Middle to late Miocene canyon cutting on the New Jersey continental slope: Biostratigraphic and seismic stratigraphic evidence

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ABSTRACT

We have identified and dated a major Miocene erosional surface (M1) on the New Jersey continental slope. This surface was penetrated at Deep Sea Drilling Project (DSDP) Site 612, which was drilled near the thalweg of a buried V-shaped canyon. Biostratigraphic data at Site 612 firmly constrain the age of strata above the buried canyon surface as Zones CN7 (=NN9) and N16 (lowermost upper Miocene); the upper Miocene surface at Site 612 lies above lowermost Oligocene strata because of coalesced unconformities. We traced the M1 erosional surface to the COST B-3 well where upper middle Miocene strata underlie it. Biostratigraphic studies of other New Jersey continental slope boreholes (ASP 14, ASP 15) suggest that elsewhere the sediments immediately below the M1 surface encompass the *Globorotalia fohsi robusta* Zone (= Zone N12–earliest N13; middle middle Miocene). The best age estimate is that M1 was eroded between 11.5 and 10.0 Ma. This erosional event apparently correlates with a similar event on the Irish and Florida continental margins and with oxygen-isotope evidence for a glacio-eustatic lowering.

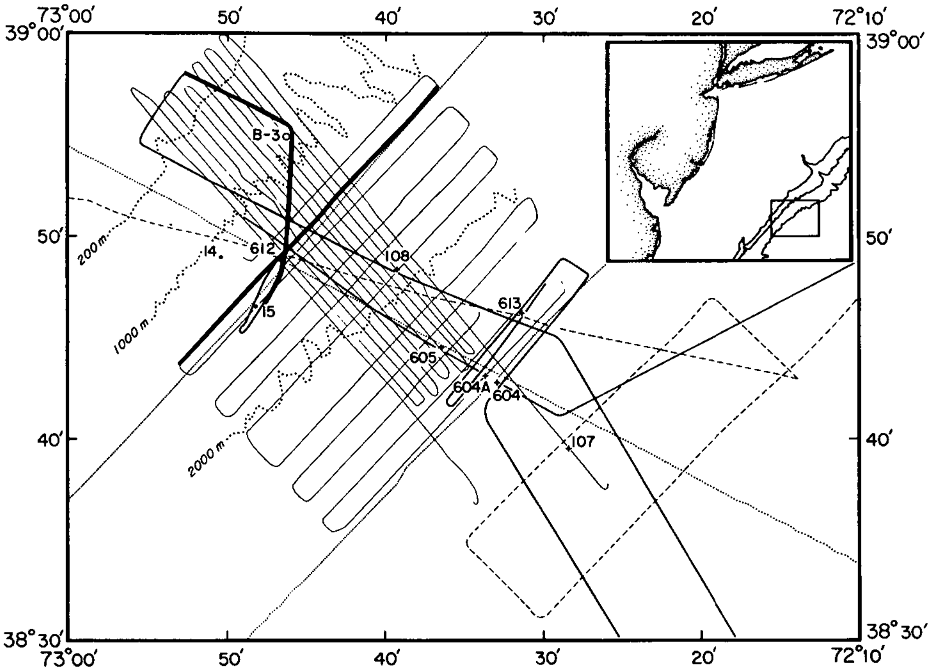

Figure 1. Location map of New Jersey continental margin showing ship tracks, COST B-3 well, Deep Sea Drilling Project Sites 107, 108, 604 (Holes 604 and 604a), 605, 612, 613, and Atlantic Slope Project boreholes 14 and 15. Inset map shows general geographic location; stipples indicate enlarged area. Heavy dashed lines show location of Figure 2 (dip line connecting Site 612 and COST B-3) and Figure 3 (strike line through Site 612).

INTRODUCTION

The cycle charts of coastal onlap published by Vail et al. (1977) and Haq et al. (1987) have stimulated interest and controversy concerning the origin and timing of unconformities eroded on passive continental margins. Deep Sea Drilling Project (DSDP) Legs 80, 93, and 95 were dedicated to testing the timing of erosional events on the Irish (Goban Spur) and New Jersey margins (Graciansky, Poag, et al., 1985; Poag, Watts, et al., 1987; Van Hinte, Wise, et al., 1987). Several unconformities and associated hiatuses were documented by drilling along these margins. We have discussed lithologic, seismic, faunal, and biostratigraphic data for these breaks on the New Jersey slope and rise (e.g., Poag, 1985; Katz and Miller, 1987; Miller and Hart, 1987; Poag and Low, 1987; Poag and Mountain, 1987). Despite these efforts, the nature and timing of erosional events are poorly constrained in certain intervals due to spot coring, coalesced unconformities, and uncertainties in seismic interpretations of complex continental slope stratigraphy.

We focus here on biostratigraphic and seismic stratigraphic evidence for a major erosional event that occurred near the middle/late Miocene boundary on the New Jersey continental slope and rise (Fig. 1). Biostratigraphic and seismic stratigraphic data from a transect drilled by DSDP Legs 93 and 95 (Sites 604, 605, 612, and 613; Fig. 1) allowed recognition of one or more erosional events near the beginning of the late Miocene. However, because of coalesced unconformities at these DSDP sites, the age of the event(s) can only be constrained by correlation with the COST B-3 well (Fig. 1). We use Melillo's (1985) revised biostratigraphy and a new direct seismic tie from DSDP Site 612 to the COST B-3 well (Figs. 1, 2) to estimate the age of this erosional event with greater precision than previously possible.

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SEISMIC STRATIGRAPHIC EVIDENCE

Site 612 is located on the continental slope of New Jersey (1404-m present water depth; Fig. 1); drilling encountered an unconformity representing a 25-m.y. hiatus between the late Miocene and earliest Oligocene (Poag, 1985; Poag, Watts, et al., 1987; Poag and Low, 1987; Miller and Hart, 1987). Correlation to a high-resolution grid of seismic data collected by the U.S. Geological Survey (Robb, 1980; Fig. 3) revealed that Site 612 was unintentionally drilled near the thalweg of a buried Miocene canyon (0.17-s subbottom at Site 612; Fig. 3) (Farre, 1985; Poag and Mountain, 1987). We call the seismic disconformity corresponding to this canyon surface reflector M1 (Fig. 3). Reflector M1 encompasses at least four coalesced unconformities at Site 612 (Poag and Mountain, 1987). However, southwest of Site 612, strata between M1 and the lowermost Oligocene surface (about 1.9–2.0-s total two-way traveltime) represent much if not all of the lower Oligocene to middle Miocene section absent at Site 612 (Fig. 3). These unsampled strata apparently crop out northeast of Site 612 in the present-day Carteret Canyon and southwest of the site (Fig. 3).

The sediments immediately above reflector M1 are seismically laminated and apparently conformable, showing little evidence of slumping into the eroded canyon. This is consistent with interpretations of the Pliocene-Miocene benthic foraminiferal assemblages as in situ (Katz and Miller, 1987). By contrast, the Pleistocene section is more complex seismically, and samples from this interval contain evidence of a shallow-water fauna (Poag and Low, 1987).

The buried canyon associated with reflector M1 may be the upper slope expression of an erosional event that cut broad, U-shaped, upper rise channels noted on U.S. Geological Survey Line 35 (Wise et al., 1986; Poag and Mountain, 1987). Unfortunately, with the available seismic data, M1 can be traced downslope for only 1 km because of exposure of Eocene strata on the lower slope. Site 604 failed to penetrate completely the coarse channel fill; Site 613 encountered an unconformity separating middle Eocene from upper Miocene strata (Fig. 1). Upper rise channel-fill sediments at Sites 604 and 613 are assigned to lower upper Miocene Zone CN7 (Wise et al., 1986; Valentine, *in* Poag, Watts, et al., 1987), the same age as sediments above reflector M1 at Site 612. The age of the youngest strata below the upper rise erosional surface is poorly constrained, and an unequivocal link with the Miocene erosional surface at Site 612 is lacking.

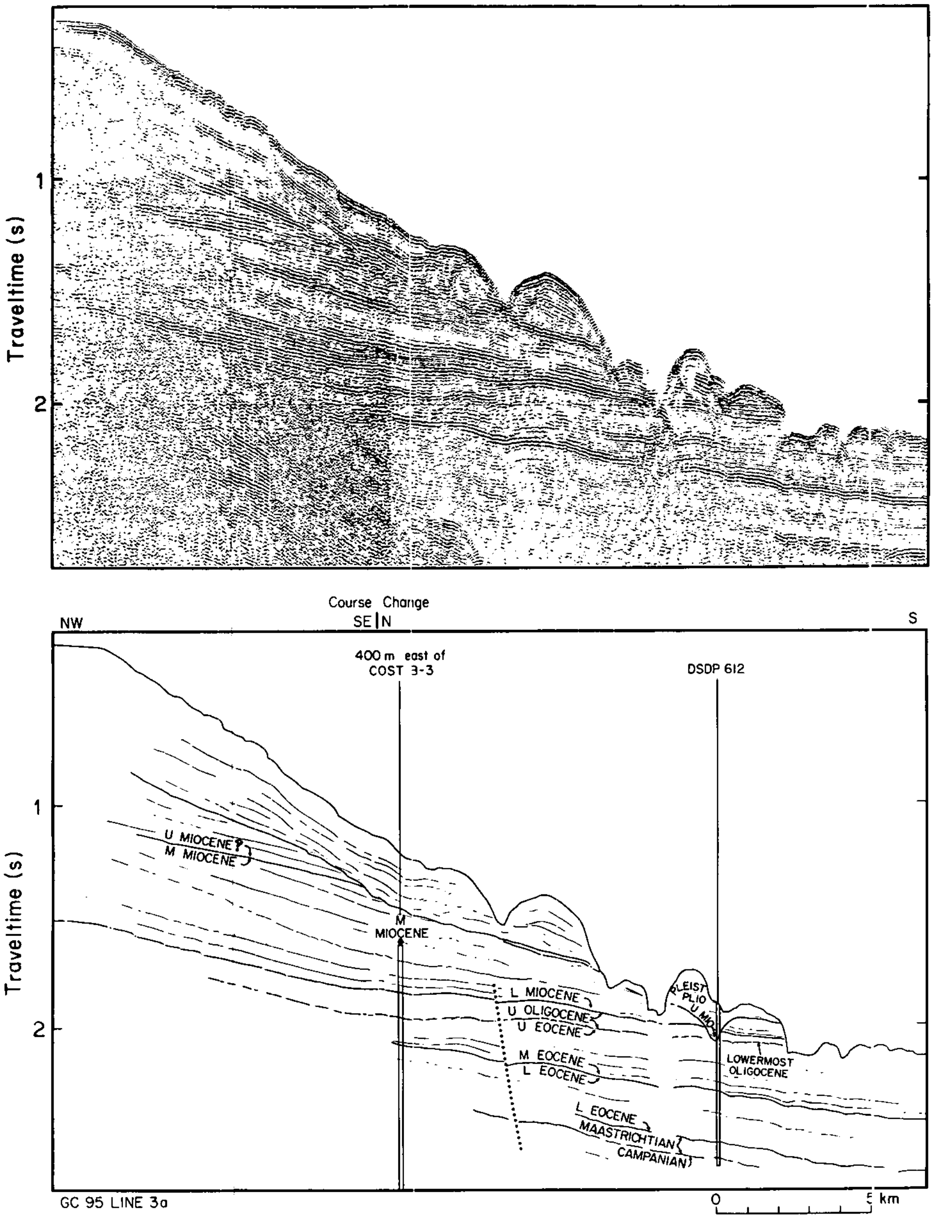

Figure 2. ***Glomar Challenger*** **Leg 95 seismic dip line 3a (top) and line-drawing interpretation (bottom) showing seismic tie between DSDP Site 612 and the COST B-3 well.**

AGE OF REFLECTOR M1 EROSIONAL SURFACE

The unconformity formed by the coalescing of reflector M1 with three other regional unconformities correlates with a 25-m.y. hiatus at Site 612 in Core 16, section 6 (135.36-m subbottom [msb]). Sediments resting on the unconformity at Site 612 are assigned to Miocene Zones N16 (Miller and Hart, 1987) and CN7 (= *Discoaster hamatus* Zone = Zone NN9) (Valentine, *in* Poag, Watts, et al., 1987), whereas sediments immediately beneath it are assigned to lowermost Oligocene Zone P18 (Miller and Hart, 1987; Poag and Low, 1987) (Fig. 4).

Considerable confusion has arisen as to the relation among the nannofossil zones, planktonic foraminiferal zones, and chronostratigraphic boundaries in the late middle to early late Miocene. Zone CN7 (=NN9) was originally thought to be late middle Miocene—older than 10.5 Ma. Miller et al. (1985) revised the placement of Zone NN9 (= CN7) and correlated the zone with the basal Tortonian (basal upper Miocene), early Zone N16, and the normal part of Chron C5 (10.0–8.9 Ma). Thus, strata immediately overlying reflector M1 at Site 612 correlate with the lower upper Miocene (basal Tortonian), providing a minimum age (older than 10.0–8.9 Ma) for the erosional event.

Other wells drilled on the New Jersey continental slope can be used to constrain the maximum age of reflector M1. The COST B-3 well was drilled on the upper slope (819-m present water depth). We have traced reflector M1 from Site 612 to the COST B-3 well (Fig. 2). By using velocity log data of Carlson (1979), we determined that reflector M1 overlies the shallowest sample taken (329 msb) by a few tens of metres; a similar seismic-borehole correlation is obtained applying the velocity log for Site 612 (Poag, Watts, et al., 1987) to the COST B-3 well.

The age of the shallowest sample at COST B-3 is debatable. Poag (1980, 1985) assigned the first sample to Zone N14 (the interval from the first occurrence of *Globigerina nepenthes* to the last occurrence of *Globorotalia mayeri/siakensis*; Blow, 1969, 1979). However, first occurrences are not recognizable in rotary-drilled wells such as the COST B-3. Melillo (1985) identified *Globorotalia fohsi robusta* and *G. acrostoma* in the first sample at the COST B-3 well. If one assumes that *G. fohsi robusta* is in situ, this interval is assignable to the *G. fohsi robusta* Zone of Bolli (1957) and Bolli and Saunders (1985), which is equivalent to Zone N12 to earliest N13 of Blow (1969) (see Berggren et al., 1985). One of us (Miller) favors assignment to this interval. However, on the basis of the presence of *G. acrostoma,* which apparently became extinct prior to the appearance of *G. fohsi robusta* (Kennett and Srinivasan, 1983), Melillo (1985) suggested that the specimens of *Globorotalia fohsi robusta* may be caved downhole and that the first sample is not younger than the *G. fohsi fohsi* Zone (approximately N11 of Blow, 1969) (Fig. 4). Still, the presence of *G. fohsi robusta* strongly suggests that sediments correlative with Zones N12 and N13 are present at or slightly above the level of the first sample taken at B-3. These disagreements illustrate problems in attempting to zone precisely a rotary-drilled well. Nevertheless, seismic-biostratigraphic correlations at the COST B-3 well and Site 612 constrain the age of reflector M1 to the late middle to earliest late Miocene.

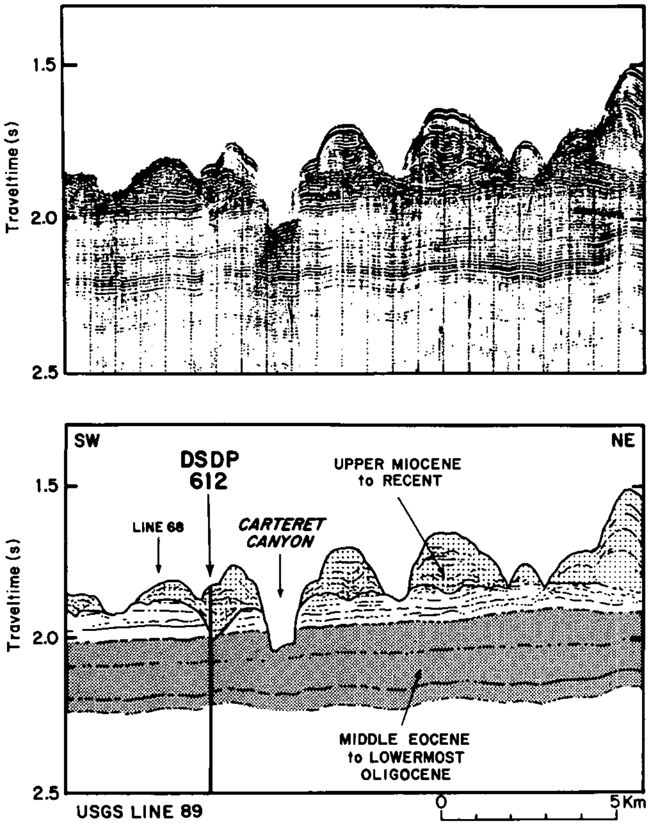

Figure 3. High-resolution seismic strike (U.S. Geological Survey) line 89 (top) collected by Robb (1980) from upper continental slope of New Jersey; bottom is line-drawing interpretation.

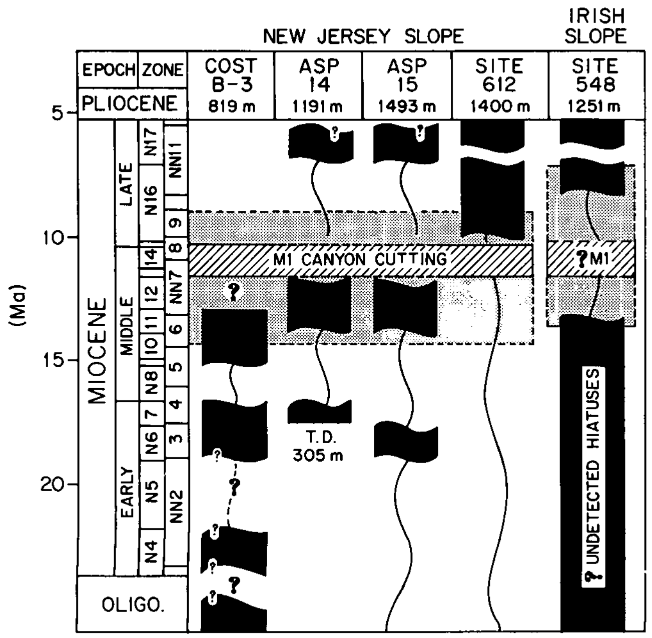

Figure 4. Miocene chronostratigraphy and correlations of seismic reflector M1, New Jersey continental slope. Irish margin record shown for comparison. Columns in black are intervals represented in boreholes and wells; vertical thin wavy lines indicate hiatuses. Diagonal-ruled area represents our best estimate of the timing of reflector M1; stippled area indicates maximum possible age uncertainty. Numbers below borehole names indicate present water depth.

Chronostratigraphic records at Atlantic Slope Project (ASP) 14 (1191 m) and ASP 15 (1493 m) boreholes can be used to constrain further the timing of Miocene continental slope erosion (Figs. 1, 4). No direct seismic ties are available into ASP 14, and the Miocene section at ASP 15 is too thin to make seismic correlations meaningful. Nevertheless, planktonic foraminifera at both ASP 14 and 15 suggest a break between the late middle Miocene (*G. fohsi lobata/robusta* Zone) and the late Miocene (Melillo, 1985).

The most conservative estimate dictates that reflector M1 must be younger than 14 Ma and older than 9 Ma; this is computed on the assumption that uppermost sediments drilled at COST B-3 are assigned to Zone N11 and that the ASP 14 and 15 records cannot be used to constrain timing of the event (stippled area, Fig. 4). On the basis of the biostratigraphic data presented here, our best estimate is that reflector M1 was cut in the late middle Miocene between 11.5 and 10.0 Ma (between the *G. fohsi robusta* Zone and Zone CN7 [= NN9], time scale of Berggren et al., 1985; diagonal-ruled area, Fig. 4). We estimate that erosion occurred at or near the middle/late Miocene boundary (revised age of 10.4 Ma; Miller et al., 1985; Berggren et al., 1985).

DISCUSSION

Vail et al. (1977) reported a major offlap event near the middle/late Miocene boundary, which corresponds to that on the New Jersey slope. The revised cycle chart of Haq et al. (1987) shows many more events than the earlier Vail curve. However, Haq et al. (1987) reported that one of their six major Cenozoic, second-order supercycle boundaries occurred near the middle/late Miocene boundary, in close agreement with the timing of the event reported here. It is clear from drilling on the New Jersey and Irish margins that only the major supercycle boundaries generally are observable as seismic discontinuities and major hiatuses. This is consistent with Haq et al. (1987), who developed the higher order cycle (third and fourth order) boundaries primarily from detailed studies of outcrops.

A hiatus occurred on the Irish margin between the middle middle Miocene (Zone NN6) and late Miocene (Zones NN11 and N16) at both Site 548 (1251 m) and Site 549 (2538 m) (Muller, 1985; Snyder and Waters, 1985). This break correlates with that noted on the New Jersey slope (Fig. 4). A seismic disconformity has been traced near Site 548 (Fig. 1 in Montadert and Poag, 1985). Unfortunately, seismic-borehole correlations are limited by poor-resolution seismic data across Site 548. The best estimate is that the erosional surface can be traced to a level of 0.32-s subbottom (282 msb) at Site 548 (Montadert and Poag, 1985). This indicates correlation with the lower upper Miocene (Zone NN11) section at Site 548 (Muller, 1985), although we speculate that the erosional surface, in fact, correlates with this major unconformity noted in the borehole. New seismic data across Site 548 are needed to resolve the seismic-borehole correlations.

A similar late middle to earliest late Miocene erosional event has been noted on the northwest Florida continental slope by Mullins et al. (1987). A canyon-cutting event has also been noted in the middle Miocene on the Somali margin by Coffin and Rabinowitz (1982), although the precise date of this erosional event is uncertain.

The canyon-cutting event noted at Site 612 correlates with evidence for an inferred glacioeustatic lowering of sea level. Both benthic and low-latitude planktonic foraminiferal δ^{18}O values increased across the middle/late Miocene boundary, suggesting increased ice volume and a sea-level drop between 30 and 90 m (summary in Miller et al., 1987). The higher estimate is similar to the amount of eustatic lowering estimated from seismic sequence analyses (Haq et al., 1987).

Additional work is needed to refine the timing of this and other erosional events on the New Jersey slope and to compare with margins having different depositional and thermal subsidence histories. Two types of data, in particular, will improve resolution: (1) seismic lines that provide direct ties among the various wells and boreholes considered here and (2) a complete record of the section missed by drilling Site 612 near the canyon thalweg. This can be done either by further deep drilling or by analyzing piston cores taken from outcrops in the modern canyons, such as Carteret Canyon (Figs. 1, 3).

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ACKNOWLEDGMENTS

Supported by National Science Foundation Grants OCE85-00859 and OCE87-0005. We thank M. E. Katz, R. Sheridan, and J. Wright for reviewing the manuscript, and R. K. Olsson for discussions. Samples were provided by the Deep Sea Drilling Project, Exxon (ASP boreholes), and Shell (COST B-3). Lamont-Doherty Geological Observatory Contribution No. 4109.

Manuscript received November 10, 1986
Revised manuscript received February 17, 1987
Manuscript accepted March 4, 1987