismic pattern is interpreted to indicate that a marine-shelf environment existed over most of the present shelf. Apparently, conditions were uniform enough so that the type of sediment deposited did not change sharply; hence, the low to modest continuity and amplitude of reflectors. On some profiles, bands of high-amplitude continuous reflectors are present and probably indicate a marine transgression over the shelf. The COST No. B-2 well penetrated a sequence of calcareous fine- to medium-grained sandstone, siltstone, shale, and limestone, probably deposited in a shallow-marine environment (Scholle, 1977, figure 4; Poag, 1977, p. 36). The COST No. B-3 well penetrated white sandstone (Cenomanian) overlain by dark brown-gray calcareous mudstone, thought to have been deposited in a marine shelf at moderate water depths. Inshore along the present coast line (Fig. 4), unit D was deposited in a nonmarine environment (Poag, 1980b) except in North Carolina where marginal marine conditions existed. Averaged interval velocities (Fig. 11) range from 2.5 to 3.6 km/s and tend to increase toward the thicker more marine part of the sequence. These velocity values characterize fairly well indurated sandstones and shale (Gardner and others, 1974) having bulk densities that range from 2.2 to 2.4 gm/cm^3. Interval velocities from the COST No. B-2 well for this unit range from 3.0 to 3.6 km/s (Smith and others, 1976); the same velocities were calculated for line 14, which transects the B-2 hole. In the COST No. B-3 well, interval velocities equivalent to this unit range from 2.6 to 3.2 km/s (Carlson, 1979).

Unit E

Unit E consists of marine-shelf deposits (Fig. 12) inferred to be Late Cretaceous and possibly early Paleocene in age. It forms a broad sheetlike deposit that extends westward onto the Atlantic Coastal Plain (Fig. 4), where

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Figure 12 near here

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marine -shelf and marginal-marine conditions existed (Poag, 1980a). As indicated in the discussion of unit D, the mutual boundary between D and E loses its identity on some of the profiles (11, 3, 29) over the southern part of the trough. Therefore, a slightly lower boundary defines the base of unit E over this area, and a dashed line of Figure 12 shows where the change of boundaries has been made. The lower boundary is marked by some onlap of basal reflectors on the faulted Long Island platform (line 9), but mostly, the unit is in apparent conformity with the underlying one. The upper contact can be marked by extremely low angle downlap of reflectors from the overlying unit, but mostly the boundary shows conformity of reflectors above and below it; some channeling and low-angle truncation can be seen along this boundary, particularly on line 12.

The unit thickens in an offshore direction (Fig. 12) in an irregular fashion. Thickness values are less than 3/4 km in the southern part of the

Figure 12. Unit E thickness, depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Velocity values are the arithmetic mean of 3 to 5 shotpoints between the black lines. Italicized values are averages for profiles that parallel the coastline. The isopachs, patterns of depositional environment, and averaged interval velocities left of the dashed line seaward of Maryland are based on using a hiatus inferred to be Cenomanian in age as the lower boundary. The isopachs, patterns, and velocity values right of the dashed line use a probable disconformity inferred to be Coniacian in age as the lower boundary.

trough and between 1/2 and 1 km in the northern part. Along the coast, the unit is 1/3 km thick or less.

On the basis of moderate to high continuity of reflectors and the low to high seismic amplitudes, a marine-shelf milieu is interpreted to have existed over most of the trough during the deposition of this unit. The unit accumulated as a broad sheet except at the seaward part of line 9, where an oblique progradation arrangement of reflectors probably indicates ancestral shelf-edge deposits. The COST No. B-2 hole penetrated medium-grained sandstone, shale, and limestone (Scholle, 1977, figure 4) deposited mainly under marine conditions (Poag, 1977, p. 36; Valentine, 1977, p. 40); a 275-m-thick interval of the section is unfossiliferous and is presumed to be nonmarine. In the COST No. B-3 well, strata equivalent to unit E are calcareous silty mudstone and thin beds of glauconitic sandstone and dolomite (Lachance, 1979) rich in "outer shelf" and "upper slope" faunal assemblages (Poag, 1980b). Coastal wells (Fig. 4) indicate a marginal-marine or marine-shelf environment for the equivalent of the section under the Atlantic Coastal Plain (Poag, 1980a).

Average interval velocities range from 2.1 to 3.2 km/s -- values that are in the range of sandstone and shale (Gardner and others, 1974). The interval velocities from the COST No. B-2 well range from 2.6 to 3.0 km/s (Smith and others, 1976) similar to those values along line 14 (2.92-3.05 km/s) adjacent to the drillsite. A short distance away, interval velocities in the COST No. B-3 well range from 2.4 to 2.6 km/s (Carlson, 1979).

Unit F

Unit F (inferred age Paleocene to middle Oligocene) is also probably of marine origin, has a range of average interval velocities from 1.9 to 2.9 km/s, and attains a maximum thickness of approximately 1/2 km (Fig. 13). Reflectors in the unit are mainly parallel (Table 1), except off Virginia and Long Island, where an oblique - progradational arrangement of the reflectors

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Figure 13 near here

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indicates a probable outbuilding of the unit at the shelf edge. The lower contact can be marked by subtle channeling and minor low-angle truncation of older reflectors, but over much of the area, it is conformable with the unit below. In the northern part of the trough, the upper contact is easily discerned largely because of downlap of reflectors in unit G above (Fig. 5A-B).

The reflectors show low to high continuity and moderate to high seismic intensity. Over most of the shelf, the pattern of the reflectors suggests marine shelf, where presumably clastic sediments and lime muds accumulated under contrasting energy conditions (well-bedded sequence near line 2; less well stratified sequence on lines 3 and 11). Off Virginia and Long Island, the arrangement of the reflectors in an oblique-progradational pattern under the outer edge of the shelf suggests that the margin may have built seaward in certain areas. Small reeflike buildups are inferred to exist along line 15; they appear on the record as small lensoid masses containing discontinuous internal reflectors. As can be seen from the isopach map (Fig. 13), unit F has an irregular pattern of thickness, probably because its geometry approximates more a sheet than a wedge.

Averaged interval velocities range from 1.9 to 2.9 km/s, but are mainly 2.2 - 2.5 km/s. The rock types are known in the two COST holes drilled off New Jersey; 0.3 km of shale, claystone, and argillaceous limestone were found in the COST No. B-2 well, and 0.35 km of white biomicritic limestone and claystone (Adinolfi and Jacobson, 1979) were found in the COST No. B-3 well. The rocks in the COST holes contain abundant "slope" planktic assemblages

Figure 13. Unit F thickness depositional environment and averaged interval velocity (km/s). The dots indicate control for thickness. Velocity values are the arithmetic mean of 3 to 5 shot points between the black lines. Italicized values are averages for the profiles that parallel the coastline.

(Poag, 1980b). Rocks in this interval have also been dredged and drilled on the Continental Slope (Weed and others, 1974)where they formed in a deep-water environment, not unlike their present environment (Poag, 1978).

Unit G

Unit G is inferred to be a series of broad progradational deltaic wedges and shelf-edge deposits of late Oligocene and Miocene age (Figs. 5B, 14). The lower boundary of the unit onlaps over the truncated edge of the underlying unit toward the inner part of the shelf. Under the

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Figure 14 near here

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middle and outer parts of the shelf, the unit broadly downlaps the older unit, building broad flat sedimentary aprons across the shelf; the aprons are shown as a low-angle foreset internal arrangement of reflectors on cross shelf profiles (Fig. 5A) whereas they are shown as low flattened mounds consisting of broadly downlapping reflectors on profiles that parallel the coast (and depositional strike). Lower reflectors of the unit above (unit H) unconformably overlie the truncated reflectors in the top of this unit, or the boundary is marked by apparent channeling of unit F. Many sections show a parallel arrangement of reflectors, though a sigmoid or complex oblique arrangement is present on many others, particularly for the northern part of the trough. Shelf-edge progradations seem to typify the southern part.

The acoustic facies (Fig. 14) are thought to be mainly those of a marine shelf, prograded at the shelf edge in the south, and to be broadly prograded south of Long Island. The area of broad progradation is similar to a deltaic lobe as was first noticed by Garrison (1970), who thought

Figure 14. Unit G, thickness depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Velocity values are the arithmetic mean of 3 to 5 shotpoints between the black lines. Italicized values are averages for profiles that parallel the coastline.

it was Oligocene in age. In the COST No. B-2 well (Scholle, 1977, figure 4), unit G is shale, coarse-grained sand, and mudstone postulated to have accumulated in a shelf and deltaic environment (Poag, 1980a). The unit was drilled in AMCOR holes 6007B, 6010, and 6011 (Hathaway and others, 1979), where a similar deltaic and marginal-marine environment was inferred (Poag, 1978 and 1980a).

The thickness of unit G (Fig. 14) increases form 0.2 km nearshore to about 1 km at the outer edge of the shelf. Over the northern part of the trough, in the area of deltaic outbuilding and shelf-edge progradation, thicknesses are greater than 0.5 km. Greater thicknesses in the southern part of the trough are concentrated toward the shelf edge and are associated with seaward progradation of the unit.

Interval velocities average from 1.7 to 2.5 km/s, -- the range of poorly indurated shale (Woollard, 1962, p. III-42). The density of sediment that has this velocity ranges from 1.8 to 2.2 gm/cm^3 (Gardner and others, 1974); as shown by Woollard (1962, p. III-6), the same densities are found for sediments of Recent to Cretaceous age on the Atlantic Coastal Plain of New Jersey.

Unit H

Unit H (Table 1) is a thin sheet of coarse- to fine-grained clastic sediment inferred to be a marine-shelf deposit of Plio-Pleistocene age (Fig. 15). The lower contact on the lines is distinguished mainly by a conformable sequence of reflectors above and a truncated group of

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Figure 15 near here

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reflectors below it. Some reflectors downlap near the seaward part of the shelf along lines 11 and 25. Reflectors in unit H are characterized by low to high continuity and by moderately high amplitude. They are mainly

Figure 15. Unit H thickness, depositional environment, and averaged interval velocity (km/s). The dots indicate control for thickness. Velocity values are the arithmetic mean of 3 to 5 shotpoints between the black lines. Italicized values are averages for profiles that parallel the coastline.

parallel or show a low-angle divergence.

The sequence is interpreted as a marine-shelf deposit (Fig. 15), and a shelf-edge progradation is evident in certain areas (lines 25, 10, and 11). The thickness of the sequence is between 0.1 and 0.3 km and increases toward the outer shelf (Fig. 15). In the AMCOR cores (6007, 6008, 6009, 6010, 6011, 6012, 6020, 6021), the unit is mainly alternating sand, silty clay, and clay (Hathaway and others, 1979) approximately 0.12 km thick inshore (6008, 6011) and more than 0.3 km on the upper slope (6012, 6021). Poag (1978) postulated marginal-marine to lagoonal and fluvial environments for the Pleistocene section drilled in the inner shelf holes; the same section offshore was formed in an inner marine shelf and lagoonal milieu.

Averaged interval velocities for unit H are between 1.51 and 2.09 km/s. The range is similar to the one Woollard (1962, p. III-42) has compiled for terrigenous mud and saturated sand and silt. Hence, poorly consolidated sand, clayey silt, and clay fit well with velocity values observed.

DISCUSSION

Having described the depositional sequences, I wish to consider larger trends in thickness, and the depths to key boundaries (base of Cenozoic and base of the Cretaceous). By combining units A and B, the thickness of probable Jurassic and Triassic rocks is obtained; a combination of the isopachs from units C, D, and E and F, G, and H gives the thickness of the Cretaceous and Cenozoic, respectively (Fig. 16).

Figure 16 near here

Units A and B together (Fig. 16A) are as much as 12 km thick in a depocenter in the northern part of the trough. The sequence thins in an irregular manner toward Long Island because it fills a north-trending graben there. Thinning toward the New Jersey coastline is abrupt, but it is irregular toward the Carolina platform in the southern part of the trough. The facies for the Jurassic and Triassic Systems (Figs. 7 and 9) are probably mainly nonmarine sedimentary rocks inshore and marine-shelf limestones interbedded with evaporites offshore. Obviously, marine waters were able to extend into the trough, though they had restricted circulation. During the Middle and late Jurassic, conditions apparently became more open so that reefs and banks could form along the seaward side of the trough, probably in a discontinuous manner.

During the Cretaceous (Fig. 16B), sediment accumulated in the trough over a broad area though at a much slower rate than sediment accumulated in the Jurassic and Triassic. The total of thickness values of the next three units (units C, D, and E) indicates that as much as 3.4 km sediment accumulated, mostly in the southern and northern parts of the trough. Sediment in the trough thins rapidly toward the Long Island and Carolina platforms and over the Great Stone dome (1 km). Beneath the Continental Slope, seaward of the trough, a broad blanket of inferred Cretaceous sediments extends to the continental rise, where it is buried by a broad fan of probable Cenozoic age. The Cretaceous units thin gradually to between 1 and 2 km near the coastline. The circular anomaly on line 2(compare Figs. 1 and 16B) is the "Great Stone dome," an intrusive body that was emplaced in the trough during the Early Cretaceous.

The Cretaceous units (Figs. 10, 11, and 12) change upward from mainly nonmarine paleoenvironment (and marine carbonate rocks towards the paleoshelf edge) to a marine-shelf setting in the youngest unit of Cretaceous age. A broad progradation during the Early Cretaceous built the shelf seaward, displacing carbonate bank deposits and eventually covering them. During subsequent marine trangressions, the shelf became more a marine site of deposition as worldwide sea level reached a maximum (Pitman, 1978; Vail

Figure 16. Isopach maps of A, units A and B combined, probable Jurassic and Triassic (?) Systems, B, units C, D, and E combined, probable Cretaceous System, and C, units F, G, and H combined, probable Cenozoic rocks. Control offshore is shown by black dots. Values from land wells are next to circled dots.

and others, 1977, pt. 4). The COST wells show a change from a shallow inner shelf setting eventually to upper slope-outer shelf conditions during the Cretaceous (Poag, 1980a,b).

Similarly, Cenozoic deposits (Fig. 16C) are broadly spread over the trough and adjacent Coastal Plain in overlapping sheets of marine and nonmarine sediment. The maximum thickness is again along the outer part of the Continental Shelf, but the maximum thickness of Cenozoic deposits is 2 km -- much less than accumulated there during the Cretaceous. Despite a broad trend toward gradual lowering of sea level during the Tertiary (Pitman, 1978; Vail and others, 1977, pt. 4), subsidence in the Baltimore Canyon trough was sufficient to maintain a marine milieu over much of the shelf; indeed deep-water conditions prevailed during the early Tertiary. Broad progradational sheets built out in the Miocene following a major sea-level drop in the Oligocene.

A structure-contour map on the base of unit C (Fig. 17A - near the base of the Cretaceous) shows that it deepens over the area to a maximum of 4 1/2 km under the outer part of the Continental Shelf. The overall pattern of the contours is a broad one opening in a seaward direction. The same seaward deepening pattern is indicated in the structure-contour on the base of unit F (near the base of the Paleocene). The base of the Tertiary reaches a maximum depth of 2 km near the outer edge of the shelf (Fig. 17B), and it probably deepens in an irregular manner over the slope -- an area that had periodic intervals of erosion during the Tertiary (Schlee and others, 1979).

An isopach map of all units combined (Fig. 17C) shows that the trough is

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Figure 17 near here

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a broad northeast-trending feature. It is thickest in the northern part, seaward of southern New Jersey, and thins abruptly toward the inner part of the

Figure 17. Structure contour maps on A, the base of unit C (near Jurassic-Cretaceous boundary, and on B, the base of unit F (near base of the Tertiary. Datum is sea level, and onland data are provided from wells shown in Figure 4. Figure 17 C is an isopach map of total sediment thickness, combining all of the thickness values from the seismic units (units A-H) offshore and the information from selected onshore Coastal Plain wells.

shelf in a transition to the Atlantic Coastal Plain. The trough is built over block-faulted rifted crust, which is most evident on the irregular and areally restricted pattern of distribution shown by unit A (Fig. 7). The area of thinning towards the Long Island platform and the Carolina platform is irregular and is marked by grabens and horsts. For the transition to the Carolina platform, the irregular contours are within the zone of major thinning. For the Long Island platform, the zone of major thinning (closeness of contours) is southeast of the area where grabens are present. Absent is good geophysical control in the inner shelf and adjacent bays to extend the basement configuration under the Atlantic Coastal Plain.

The profiles indicate that the trough first formed mainly under the New Jersey shelf and gradually spread to the west and south during post-rifting subsidence (Falvey, 1974). The trough is asymmetrical in cross section because the slope of the basement is much less under the Coastal Plain than it is under the shelf, where pronounced steepening (hinge zone?) occurs.

The general pattern of margin formation inferred for the Baltimore Canyon trough is very similar to that of the Scotian basin off eastern Canada (Given, 1977; Bally, 1976; Jansa and Wade, 1975 a, b; King, 1975; Eliuk, 1978). As can be seen from the schematic cross section (Given, 1977, figure 18g) of the Scotian margin (Fig. 18), the margin has seven main elements: 1) a rifted continental basement containing Permian and Triassic (?) clastic sedimentary rocks from pre-rift basins, 2) a rift-valley stage in the Late Triassic and

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Figure 18 near here

Early Jurassic (deposition of red beds and evaporite deposits) after an interval of uplift and erosion (of elevated-tilted edges of blocks), 3) a first major marine transgression (Middle Jurassic) during which limestone was deposited offshore and nonmarine clastic sediments were deposited inshore, 4) localization

Figure 18. Schematic section through the northern Scotian basin showing main stratigraphic units (from Given, 1977).

of carbonate banks over basement highs (Middle and Late Jurassic), 5) a major deltaic-regressive phase during the Early Cretaceous, 6) a Late Cretaceous transgression, and 7) a Tertiary (Paleocene) regression during which the broad configuration of the margin was established by progradation of the shelf (as overlapping wedges of clastic sediment) and deposition of a lower slope-rise wedge of sediment. A similar pattern exists in the Baltimore Canyon trough. The regressive and transgressive cycles were probably more prevalent in the Cretaceous System of the Baltimore Canyon trough than in the Scotian basin. Given (1977) distinguished a Permian(?) pre-rift basin. Whether Permian rocks exist under the Baltimore trough is not known, nor do we know how to distinguish them from the rocks in syntectonic rift-basins of Late Triassic and Early Jurassic age. Notwithstanding these minor differences, both margins appear to fit the models of Falvey (1974) and Kinsman (1975) for Atlantic-type margins, where a rift phase is followed by a broad subsidence phase. Falvey's model involves block faulting and accumulation of red beds and evaporite deposits (see Van Houten, 1977), and Kinsman's model involves subsidence and accumulation of a massive sedimentary prism over deposits of an earlier formed phase. Clearly, the paleogeographic reconstruction and seismic stratigraphy given in this paper will need to be modified as exploratory drill holes sample the acoustic-stratigraphic units.

As additional unconformities are recognized in drill holes, the ages and number of the units may need to be changed. But the broad outlines of the trough and its history of subsidence and sedimentation are clear. This study should motivate others to question why the crust has reacted as it has, and where the continental-oceanic crustal boundary is with respect to this broad sedimentary prism.

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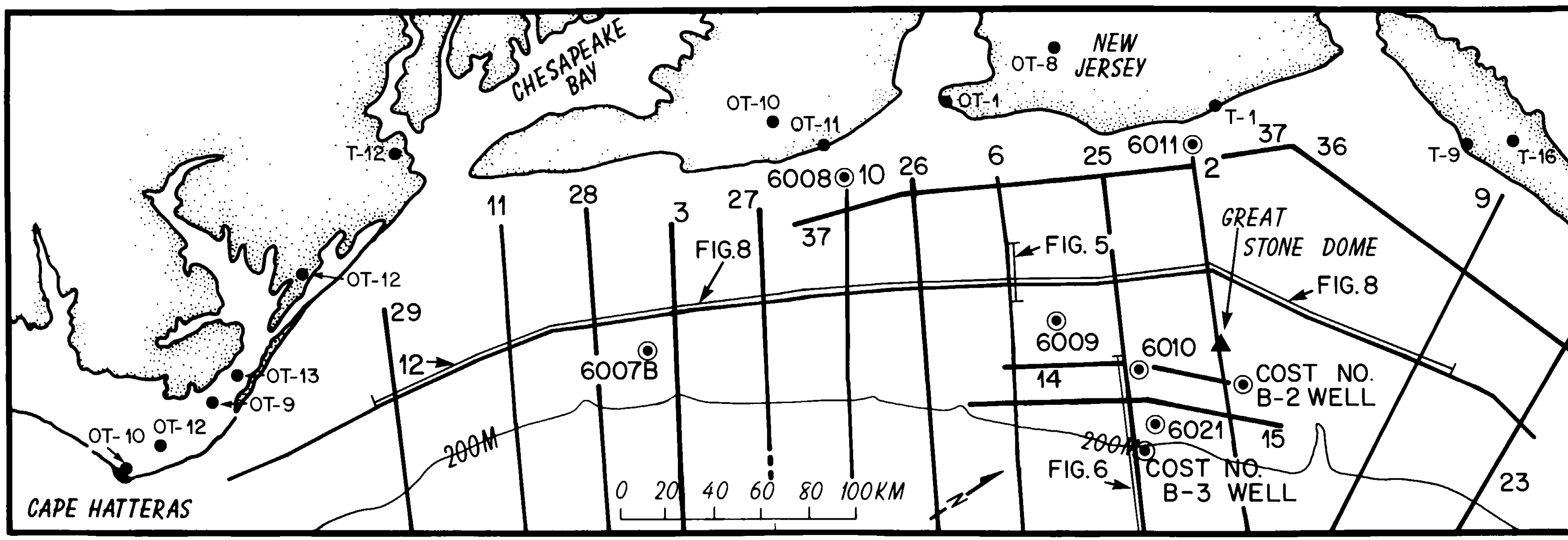

CHESAPEAKE BAY
NEW JERSEY
OT-8
OT-1
T-1
OT-10
OT-11
T-12
OT-12
OT-13
OT-9
OT-10
OT-12
CAPE HATTERAS
T-9
T-16
6011
6008
6007B
6009
6010
6021
GREAT STONE DOME
COST NO. B-2 WELL
COST NO. B-3 WELL
FIG. 5
FIG. 6
FIG. 8
FIG. 8
200M
200M
0 20 40 60 80 100KM
2
3
6
9
10
11
12
14
15
23
25
26
27
28
29
36
37
37

Figure 1

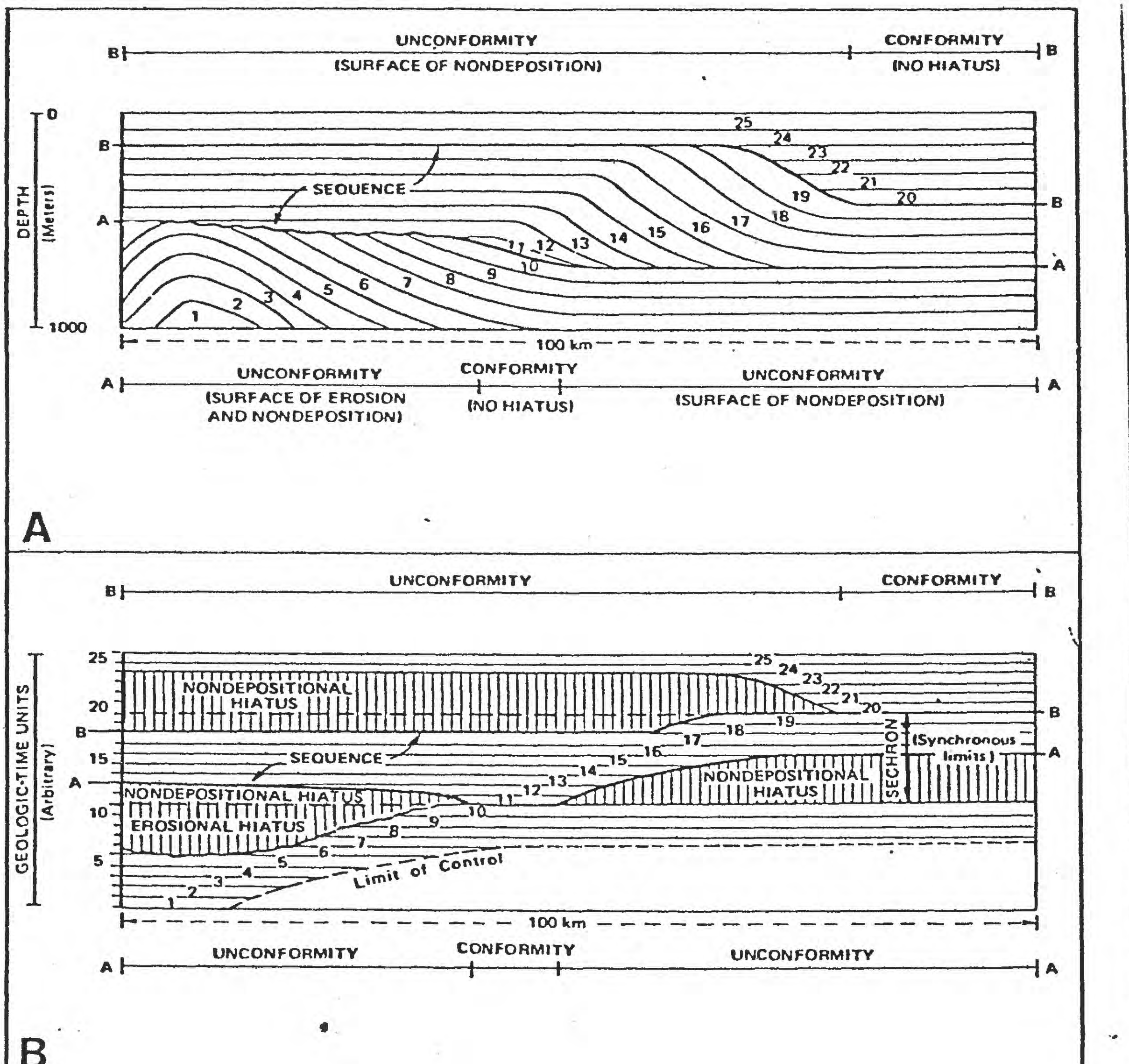

UNCONFORMITY
(SURFACE OF NONDEPOSITION)
CONFORMITY
(NO HIATUS)
DEPTH (Meters)
0
1000
SEQUENCE
100 km
UNCONFORMITY
(SURFACE OF EROSION AND NONDEPOSITION)
CONFORMITY
(NO HIATUS)
UNCONFORMITY
(SURFACE OF NONDEPOSITION)
A
UNCONFORMITY
CONFORMITY
GEOLOGIC-TIME UNITS (Arbitrary)
NONDEPOSITIONAL HIATUS
SEQUENCE
NONDEPOSITIONAL HIATUS
EROSIONAL HIATUS
NONDEPOSITIONAL HIATUS
SECHRON
(Synchronous limits)
Limit of Control
100 km
UNCONFORMITY
CONFORMITY
UNCONFORMITY
B

Figure 2

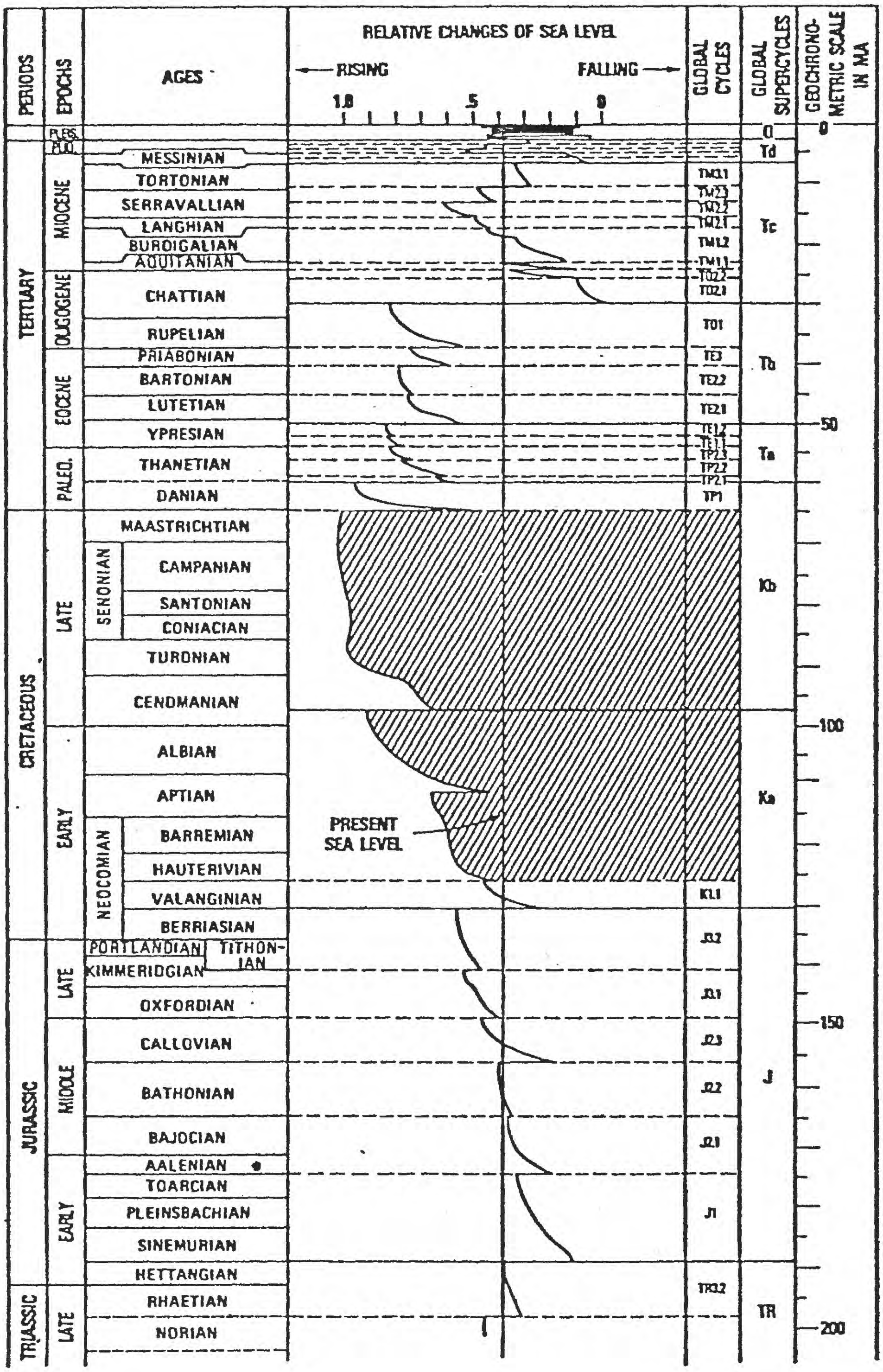
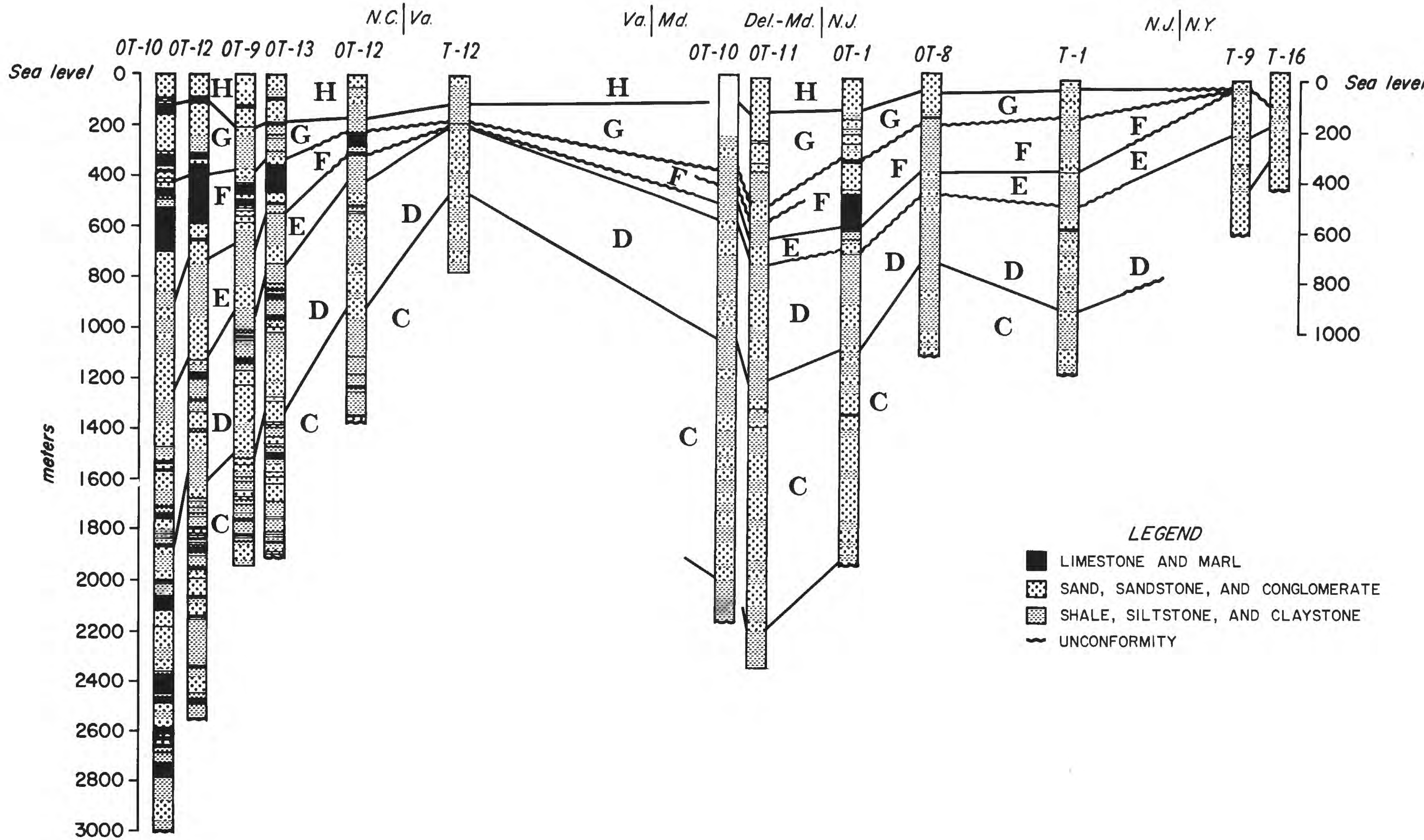

PERIODS
EPOCHS
AGES
RELATIVE CHANGES OF SEA LEVEL
RISING
FALLING
1.0
.5
0
GLOBAL CYCLES
GLOBAL SUPERCYCLES
GEOCHRONO-METRIC SCALE IN MA
PLEIS.
PLIO.
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
THANETIAN
DANIAN
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
PORTLANDIAN
TITHONIAN
KIMMERIDGIAN
OXFORDIAN
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
TOARCIAN
PLEINSBACHIAN
SINEMURIAN
HETTANGIAN
RHAETIAN
NORIAN
TERTIARY
MIOCENE
OLIGOCENE
EOCENE
PALEO.
CRETACEOUS
LATE
SENONIAN
EARLY
NEOCOMIAN
JURASSIC
MIDDLE
TRIASSIC
PRESENT SEA LEVEL
TM3.1
TM2.3
TM2.2
TM2.1
TM1.2
TM1.1
TO2.2
TO2.1
TO1
TE3
TE2.2
TE2.1
TE1.2
TE1.1
TP2.3
TP2.2
TP2.1
TP1
KL1
J3.2
J3.1
J2.3
J2.2
J2.1
J1
TR3.2
Q
Td
Tc
Tb
Ta
Kb
Ka
J
TR
0
50
100
150
200

Figure 3



N.C. | Va.
Va. | Md.
Del.-Md. | N.J.
N.J. | N.Y.
OT-10 OT-12 OT-9 OT-13 OT-12 T-12 OT-10 OT-11 OT-1 OT-8 T-1 T-9 T-16
Sea level
meters
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000
0 200 400 600 800 1000
H G F E D C
LEGEND
LIMESTONE AND MARL
SAND, SANDSTONE, AND CONGLOMERATE
SHALE, SILTSTONE, AND CLAYSTONE
UNCONFORMITY

Figure 4A

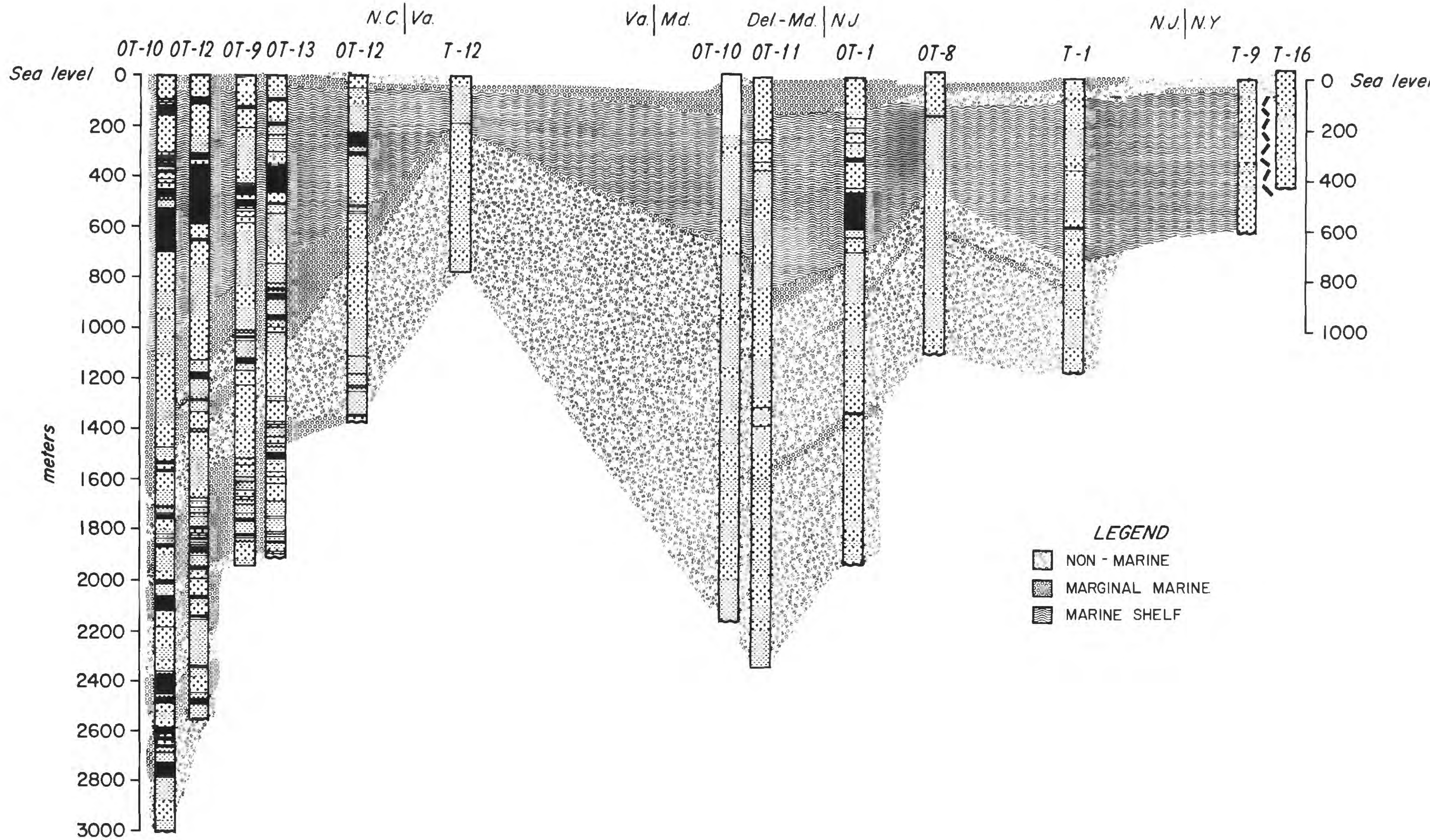

N.C. | Va.
Va. | Md.
Del.-Md. | N.J.
N.J. | N.Y.
OT-10 OT-12 OT-9 OT-13 OT-12 T-12 OT-10 OT-11 OT-1 OT-8 T-1 T-9 T-16
Sea level
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
meters
0 Sea level
200
400
600
800
1000
LEGEND
NON - MARINE
MARGINAL MARINE
MARINE SHELF

Figure 4B

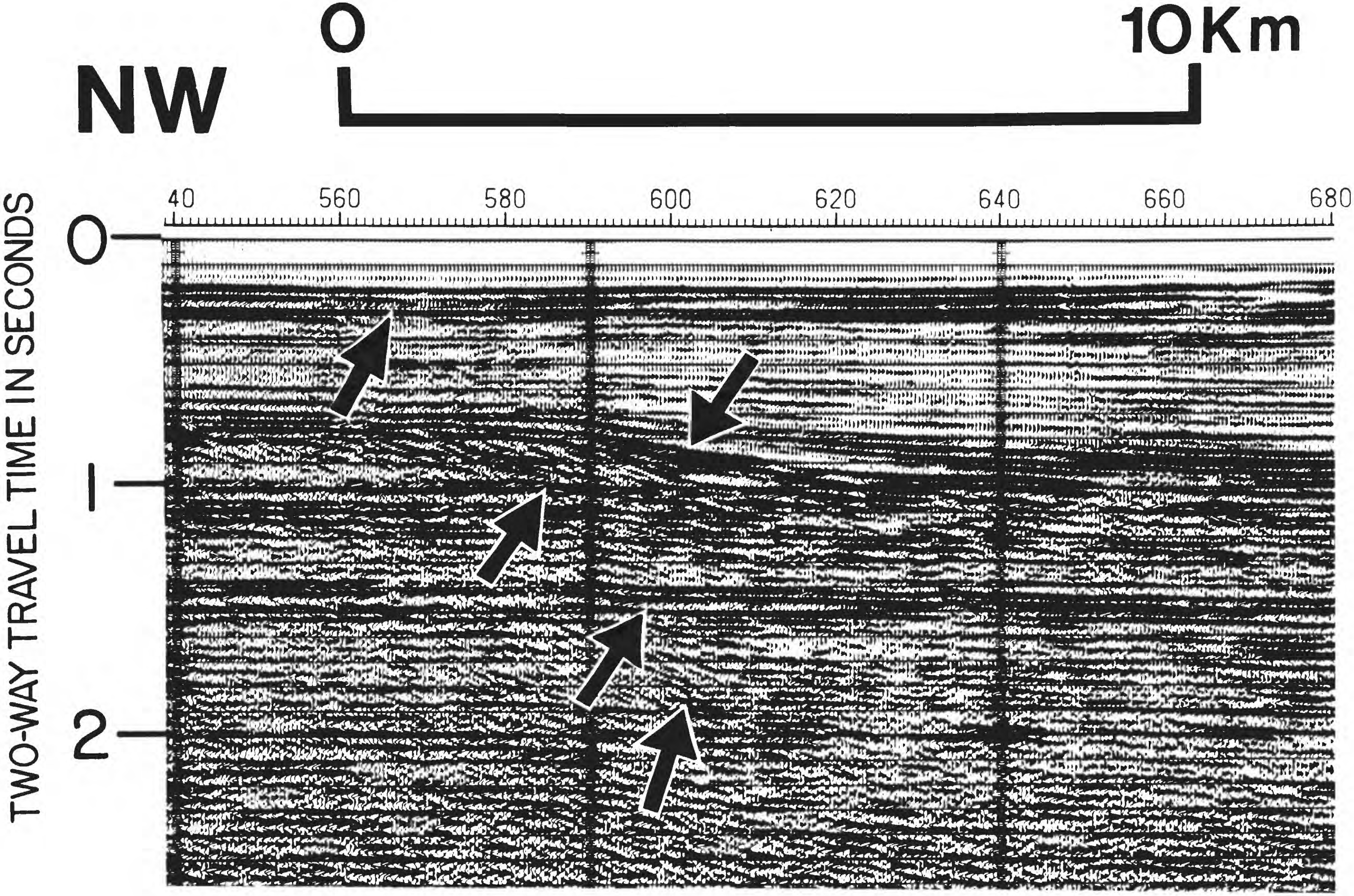

NW
0
10Km
40
560
580
600
620
640
660
680
TWO-WAY TRAVEL TIME IN SECONDS
0
1
2

Figure 5A

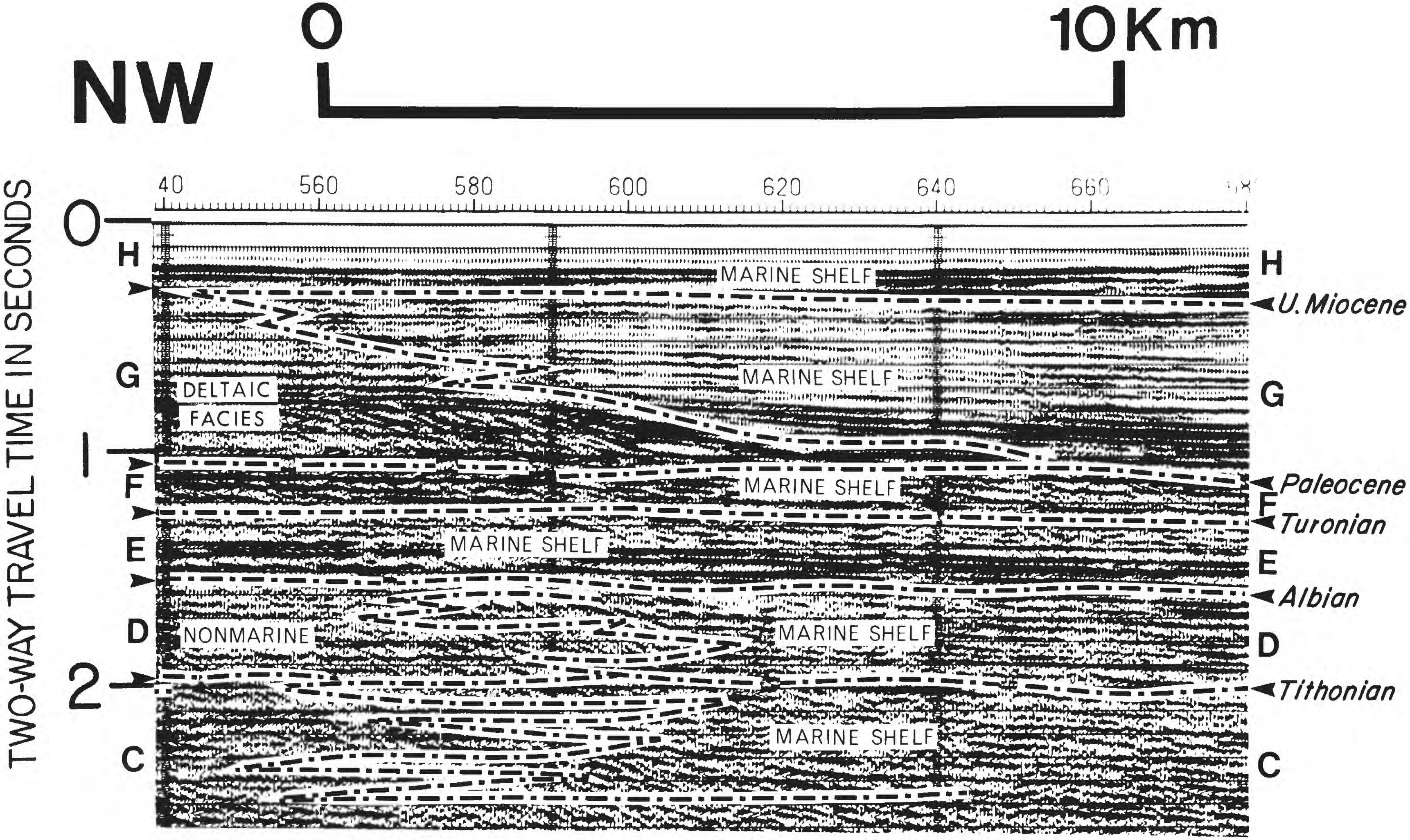

NW
0
10Km
TWO-WAY TRAVEL TIME IN SECONDS
0
1
2
40
560
580
600
620
640
660
H
G
F
E
D
C
MARINE SHELF
DELTAIC
FACIES
MARINE SHELF
MARINE SHELF
MARINE SHELF
NONMARINE
MARINE SHELF
MARINE SHELF
U. Miocene
Paleocene
Turonian
Albian
Tithonian

Figure 5B

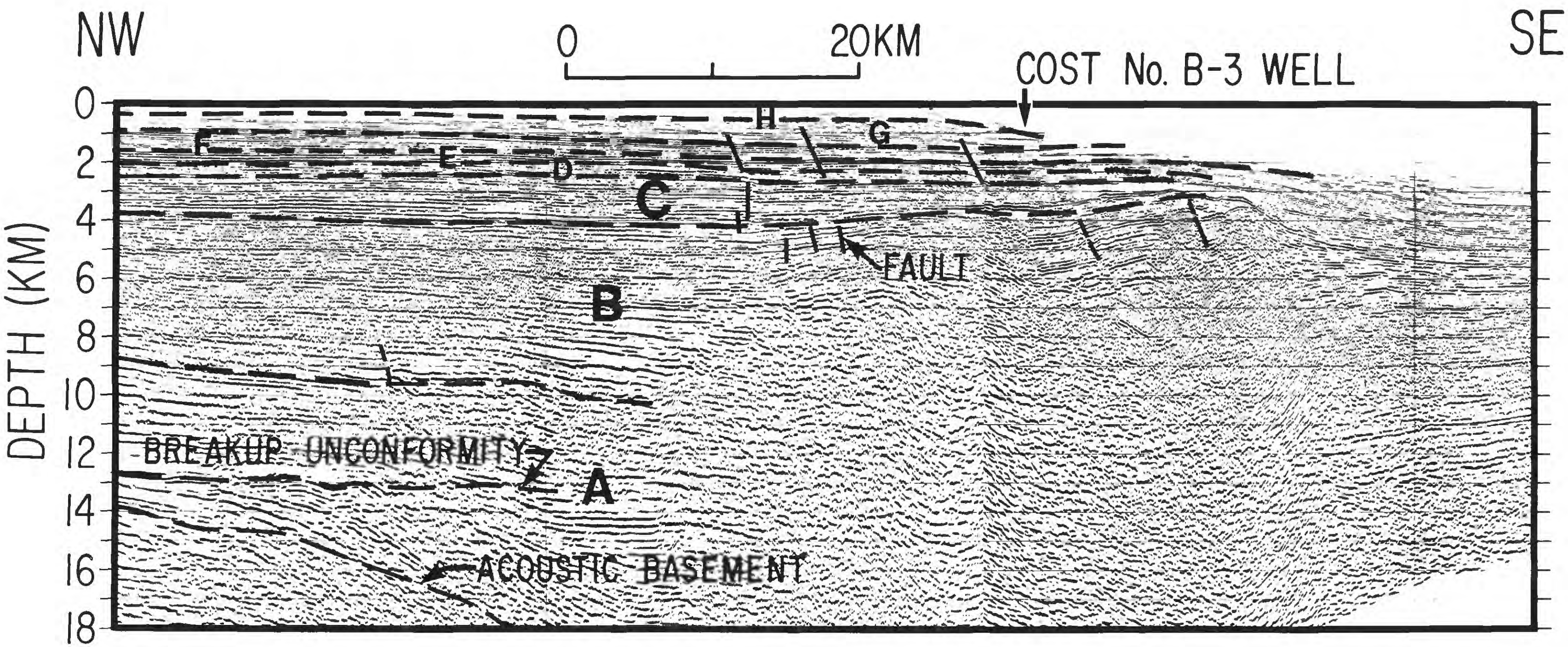
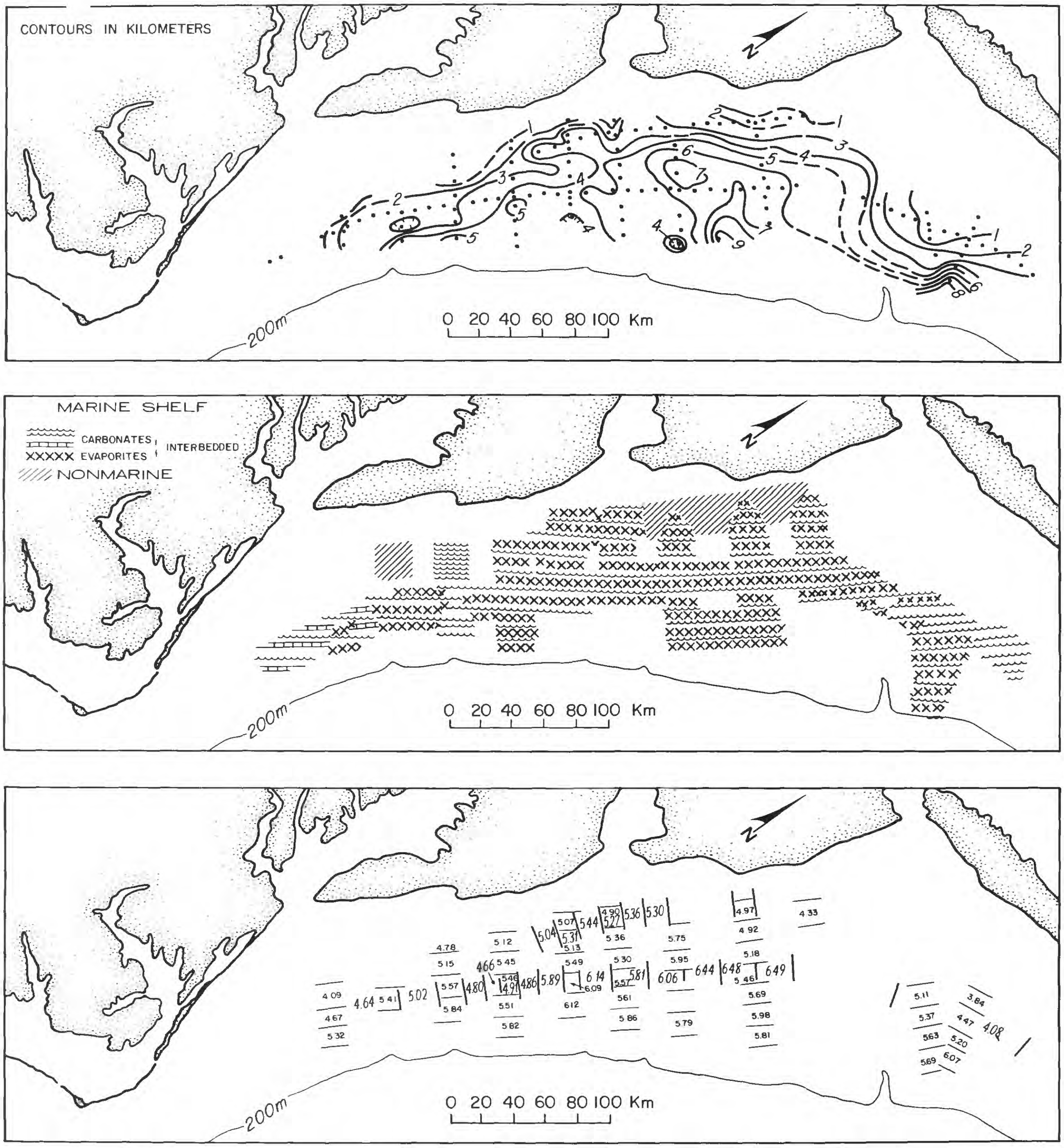

NW
0
20KM
SE
COST No. B-3 WELL
DEPTH (KM)
0
2
4
6
8
10
12
14
16
18
H
G
F
E
D
C
B
A
FAULT
BREAKUP UNCONFORMITY
ACOUSTIC BASEMENT

Figure 6



CONTOURS IN KILOMETERS
200m
0 20 40 60 80 100 Km
MARINE SHELF
CARBONATES
EVAPORITES
INTERBEDDED
NONMARINE
200m
0 20 40 60 80 100 Km
200m
0 20 40 60 80 100 Km

Figure 7

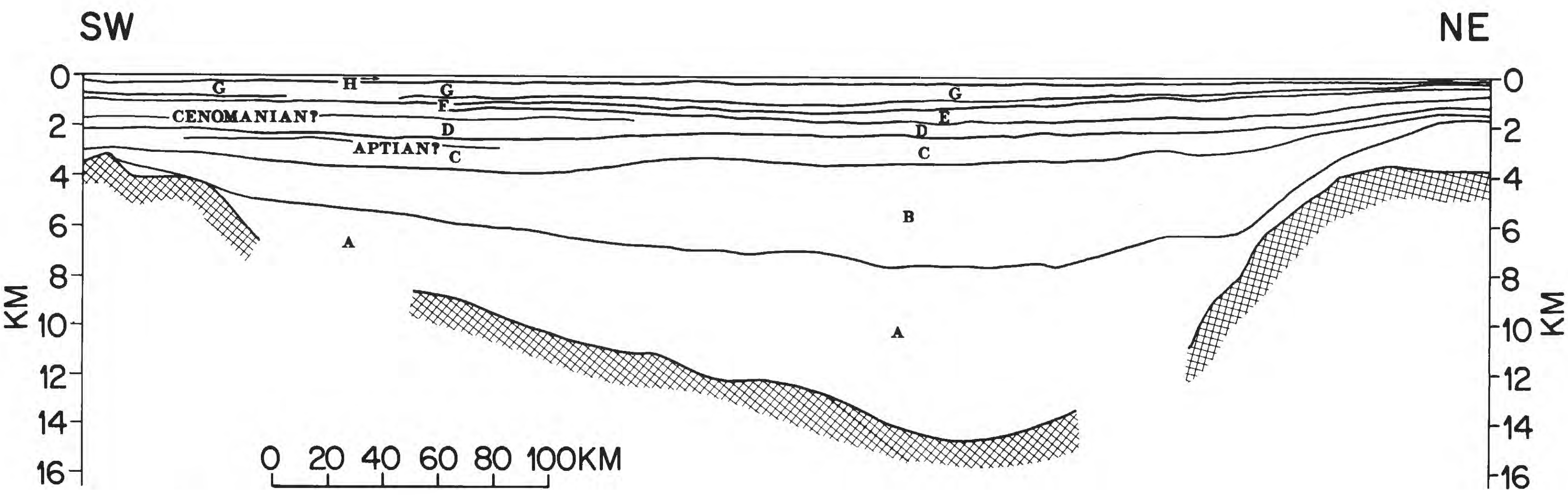

SW
NE
0
2
4
6
8
10
12
14
16
KM
H
G
F
E
D
C
B
A
CENOMANIAN?
APTIAN?
0 20 40 60 80 100KM

Figure 8

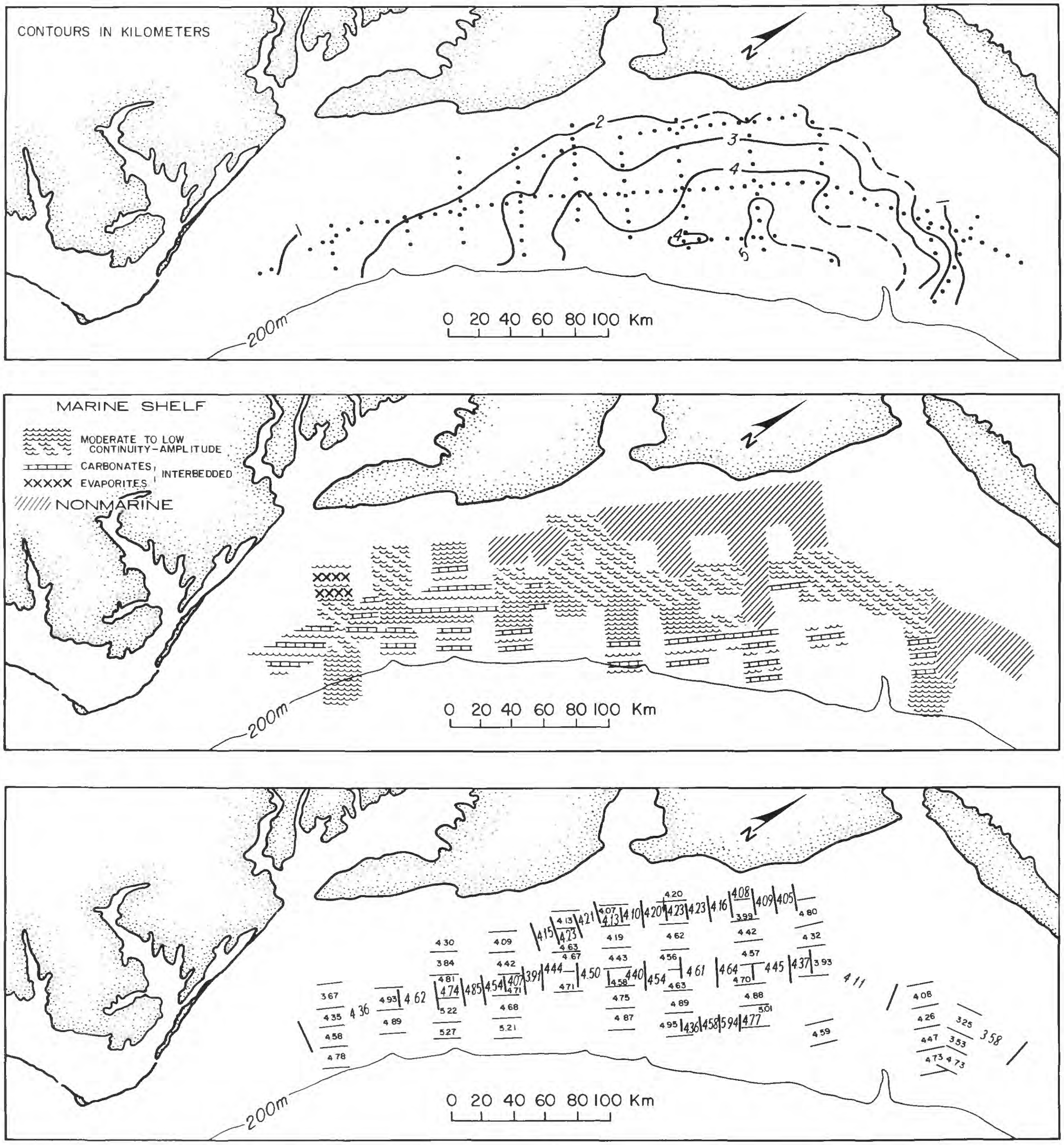

CONTOURS IN KILOMETERS
N
2
3
4
4
5
200m
0 20 40 60 80 100 Km
MARINE SHELF
MODERATE TO LOW CONTINUITY-AMPLITUDE
CARBONATES
XXXXX EVAPORITES
INTERBEDDED
NONMARINE
N
200m
0 20 40 60 80 100 Km
N
200m
0 20 40 60 80 100 Km

Figure 9

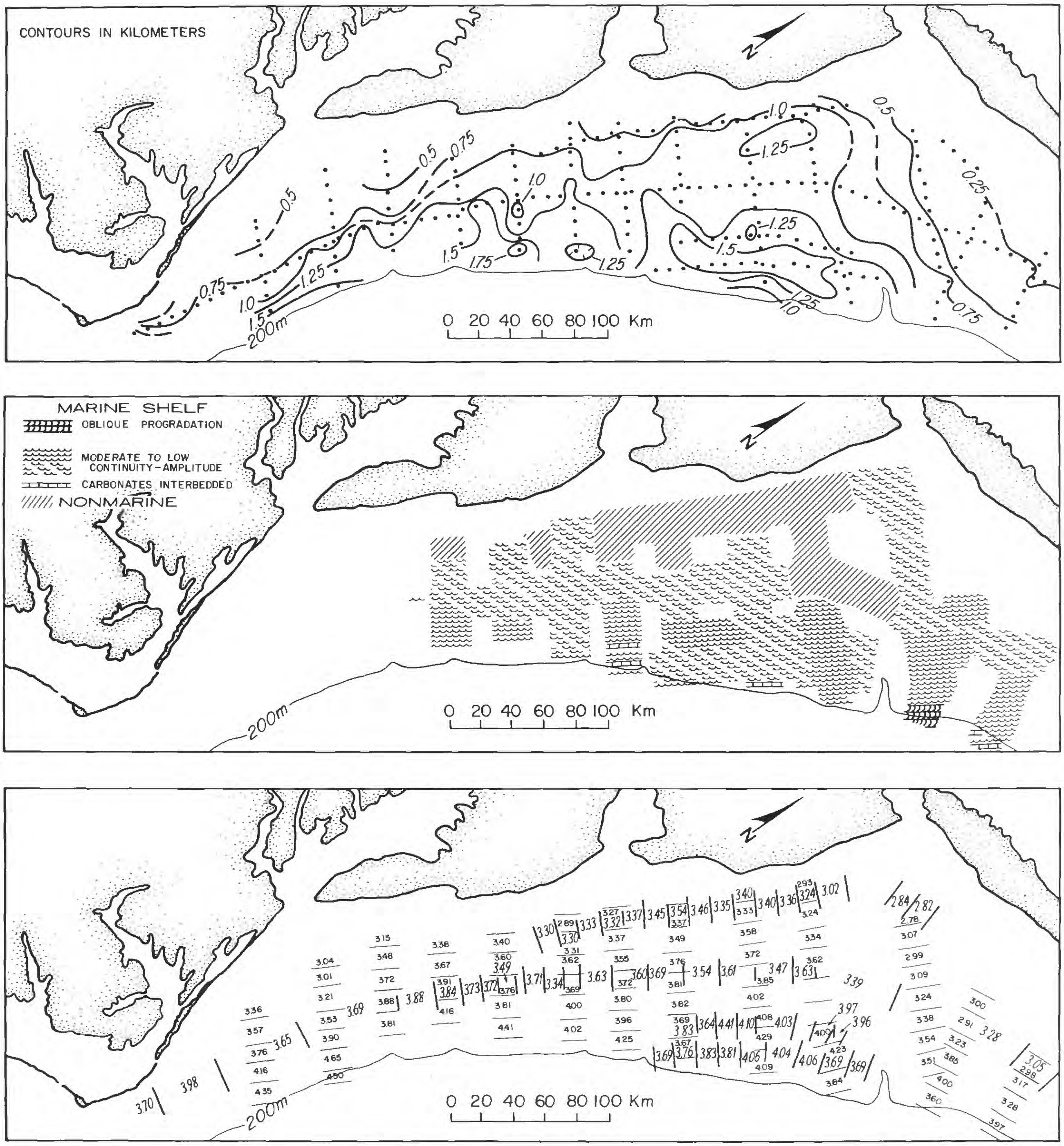

CONTOURS IN KILOMETERS
0 20 40 60 80 100 Km
200m
MARINE SHELF
OBLIQUE PROGRADATION
MODERATE TO LOW CONTINUITY-AMPLITUDE
CARBONATES INTERBEDDED
NONMARINE
0 20 40 60 80 100 Km
200m
0 20 40 60 80 100 Km
200m

Figure 10

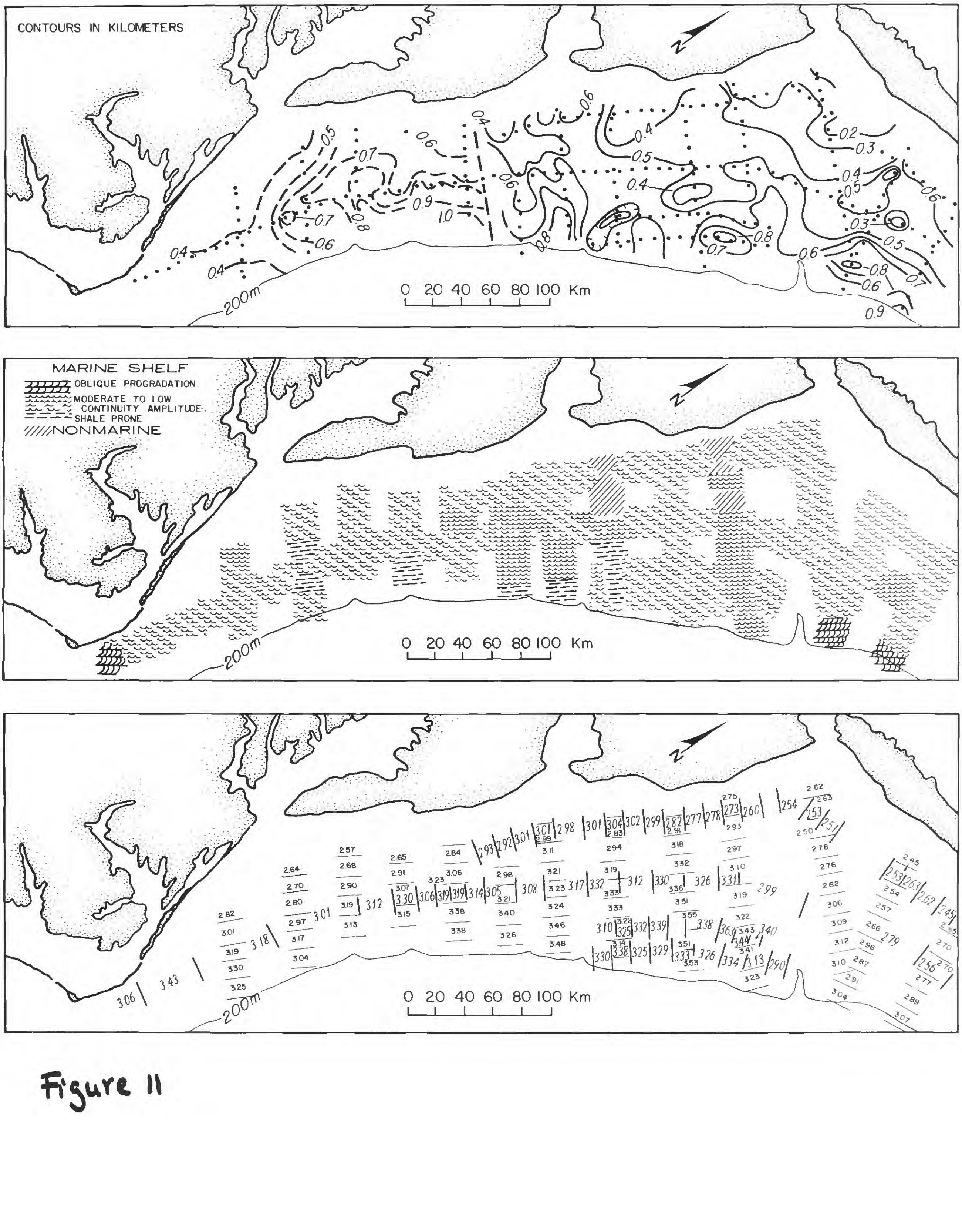

CONTOURS IN KILOMETERS
N
0 20 40 60 80 100 Km
200m
MARINE SHELF
OBLIQUE PROGRADATION
MODERATE TO LOW CONTINUITY AMPLITUDE
SHALE PRONE
NONMARINE

Figure 11

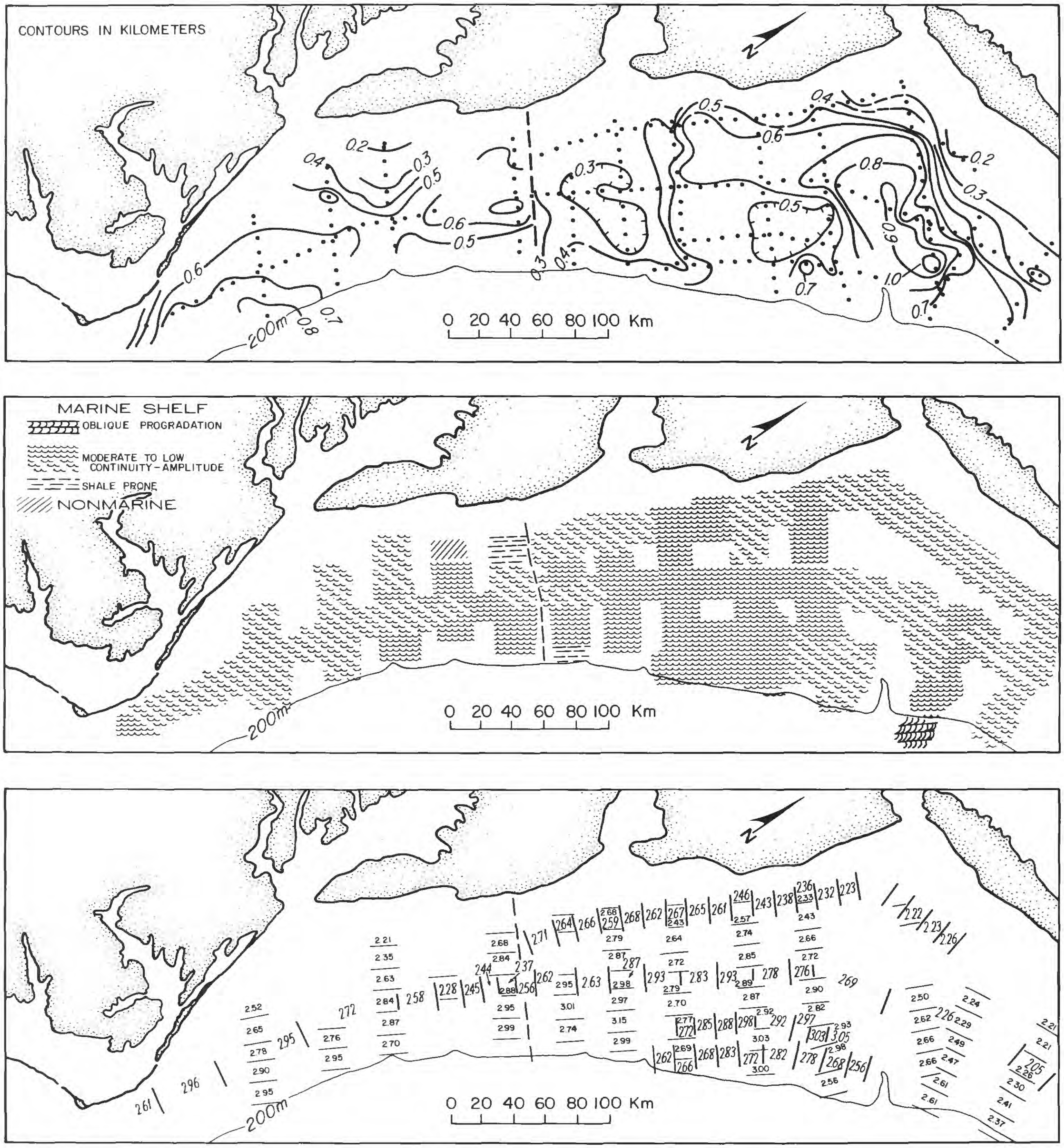
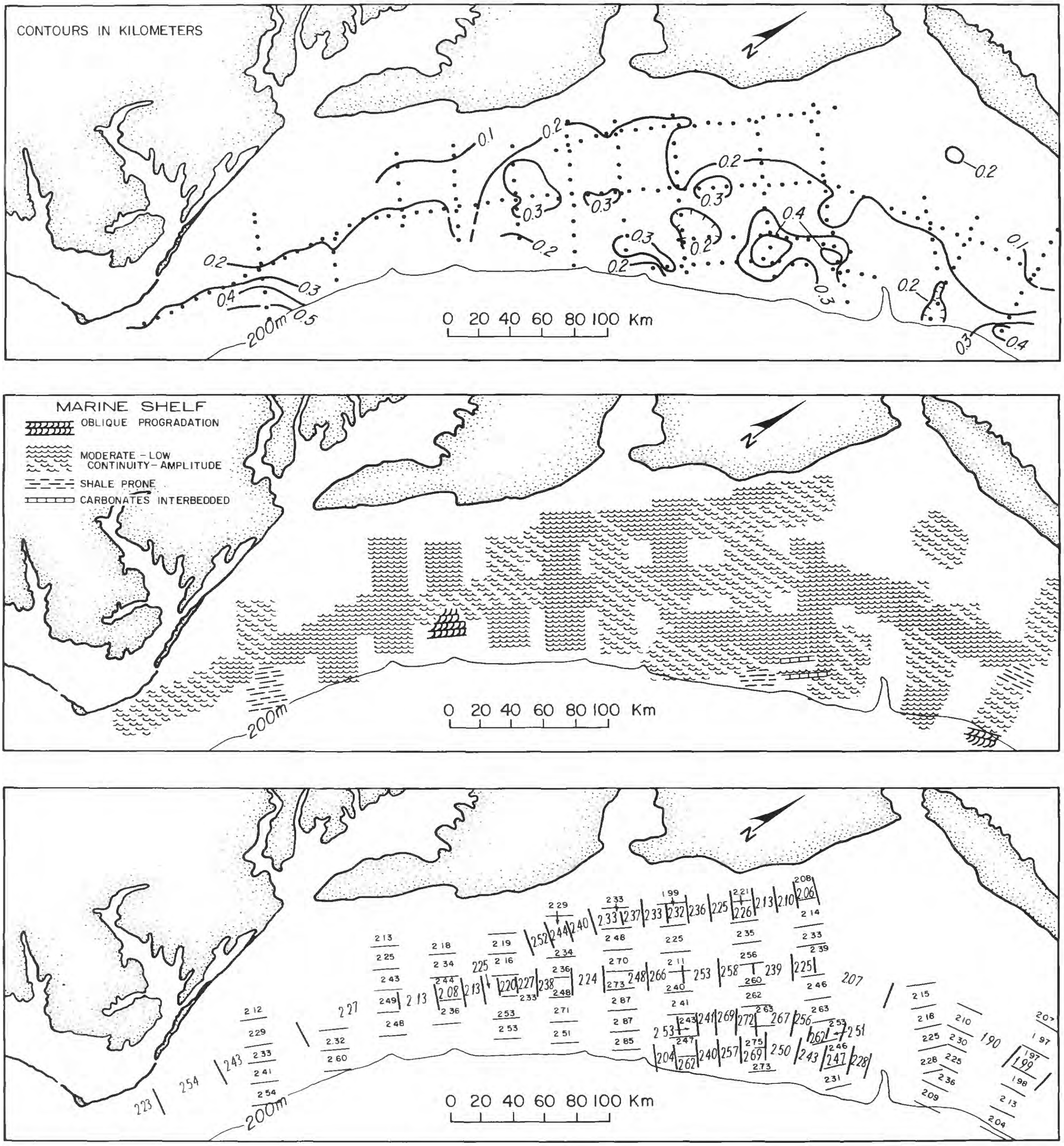

CONTOURS IN KILOMETERS
N
0 20 40 60 80 100 Km
200m
MARINE SHELF
OBLIQUE PROGRADATION
MODERATE TO LOW CONTINUITY-AMPLITUDE
SHALE PRONE
NONMARINE
N
0 20 40 60 80 100 Km
200m
N
0 20 40 60 80 100 Km
200m

Figure 12



CONTOURS IN KILOMETERS
0 20 40 60 80 100 Km
200m
MARINE SHELF
OBLIQUE PROGRADATION
MODERATE - LOW CONTINUITY- AMPLITUDE
SHALE PRONE
CARBONATES INTERBEDDED
0 20 40 60 80 100 Km
200m
0 20 40 60 80 100 Km
200m

Figure 13

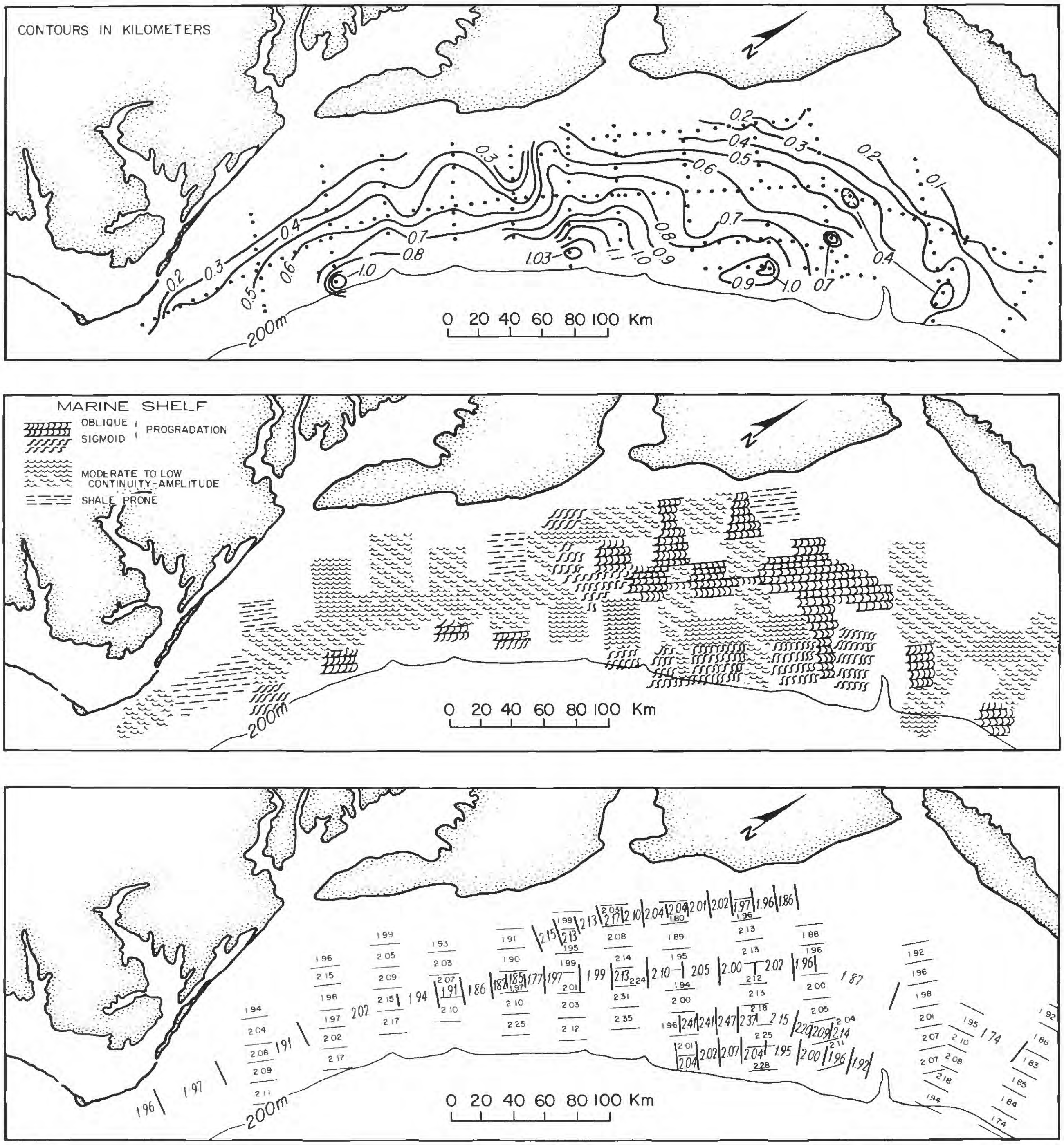

CONTOURS IN KILOMETERS
N
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.03
0.1
200m
0 20 40 60 80 100 Km
MARINE SHELF
OBLIQUE
SIGMOID
PROGRADATION
MODERATE TO LOW CONTINUITY-AMPLITUDE
SHALE PRONE
N
200m
0 20 40 60 80 100 Km
N
200m
0 20 40 60 80 100 Km

Figure 14

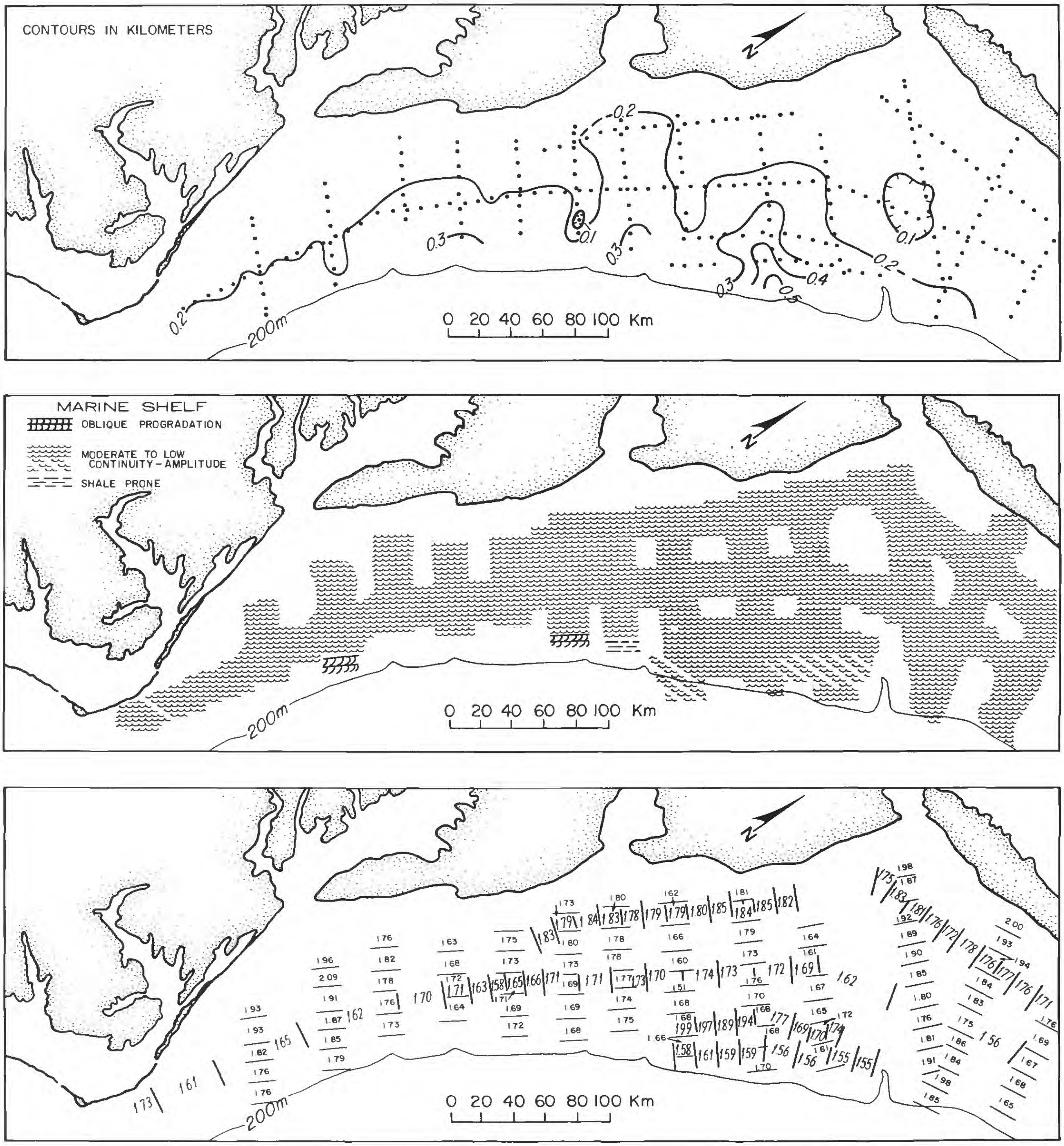

CONTOURS IN KILOMETERS
N
0.2
0.3
0.1
0.4
0.5
200m
0 20 40 60 80 100 Km
MARINE SHELF
OBLIQUE PROGRADATION
MODERATE TO LOW CONTINUITY - AMPLITUDE
SHALE PRONE
N
200m
0 20 40 60 80 100 Km
N
200m
0 20 40 60 80 100 Km

Figure 25

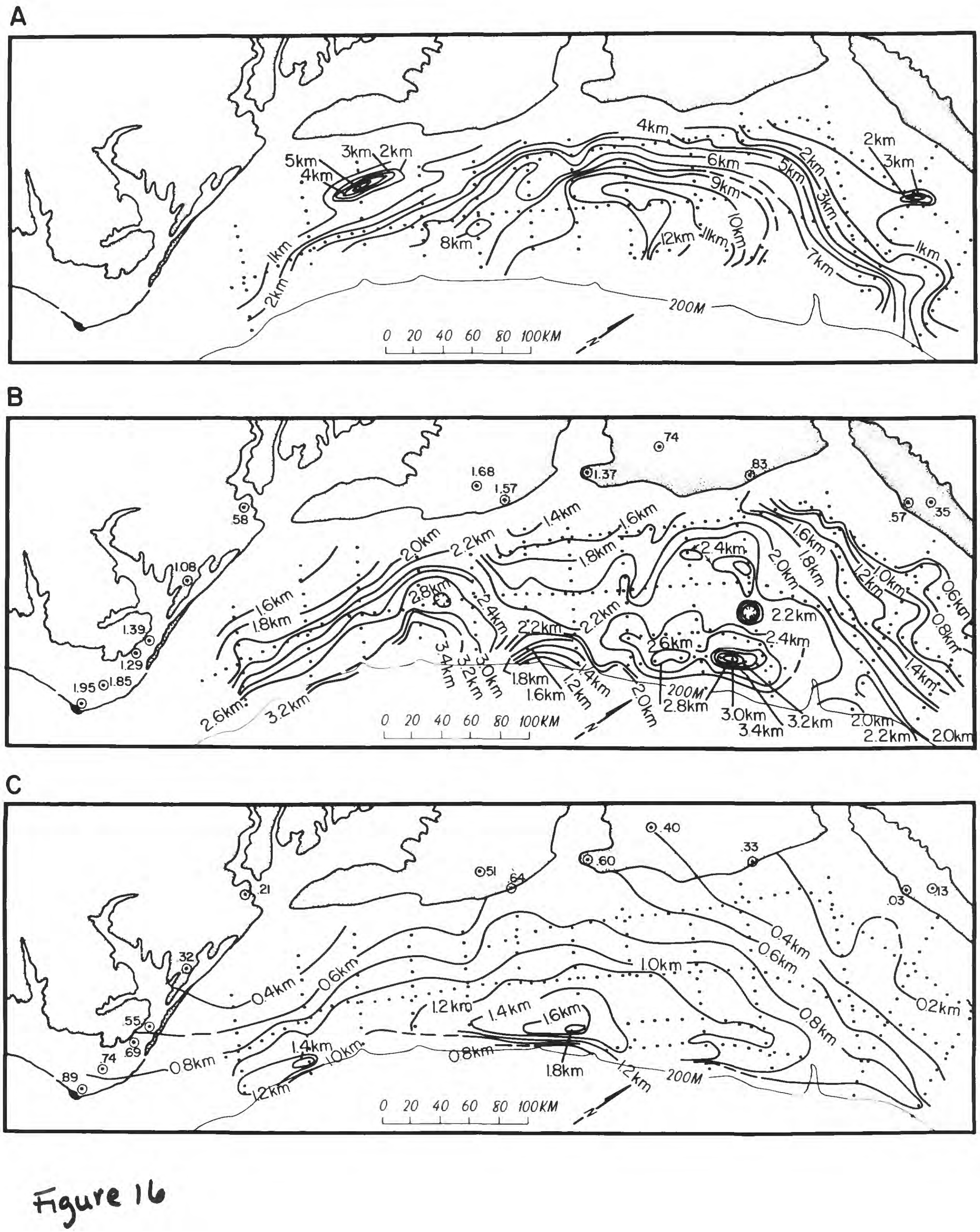

A
5km
3km
2km
4km
4km
6km
2km
5km
9km
3km
10km
8km
12km
11km
1km
7km
1km
2km
3km
2km
200M
0 20 40 60 80 100KM
B
74
1.68
1.37
83
1.57
58
.57
35
1.4km
1.6km
2.0km
2.2km
1.8km
2.4km
1.6km
1.8km
1.08
1.6km
2.0km
1.2km
1.0km
0.6km
1.8km
2.8km
2.4km
2.2km
2.2km
2.2km
0.8km
1.39
2.2km
2.6km
2.4km
1.29
3.4km
3.2km
3.0km
1.8km
1.6km
1.2km
1.4km
2.0km
200M
2.8km
3.0km
3.4km
3.2km
1.4km
1.95
1.85
2.6km
3.2km
2.0km
2.2km
2.0km
0 20 40 60 80 100KM
C
.40
.33
.60
.51
.64
.21
.03
.13
0.4km
0.6km
1.0km
.32
0.4km
0.6km
0.2km
1.2km
1.4km
1.6km
0.8km
.55
1.4km
.69
.74
0.8km
1.0km
0.8km
1.8km
1.2km
200M
.89
1.2km
0 20 40 60 80 100KM

Figure 16

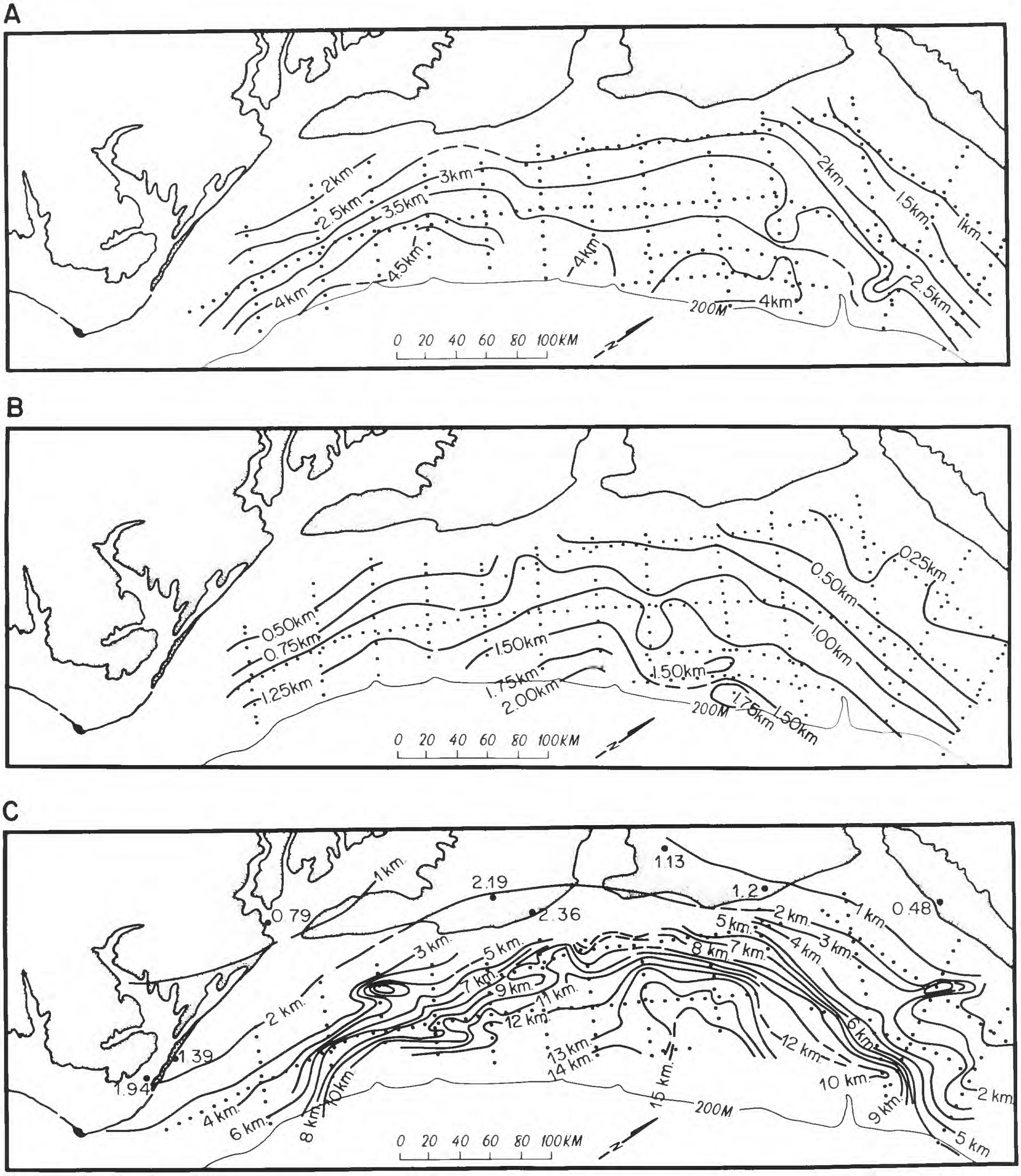

A
2km
3km
2.5km
3.5km
4.5km
4km
4km
200M
4km
2km
1.5km
1km
2.5km
0 20 40 60 80 100KM
B
0.50km
0.75km
1.25km
1.50km
1.75km
2.00km
1.50km
200M
1.75km
1.50km
0.50km
0.25km
1.00km
0 20 40 60 80 100KM
C
1km
2.19
1.13
1.2
0.79
2.36
0.48
2 km
1 km
5 km
3 km
4 km
7 km
8 km
3 km
5 km
7 km
9 km
11 km
12 km
2 km
1.39
1.94
4 km
6 km
8 km
10km
13 km
14 km
15 km
12 km
6 km
10 km
200M
9 km
2 km
5 km
0 20 40 60 80 100KM

Figure 17

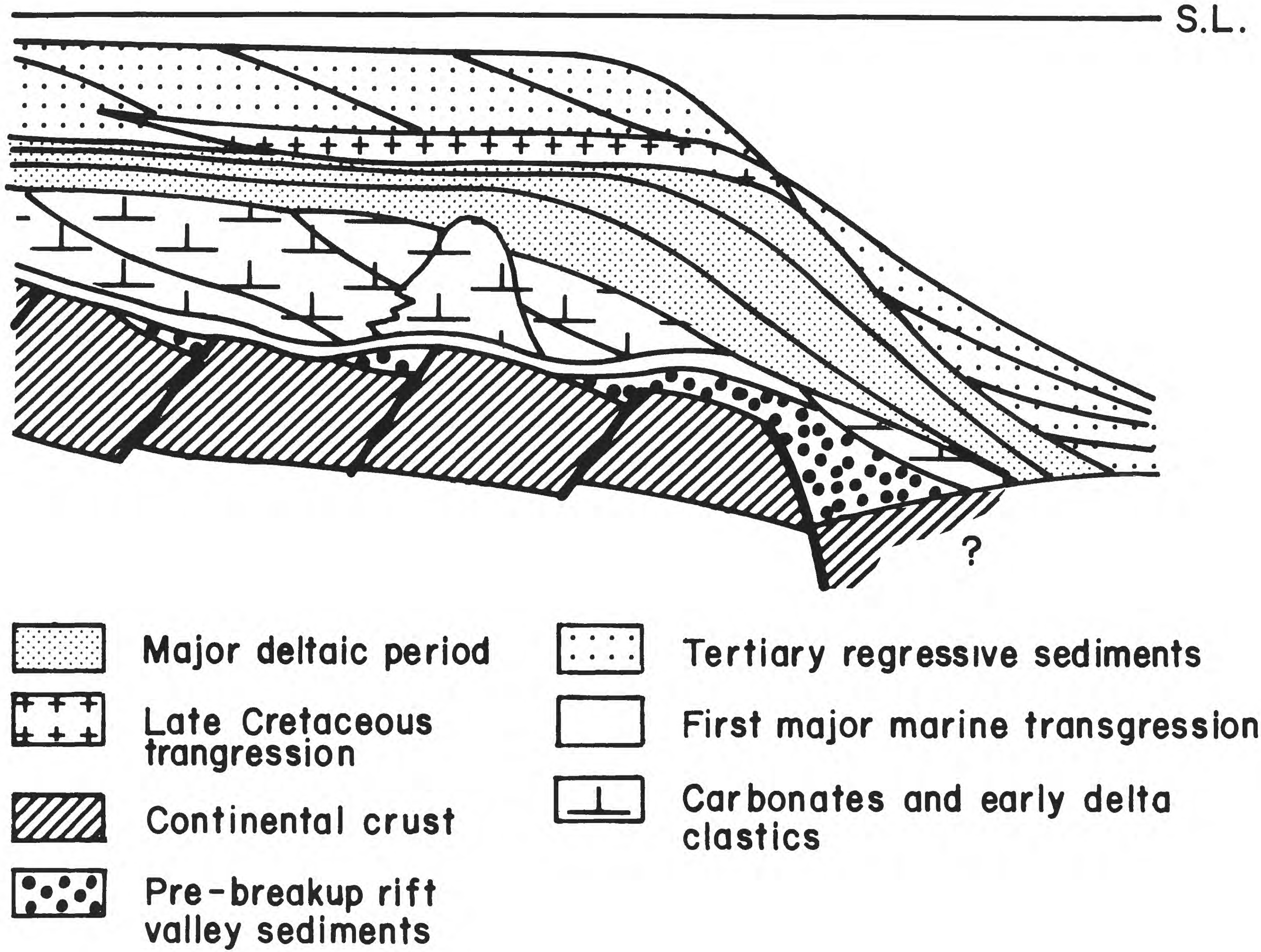

S.L.
?
Major deltaic period
Late Cretaceous trangression
Continental crust
Pre-breakup rift valley sediments
Tertiary regressive sediments
First major marine transgression
Carbonates and early delta clastics

Figure 18