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Mesozoic–Cenozoic regressions and the development of the margin off northeastern North America

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ABSTRACT

The development of the passive margin off northeastern North America was influenced by three major pre-Quaternary regressions. The first occurred in latest Early Jurassic as a result of the separation of Africa from N. America. The second took place from latest Jurassic to earliest Late Cretaceous in response to the opening of the Bay of Biscay and the separation of North America and Eurasia. During this second regression, large segments of the shelf were uplifted and eroded, and terrigenous wedges prograded over and buried outer shelf Mesozoic reef/bank carbonate complexes. The first submarine canyons were cut by turbidity currents on the continental slope at this time. The third regression acompanied a world-wide cooling which began in the late Eocene. Once again, the shelf underwent erosion and canyons were carved or exhumed by turbidity flows on the outer shelf and continental slope. These canyons served as conduits for the transport of large quantities of sediment to the continental rise. Despite the fact that eustatic sea-level changes caused by continental glaciation during the Plio-Pleistocene have modified and occasionally completely obliterated the effects of these earlier regressions, their significance for the evolution of the margin off northeastern North America is apparent.

Introduction

In his numerous publications Bruce C. Heezen demonstrated that the two major processes that controlled the Quaternary development of passive margins, such as the one off northeastern North America, are turbidity and bottom currents. The former introduces the detritus into the basin and the latter re-distributes the detritus brought into the basin. As will be demonstrated below both of these processes were active not only in the Quaternary, but throughout the sedimentary history of the margin. Undoubtedly, much of the present surface morphology of mid-plate margins like the one off northeastern North America is the result of Pleistocene and Holocene events. Estuaries, barrier islands, lagoons, and deltas near the shoreline developed during the last 7000 years in response to a reduction in the rate of rise of Holocene sea level (Moore and Curray, 1974). Shelf morphology was produced by repeated migrations of the shoreline associated with Plio-Pleistocene sea-level fluctuations. At times when the surf zone was located near the present shelf edge, deposition took place at the top of the continental slope. Sediments were then transported down slope by turbidity currents, gravitational slides, slumping, and creep. Because these processes caused considerable erosion on the slope, canyons and gullies were cut which served as natural conduits of sediment from the outer shelf to the continental rise. Detritus carried to the continental rise by turbidity currents resulted in a complex stratigraphic development consisting of overlapping channel, levee, and overbank deposits. Bottom currents introduced further complexity by moving the turbidites laterally along the rise.

For many years, it was felt that Quaternary events were drastically different from those that previously predominated on passive margins. Moore and Curray (1974) stated that, although regressions and

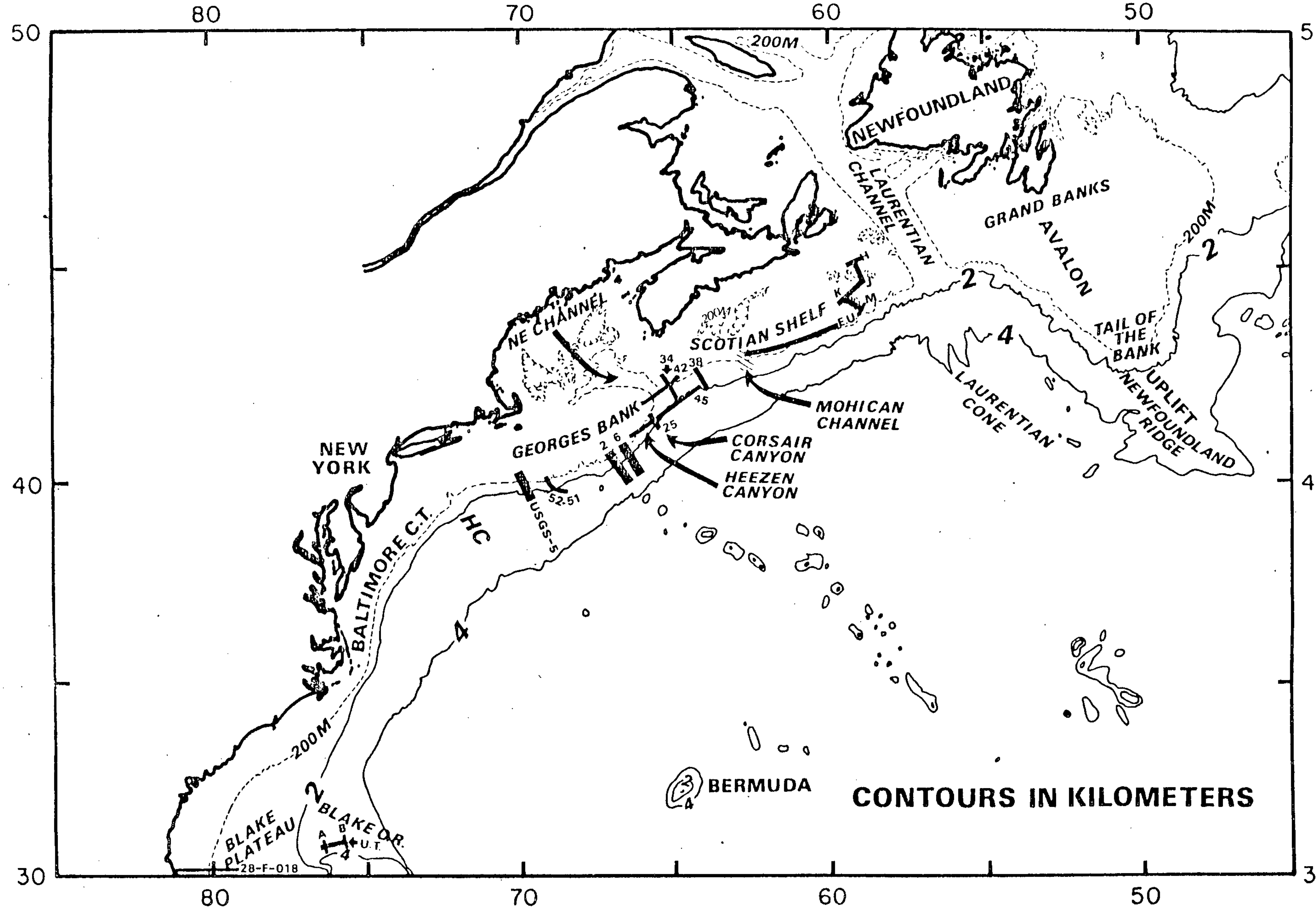

Figure 1 Chart showing positions of seismic reflection profiles in Figures 2–6 and 11. HC, Hudson Canyon

transgressions may have occurred in pre-Quaternary time, their rates were much slower during rare glacial periods. According to these authors, the ideal non-Quaternary margin consisted of the following: (1) a shore zone of prograding beaches devoid of estuaries, with barrier islands and lagoons existing primarily on delta complexes; (2) muddy shelf sediments and a smooth continental slope; (3) turbidity current activity and other gravitational processes restricted to the vicinity of long-lived submarine canyons; and (4) lobate continental rises which were well developed only in the area of these canyons.

Multichannel seismic reflection profiles of the margin off northeastern North America collected by the Geological Survey of Canada (Gradstein *et al.*, 1977; Grant, 1977; Jansa and Wade, 1975; King and Young, 1977) and the United States Geological Survey (Folger *et al.*, 1979), when used in conjunction with the wells drilled on the shelf (Given, 1977; Hathaway *et al.*, 1976; Jansa and Wade, 1975; McIver, 1972; Scholle, 1977) and in the deep sea (Tucholke and Mountain, 1979), demonstrate that the evolution of this mid-plate margin differs from the pre-Quaternary margin development envisioned by Moore and Curray (1974). For example, a multichannel profile from the Blake Outer Ridge shows evidence of nine erosional episodes beneath the continental slope and rise (Vail *et al.*, 1980). Three of these occurred during the Miocene, one during the Oligocene, another during the Eocene, one during the Paleocene, two during the Late Cretaceous, and one during the Early Cretaceous (Vail *et al.*, 1980). Multichannel profiles from the lower continental rise northeast of the Blake Outer Ridge also indicate that Horizon Beta is an unconformity (Shipley and Watkins, 1978). This would indicate that bottom currents were active in moulding the rise as early as Middle Cretaceous. Other profiles demonstrate that the continental slope throughout much of its development has been a site of alternating periods of erosion and deposition (Figures 1–3; Austin, 1978; Jansa and Wade, 1975; King and Young, 1977; Uchupi *et al.*, 1977; Uchupi and Austin, 1979a). In some sections of the slope off northeastern North America, the erosional surfaces are so close together that only fragments of the constructional events remain (King and Young, 1977; Uchupi *et al.*, 1977). On other segments, the erosional episodes are separated by thick constructional sequences. In the discussion below, we will use these new data to demonstrate the importance of pre-Quarternary events for the development of a mid-plate margin.

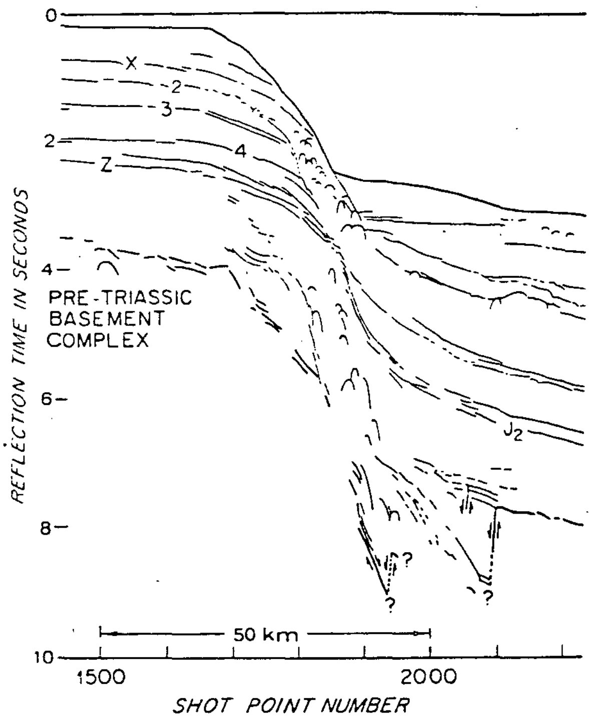

Figure 2 Line drawing of part of USGS CDP Line 5 (48 channels) collected over the continental slope south-southeast of Cape Cod. For location of profile, see Figure 1. This profile illustrates the complex stratigraphy of the continental slope produced by alternating periods of erosion and deposition. Reflector identifications are as follows: J_2, post Blake Spur Anomaly time; 165 my (basal Callovian: Leg 76 Scientific Party, 1981); Z, top of Bajocian (top of Early Jurassic); 4, Hauterivian–Barremian; 3, Albian–Aptian; 2, Cenomanian; X, Cenomanian–Turomian. Line drawing and reflector identifications modified from Austin (1978). Vertical exaggeration ×13 (based on a water velocity of 750 m/s)

Latest Early Jurassic

The first extensive marine incursion into the North American basin is marked by Early Jurassic evaporites beneath the Grand Banks, Scotian Shelf, Georges Bank, the shelf off New Jersey, and the continental rise from the Grand Banks to the Carolinas (Folger *et al.*, 1979; Grow and Markl, 1977; Jansa and Wade, 1975; Parsons, 1975; Uchupi *et al.*, 1977). Off the Canadian Maritime Provinces, the evaporites were replaced by dolomited limestones and anyhydrites late in the Early Jurassic. In Latest Early Jurassic 175 my ago, there was an abrupt change in the depositional regime of the Scotian Shelf from carbonates to clastics (Mohican Formation). Jansa and Wade (1975) ascribe this change in sedimentation to uplift associated with the initiation of sea floor spreading.

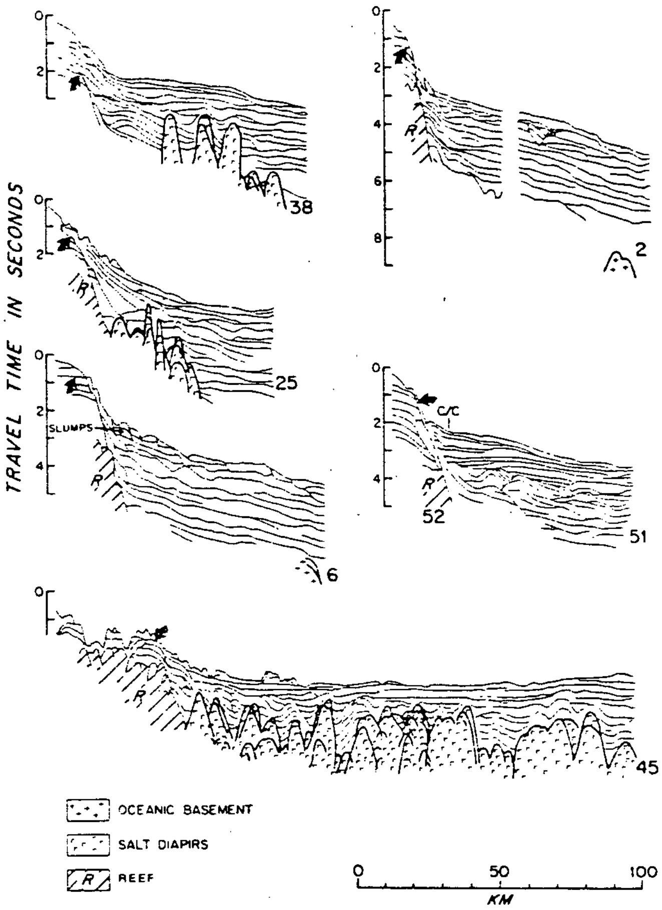

Figure 3 Line drawings of single-channel seismic reflection profiles of the continental slope and upper rise south of the western Scotian Shelf and Georges Bank. See Figure 1 for locations of profiles. Arrow indicates hiatus of Late Eocene/Oligocene age. Note that, along profile 45, three generations of canyons can be distinguished: the gullies entrenched into the reef (R), a second cycle of canyon-cutting, represented by the erosional remnant noted by the arrow, and a third by the canyons entrained into the present sea floor. From Uchupi *et al.* (1977). Vertical exaggeration ×13 (based on a water velocity of 750 m/s). Published with permission of the American Association of Petroleum Geologists

The Early Cretaceous Regression—the Avalon Unconformity

From latest Jurassic to earliest Late Cretaceous, another major facies change occurred on the margin off the Canadian Maritime provinces and New England (Austin, 1978; Cutt and Laving, 1977; Given, 1977; Jansa and Wade, 1975) which has been ascribed to the opening of the Bay of Biscay and separation of North America and Eurasia 125–90 Ma ago (Jansa and Wade, 1975). Tectonism in the Grand Banks area was most intense toward the end of the Early Cretaceous, during which time a widespread uplift occurred. Material eroded from the uplifted area was transported into the adjacent deep-sea basins, and in the process a pronounced unconformity (the Avalon unconformity) developed on the shelf.

In seismic profiles, this Avalon unconformity is best developed along the crest of the Avalon uplift, a positive structural element extending from the northern part of the Grand Banks through the tail of the Bank to the Newfoundland Ridge (Figure 1; Jansa and Wade, 1975; Grant, 1977). Its prominence diminishes away from the structural high, first becoming an intraformational unconformity before disappearing in conformable beds (Jansa and Wade, 1975). Along the crest of the Avalon uplift, the unconformity spans the interval from latest Jurassic to earliest Late Cretaceous. Along the western edge of the Avalon uplift, the hiatus encompasses the late Albian and most or all of the Cenomanian, while northeast of the Avalon uplift the sedimentary break is pre-Barremian in age (Cutt and Laving, 1977; Jansa and Wade, 1975).

The Scotian Shelf also was affected by the Early Cretaceous regression. At the end of the Jurassic, a massive regressive wedge known as the Sable Island

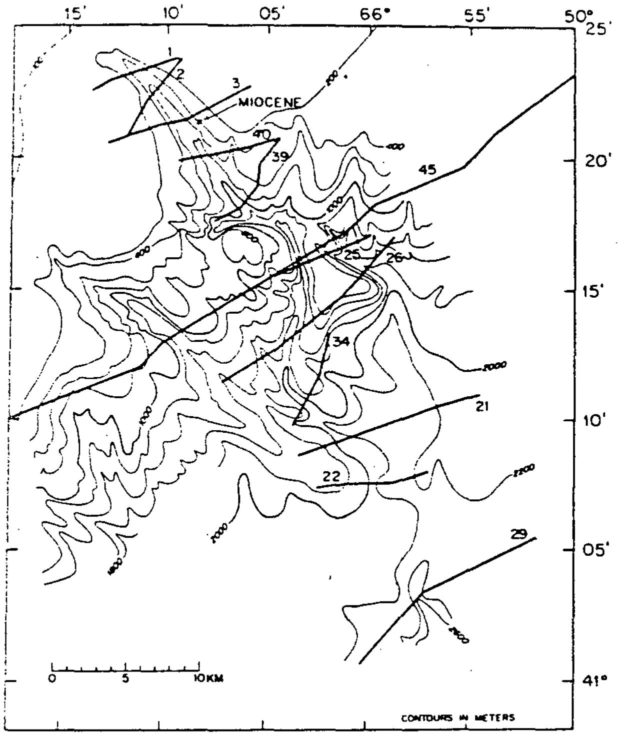

Figure 4 Bathymetric chart of Corsair Canyon showing the positions of the single-channel seismic profiles in Figure 5. From Uchupi *et al.* (1977). Published with permission of the American Association of Petroleum Geologists

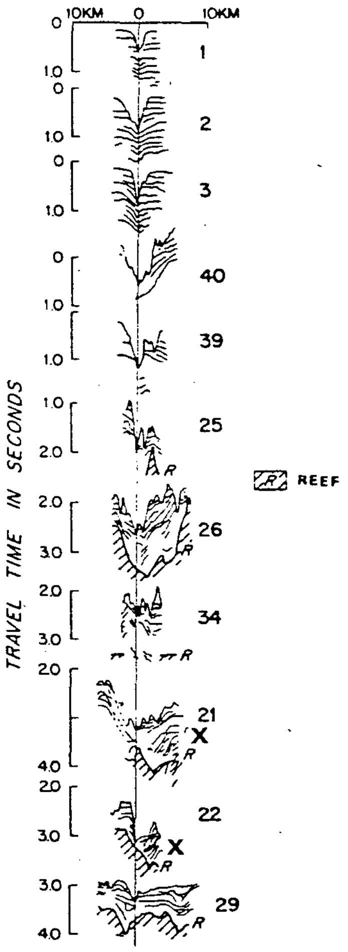
CORSAIR CANYON

Figure 5 Line drawings of single-channel seismic reflection profiles of Corsair Canyon. See Figure 4 for locations of profiles and see Figure 1 for location of Corsair Canyon. The present canyon cuts into strata filling an older canyon in the Mesozoic reef which forms the foundation of the continental slope. Along profiles 21 and 22, the fill is made up of two sedimentary sequences separated by a hiatus. Thus, at least two canyon-cutting episodes took place after the canyon which was cut into the reef was filled. The letter X indicates the strata into which the second canyon was cut. From Uchupi *et al.* (1977). Published with permission of the American Association of Petroleum Geologists

delta (McIver, 1972; Given, 1977) migrated southwestward over massive Jurassic carbonates. By the end of the Neocomian, further progradation of the delta resulted in the near complete obliteration of the carbonate facies. By Albian time, the delta could no longer be recognized, and the eastern Scotian Shelf was a large coastal complex of streams, marine embayments, marine bars, tidal channels, and estuaries (Given, 1977). This morphology is comparable to the present coastal zone off eastern United States. The western Scotian Shelf underwent erosion from the late Aptian to the end of the Albian (Williams, 1975). In contrast to the Grand Banks, the Early Cretaceous hiatus cannot be recognized in the seismic reflection profiles across the western Scotian Shelf (Austin, 1978; Jansa and Wade, 1975).

On Georges Bank west of the Scotian Shelf, the latest Jurassic–Early Cretaceous appears to have been marked by an influx of terrigenous material (Austin, 1978). The regressive wedge extended to the southern edge of the bank, overwhelming and killing a Mesozoic reef/carbonate bank complex that apparently existed on the outer shelf/continental slope until that time. Direct deposition on the slope resulted in unstable conditions and transferral of detritus to the base of the continental slope by gravitational processes. Turbidity currents carved canyons out of Neocomian reefal/platform limestones and mid-Cretaceous (?) calcareous sandstones (Ryan *et al.*, 1978; Figures 3–5). These canyons, subsequently filled with Maestrichtian calcareous glauconitic sandy mudstone and Eocene mudstones, calcareous grainstones and chalky limestones, influenced the development of the canyons which were eroded during the Plio-Pleistocene regressions (Austin, 1978; Uchupi *et al.*, 1977).

West of Georges Bank, the Early Cretaceous regression is marked by the unconformity just below the Lower–Upper Cretaceous boundary on the shelf south of New York. Mattack (1977) believes that this unconformity is due to the reactivation of the Great Stone Dome, an intrusive beneath the mid-shelf. The Early Cretaceous plate re-arrangement also may have affected the margin off the Carolinas, as the depositional sequence in the area of the Blake Outer Ridge is disrupted by a hiatus of mid-Aptian age (Vail *et al.*, 1980).

An isopach map of the Hauterivian/Turonian deep-sea black clays off the eastern United States shows several lobes, one southwest of Georges Bank and the other southeast of the Baltimore Canyon Trough (Tucholke and Mountain, 1979). This distribution, coupled with the landward thickening of the black sediments, is indicative of deposition by turbidity currents that reached the deep sea by way of canyons similar to those cut into the Mesozoic reef along the southern edge of Georges Bank.

Latest Cretaceous–Cenozoic Regressions

The Early Cretaceous regression was terminated by a world-wide transgression during which both the margin and adjacent coastal plains were flooded. Like the preceding regression, the Late Cretaceous transgression was probably due to a change in plate geometry. In this case, the change consisted of an increase in the rate of sea-floor spreading. This, in turn, decreased the average depth of the oceanic basins with a resultant marginal inundation (Hays and Pitman, 1973).

The transgressive phase was followed by a series of regressions from the latest Cretaceous to the Pleistocene. In contrast to the Early Cretaceous regression, those that took place from latest Cretaceous to the Pleistocene were in response to the fluctuations of continental glaciers.

Oxygen isotopic composition of plaktonic foraminifera from several Deep Sea Drilling Project sites indicate that there was a small temperature drop near the Tertiary–Cretaceous boundary (Savin *et al.*, 1975). During this minor cooling period, the Scotian Shelf and Grand Banks appear to have undergone erosion (King and MacLean, 1975, 1976; King *et al.*, 1974; Williams, 1975). The inadequacy of the available data makes it impossible to determine the effect that this regressive episode had on the depositional regime over the rest of the continental shelf off northeastern North America. Beyond the slope, however, turbidity currents began to develop a

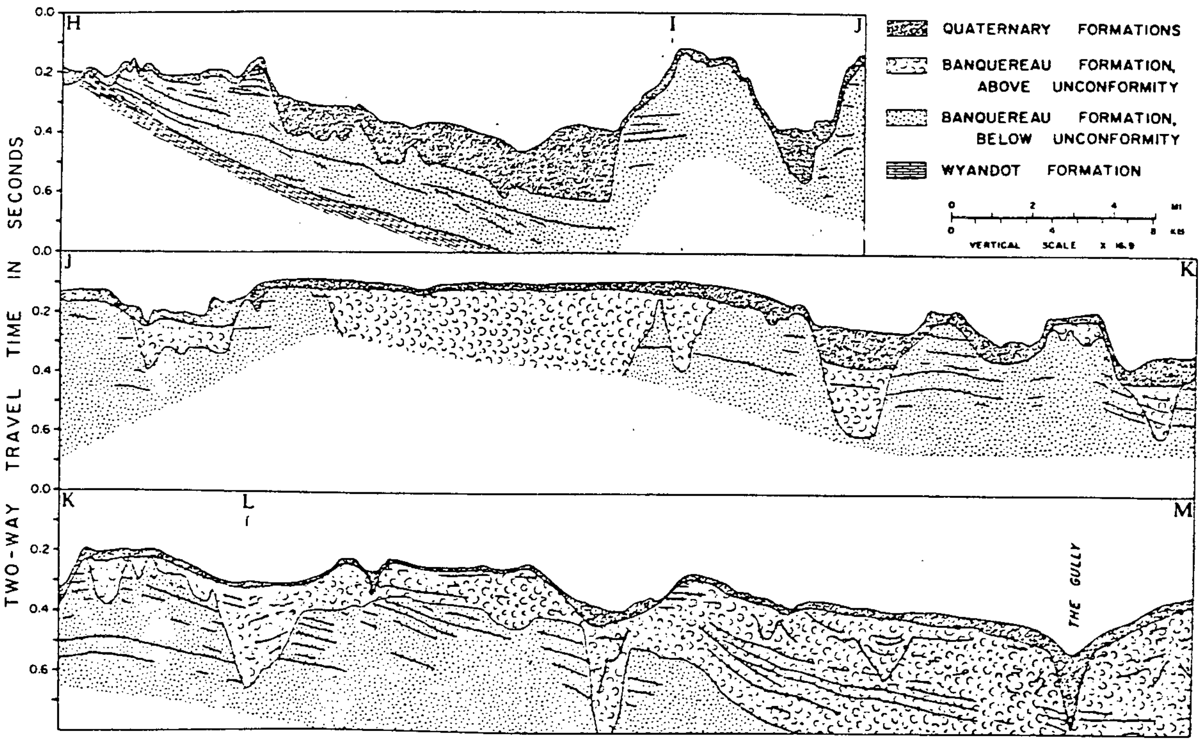

Figure 6 Line drawing of seismic reflection profile from the eastern end of the Scotian Shelf. From King *et al.* (1974, Figure 5). The Late Eocene unconformity is the one dividing the Banquereau Formation. The unconformity along H–J is Plio-Pleistocene in age. See Figure 1 for location of profile. Reproduced by permission of the National Research Council of Canada from the *Canadian Journal of Earth Sciences*, 11, 89–100, 1974

continental rise. At the time that Horizon A* (a middle-to-upper Maestrichtian chalk and limestone) was being deposited, gravitational processes extended basinward to form a continental rise and abyssal plain. According to Tucholke and Mountain (1979), for the first time in the depositional history of the North American basin, turbidity deposition exceeded pelagic deposition.

The best documented early Cenozoic regressive episode is that which occurred in the Late Eocene–Late Oligocene (Ingle, 1977). An initial sharp temperature drop, followed by a more gradual lowering of temperature, culminated in a Late Oligocene minimum (Savin *et al.*, 1975). This abrupt decrease in surface and deep sea-water temperatures in Late Eocene–Oligocene had world-wide significance. Newly created cold abyssal water masses eroded large areas of the Indian Ocean, South Pacific, and North Atlantic sea floors (Kennett, *et al.*, 1972; Kidd and Davies, 1978; Laughton, 1972; Rona, 1973). Coincident with this erosion of the deep sea, a marked degradation by a combination of fluvial and submarine processes took place on such passive margins as the ones off west Africa (Dingle, 1971; Seibold and Hinz, 1974) and Australia and New Zealand (Carter and Landis, 1972; Quilty, 1977).

The regression accompanying this cooling episode caused considerable erosion on the Scotian Shelf. According to King *et al.* (1974), the Late Eocene hiatus is of broad regional extent and manifests itself as a channel-and-fill horizon (Figure 6). According to these authors, the unconformity represents a former subaerially eroded surface. It is during this Late Eocene fluvial cycle that the cuestas and lowlands of the Canadian Maritime and New England margins were eroded out of older shelf strata (King *et al.*, 1974; Oldale and Uchupi, 1970). The late Eocene fluvial surface was later buried, and then partially exhumed by fluvial and glacial processes during the Plio-Pleistocene.

Some of the Eocene channels described by King *et al.* (1974) from the Scotian Shelf extend onto the outer shelf and upper slope (Figures 7 and 8). The most prominent of these shelf-edge canyons is the buried Mohican Channel (Figures 1 and 7), a feature cut into deep-water Cenomanian shales and filled with Miocene and younger deposits (Given, 1977). Since 1290 m of the 1500 m canyon-fill consists of Quaternary sediments (Jansa and Wade, 1975), the channel must have persisted as a topographic low from its formation in Late Eocene until the Quaternary, when it was finally filled.

In the area of the Laurentian Cone, buried shelf-edge canyons can be traced across the slope into the deep sea (Figure 9), and they display their greatest

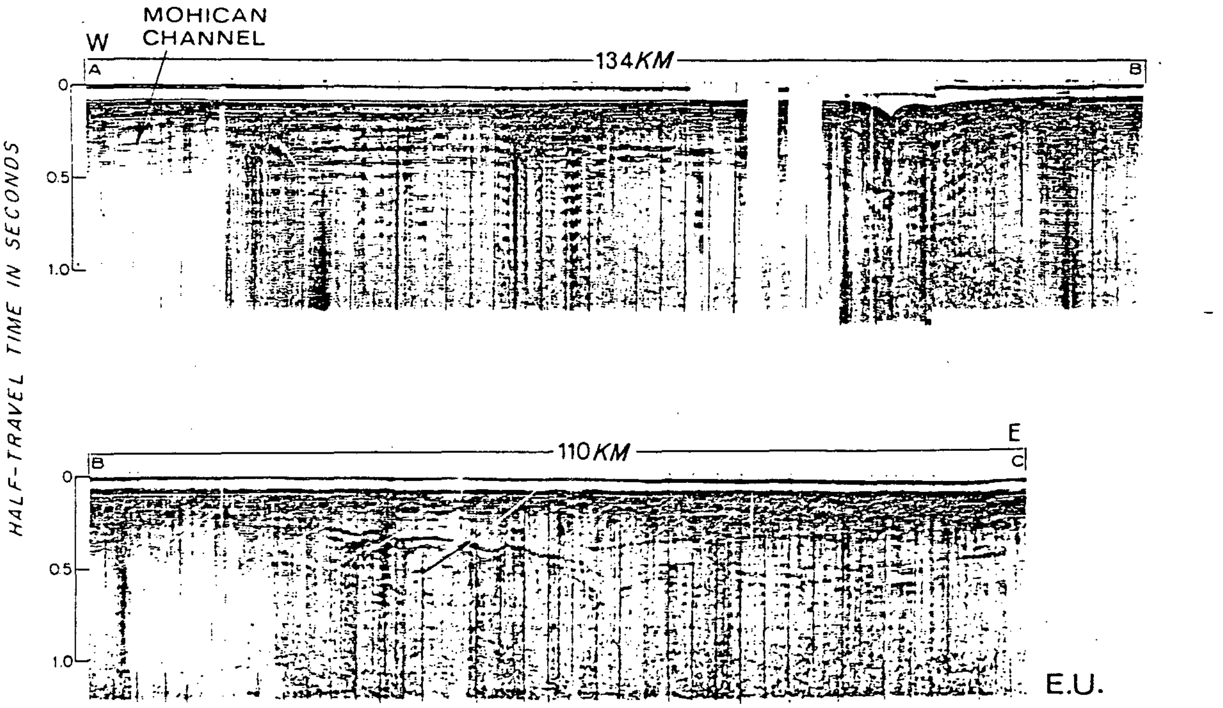

Figure 7 Single-channel seismic reflection profile showing the Late Eocene channels (arrow) entrenched into the outer shelf off Nova Scotia. From Emery and Uchupi (1972, Figure 153). See Figure 1 for location of profile. Published with permission of the American Association of Petroleum Geologists

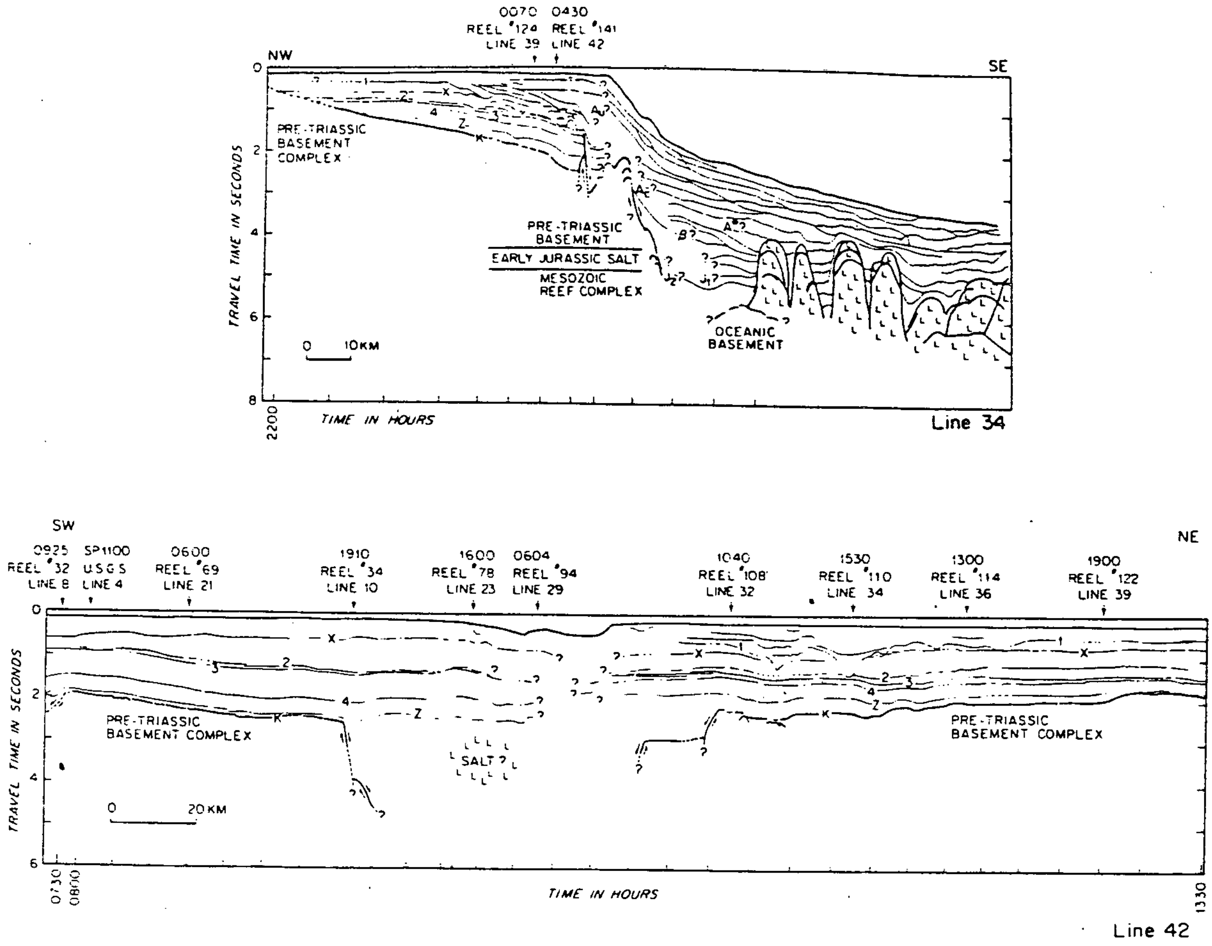

Figure 8 Line drawings of six-channel seismic reflection profiles of the western Scotian Shelf. The cut-and-fill topography on the outer shelf along line 34 is believed to reflect the Late Eocene and Oligocene regression. Line 42, paralleling the Scotian Shelf's edge, shows the Late Eocene and Oligocene channels capped by sediments over 1 second thick. Note that the channels do not extend across Northeast Channel (the low below the words 'line 29') to Georges Bank (the high to the left of Northeast Channel). From Austin (1978). Reflector identifications on the shelf are as follows: K, basal unconformity (Early Jurassic); Z, top of Bajocian (top of Early Jurassic); 4, Hauterivian–Barremian; 3, Albian–Aptian; 2, Cenomanian; X, Cenomanian–Turonian; 1, Oligocene. On the slope and upper rise, the reflectors are: J_2, post 165 ma BP (Middle Jurassic; age of Blake Spur Anomaly); J_1, Jurassic–Cretaceous boundary, 136 ma BP; β, Hauterivian–Barremian, A*, Maestrichtian, Ac, upper-lower to lower-middle Eocene chert, Au, Oligocene to earliest Miocene unconformity. The 'L' pattern denotes salt diapirs. Salt is postulated to be of Early Jurassic age. Vertical exaggeration of profiles is ×13 (based on a water velocity of 750 m/s). See Figure 1 for locations of profiles

reliefs (over 1 km) on the continental slope and upper rise. In plan view, the Late Eocene–Oligocene unconformity in the continental rise resembles the surface of a deep-sea fan with its meandering channel and levee divides. Uchupi and Austin (1979b) have interpreted this broadly undulating unconformity as the top of a cone emplaced by turbidity currents during the Late Eocene–Oligocene regression. According to the authors, the development of the Laurentian Cone began with the deposition of this regressive wedge.

The Late Eocene–Oligocene unconformity is well defined by the closely-spaced single-channel seismic reflection profiles recorded in the vicinity of Hudson Canyon (Figures 10–13). This unconformity, reflector X, displays noticeable relief along some of the profiles, which indicates the considerable amount of erosion that the slope underwent at this time. Recovery of Middle-Eocene strata from beneath the unconformity at DSDP site 108 (Ewing and Hollister, 1972) indicates that erosion of reflector X occurred in post Middle-Eocene time. As shown by seismic lines 61, 66, and 69 (Figure 12), the present shelf and slope are the surface of a sediment wedge deposited atop the post Middle-Eocene hiatus. The seaward edge of this sediment wedge (the continen-

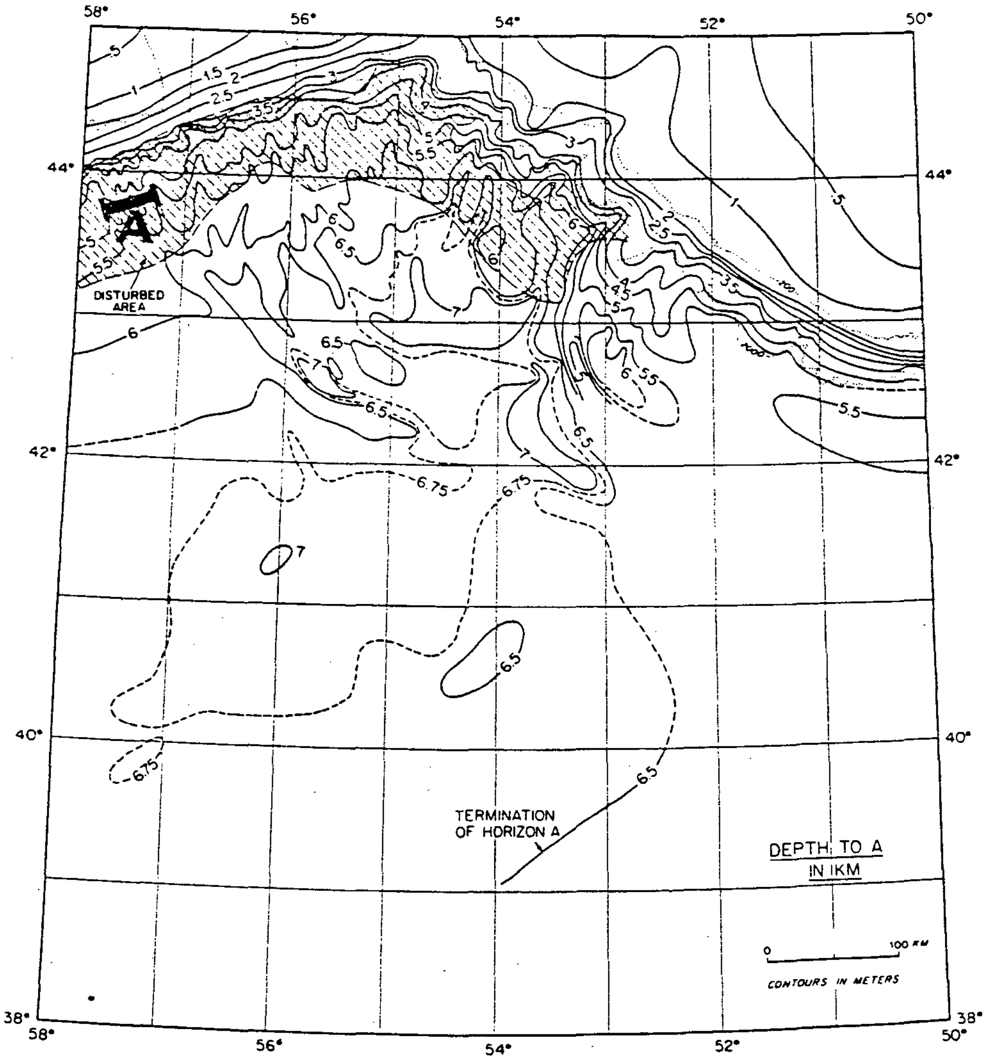

Figure 9 Depth to the top of Horizon A (in kilometres) in the area of the Laurentian Cone region. Datum is sea level. From Uchupi and Austin (1979b). The disturbed zone indicated by hatchures is interpreted to be due to the plastic flow of Early Jurassic salt. Note that the surface defined by Horizon A closely resembles the surface of a deep-sea cone. Uchupi *et al.* believe that this cone was deposited during the Late Eocene–Oligocene regression. The letter A shows the location of the seismic profile in Figure 16. Reproduced by permission of the National Research Council of Canada from the *Canadian Journal of Earth Sciences*, **16**, 1726–52, 1979

tal slope) was deeply eroded and the slope retreated a considerable distance during the Plio-Pleistocene regressions. Along profile 69, this erosion extended down to reflector X.

Profiles across Hudson Canyon, the most prominent submarine canyon off the east coast of the United States, are displayed in Figure 13. These profiles, which cross the canyon axis nearly at right angles, demonstrate the erosional origin of the canyon. The post Middle-Eocene unconformity can be traced up canyon from its deep-sea channel extension on the upper rise (profile 20) to the upper part of the continental slope (profile 35). Data as to whether the canyon was initially eroded during the post Middle-Eocene regression are inconclusive. The recovery of strata containing Miocene foraminifera along profile 35 (sample was dated by W. Berggren of Woods Hole) by the submersible *Alvin* (dive No. 415) from a greater depth (1437 m) than the Eocene unconformity (approximately 1200 m) could mean either: (1) that the canyon was carved during the Eocene–Oligocene regression and the Miocene sediment represents canyon-fill; or (2) that the Miocene sediment was displaced from farther up the side of the canyon by mass-wasting. Visual observations of the outcrop block from which *Alvin*

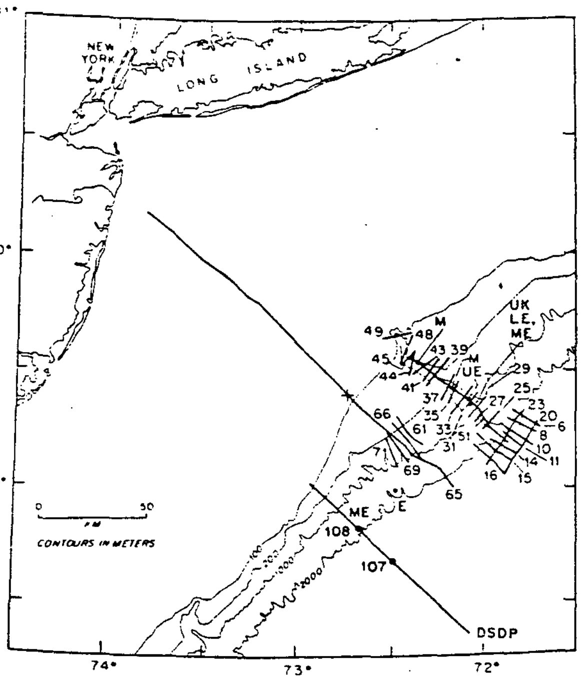

Figure 10 Chart of Hudson Canyon showing positions of the seismic reflection profiles in Figures 11–13. Numbers 107 and 108 are DSDP sites (Ewing and Hollister, 1972). On site 108, ME is the middle Eocene which the well bottomed in. The full circles with the letters UK, LE, ME, UE, E, and M show the positions from which Upper Cretaceous, lower, middle, and upper Eocene, Eocene, and Miocene rocks were dredged from the continental slope (Weed *et al.*, 1974). The Miocene strata near profile 35 was recovered by the submersible *Alvin*. The (+) sign along line 65 indicates the position of the COST B-2 well (Scholle, 1977)

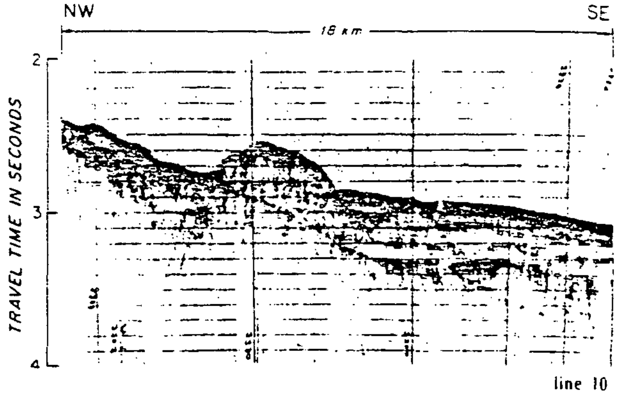

Figure 11 Single-channel seismic reflection profile from the vicinity of Hudson Canyon. Reflector X is the Late Eocene–Oligocene hiatus. See Figure 10 for location of profile. This recording and those in Figures 12 and 13 were obtained using a 40 in^3 air gun as a sound source. Vertical exaggeration is ×7 (based on a water velocity of 750 m/s)

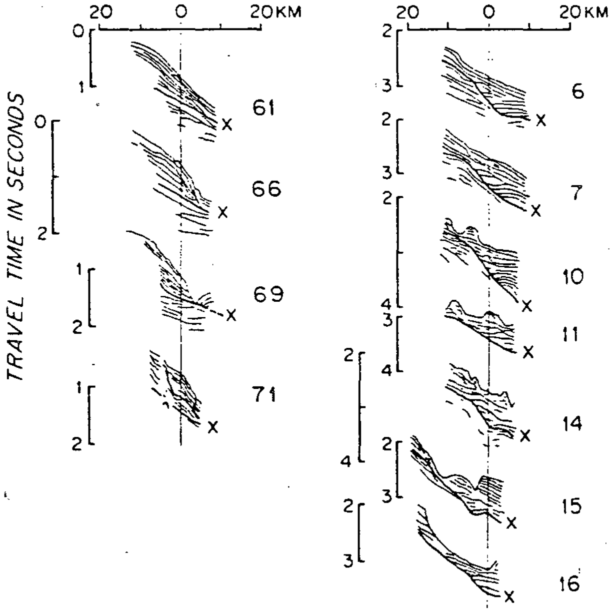

Figure 12 Line drawings of single-channel seismic reflection profiles of the continental slope in the area of Hudson Canyon. See Figure 10 for locations of profiles. Reflector X is the Late Eocene–Oligocene unconformity. Vertical exaggeration ×20 (based on a water velocity of 750 m/s)

took the Miocene sample revealed near-vertical layering, which tends to support the latter origin.

The Late Eocene–Oligocene regression also affected the sedimentary regime south of Hudson Canyon. According to Folger *et al.* (1979), the shelf's edge south of New York retreated 20 km during the regression. In the area of the Blake Outer Ridge, canyons with reliefs of about 0.5 s (round-trip time) are entrained into the upper rise strata (Shipley *et al.*, 1978; Figure 14). Farther west, off Florida, a Late Eocene–Oligocene unconformity is also discernible (Paull, 1978; Figure 15).

Like the continental slope farther north, the steep escarpments off the Blake Plateau and the Bahamas probably owe much of their morphology to submarine erosion during the Eocene–Oligocene regression (Paull and Dillon, 1980b). On the Blake Plateau itself changes in sea level during the Cenozoic caused the Gulf Stream to shift its position (Paull, 1978; Paull and Dillon, 1980a; Pinet *et al.*, 1981). During high stands the Stream which had migrated into the region in the Paleocene–Early Eocene migrated westward eroding the shelf. This westward shift occurred in the Early Eocene, Early Oligocene, Middle Miocene, and in the Pleistocene interglacials. During the Middle–Late Oligocene, Early Miocene, latest Miocene and Pleistocene gla-

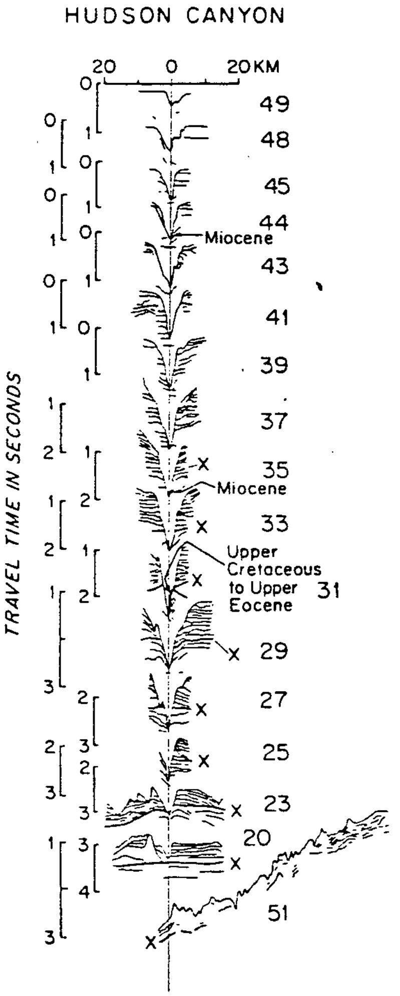

Figure 13 Line drawings of single-channel seismic reflection profiles of Hudson Canyon. See Figure 10 for locations of profiles. Reflector X is the Late Eocene–Oligocene unconformity. Vertical exaggeration ×20 (based on a water velocity of 750 m/s)

cial sea level lowstands the Gulf Stream migrated eastward into deeper water eroding the central part of the Gulf Stream south of latitude 31°N.

Landward of the continental shelf the scarcity of Oligocene deposits on the Atlantic Coastal Plain (Folger *et al.*, 1978; Maher, 1965) indicates that the Late Eocene–Oligocene regression also affected this presently emergent segment of the margin. Seaward of the shelf erosion of the Paleogene continental rise by bottom currents created a regional unconformity that extends from the Bahamas to the Canadian Maritime provinces. This deep-sea unconformity (Horizon Au) was probably carved some time between the Late Eocene and Early Miocene (Tucholke and Mountain, 1979). On the other hand, bottom current was not significant in the region of the proximal end of the Laurentian Cone where deep-sea channels and associated levees persisted from the Late Eocene to the Pleistocene (Figure 16; Parsons, 1975; Uchupi and Austin, 1979b).

The Late Eocene–Oligocene regression was followed by a warming trend and associated transgression which began in latest Oligocene and continued into the early Miocene (Haq *et al.*, 1977). This was followed by a fall in sea level of about 40 m in the latest Miocene (Messinian) (Berggren and Haq, 1976). The effect of the Late Miocene regression does not appear to have greatly influenced the sedimentary regime of the northeastern North American margin. This regressive episode was succeeded by the well-documented regressions due to the massive Plio-Pleistocene polar glaciations.

Concluding Remarks

In the foregoing brief description of the geologic development of the margin off northeastern North America, it has been demonstrated that processes generally believed to have been unique to the Quaternary took place throughout much of the history of this margin. To date, the pre-Quaternary segments of most margins are *terra incognita*. Where such information is available, as for example off eastern Canada and the adjacent eastern United States, it is evident that the development of the pre-quaternary margin was as complex as the Quaternary one. Regressions in the Cenozoic were caused by continental glaciation, while those in the Mesozoic appear to have been due to changes in plate geometry. Because climatic changes were of shorter duration than those associated with modifications in plate geometry, the time interval between cause and effect was probably shorter during the Cenozoic regressions. Consequently, sedimentation changes during the Cenozoic may have been more abrupt than those which occurred during the Mesozoic, and this could explain their prominence in the geologic record.

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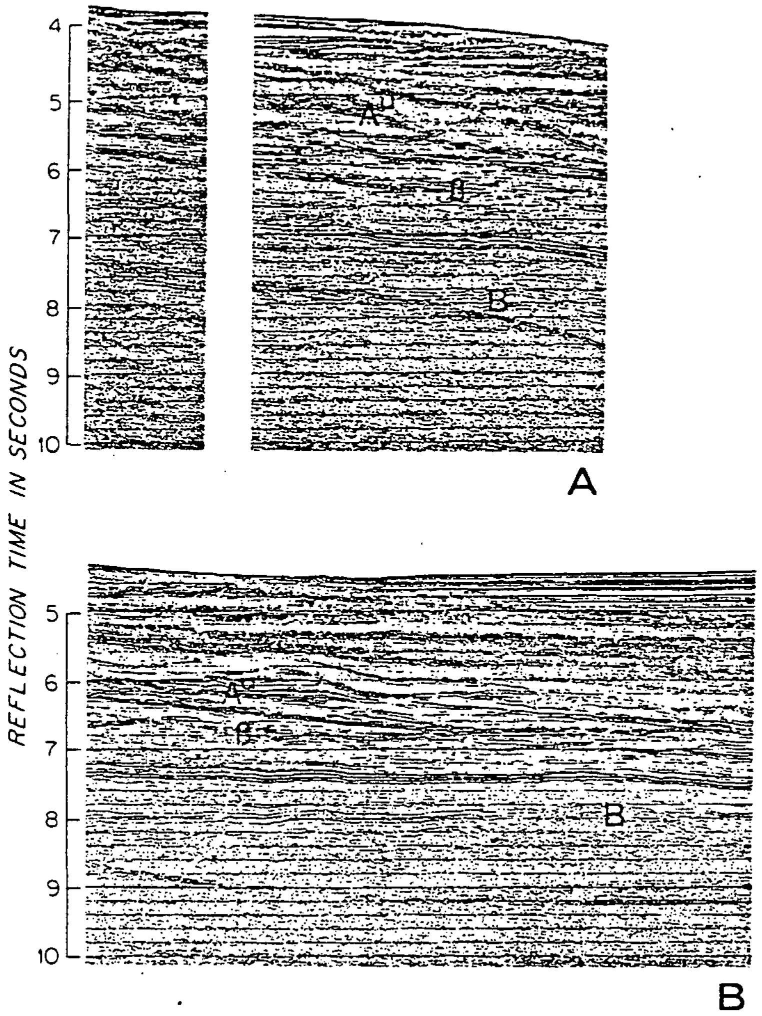

Figure 14 24-channel seismic reflection profile of the landward end of the Blake Outer Ridge. See Figure 1 for location of profile. Note the erosional nature of Horizons Au and β. Profile courtesy of R. T. Buffler of Geophysics Laboratory, Marine Science Institute, University of Texas, Galveston, Texas

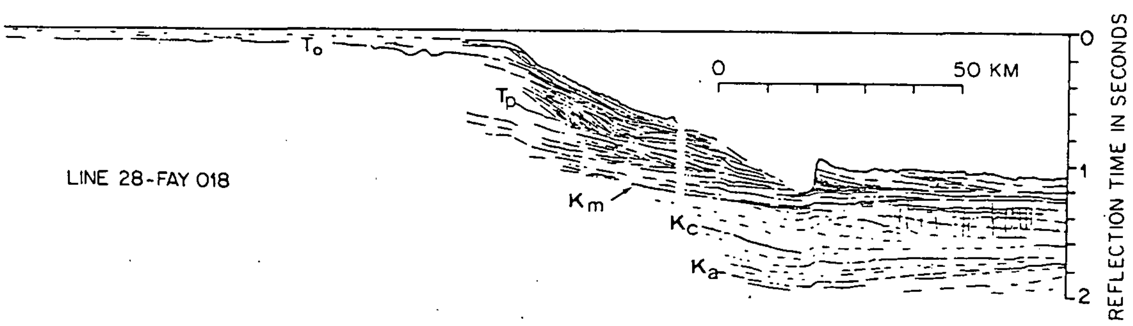

Figure 15 Line drawing of a single-channel seismic reflection profile of the shelf and Florida–Hatteras Slope west of the Blake Plateau. See Figure 1 for location of profile. This wedge is separated into three units by Paleocene and Oligocene hiatuses. The Late Paleocene erosion is probably related to the initiation of the Gulf Stream. The regional unconformity separating the Oligocene from Miocene and younger sediments was formed by a combination of fluvial erosion on the shelf and erosion by the Gulf Stream, in deeper water during the Late Eocene–Oligocene eustatic drop in sea level. Profile is from Paull (1978). Reflector identification is as follows: Ka, Albian; Kc, Coniacian; Ks, Santonian; Km, Maestrichtian; Tp, Paleocene; and To, Oligocene. Vertical exaggeration of profile × 37 (based on a water velocity of 750 m/s)

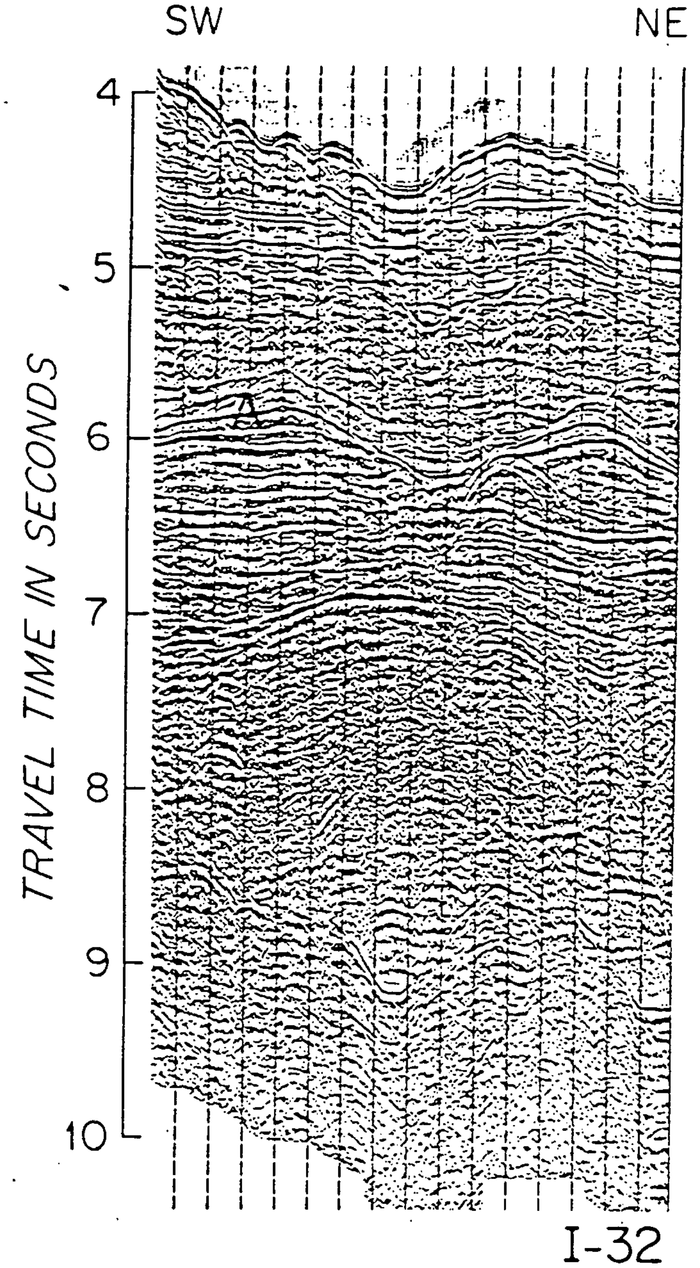

Figure 16 24-channel seismic reflection profile from the upper continental rise off the eastern Scotian Shelf. See Figure 9 for location of profile. Note that the channel incised into the present sea floor is offset from the one cut into the Late Eocene Horizon A. Profile courtesy of Imperial Oil Limited. Vertical exaggeration about × 10 (based on a water velocity of 750 m/s)

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