32. THE NEW JERSEY TRANSECT: STRATIGRAPHIC FRAMEWORK AND DEPOSITIONAL HISTORY OF A SEDIMENT-RICH PASSIVE MARGIN[1]

C. Wylie Poag, U.S. Geological Survey, Woods Hole[2]

ABSTRACT

The results from Leg 95 of the Deep Sea Drilling Project bring to completion a series of geological and geophysical studies along a 700-km transect of the New Jersey continental margin. Integration of outcrop, borehole, and seismic reflection data along this transect has revealed the regional stratigraphic framework and has allowed a comprehensive interpretation of the depositional history of the Baltimore Canyon Trough and the adjacent North American Basin. The depositional sequences documented at the boreholes are extrapolated along the grid of seismic profiles to produce isopach maps.

Analyses of these data show that sediment dispersal on the New Jersey margin has been governed in large part by sea-level changes, but modified by temporal changes in shelf-edge physiography, sediment sources, and deposition rates. Notable examples include the buildup of a shelf-edge reefal system during the Late Jurassic; its subsequent burial in the Late Cretaceous, as massive turbidity currents and debris flows reached the lower rise; the appearance of a dual shelf-edge system and widespread carbonate production during the Paleogene; rapid progradation of thick deltaic prisms during the middle Miocene; and deep incision of the shelf edge by submarine canyons during the Pleistocene.

Massive downslope gravity flows have dominated both the depositional and erosional history of the New Jersey margin during most of the last 135 m.y. The importance of periodic widespread erosion is recorded by correlative unconformities at the boreholes. These unconformities also correlate well with supercycle boundaries of the Vail depositional model, thereby providing field validation of the supercycle framework of the model.

INTRODUCTION

The New Jersey Transect was originally conceived as a standard reference section for an Atlantic-type passive margin, to extend from the inner edge of the coastal plain, across the thick sedimentary prism of the Baltimore Canyon Trough, to the outer edge of the continental rise in the North American Basin (Fig. 1). To a data base of outcrops and subsurface borings on the coastal plain, a series of boreholes on the continental shelf and upper continental slope was added, and more than 20,000 line-km of multichannel and single-channel seismic reflection lines (Fig. 2). Continuous coring on the lower continental slope and on the upper and lower continental rise by Deep Sea Drilling Project (DSDP) Legs 93 (van Hinte, Wise, et al., 1985a, b, in press) and 95 (Poag, 1985b) completed the middle segment and the seaward end of the transect. A multichannel seismic profile (U.S.G.S. Profile 25), which crosses the deepest part of the trough, was chosen as the standard reference profile along which the four updip DSDP sites were placed. A second profile, *Conrad* 21 (obtained by Lamont-Doherty Geological Observatory), intersects the seaward end of U.S.G.S. Profile 25 (Fig. 2) and crosses the lower continental rise, eventually reaching DSDP Sites 603 and 105, the terminal sites on the New Jersey Transect. At this writing, the New Jersey Transect is unique, there being no comparable publicly available data set on any other continental margin. Thus the analyses and interpretations carried out in conjunction with the DSDP studies (some of which have been published in prior reports; von Rad, 1984; Poag, 1985b; van Hinte, Wise, et al., 1985a, b), contribute a significant body of knowledge regarding the stratigraphic framework and depositional history of the continent-to-ocean transition in a sediment-rich pull-apart basin. These investigations compliment analogous (but somewhat more limited) studies of the sediment-starved Irish margin (Goban Spur, Leg 80—Graciansky, Poag, et al., 1985) the northwest African margin (Mazagan Plateau, Leg 79—Hinz, Winterer, et al., 1984) and the margin of Northwest Australia (von Rad and Exon, 1982).

PREVIOUS STUDIES

Although stratigraphic, sedimentological, and paleontological studies of the Atlantic Coastal Plain (north of Cape Hatteras) have a long history (e.g., Richards, 1945; Anderson et al., 1948; Murray, 1961; Brown et al., 1972; Olsson, 1964, 1970, 1975; Perry et al., 1975), regional summaries that included the continental shelf were not published until the early 1970s (Maher, 1971; Emery and Uchupi, 1972).

Soon thereafter petroleum exploration began in the offshore region of New Jersey and gave impetus to a series of important research papers describing and interpreting the sedimentary sequences of the continental shelf (Minard et al., 1974; Mattick et al., 1974; Sheridan, 1974; Schlee et al., 1976; Hathaway et al., 1979; Scholle, 1977, 1980; Mattick and Hennessy, 1980; Poag, 1978, 1979, 1980, 1985a; Schlee, 1981; Libby-French, 1981, 1984; Robb, Hampson, Kirby, et al., 1981; Robb, Hampson, and Twichell, 1981; Robb et al., 1983; Poag and Schlee, 1984).

[1] Poag, C. W., Watts, A. B., et al., Init. Repts., DSDP 95: Washington (U.S. Govt. Printing Office).
[2] Address: U.S. Geological Survey, Woods Hole, MA 02543.

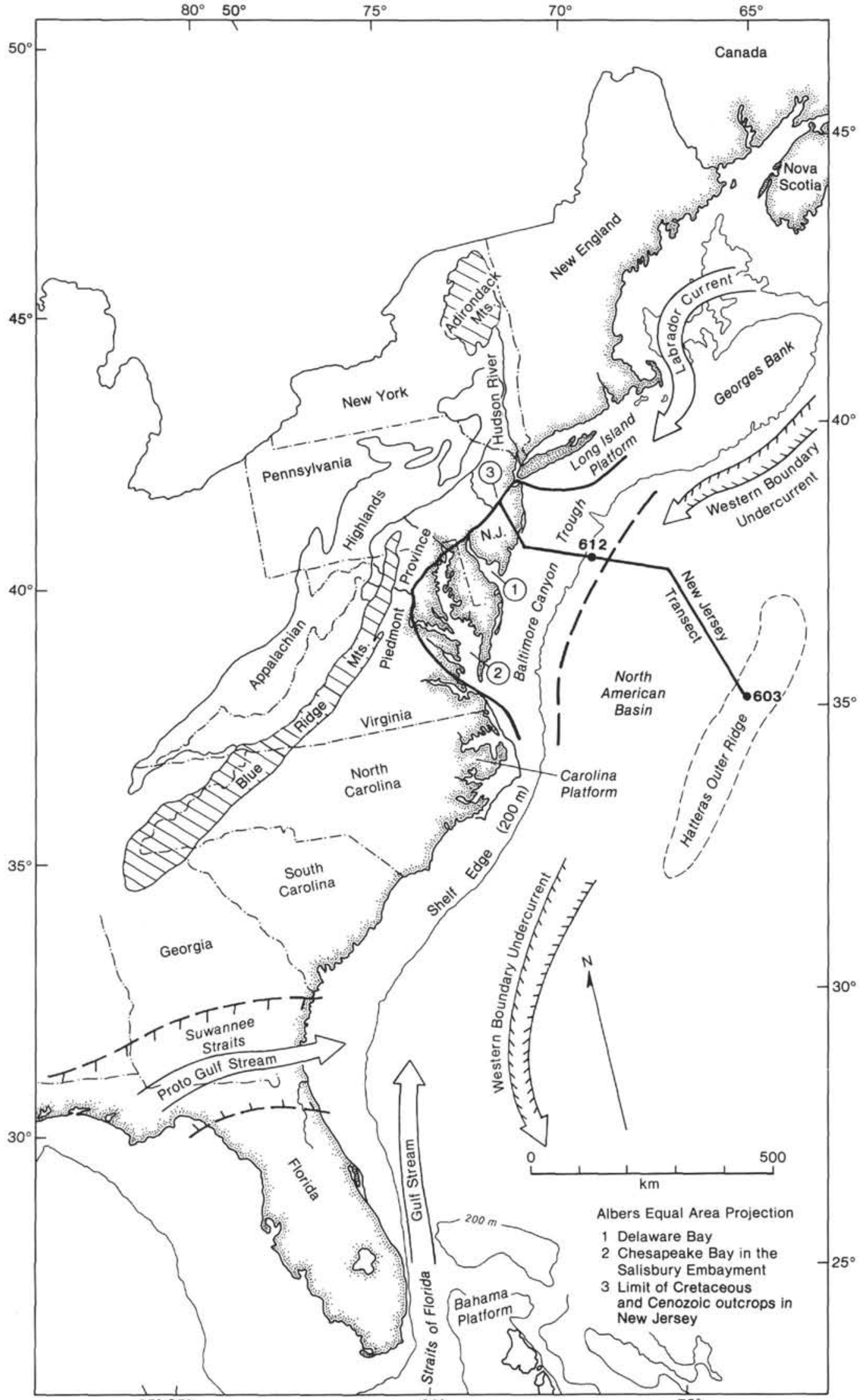

Figure 1. Physiographic, geologic, and oceanographic features of the United States Atlantic margin.

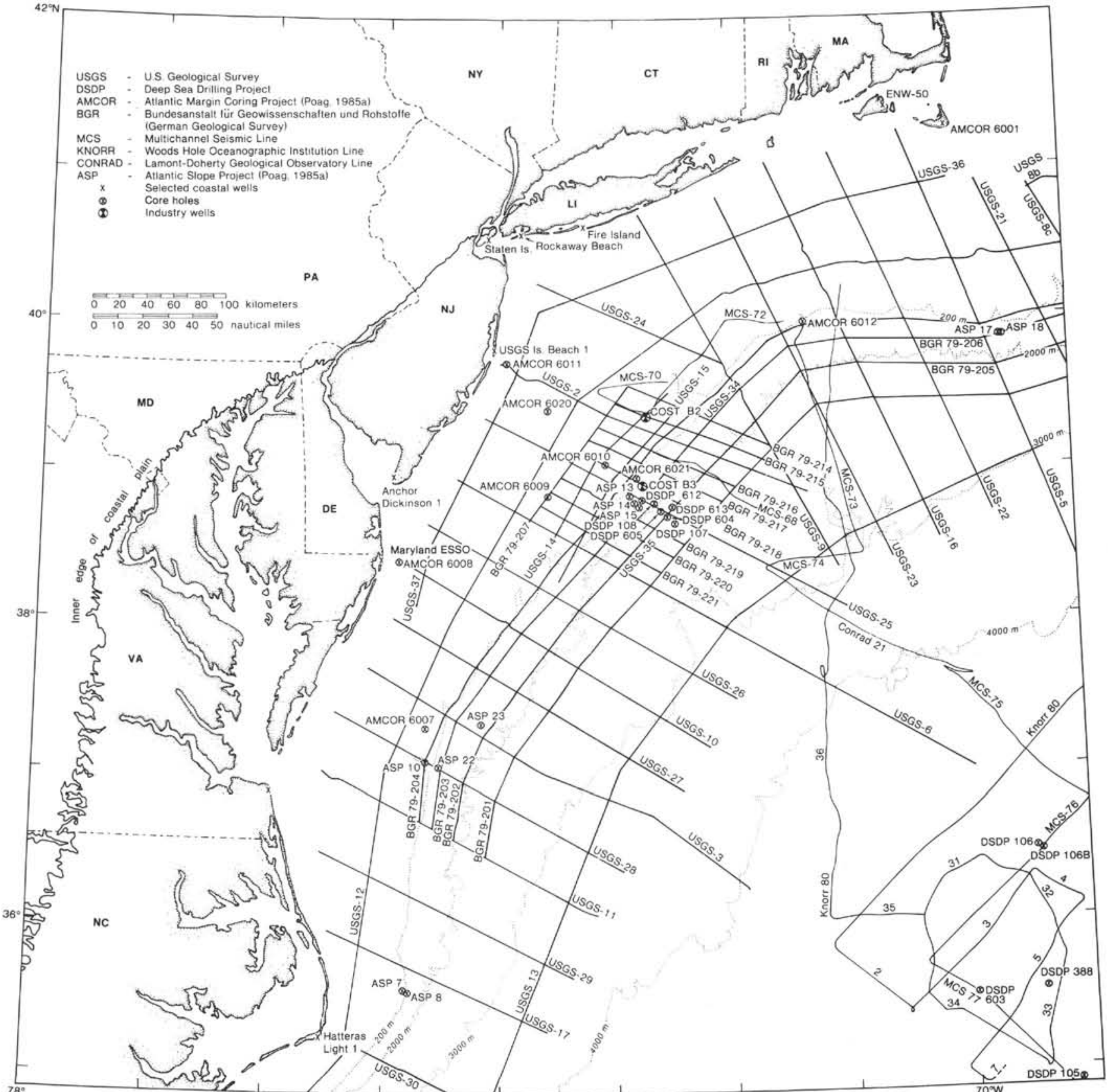

Figure 2. Locations of multichannel seismic reflection profiles and selected boreholes of the Baltimore Canyon Trough and western North American Basin. The *Conrad* 21 profile is divided into five discontinuous segments (MCS-73 thru MCS-77).

Knowledge of the continental slope and rise has also increased significantly in spite of the sparsity of geologic samples to calibrate the seismic reflection profiles in this region. The principal deep-sea geologic data have been collected by the Deep Sea Drilling Project, which drilled several sites during Leg 11 (Hollister, Ewing, et al., 1972) and Leg 43 (Tucholke, Vogt, et al., 1979) to document the sedimentary record of the lower rise. Important discussions of relevant deep-sea data are included by Jansa et al. (1979), Tucholke and Mountain (1979, in press), Tucholke and Laine (1982), Tucholke et al., (1982), Mountain and Tucholke (1985), Ewing and Rabinowitz (1984), Emery and Uchupi (1984), Poag (1985b), and Schlee and Hinz (in press).

These and other studies have established the presence off the U.S. middle-Atlantic states of a deep (~18-km thickness of sedimentary rocks), elongate, sedimentary basin (margin sag basin; Kingston et al., 1983; Emery and Uchupi, 1984)—named the Baltimore Canyon Trough (Maher, 1965). The Baltimore Canyon Trough underlies the continental shelf and slope for 500 km between Long Island (Long Island Platform) and Cape Hatteras (Carolina Platform) (Fig. 1; Schlee, 1981; Poag, 1985a), encompassing along its shoreward flank the coastal plain embayments of New Jersey, Delaware, Maryland, and Virginia (principally the Salisbury Embayment). A structural hingeline separates the more rapidly subsiding offshore part of the trough (which consequently has the thickest sediment column) from the onshore part (present coastal plain), which may have undergone partially compensating uplift (Watts, 1982; Hack, 1982).

The trough is bounded to the west by the uplifted rocks of the Appalachian orogen (Appalachian Highlands, including the Blue Ridge Mountains in Virginia and the Adirondack Mountains of New York; Fig. 1). Precambrian to Pennsylvanian sedimentary and metasedimentary rocks (with lesser amounts of volcanic and granitic rocks) form the high-relief (currently 240–1200 m) hinterland sources from which terrigenous sediments of the Baltimore Canyon Trough were derived (Hack, 1982). A terrain of intermediate elevation and low relief (currently 90–120 m; Piedmont Province), containing igneous and metasedimentary rocks, forms a transition between the Appalachian Highlands and the inner edge of the Atlantic Coastal Plain (Fig. 1). The mineralogic composition of some basal Cretaceous and younger rocks of the coastal plain and continental shelf (Glaser, 1969) indicates a Piedmont origin, implying a higher relief for the Piedmont Province during the Mesozoic.

The seaward (southeast) margin of the Baltimore Canyon Trough is marked by a buried reef-supported shelf edge that formed a steep reef-front slope during the Mesozoic. Seaward of this boundary is the North American Basin (Fig. 1), which encompasses the continental rise and abyssal plains of the western North Atlantic between the Newfoundland Ridge, the Bahama Platform and Antilles Island Arc, and the Mid-Atlantic Ridge (Emery and Uchupi [1984] use North America Basin as a physiographic term; to the depositional basin seaward of the Baltimore Canyon Trough, they apply the term Hatteras Basin).

OBJECTIVES

Given a large pool of geological and geophysical data on the coastal plain and continental shelf, and a depositional model purporting to explain the depositional relationships observed (Vail et al., 1977; Poag and Schlee, 1984; Poag, 1985a), the sites for DSDP drilling (Legs 93 and 95) were selected to answer the following specific questions:

1. Do angular relationships (truncation and onlap) between seismostratigraphic sequences represent unconformities that can be identified by lithic and biostratigraphic discontinuities in boreholes?
2. If the seismic and borehole unconformities match, at what stratigraphic levels do they occur, how long are the hiatuses, and what caused the unconformities?
3. Does the pattern of depositional sequences and their bounding unconformities correlate closely with the framework of the Vail depositional model, or are there better explanations?
4. How do the stratigraphic framework and depositional history of the lower continental slope and continental rise relate to those of the continental shelf and coastal plain?
5. What were the chief agents of sediment dispersal on the lower continental slope and rise?
6. Did deep-water paleoceanographic changes and tectonic changes around the North Atlantic affect the depositional history of the lower slope and upper rise off New Jersey? If so, are the effects the same as on the middle and lower rise?
7. Can a series of well known deep-sea seismic "horizons" validly be extended into the thickened wedge of margin sediments off New Jersey?

Contemplation of those questions quickly suggested that the DSDP data alone were insufficient to achieve comprehensive resolutions. Therefore, this presentation relies heavily on data from the upper continental slope and continental shelf and also includes the coastal plain history. A series of isopach maps of selected depositional sequences are particularly useful in revealing regional depositional and erosional patterns essential to the synthesis desired. Thus I treat the DSDP results as a subset (although a critical subset) of a larger data base derived from the entire Baltimore Canyon Trough and North American Basin complex.

DSDP CORING RESULTS

Five core sites were drilled using the *Glomar Challenger* to complete the middle part and seaward end of the New Jersey Transect. Prior investigations of the Atlantic Coastal Plain (Owens and Gohn, 1985; Ward and Strickland, 1985) and continental shelf (Schlee, 1981; Poag and Schlee, 1984; Poag, 1985a; Poag and Ward, in press) indicated that a series of widespread depositional sequences, bounded by erosional unconformities, could be traced throughout the Baltimore Canyon Trough and even northeastward into the adjacent Georges Bank Basin and southwestward into the Blake Plateau Basin (Poag and Hall, 1979; Poag, 1982; Schlee and Fritsch, 1982; Schlee et al., 1985). Along the lower slope and upper rise, U.S.G.S. seismic Profile 25 showed that several of these depositional units, some as old as Late Cretaceous, were within reach of the *Glomar Challenger*'s drillstring. Their boundaries produce high-amplitude reflections that truncate underlying reflections, and often are onlapped by younger reflections, which are the chief criteria for recognizing "seismic" unconformities (Vail et al., 1977). Thus four sites along Profile 25 (Sites 604, 605, 612, 613; Poag, 1985b; van Hinte, Wise, et al., 1985a) were chosen to sample these strata and document the middle segment of the New Jersey Transect (Fig. 2). A fifth site (Site 603; van Hinte, Wise, et al., 1985b) was placed near the extreme end of profile *Conrad* 21 (segment MCS-77; Fig. 2), at a position where the oldest Jurassic strata in the North American Basin might be reached. Site 603 (along with previously drilled Site 105) documents the seaward end of the New Jersey Transect.

At each site the scientific party attempted to core the sedimentary section as completely as possible, given the constraints of schedule deadlines and equipment durability. Schlumberger logging equipment was available on Leg 95, enabling the party to obtain downhole geophysical logs at Sites 612 and 613. Extensive analyses and interpretation of lithologic, sedimentologic, paleontologic, and geochemical data are discussed in detail elsewhere in this volume and in Volume 93 of this series (van Hinte, Wise, et al., in press). The following section summarizes these results in geographic sequence from the most landward to the most seaward location, and from oldest to youngest stratigraphic unit. In order to conserve space, I have not cited the specialty chapters of this volume and Volume 93 each time data from those chapters are presented. The reader should, however, refer to those chapters for more comprehensive discussions and data sets.

The most landward drilling was carried out on the lower continental slope at Site 612. Its position, ~92 km northeast of the intersection of USGS multichannel seismic Profiles 25 and 34 (Figs. 2, 3) affords an excellent correlation with most of the Upper Cretaceous and Cenozoic sedimentary sequences previously identified on the continental shelf and upper continental slope (Schlee, 1981; Poag and Schlee, 1984; Poag, 1985a). Site 612 is located in 1404 m of water 5 km updip of a broad submarine outcrop of middle Eocene biosiliceous chalk and limestone (Hollister, Ewing, et al., 1972; Robb et al., 1983). The hole is the stratigraphic link between the COST B-3 well (12 km north on the upper continental slope) and Site 605 (17 km southeast on the uppermost continental rise). Hole 612 was continuously cored to 675.3 m below the seafloor; core recovery was 86% complete. Five distinct lithologic units were documented at Site 612 (Fig. 3). The oldest unit cored is of Campanian age, and is the oldest unit discussed in this section. The pre-Campanian lithologic units drilled at Site 603 (and 105) are discussed in later sections of this chapter.

Lithologic Unit V—Campanian

The lowermost lithologic unit (Unit V; Campanian age) comprises 27.8 m of thinly laminated, black, foraminifer and nannofossil chalks, alternating with mudstones and shales. The major mineralogical constituents in the Campanian strata are of terrigenous origin (stable illitic clay), quartz (fine sand and silt), feldspar, and mica. A clay enrichment relative to overlying Maestrichtian strata is mainfest by higher values on the gamma-ray log. The dark color, relatively high total organic carbon (TOC 2.67%; highest at site), sparsity of ichnofauna (mainly *Chondrites*), low concentration of manganese and enrichment in iron sulfides (mackinawite, marcasite, pyrite), and an enrichment in dinoflagellates and benthic foraminifers relative to planktonic foraminifers in some intervals suggest deposition in oxygen-depleted conditions.

Contact between Lithologic Units V and IV

The contact separating lithologic Unit V from overlying Unit IV at Site 612 is an unconformity of apparently erosional origin (at 612-69-3, 8 cm; Fig. 4F). The acoustic impedance change at the contact produces a strong undulating reflection (at 2.57 s on seismic Profiles 25 and 34), which can be traced widely across the margin, often truncating underlying reflections. Mineralogical and microfaunal changes across the contact indicate significant paleoenvironmental shifts during the approximate 1-m.y. hiatus. Extensive burrowing across the contact brings Maestrichtian microfossils as deep as 10 cm into the Campanian section, and reworked Campanian microfossils are known as high as 4 cm above the contact.

Diagenesis has produced a concentration of manganese, pyrite, and marcasite immediately below the contact, and of calcite cement just above the contact. Campanian fossils were not encountered at the other core sites, but equivalent strata may be present among the varicolored mudstones at Site 603.

Lithologic Unit IV—Maestrichtian

Lithologic Unit IV at Site 612 comprises 84.6 m of dark gray, marly, intensely burrowed, foraminifer-nannofossil and nannofossil-foraminifer chalk, including some lithified limestone layers (Fig. 3). Terrigenous components (minerals and organic carbon) are present throughout, but decrease significantly toward the top of the unit. Calcareous microfossils indicate an age of middle and possibly early Maestrichtian for Unit IV. Radiolarians are present as well, but are rare and poorly preserved.

Sixteen kilometers downdip at Site 605, the upper part of the Maestrichtian section was also cored (Fig. 5). There, 57 m of middle and upper Maestrichtian strata (lithologic Unit VA of van Hinte, Wise, et al., in press) are composed of green, argillaceous, foraminifer-nannofossil limestone. Maestrichtian strata were not encountered at the other DSDP sites on the New Jersey Transect. However, it is possible that the barren terrigenous sands of Cores 22–25 in Hole 603B (Fig. 6) may include part of the Maestrichtian; also, undifferentiated Maestrichtian–Danian ichthyoliths are present in Core 8 at nearby Site 105 (Fig. 2).

Contact between Lithologic Units IV and III

The top of the Maestrichtian section (lithologic Unit IV) at Site 612 is approximately at the top of Core 612-61, below a 9-m interval that was not recovered. Because this short 9-m interval separates middle Maestrichtian from lower Eocene strata (an interval of ca. 16 m.y.), I presume that more than one unconformity is present in the uncored interval. Sharply increased gamma-ray values within the unrecovered interval indicate a significant increase in clay minerals and/or glauconite, which are typical characteristics of the lower Paleocene section at Site 605. Thus I infer that the 9-m uncored section represents the Paleocene series, which thins updip from Site 605 (seen on seismic Profile 25 and parallel dip-profiles), and pinches out altogether (was eroded) a few kilometers updip from Site 612 (verified by the absence of Paleocene strata in the COST B-3 well).

The Paleocene section at Site 605 (Fig. 5; see also lithologic Units VA and IVA of van Hinte, Wise, et al., in press) comprises 176 m of dark greenish gray, argillaceous, nannofossil limestone and nannofossil claystone overlying 19 m of glauconitic, silty, nannofossil marl and foraminifer-bearing mudstone. Early, middle, and late Paleocene microfossils are present in a nearly com-

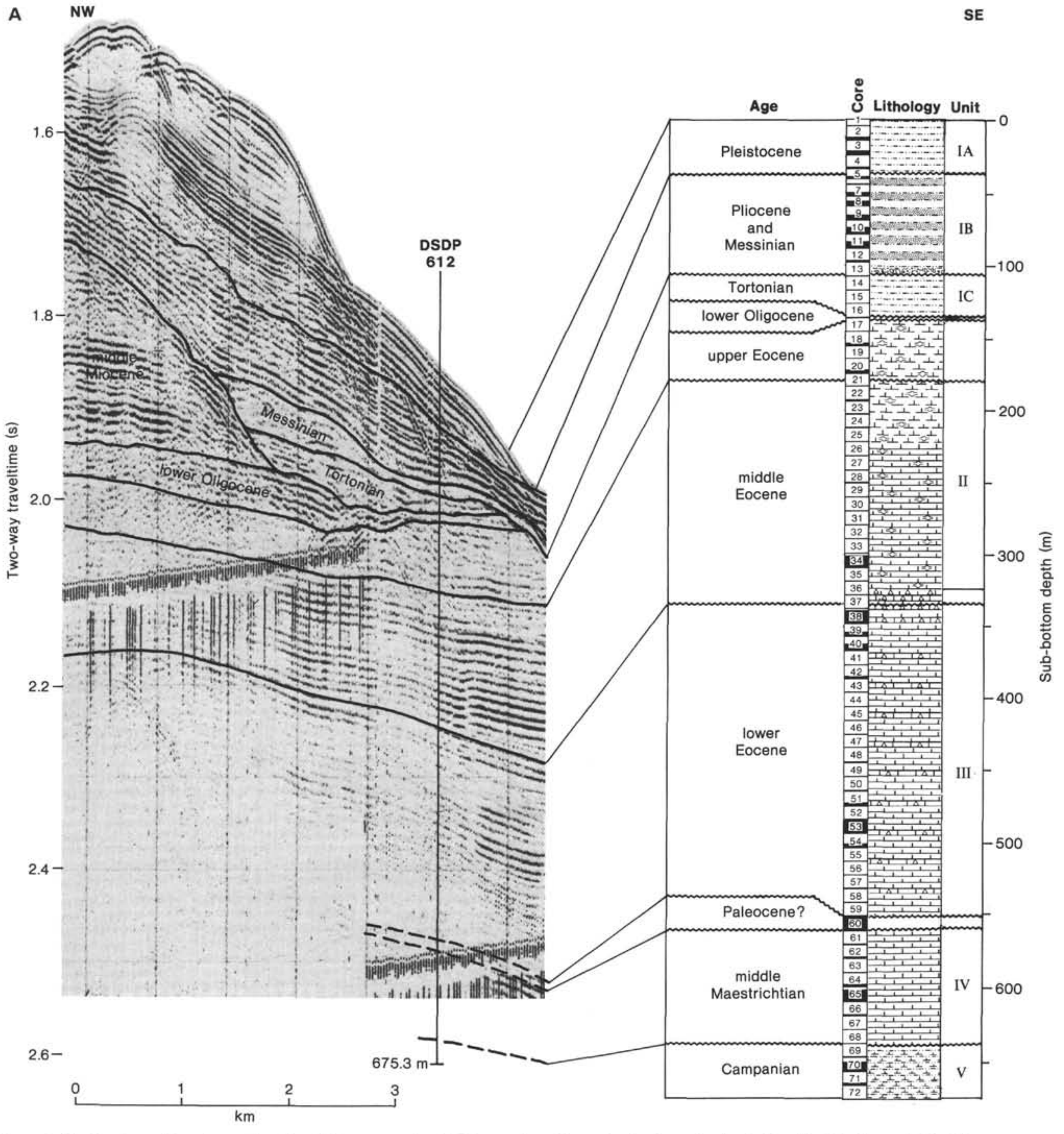

Figure 3. A. Stratigraphic column for Site 612 compared with dip section along single-channel seismic Profile 69. The middle Miocene sequence, sampled updip at the COST B-3 well, is truncated by erosion 1.6 km northwest of Site 612. Messinian and Tortonian strata fill a local channel cut into the upper Eocene surface. The lower Oligocene sequence also has been truncated and severely thinned. B. Stratigraphic column for Site 612 compared with strike section along single-channel seismic Profile 89. This profile parallels multichannel Profile 34 (Fig. 2) and crosses Site 612 parallel to the slope contours, showing the downslope channeling on the upper Eocene surface. The channel whose southwest margin was penetrated at Site 612 is a local feature, having been filled with Tortonian, Messinian, and Pliocene sediments before being more broadly blanketed by Pleistocene strata. Note that the lower and middle Miocene strata, not present at Site 612, are well represented southwest of the site. Middle Eocene strata appear to crop out in the walls and floor of Carteret Canyon.

plete section, but at least one significant unconformity separates the upper and lower Paleocene sections. Minor amounts of quartz (chiefly silt size) and mica persist throughout the Paleocene interval, attesting to distant terrigenous sources.

Lithologic Units III and II—Eocene and Oligocene

The depositional regime of the New Jersey margin changed significantly by the early Eocene, when lithologic Unit III began to accumulate. At Site 612, Units

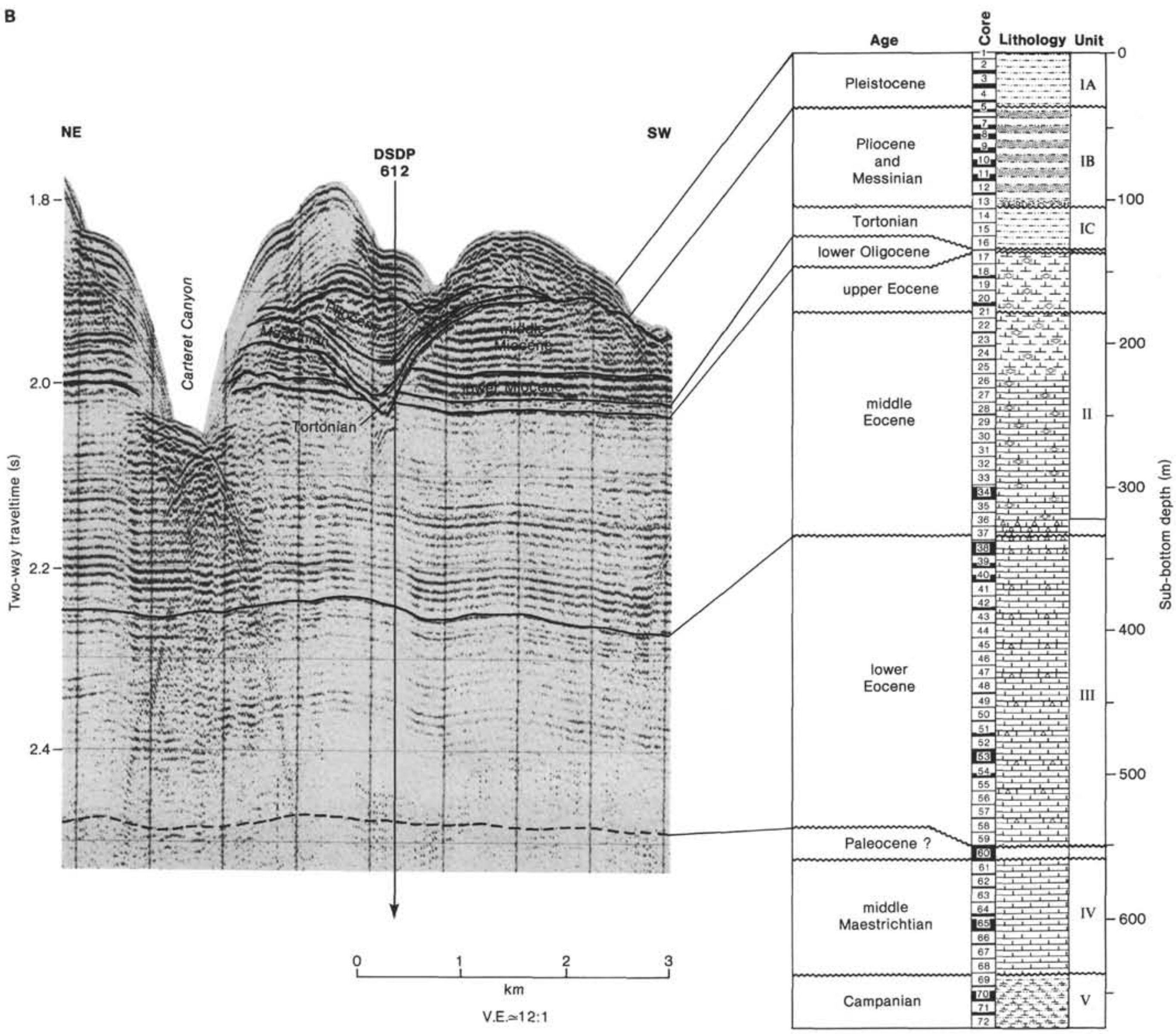

Figure 3 (continued).

III and II consist of 420 m of dominantly light gray, biosiliceous, nannofossil-foraminifer oozes and chalks (Fig. 3). The pelagic carbonate regime responsible for these deposits lasted into the early Oligocene, but deposition was interrupted by at least two significant erosional events. Diagenetic characteristics separate Unit III from Unit II. Unit II is 187.4 m thick and contains rich middle Eocene to lower Oligocene calcareous and siliceous microfossil assemblages. The abundance of well-preserved radiolarians and diatoms is especially characteristic of Unit II. A zone of progressive, downward-intensifying silica diagenesis begins around 245 m sub-bottom depth and culminates in a zone of porcellanite at the base of the middle Eocene section. Sonic velocities peak in this interval (2.28–2.52 km/s). The top of the porcellanite at 323.4 m is taken as the top of lithologic Unit III (ca. 231 m thick), below which variably intense diagenesis has converted many of the siliceous skeletal remains to silica cement.

Both Units III and II contain bathyal microfossil assemblages, including abundant planktonic species. Extensive burrowing, a rich ichnofauna, diverse benthic microfossils, and sparse total organic carbon attest to nutrient-enriched, well-oxygenated, seafloor environments. The sparsity of terrigenous minerals indicates that the site lay far from the shoreline for most of the 20 m.y. of the early Eocene to early Oligocene. Similar lithologies, microfossil suites, and paleoenvironments were encountered in the lower to middle Eocene sections drilled downdip at Sites 605 and 613 (Figs. 6, 7).

The diagenetic succession documented at Site 612 also can be traced in equivalent sections at Sites 605 and 613, and extends to several other deep-sea sites in the North American Basin that cored the middle and lower Eocene section. The porcellanite 'front," which marks the most intense transformation of biosilica, is diachronous, occurring 8 m above the unconformable lower Eocene–middle Eocene contact at Site 612 (see Fig. 4E) and

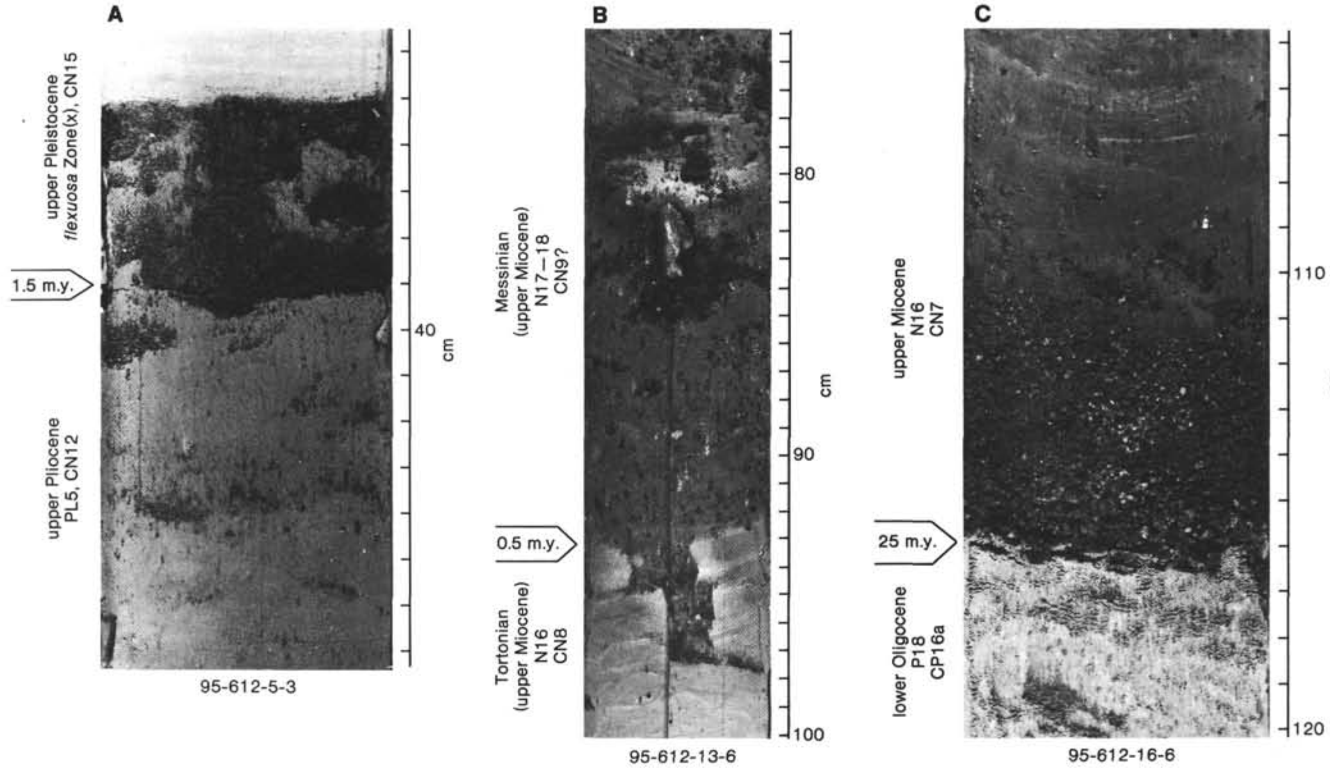

Figure 4. Photographs of significant unconformities and other lithologic features found in cores along the New Jersey Transect. A. 95-612-5-3: upper Pleistocene medium blue gray, homogeneous, sparsely burrowed mud, separated from upper Pliocene brown gray, homogeneous, sparsely burrowed mud by approximately 4-cm zone of dark green to blackish glauconitic sand mixed with brown gray mud. B. 95-612-13-6: upper Miocene (Messinian) green gray homogeneous mud containing scattered specks and pockets of dark green to black glauconitic sand (bone fragment at 81–83.5 cm), overlying and filling burrows within upper Miocene (Tortonian) blue gray homogeneous mud. C. 95-612-16-6: upper Miocene dark olive gray homogeneous mud, separated from lower Oligocene light gray, mildly burrowed biosiliceous, foraminifer, nannofossil ooze, containing volcanic ash shards, by a 5-cm section of dark gray glauconitic quartzose sand. D. 95-612-21-5: upper Eocene light brown and gray, biosiliceous, nannofossil ooze, separated from middle Eocene light gray and light brown, biosiliceous, nannofossil ooze by a 2-cm section of dark green glauconitic, quartzose sand containing microtektites and shocked glass. E. 95-612-37-3: middle Eocene blue gray, slightly glauconitic, biosiliceous foraminifer, nannofossil chalk, separated from lower Eocene brown gray, thinly laminated, porcellanitic, nannofossil chalk by a 13-cm disturbed section of intense reworking and burrowing, containing a clast of Upper Cretaceous chalk at 75–78 cm. F. 95-612-69-3: middle Maestrichtian dark gray, glauconitic, marly foraminifer, nannofossil chalk, separated from upper Campanian dark gray to black pyritic, glauconitic, foraminiferal chalk and shale by a 5-cm section of reworked sediments. G. 93-605-6-4: lower Pleistocene light blue gray, silty, homogeneous clay, separated from middle Eocene grayish olive green, biosiliceous, calcareous clay by a 4-cm section of Pliocene(?) medium gray, glauconitic, pyritic, calcareous clay. H. 93-605-22-3: middle Eocene light blue gray, porcellanitic nannofossil limestone, separated from lower Eocene dark green gray, argillaceous, porcellanitic nannofossil chalk by a 7-cm disturbed section of mixed lithologies. I. 93-605-44-5: lower Eocene light green gray, lightly burrowed argillaceous porcellanitic, foraminifer, nannofossil limestone, separated from upper Paleocene dark blue gray, densely burrowed, marly, foraminifer, nannofossil limestone by a 4-cm section disturbed by expansion fractures in lower lithology. J. 93-605-64-1: lower Paleocene dark gray, densely burrowed (all burrows horizontal), argillaceous, nannofossil limestone, overlying light blue gray, sparsely burrowed, foraminifer limestone. K. 93-605-66-1: lower Paleocene light blue gray, burrowed, slightly laminated, foraminifer mudstone, separated from upper Maestrichtian gray, mildly burrowed, argillaceous, foraminifer, nannofossil limestone by a 15-cm zone of disturbance that obscures contact. L. 95-613-11-3: lower Pleistocene dark greenish gray, glauconitic, calcareous, sandy mud, overlying upper Pliocene dusky, yellow green, homogeneous, nannofossil, diatom mud. M. 93-604-6-3: upper Pleistocene blue gray, homogeneous, silty clay, separated from upper Pleistocene olive brown, heavy-mineral-rich, silty clay by a 15-cm zone of mixing. N. 93-604-10-1: clast of Eocene light gray, biosiliceous, nannofossil ooze, overlying (enclosed by) upper Pleistocene dark green to black glauconitic sand and brown sandy silt. O. 93-604-17-4: lower Pleistocene(?) olive gray, sandy, silty clay, overlying upper Pliocene(?) greenish gray, homogeneous, calcareous, silty clay. P. 93-604-26-2: lower Pliocene dark olive green, biosiliceous, glauconitic claystone, separated from upper Miocene brownish gray conglomerate (containing quartz pebbles, claystone clasts, and glauconitic sand in clay matrix) by a 5-cm dark brown conglomeratic zone. Three erosional surfaces identified in conglomeratic section. Q. 93-604-27-1: clasts of Eocene light greenish gray, biosiliceous, nannofossil chalk encompassed in upper Miocene grayish olive green, glauconitic, pebbly, sandy siltstone.

ca. 2 m below the same unconformity at Sites 605 and 613 (Figs. 6, 7).

At the seaward end of the New Jersey Transect (Site 603), the Eocene section is abbreviated, consisting of 59.4 m of radiolarian claystone, entirely of early Eocene age (Fig. 6). The claystones are essentially carbonate-free, presumably having accumulated below the calcite compensation depth (CCD). Calcareous nannofossils are present, however, in trace quantities. Porcellanite formation is weak to moderate throughout this section (no hard nodules or layers), having been retarded by the clayey sediments; no "diagenetic front" developed. At other deep-sea sites near Site 603 (e.g., 105, 106) similar lithic and stratigraphic relationships prevail.

Ypresian–Lutetian Unconformity

Two important regional unconformities (and perhaps a third) are recorded within the pelagic carbonates of

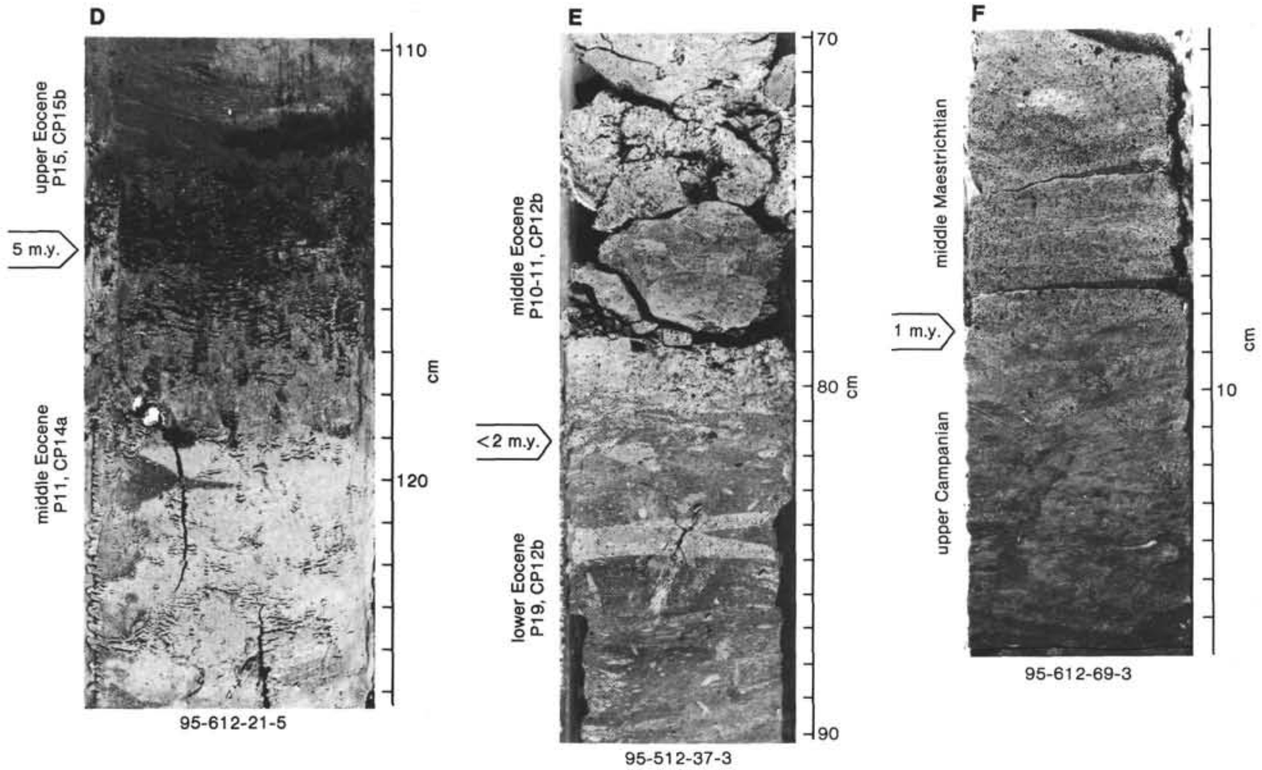

Figure 4 (continued).

lithologic Units III and II at Site 612. The oldest unconformity separates the lower Eocene (Ypresian Stage) and middle Eocene (Lutetian Stage) sections with a hiatus of <2 m.y. (Fig. 4E). Reworked clasts of hard Upper Cretaceous chalk at several spots just above the scoured contact indicate the presence of a debris-flow deposit. This contact is 8 m below the porcellanitic "front"; their closeness makes it impossible to recognize two separate seismic reflections for the two horizons. A strong impedance contrast associated with these horizons produces a high-amplitude seismic reflector that can be traced widely throughout the margin; the reflector is equivalent to horizon A^c of the deep sea. The Ypresian-Lutetian unconformity is also documented at several places on the coastal plain (Ward and Strickland, 1985) and southward on the continental slope of Georgia (Popenoe, 1985). Downdip at Site 613, the Ypresian-Lutetian contact is marked by a zone of slumping (Fig. 7). At Site 603, middle-to-lower Miocene siliciclastics rest directly on lower Eocene siliceous claystones (Fig. 6).

Lutetian-Priabonian Unconformity

The second significant Eocene unconformity at Site 612 separates the middle Eocene (Lutetian) section from the upper Eocene (Priabonian) section (Fig. 4D). The contact is an irregular scour surface separating medium gray, biosiliceous, sparsely burrowed, nannofossil ooze (below) from dark greenish gray, glauconitic, quartz sand, characterized by its content of microtektites (above). Planktonic foraminifers show that Zones P12–14 are missing, indicating a hiatus of ca. 6 m.y.

Priabonian-Rupelian Contact

A third possible unconformity within the section represented by lithologic Units III and II may be present at the upper Eocene (Priabonian)–lower Oligocene (Rupelian) contact. Priabonian strata consist of grayish, yellow green, homogeneous, biosiliceous, foraminiferal, nannofossil ooze, which extends upward from Section 612-17-1 to the top of the core catcher in Core 612-16. Section 612-16-7 and basal Section 612-16-6 comprise distinctly lighter gray, biosiliceous, foraminiferal, nannofossil ooze, containing significant quantities of volcanic glass shards and abundant specimens of the encysted alga *Bolboforma*. There is no transition zone between the two lithologies; however, the contact was not actually recovered, having been lost between 612-16,CC and the base of 612-16-7.

Lithologic Unit I—Miocene to Holocene

A depositional regime dominated by terrigenous detritus and characterized by low carbonate content replaced the Paleogene carbonate regime during the late Oligocene and has been maintained to the present (Poag, 1985a). These terrigenous sediments at Site 612 have been included in lithologic Unit I, which is further divided into subunits—A-C (Fig. 3A). The oldest subunit IC is 28.4 m thick, consisting of dark gray to olive gray muds that contain light brown, irregularly dispersed barite concretions, and as much as 40% diatom frustules. Subunit IC is separated from Unit II by a scour surface that represents a hiatus of as much as 25 m.y. (Tortonian strata resting upon Rupelian; Fig. 4C).

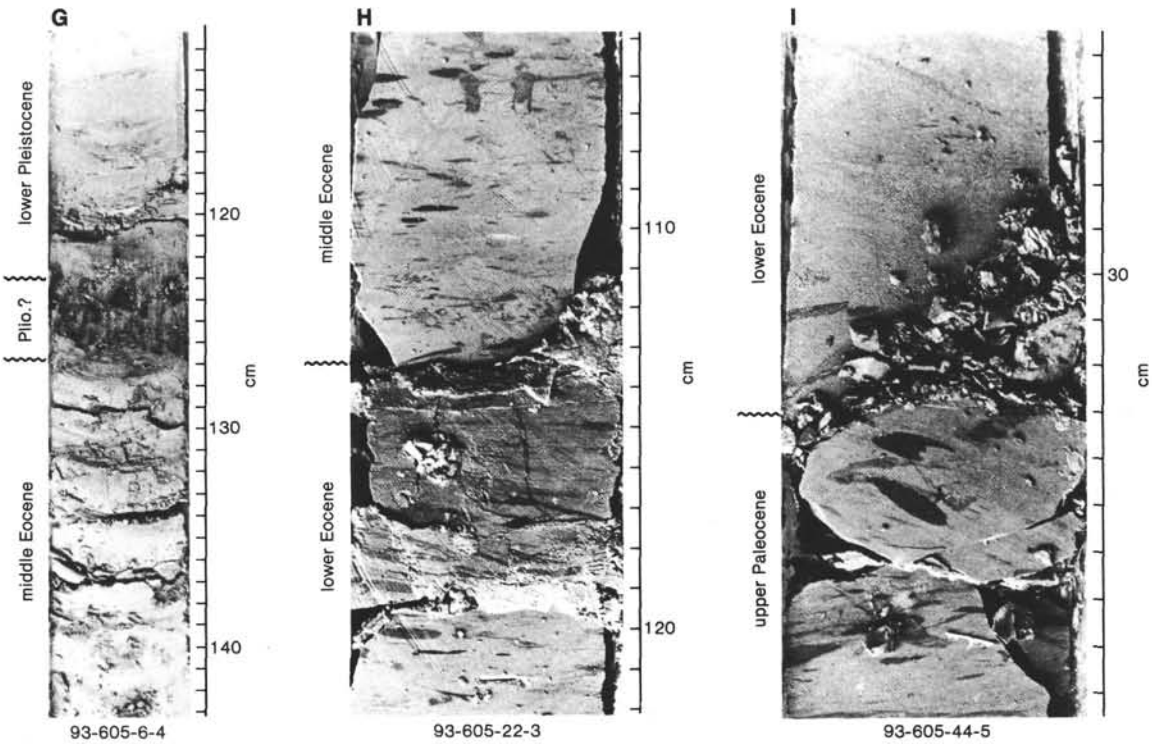

Figure 4 (continued).

A succession from coarse sand to fine sand to faintly laminated mud indicates turbidite deposition above the scour surface. This unconformity forms the flank of a downslope-trending channel, through which Site 612 was drilled (Fig. 3).

Lithologic Subunit IB is 69.95 m thick and consists of alternating intervals of mud and glauconitic sand. The muddy sediments are interrupted repeatedly by glauconite-quartz sands, which commonly have sharp, eroded basal contacts. Some beds contain as much as 50% glauconite, whose grains are fresh, irregular, and unoxidized, indicating little transport. Subunit IB is separated from Subunit IC by a sharp erosional surface representing the Tortonian–Messinian contact; a hiatus of ca. 0.5 m.y. is indicated by the microfossil record (Fig. 4B). The bulk of Subunit IB, however, is of Pliocene age.

The uppermost subunit (IA) is 36.95 m thick, consisting of upper Pleistocene and Holocene muds (the plethora of glauconite sand beds seen in Subunit IB is noticeably absent in Subunit IA). The lower contact of Subunit IA is an unconformable surface representing a hiatus of ca. 1.5 to 2 m.y., as indicated by the planktonic microfossil record (Fig. 4A).

Lithologic Unit I is recognizable on the upper rise at Sites 605 (Fig. 5), 613 (Fig. 7), and 604 (Fig. 8), and as far downdip as Site 603 (Fig. 6) on the basis of its abrupt upward change to terrigenous siliciclastic sediments. The age of this unit downdip is also Miocene to Holocene. Further lithic subdivision of Unit I in the downdip locations, is often more complicated, however, than the succession at Site 612, especially because of the increase in turbidites and debris-flow deposits, general basinward fining, and the added influence of a fluctuating CCD. The Miocene and Pleistocene sections on the upper rise (Sites 604, 605, 613) are particularly characterized by conglomeratic sands and reworked chunks of white Eocene chalk derived from upslope sources. On the lower rise, in contrast, the terrigenous components are dominantly clay (e.g., Site 603), but silt-size quartz, mica, feldspar, and other terrigenous minerals persist, even there.

EXTRAPOLATION OF BOREHOLE DATA ALONG THE REGIONAL SEISMIC GRID

The immediate results of lithologic, microfossil, and geophysical-log analyses provided a positive test of the coarse framework of the Vail depositional model (Vail et al., 1977), in which a series of eight Late Cretaceous and Cenozoic depositional supersequences are separated by widespread ("global") unconformities, whose stratigraphic positions are fixed by microfossil biozonation (and then correlated with a paleomagnetic and radiometric time scale). Drilling on the slope and upper rise sampled each supersequence, Kb through Q (Fig. 9) and found erosional unconformities or slump zones (lithic and biostratigraphic discontinuities) at all the contacts. Coring at Sites 612 and 604 also confirmed the presence of an unconformity within supercycle Te (Tortonian–Messinian contact), and the cores from Site 612 documented an unconformity at the Campanian–Maestrichtian contact (Fig. 4F; contact between supercycles UZA-3 and UZA-4 of Haq et al. [in press]; Fig. 9). Geophysical logging at two sites (612, 613) showed that physical discontinuities correlated with impedance contrasts on the seismic reflection profiles and with sonic velocity changes in the boreholes, confirming that the Vail technique of seismostratigraphic sequence analysis is valid in the study area. Thus a reliable basis in ground truth was established for

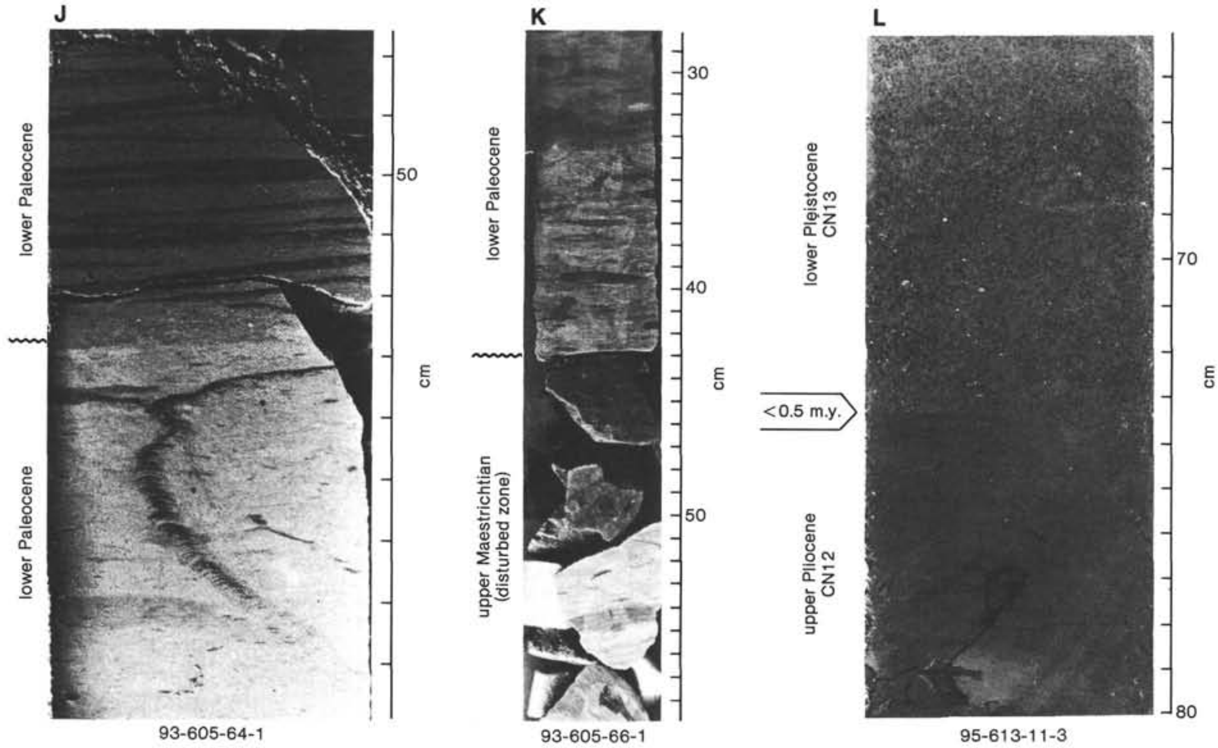

Figure 4 (continued).

A carbonate platform, first established in the Early Jurassic, persisted in the outer part of the Trough throughout the Jurassic, and its prograding seaward edge was marked by an elongate reefal structure at least as early as the Callovian? (Fig. 20, back pocket; Poag, 1985a).

By Oxfordian time the reefal structure dominated the shelf-edge physiography, its crest towering as much as 1.5 to 2.5 km above the floor of the adjacent North American Basin (Poag, 1985a). The reef system formed an elongate, discontinuous barrier that stretched approximately 6000 km from the Blake Plateau Basin (off Florida) to Newfoundland (Grow et al., 1979; Jansa, 1981). The thickness of Oxfordian beds at the shelf edge cannot be accurately measured from seismic profiles because of the lack of coherent energy return, but the back-reef area served as a narrow elongate depocenter where faulting and differential compaction allowed at least 2 km of fine- to coarse-grained carbonate deposits to accumulate (Poag, 1985a). Paralic and inner sublittoral environments persisted near the COST B-2 well site, and alluvial and deltaic environments were dominant farther shoreward, especially in the vicinity of the proto-Hudson River (Fig. 1; Lovegreen, 1974; Libby-French, 1984).

The close of the Kimmeridgian brought an end to the rapid subsidence of the Baltimore Canyon Trough, which is reflected in the abrupt upward change to thinner depositional sequences (Fig. 20, back pocket). Limestones continued to accumulate in the outer part of the trough through the Tithonian–Berriasian (the North Atlantic had widened to 1600–1800 km by this time [Fig. 21]) interval, as sampled at the COST B-3 and other exploratory wells (Libby-French, 1984; Edson, 1986; Karlo, 1986). The proto-Hudson River system still distributed coarse terrigenous detritus to the inner shelf. Dominance of carbonate deposition in the North American Basin during the Jurassic and earliest Cretaceous (Sites 105, 603; Hollister, Ewing, et al., 1972; van Hinte, Wise, et al., in press), suggests that the shelf-edge reefal system was an effective (though incomplete) barrier to terrigenous detritus entering the deep sea.

The Hauterivian sequence is the oldest unit that can be traced on Profile 25 (Fig. 20, back pocket) across the top of the shelf-edge reefal system. In the COST B-2 and B-3 wells, Hauterivian rocks are shaley limestones interbedded with thin intervals of sandstone. This overtopping of the reef by terrigenous sediments is dramatically expressed in the deep sea by the introduction of sandy turbidites (bearing land-plant debris) as far basinward as Site 603 (ca. 500 km from the Early Cretaceous shelf edge; Figs. 1, 6). (The supply of terrigenous detritus at Site 603 began in the late Valanginian and dominated in the Hauterivian).

Thick deposits of terrigenous detritus (white, medium- to coarse-grained, noncalcareous sandstones, containing terrestrial palynormorphs) continued to bury the shelf-edge reefal system during the Barremian, and paralic and inner sublittoral environments persisted near the COST B-3 well site through the Aptian and Albian. The buried Late Jurassic reefal system maintained some physiographic relief between its crest and back-reef "moat" into the Aptian, but by the end of the Albian, the moat off New Jersey was filled; a significant fore-reef slope was maintained, however (Fig. 20, back pocket). In the deeper parts of the North American Basin, the Barremian to Albian interval also is characterized by relatively thick deposits of terrigenous debris. At Site

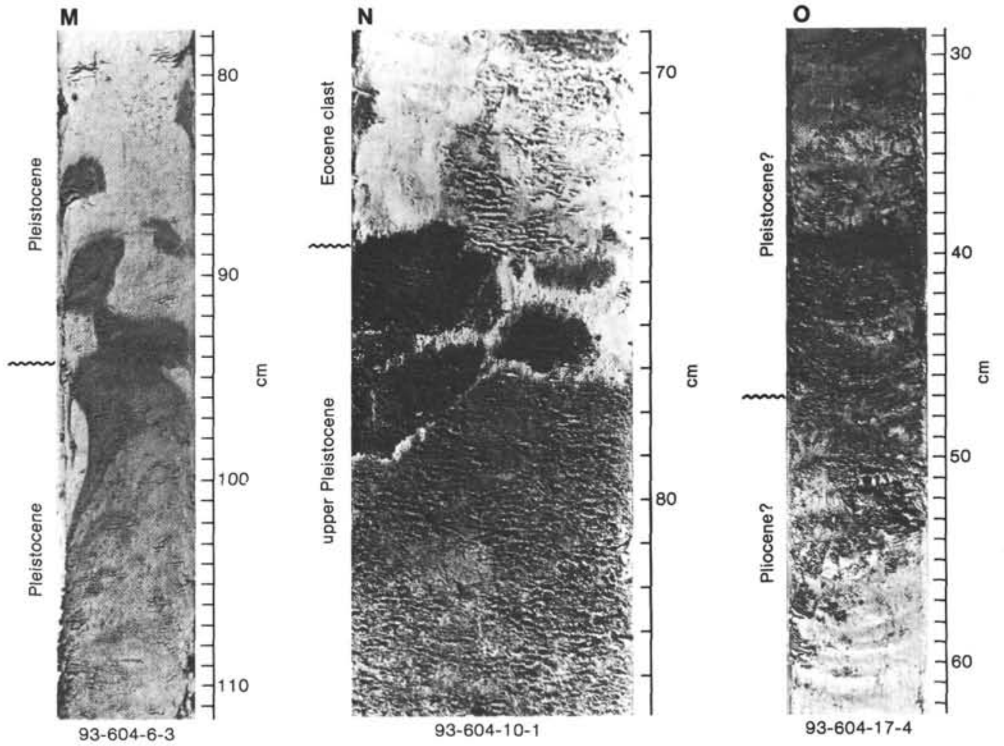

Figure 4 (continued).

extrapolating the depositional framework across the Baltimore Canyon Trough and the western margin of the North American Basin along a series of seismic reflection profiles. These results refute the claim of Thorne and Watts (1984) that seismic sequence analysis is useless in predicting the stratigraphic succession of continental shelves and slopes.

A multichannel seismic reflection grid consisting of 14 dip lines and 10 strike lines (Fig. 2) provides the principal network from which isopach maps were constructed for depositional sequences (Figs. 10–18; time constraints prevented inclusion of all the sequences in this map series; more limited maps of the lower Eocene, Pliocene, and Pleistocene sequences are taken from Poag and Mountain, this volume). An additional 15 high-resolution, single-channel profiles provide more detailed stratigraphic and thickness data in the vicinity of the updip DSDP boreholes (604, 605, 612, 613). These isopach maps help to demonstrate more clearly the chief attributes of depositional style and fabric, and the regional aspects of depositional history. More generalized sets of isopach maps for some of these units have been published by Tucholke and Mountain (1979; 1986), Schlee (1981), Ewing and Rabinowitz (1984), Emery and Uchupi (1984), Mountain and Tucholke (1985), and Schlee and Hinz (in press). The stratigraphic relationships and depositional characteristics of the mapped sequences are tabulated in Figure 19.

Pre-Campanian Depositional History

Synrift sedimentary rocks as old as the Triassic are presumed to fill the oldest depocenters of the Baltimore Canyon Trough (Poag, 1985a). By analogy with strata of this age in Triassic grabens of the coastal plain (Van Houten, 1969; Manspeizer, 1982, 1985), these strata include reddish brown mudstones, petromict conglomerates, arkosic sandstones, gray to black lacustrine shales, evaporites, and coal lenses. Tholeiitic lava flows, sills, and dikes may be the sources of some of the high-amplitude, steeply dipping reflections (Norian?–Carnian?) seen near the center of the trough on Profile 25 (Fig. 20, back pocket).

A marine transgression of warm Tethyan waters began to onlap the eroded upper Triassic surface during the transition to the Jurassic. The Trough was quite narrow (the North Atlantic was only about 200–250 km wide; Fig. 21; Klitgord and Schouten, 1986), and restricted circulation in a warm, arid climatic regime probably produced the evaporitic deposits that were encountered on the flanks of the Schlee Dome (formerly known informally as the "Great Stone Dome"; Fig. 22; Grow, 1980) and that constitute the diapiric Klitgord Dome (Fig. 23). Rocks of Early Jurassic age appear to be restricted to the center of the Baltimore Canyon Trough, as seen on Profile 25 (Fig. 20, back pocket; Hettangian?–Rhaetian?), and constitute an early postrift transitional facies that was deposited after the major rift phase ended, but prior to the onset of seafloor spreading.

Rocks of presumed Pliensbachian to Sinemurian age appear to represent deposition during the first phase of seafloor spreading in the Baltimore Canyon Trough and are more widespread than the older sedimentary sequences. High-amplitude reflections in the outer Trough suggest carbonate deposition, but shoreward, the seismic reflection characteristics (discontinuous, variable-amplitude reflections) suggest deposition of marine and nonmarine siliciclastics.

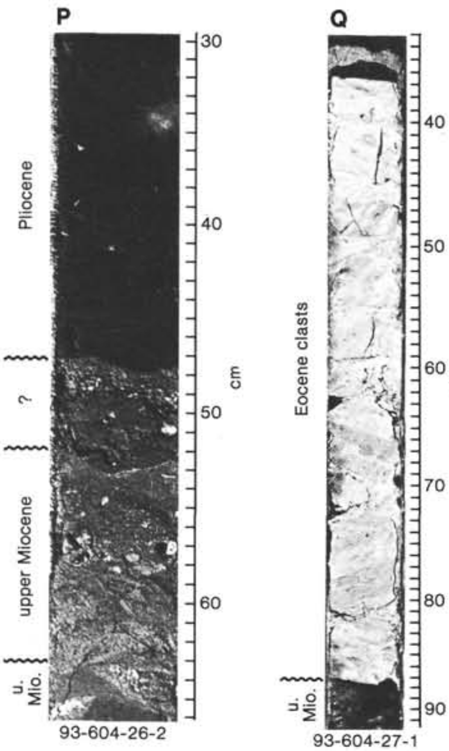

Figure 4 (continued).

603 (Figs. 6, 9), a 190-m Barremian section is noted for massive, unconsolidated, micaceous, quartzose sands (as thick as 10 m), containing interclasts of terrestrial plant fragments and shallow water molluscan shells. The Aptian–Albian section typically contains thick beds of black, organic-rich claystone and shale of the Hatteras Formation.

During the early Cenomanian, a major marine transgression spread microfossil-rich silty shales from the outer Baltimore Canyon Trough to the inner part of the present coastal plain (Petters, 1976). The upper part of the Cenomanian section was subsequently eroded during a sea level drop (Poag, 1985a), which provided quartz and mica-rich terrigenous detritus to the deep sea (e.g., Site 603).

The Turonian interval on the shelf and upper slope segment of Profile 25 (Fig. 20, back pocket) is represented by a pair of closely spaced high-amplitude reflections that can be traced widely across the trough, although they appear to be absent across the top of the buried Late Jurassic shelf edge. One hundred to two hundred meters of dark gray shale and calcareous sandstone constitute most of the fossil-rich Turonian section from the COST B-3 well to the Island Beach well (on the present New Jersey coastline; Figs. 2 and 9). Only the lower part of the Turonian is represented in those wells, however, as a widespread erosional interval has removed the upper part. Sand and claystone constitute the undifferentiated Cenomanian–Turonian section at the seaward end of the New Jersey Transect (Site 603).

Santonian and Coniacian strata form a thick wedge (as much as 500 m) of sediments along the outer part of the Baltimore Canyon Trough. At the COST B-3 site, the section is chiefly dark brown and gray, calcareous, silty sandstone, interbedded with hard, brown, blocky dolomite, and thin beds of green glauconitic sandstone (Fig. 9). Poorly preserved microfossils and gypsum mark the basal transgressive sand.

The Santonian–Coniacian section thins shoreward to 52 m at the Island Beach well and comprises chiefly lignitic, sideritic, micaceous, glauconitic, and shelly sand. At the downdip extreme of the transect (Site 603), poorly fossiliferous, variegated, quartz- and mica-bearing claystones contain layers and lenses of silt and sand, attesting to the continued long-distance transport (~500 km) of terrigenous debris to the deep North American Basin during the Santonian and Coniacian (Fig. 9).

Campanian (Sequence 12) Depositional History

Because rocks of the post-Santonian interval were the prime targets of the four updip DSDP drill sites off New Jersey, these rocks have undergone more detailed analyses and interpretation than the older section. Figure 19 shows the general stratigraphic relationships and the lithic and seismic facies characteristics of the 12 post-Santonian depositional sequences of the upper continental rise prism. Figure 20 (back pocket) shows the distribution of Campanian sediments (Sequence 12) along Profile 25, and Figure 10 shows the distribution and thickness over the Baltimore Canyon Trough and inner North American Basin. Campanian strata constitute a relatively thin (95 to 165 m) northeast-thickening sequence across the Campanian shelf, which extended more than 250 km from west of its present outcrop (in western New Jersey; Fig. 1) to the vicinity of DSDP Site 612. The Campanian shelf break is subparallel to the Holocene shelf break, and is associated with a paired regional growth-fault system (herein termed the Gemini fault system) that rims the outer margin of the Baltimore Canyon Trough (Figs. 10; 20, back pocket. An additional series of subparallel normal faults (some of them growth faults) underlies the outer Trough between Schlee Dome and the B-3 well (Fig. 10), but they have little effect on the distribution or thickness of the Campanian section. On the inner part of the Campanian shelf, at the Island Beach well (Figs. 2, 9), a 165-m section includes dark, greenish gray to black, calcareous, fossiliferous, lignitic, pyritic, micaceous clays and silty clays of the Marshalltown Formation, which are topped by calcareous, glauconitic, clayey, quartzose sands and glauconitic clay interbeds of the Wenonah, Mt. Laurel, Navesink, and Red Bank formations (Petters, 1976). Diverse and abundant microfaunas indicate deposition in middle to outer sublittoral environments (100–200 m). The shoreline was approximately 50 km west of the present outcrop, where microfauna indicate 50 to 100 m paleodepths (Olsson and Nyong, 1984; Nyong and Olsson, 1984).

On the outer shelf, the COST B-2 well (Figs. 9; 20, back pocket) encountered 120 m of silty, calcareous sandstones, gray to black micaceous siltstones, and claystones containing outer sublittoral to upper bathyal microfau-

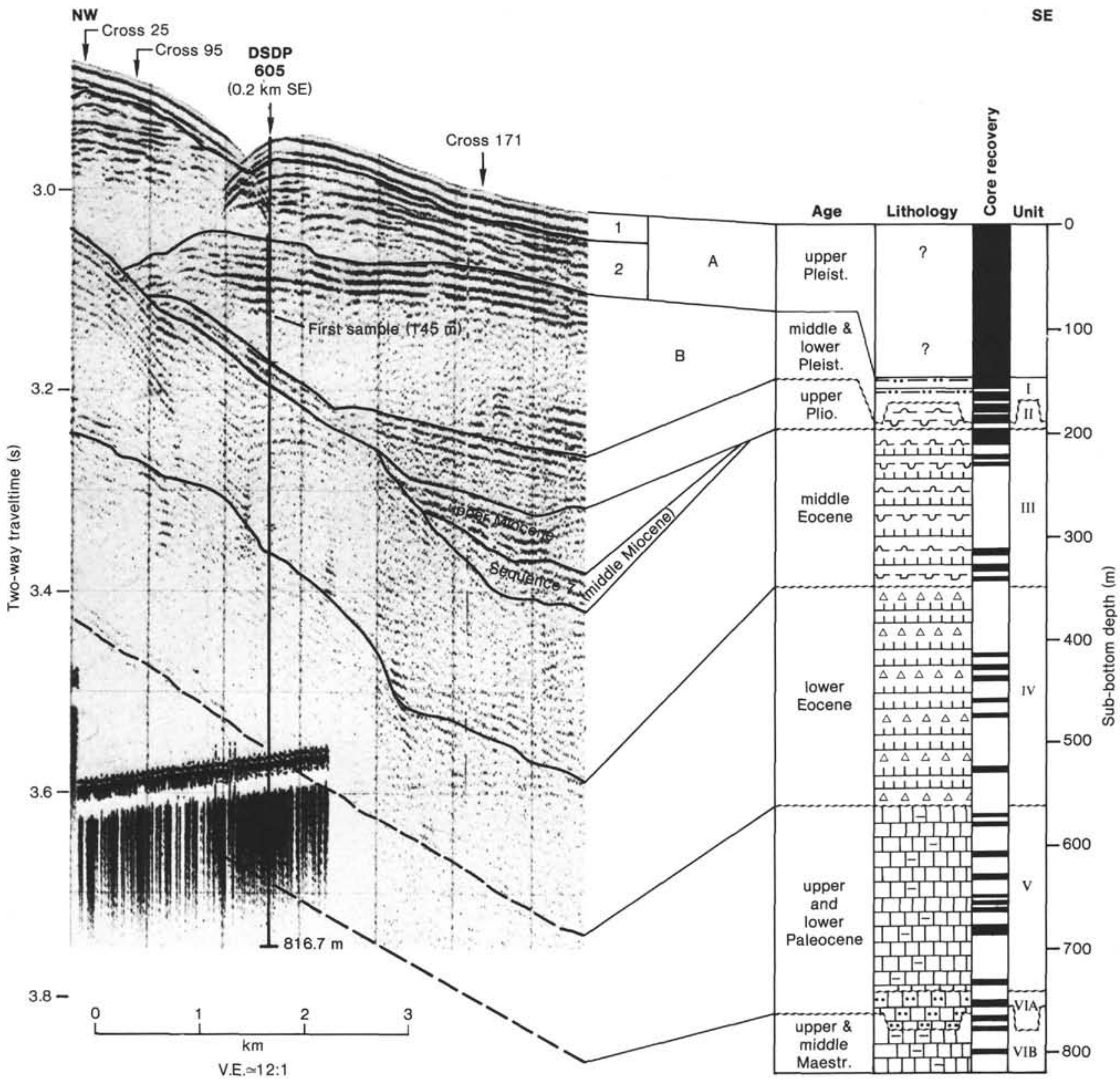

Figure 5. Stratigraphic column for Site 605 compared to its projection on single-channel seismic Profile 75 (dip section), which runs subparallel to multichannel Profile 25 (Fig. 2). Units A (upper) and B (lower) of the Pleistocene are well defined here; lower Pleistocene Unit B is truncated ca. 1 km northwest of Site 605. The first sample retrieved at Site 605 came from the lower Pleistocene. The thin tongue of Pliocene strata crossing the site was not recovered. Note that the upper Miocene sequence and Sequence 7 (middle Miocene) pinch out downdip, 1 km before reaching Site 605.

nas (200–300 m). The COST B-3 well, located near the Campanian shelf break, encountered 95 m of dark brown gray, calcareous, silty mudstone containing rich microfaunal assemblages of upper bathyal origin (300–350 m).

The Campanian shelf break is marked by a rapid seaward thickening of the Campanian depositional sequence (Sequence 12) as it crosses the Gemini fault system and forms a lenticular slope-front fill (Figs. 10; 20, back pocket). Site 612 sampled 28 m of dark gray to black chalks, shales, and mudstones, which constitute approximately the upper one-sixth of the Campanian slope-front fill (total thickness here is ca. 200 m). The dark, pyritiferous, organic-rich shales near the base of the cored section suggest that an oxygen minimum zone may have impinged upon the seafloor between Site 612 and the B-3 well during the late Campanian. Enrichment of the dinoflagellate assemblage and a low-diversity assemblage of planktonic foraminifers may be further evidence of oxygen depletion.

Nyong and Olsson (1984) noted benthic foraminiferal assemblages dominated by agglutinated species in the upper Santonian of the COST B-2 and B-3 wells, and in the lowest Campanian of the B-2 well, and interpreted them as an indication of oxygen-depleted waters. A sparse

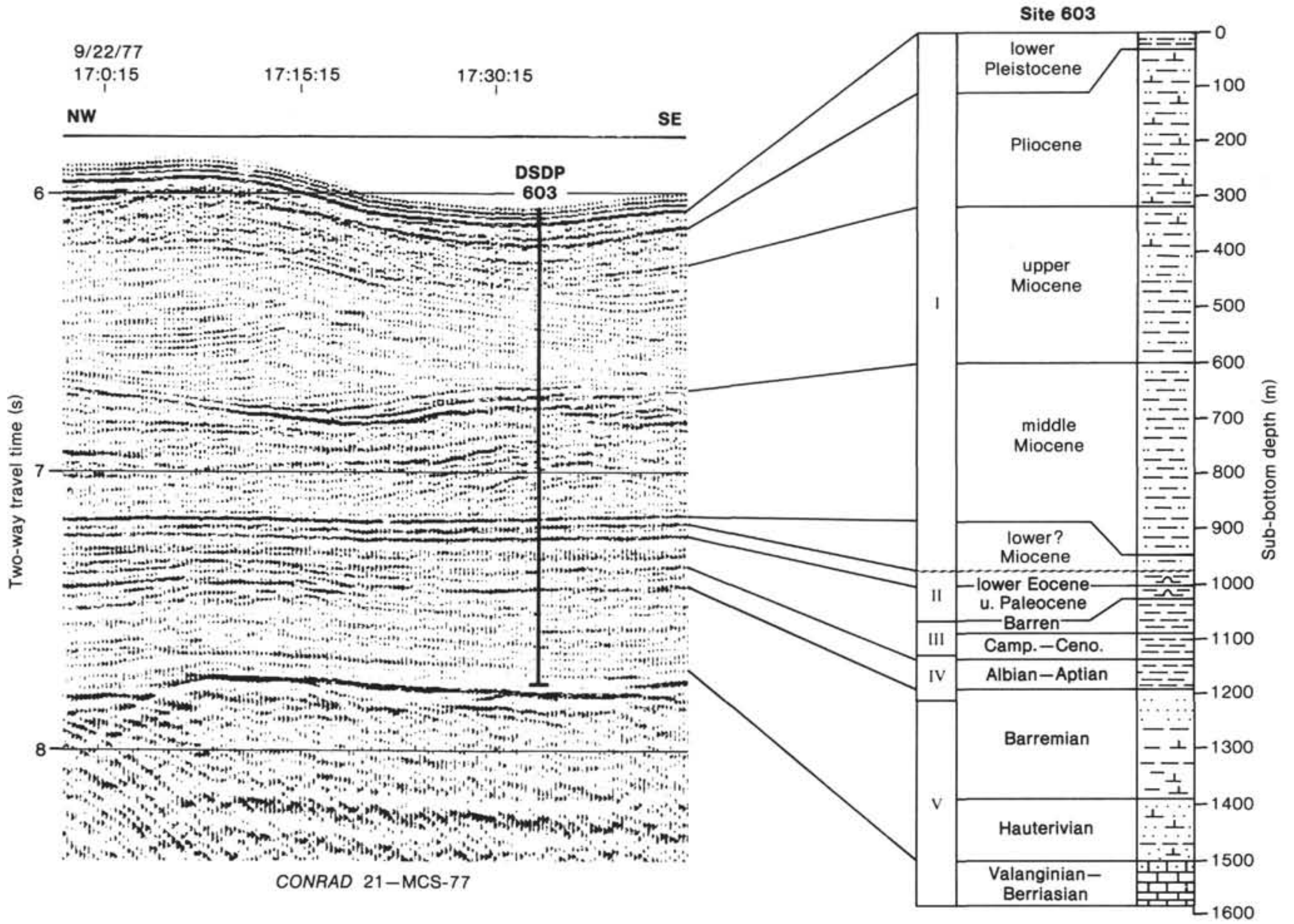

Figure 6. Stratigraphic column for Site 603 compared with multichannel seismic Profile *Conrad* 21 (segment MCS-77), a dip section. The middle Miocene sequences drilled here and dated by microfossils can be traced updip to multichannel Profile 25 (Fig. 20, back pocket), where they are correlative with Sequences 7 and 6.

component of planktonic foraminifers (15–30%), accompanied by low species diversity among benthic taxa, and a lithology of dark organic-rich, pyritiferous, glauconitic shales were cited as supporting evidence. They also noted, however, that the preservation of foraminifers was moderate to very poor, which suggests that the faunal characteristics may be related to diagenetic alteration of the original assemblage, rather than to unusual paleoenvironmental conditions, such as an oxygen minimum zone. At any rate, no oxygen depletion was inferred by these authors at the B-well sites during the *late* Campanian, when it appears to have affected Site 612.

Northeast of seismic Profile 6, the Campanian slope-front fill formed a thick, elongate, double lens characterized by many chaotic and onlapping seismic reflections. Its maximum thickness (ca. 500–600 m) occurs in two subovate pods near the center of the study area (Fig. 10) and in an elongate lens trending downslope along Profile 79-214 in the northeast corner of the study area (Fig. 10). Superimposed on the generally longslope-trending lenticular geometry of this Campanian sequence is a series of downslope-trending, thickened pods, which alternate across the slope with thinner intervening swaths to produce a "ribbed" downslope fabric. Along strike profiles (e.g., Profiles 34 and 35—Fig. 24, back pocket), the ribbing is produced both by erosion of deep channels in the upper surface of the sequence (thinning) and by filling channels cut into the underlying Santonian surface (thickening). Farther basinward (to the southeast), where the sequence thins again to 0.2 s or less, the principal component of the ribbed fabric is the filling of broad channels (as wide as 17 km; Fig. 10) and an ovate depression, where the thickness reaches more than 0.3 s.

Southwest of Profile 6, a different depositional pattern is seen on Figure 10. The Campanian shelf break is farther westward, and the prism of slope-front fill is much thinner than to the northeast. A period (or several periods) of erosion has removed a considerable amount of the Upper Cretaceous to lower Paleogene section over the crest of the buried Jurassic shelf-edge reef, producing an unconformity at which lower Eocene rocks lie directly on Santonian and older rocks. The Campanian section seaward of this segment of the Jurassic reef crest is thin (seldom reaching 0.2 s). The strike profiles in this area clearly show, however, that the downslope channeling, which is strongly developed to the northeast, is present here as well, though it is less intense.

Evidence of Campanian strata at the seaward end of the New Jersey Transect is scanty. At Site 603 (Figs. 6 and 9), an unfossiliferous series of dark, reddish gray

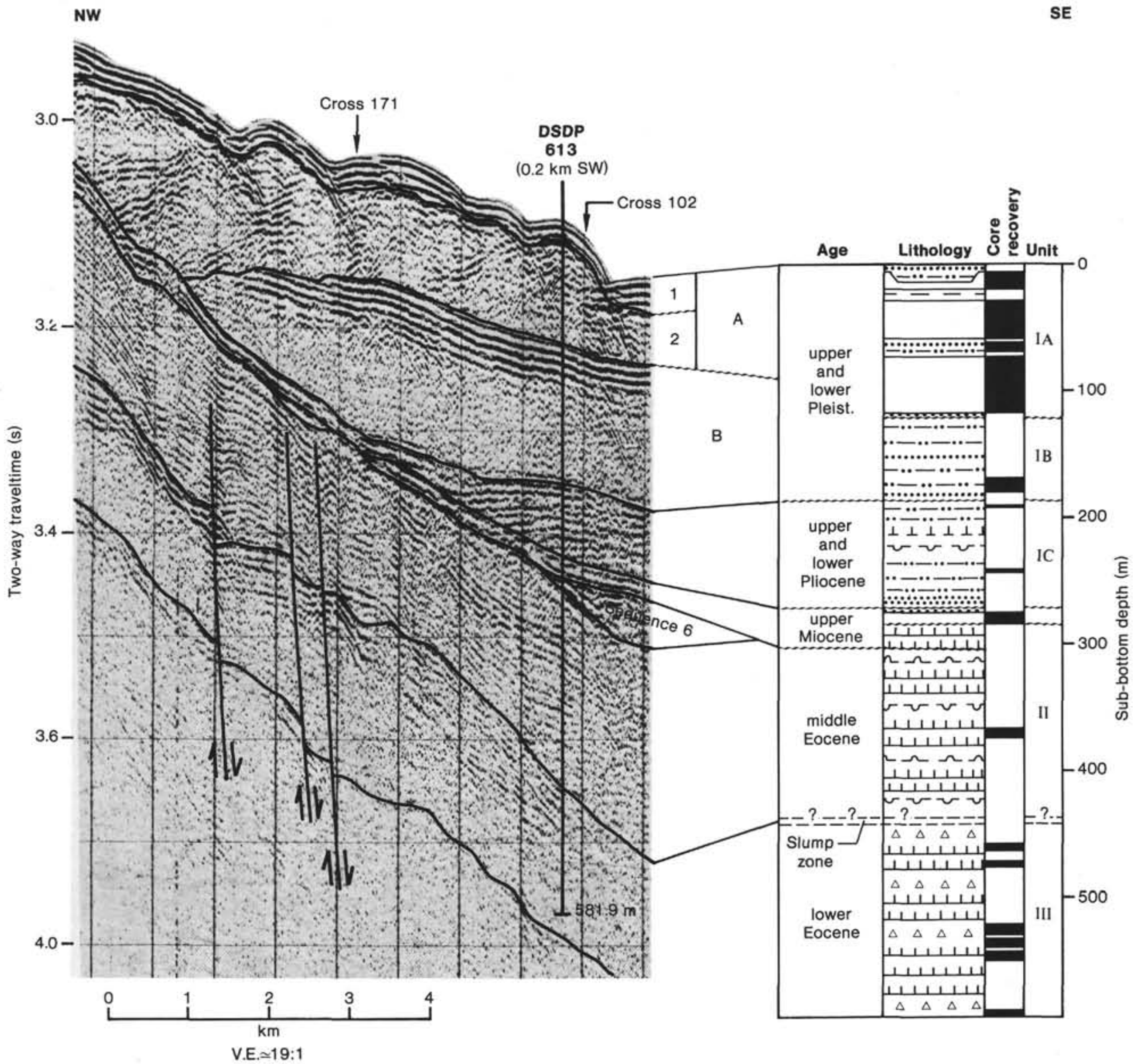

Figure 7. Stratigraphic column for Site 613 compared with single-channel seismic Profile 105, which runs subparallel to multichannel profile 79-218 (Fig. 2). The upper (A) and lower (B) Pleistocene units are well represented here, being separated by an erosional unconformity. The Pliocene thins rapidly updip from Site 613, and the upper Miocene is a thin updip tongue where penetrated by the drill. The feather edge of Sequence 6 (middle Miocene) was penetrated, but not sampled, because of poor recovery in Core 613-20. Note the sinuous, truncated, and faulted reflections in the Eocene sequences. All the sequence boundaries are unconformities.

and brown, terrigenous, silt-rich claystone, glauconite- and mica-rich quartz sand, and sandstone (34 m total thickness) separates upper Paleocene radiolarian claystones from undifferentiated Campanian(?)–Coniacian(?) terrigenous claystones. At Site 105 (Figs. 9; 25, back pocket), the section presumed by Tucholke (1979) to represent the Campanian interval is composed of multicolored (reddish brown, yellow, orange, olive green, black), silty, zeolitic, noncalcareous clays (Hollister, Ewing, et al., 1972). Studies in, and subsequent to, the original *Initial Reports* volume (Leg 11—Hollister, Ewing, et al., 1972) revealed dinoflagellates and ichthyoliths of late Oligocene and undifferentiated Tertiary age in this section (105-5 to 7; Kaneps et al., 1981). Below this section, an undifferentiated Maestrichtian–Danian (ichthyolith dated) section rests on Cenomanian to Albian (dinoflagellate dated) black clays.

On multichannel seismic profiles, the Campanian sequence comprises broad zones of moderately high-amplitude, parallel-to-subparallel, continuous reflections that suggest relatively uniform deposition. The zones are interrupted, however, at irregular intervals by chaotic or poorly defined reflections that indicate downslope mass movement. The latter are particularly prevalent in the slope-front fill between Profiles 35 and 79-201 (Figs. 2; 20A,B, back pocket).

The upper surface of the Campanian sequence is an unconformity that persists over the present coastal plain, shelf, slope and rise, suggesting that it was caused by a significant sea-level fall (Poag and Schlee, 1984; Poag,

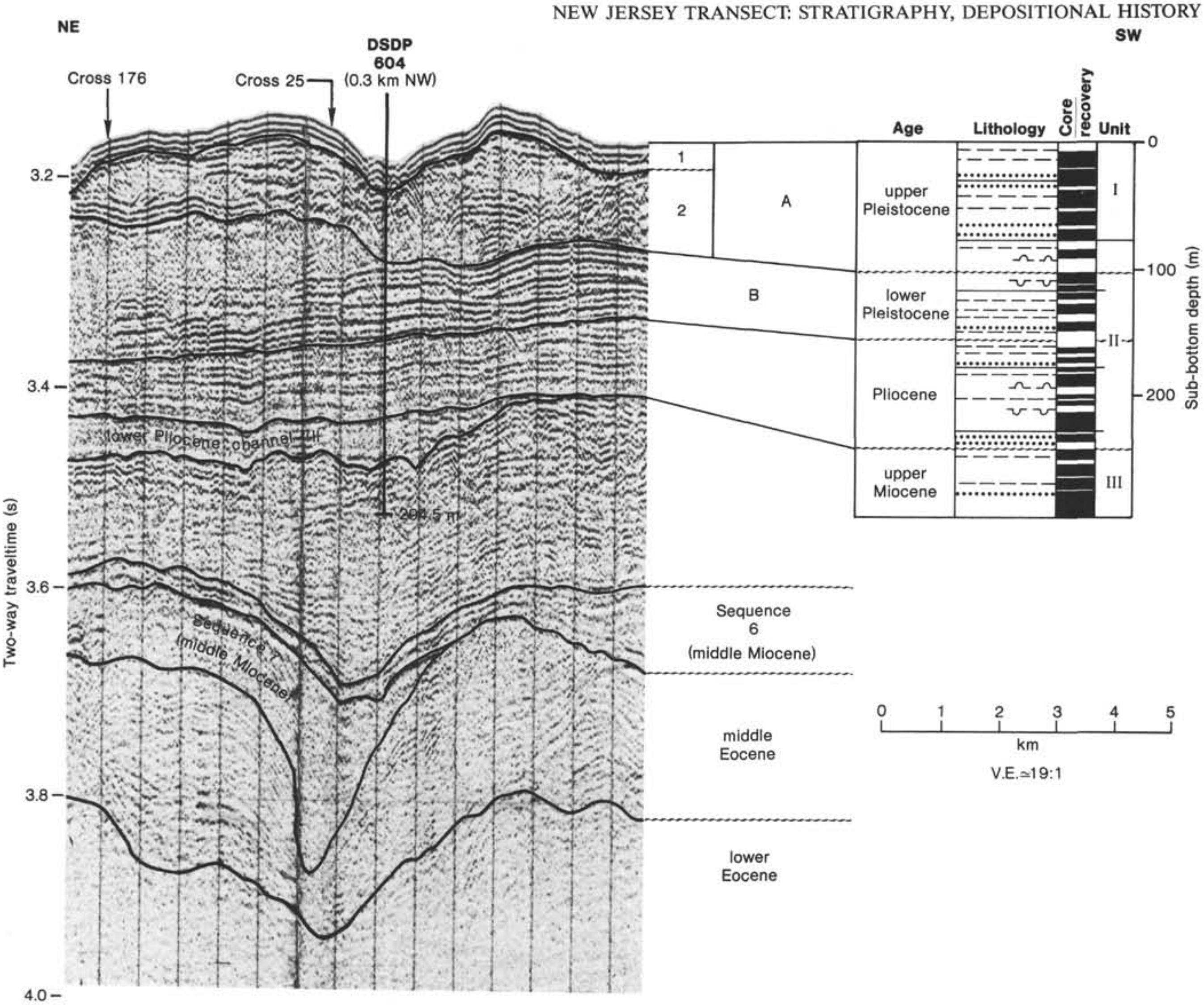

Figure 8. Stratigraphic column for Site 604 compared with its projection on single-channel seismic Profile 170, which runs parallel to multichannel Profile 35 (Fig. 2). Note the erosional truncation of reflections along the upper surface of the lower Pleistocene section. The lower part of the Pliocene sequence is a thin channel-fill deposit. Note the deep channel on the middle Eocene surface, which is filled with middle Miocene strata of Sequence 7.

1985a). Olsson (1978) and Nyong and Olsson (1984) have noted that the paleoenvironment of the basal Maestrichtian sequence beneath the New Jersey Coastal Plain indicates deposition during a lowered sea level. Owens and Gohn (1985) have shown that the regressive facies at the Campanian–Maestrichtian contact can be traced from the Southeast Georgia embayment to the Long Island platform.

Maestrichtian (Sequence 11) Depositional History

The general distribution and depositional fabric of the Maestrichtian sequence (Sequence 11) are similar to those of the Campanian sequence, but the Maestrichtian sequence is thinner (Figs. 11; 20, back pocket). A broad Maestrichtian shelf, like that of the Campanian, was covered by a thin blanket of sediments (less than 0.1 s thickness). There are several broad patches where Maestrichtian strata appear to be entirely missing due to erosion. This is especially marked over the crest of the low-relief Grow Dome (Fig. 26), on the flank of which the Shell 272-1 well was drilled. At the Island Beach well site (Fig. 9), 6 m of glauconitic, calcareous, gray clay and thin limonitic limestone accumulated in inner sublittoral environments (Poag, 1985a). On the outer Maestrichtian shelf (COST B-2 well), 30 m of silty gray to brown, micaceous claystone and sandstone contain fragile, thin-walled agglutinant foraminifers of paralic origin.

The Maestrichtian shelf break shifted seaward about 10 km (along Profile 25; Fig. 20, back pocket) relative to the Campanian shelf break to a position near DSDP Site 605. At the COST B-3 well, 24 m of early Maestrichtian, dark brown gray, calcareous, silty mudstones contain outer sublittoral (100–200 m) microfaunas. At Site 612, the Maestrichtian sequence thickens relative to updip localities (84.6 m) and consists of dark gray, intensely burrowed, foraminifer-nannofossil chalk, having lithified limestone interbeds. Terrigenous components are

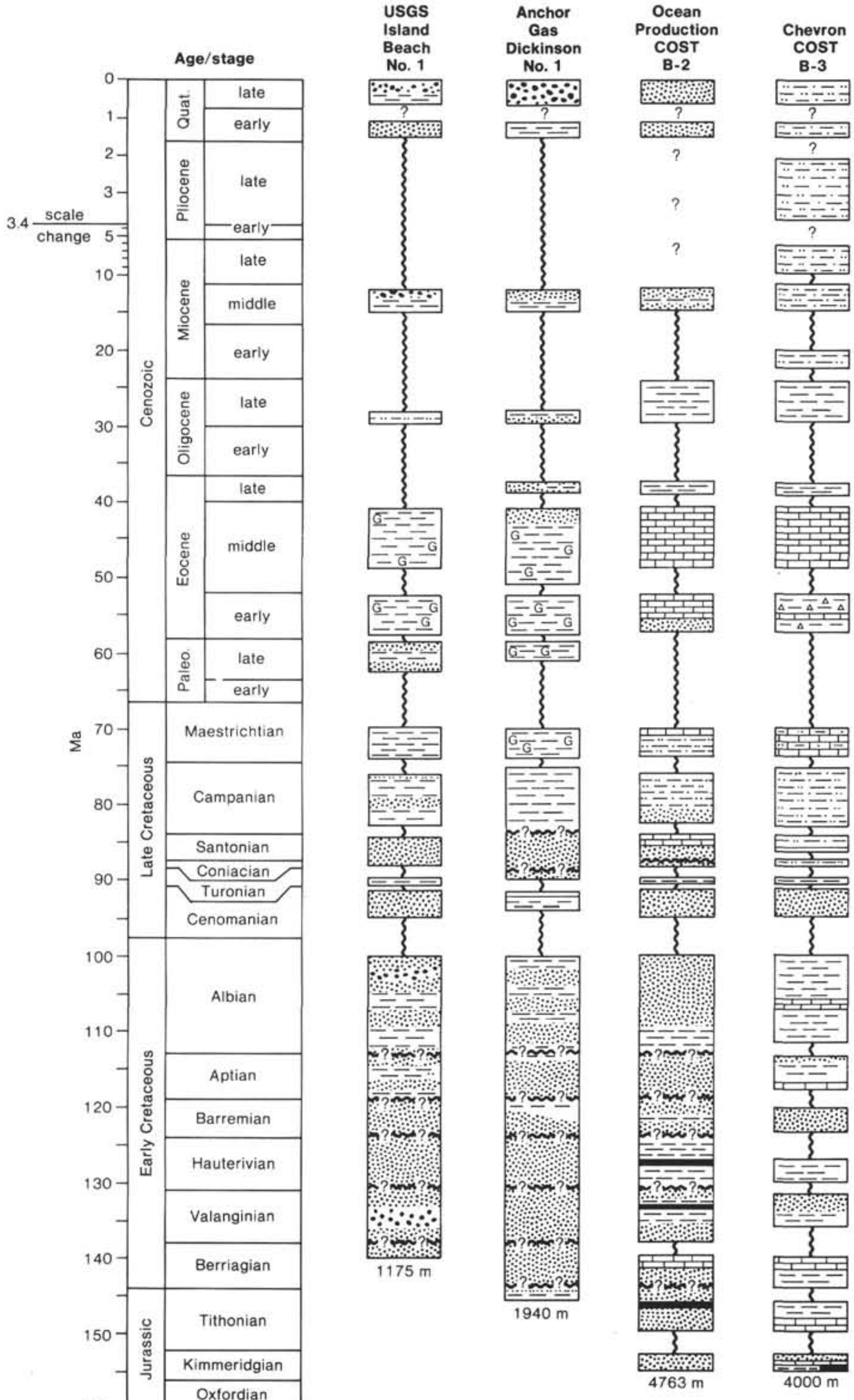

Figure 9. Stratigraphic columns of key boreholes along the New Jersey Transect. Cenozoic time scale is from Berggren et al. (1985). Cretaceous and Jurassic time scales are from Kent and Gradstein (1985). Vertical and horizontal wavy lines indicate unconformities. A^u is a regional unconformable seismic horizon of the North American Basin (Tucholke and Mountain, 1979; 1986). Supersequence terminology for the Cenozoic is from Vail and Mitchum (1979); for the Mesozoic it is from Haq et al. (in press). Total depth of each borehole is listed at the base of each stratigraphic column. Lithologic symbols are standard DSDP patterns, except for the heavy black bars, which represent coal beds. Note the change in the vertical scale at 3.4 Ma.

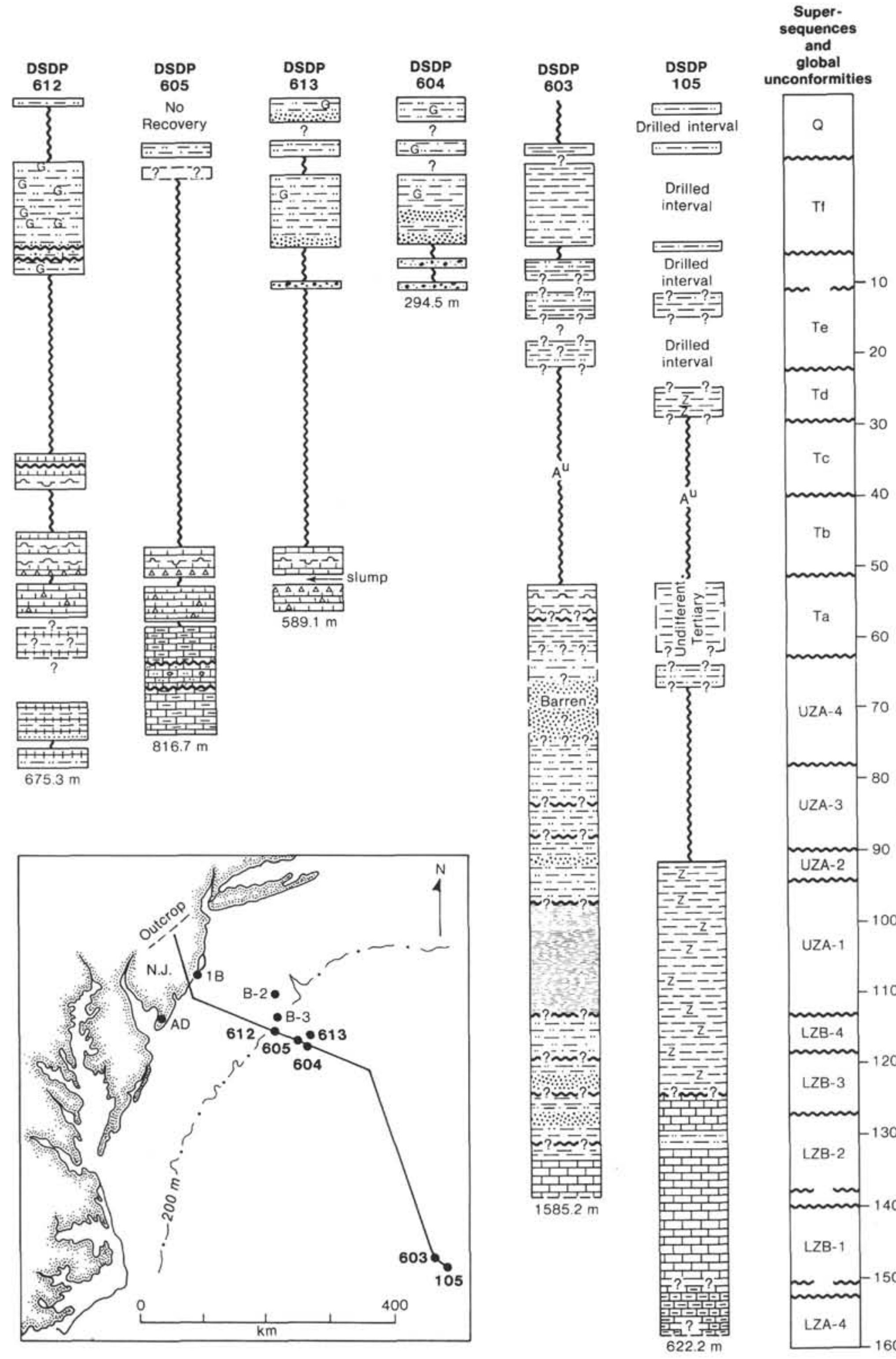

Figure 9 (continued).

present throughout, but decrease significantly toward the top. Rich early and middle Maestrichtian microfaunas indicate upper bathyal paleodepths (200–500 m), although the site occupied the outer Maestrichtian shelf.

Downdip at Site 605, the Maestrichtian section is about twice as thick (ca. 200 m) as at Site 612 (Fig. 20, back pocket), as it represents the upper part of a rapidly thickening slope-front fill (maximum thickness on Profile 25 is ca. 400 m). Only the upper 57 m of this sequence was cored, revealing chiefly dark gray, clayey, middle Maestrichtian nannofossil and foraminifer limestones (basal 38 m), overlain by 19 m of upper Maestrichtian fora-

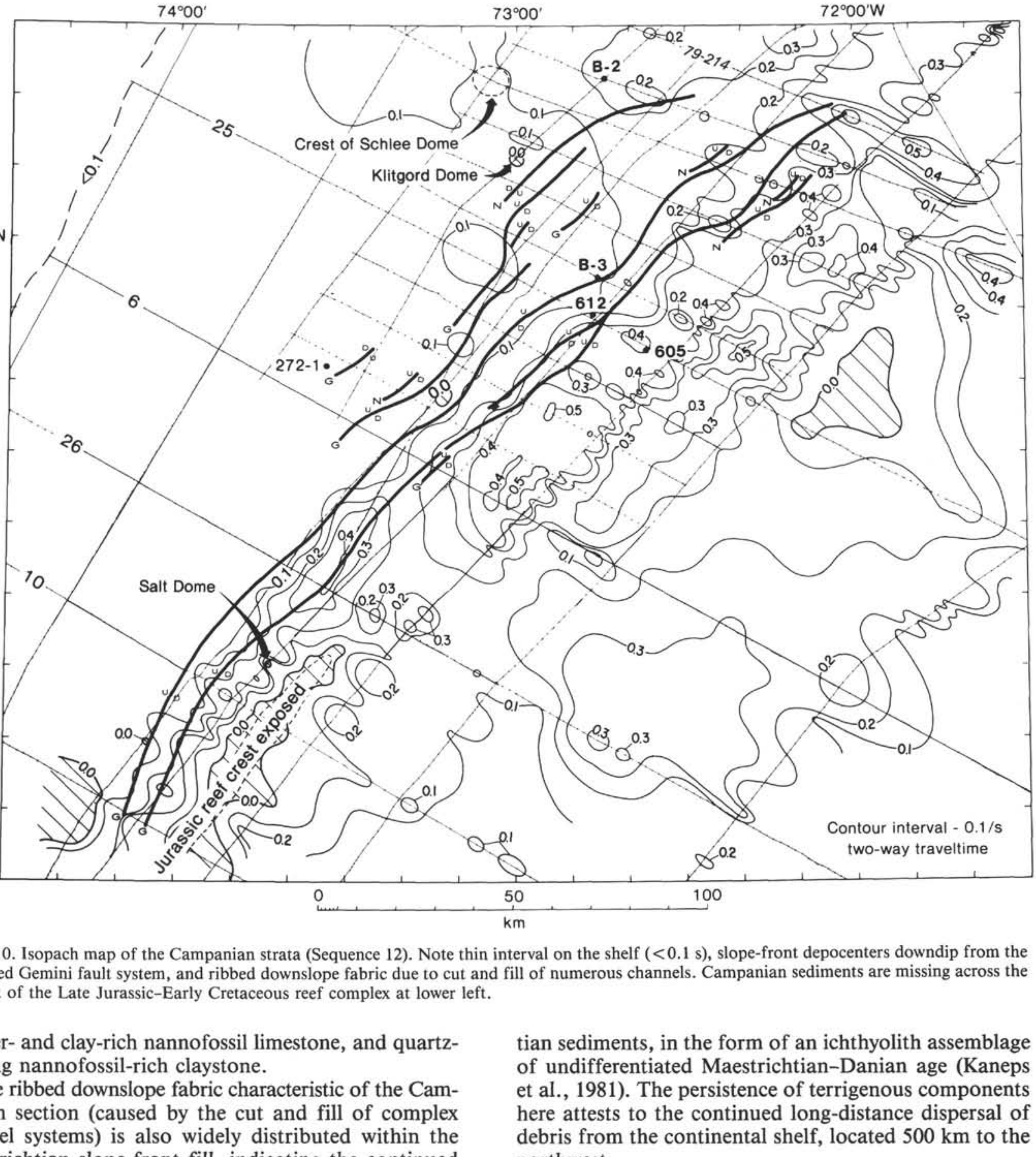

Figure 10. Isopach map of the Campanian strata (Sequence 12). Note thin interval on the shelf (<0.1 s), slope-front depocenters downdip from the paired Gemini fault system, and ribbed downslope fabric due to cut and fill of numerous channels. Campanian sediments are missing across the crest of the Late Jurassic–Early Cretaceous reef complex at lower left.

minifer- and clay-rich nannofossil limestone, and quartz-bearing nannofossil-rich claystone.

The ribbed downslope fabric characteristic of the Campanian section (caused by the cut and fill of complex channel systems) is also widely distributed within the Maestrichtian slope-front fill, indicating the continued importance of downslope mass sediment dispersal. Even as far as 100 km downdip from Site 605 (on Profile 13, in the lower right corner of Fig. 11) the mid-rise deposits are marked by broad (20-km-wide) southeast-trending erosional swaths and intervening sedimentary thickening.

At the seaward end of the New Jersey Transect (Sites 603, 105; Figs. 6; 25, back pocket), a section of possible Maestrichtian age is chiefly nonfossiliferous silty claystone and micaceous, glauconitic sandstone. Core 105-8 contains the only fossil evidence of possibly Maestrichtian sediments, in the form of an ichthyolith assemblage of undifferentiated Maestrichtian–Danian age (Kaneps et al., 1981). The persistence of terrigenous components here attests to the continued long-distance dispersal of debris from the continental shelf, located 500 km to the northwest.

The top of the Maestrichtian sequence is a major erosional unconformity that has been widely sampled from coastal plain outcrops to the deep sea, and can be traced on seismic profiles throughout the study area. On the coastal plain there is a general consensus (Owens and Gohn, 1985) that an unconformity separates the Maestrichtian and Danian sections, although parts of the uppermost Maestrichtian planktonic foraminiferal zone have been reported at scattered localities (Olsson, 1964; Hazel and Brouwers, 1982). Only lower Maestrichtian strata are present in the Anchor-Dickinson, Island Beach,

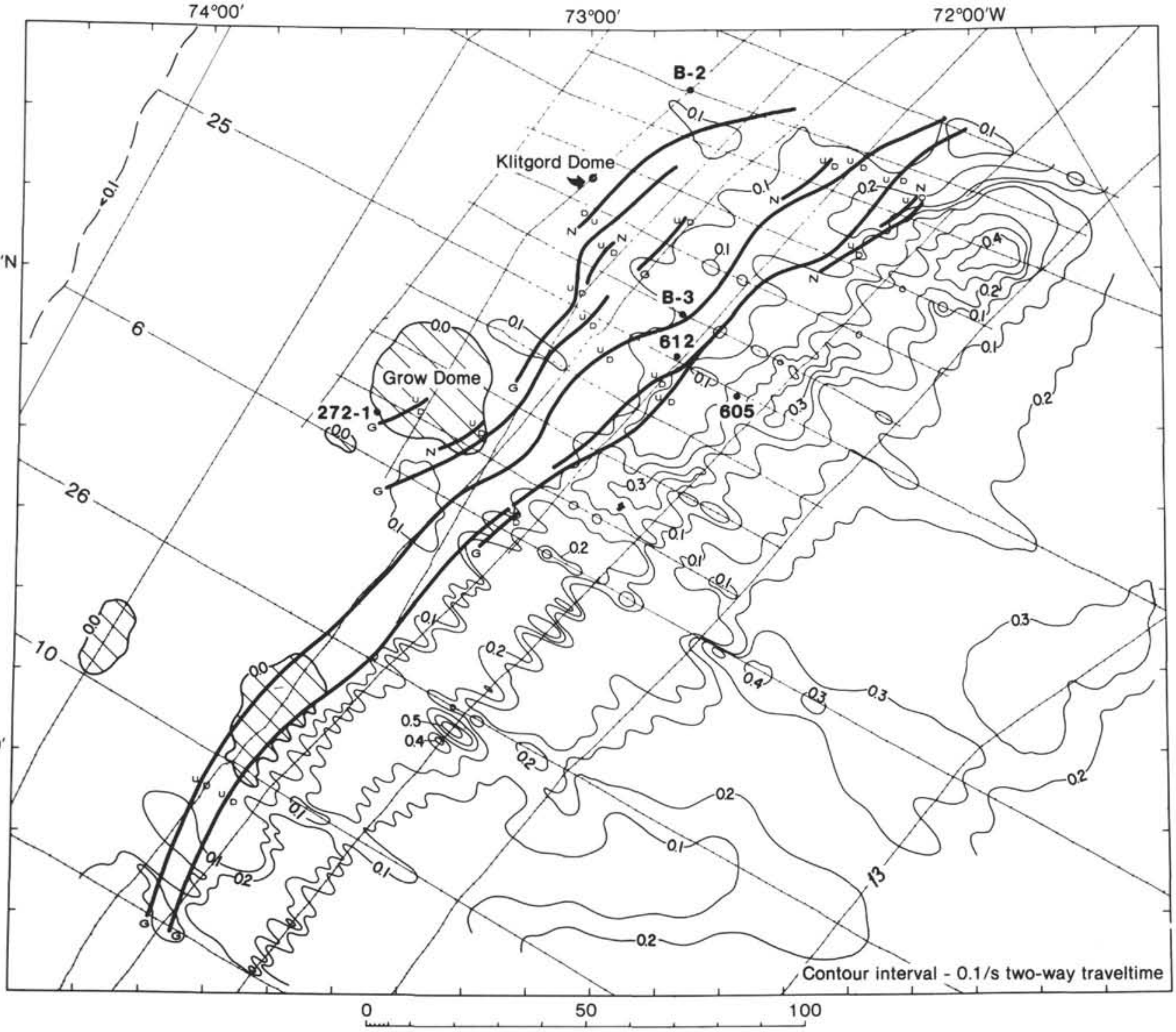

Figure 11. Isopach map of the Maestrichtian strata (Sequence 11). Note thin interval on the shelf (<0.1 s) and several large erosional patches. Slope-front depocenters parallel the Gemini fault system. Two thickened pods on the upper rise may represent submarine fans. Downslope ribbed fabric caused by cut and fill of submarine channels.

and COST B wells (Fig. 9), and the entire Maestrichtian section is missing at the Shell 272-1 location on the flank of Grow Dome (Figs. 11, 26). Early and middle Maestrichtian microfaunas were recovered at Site 612. At Site 605, the Maestrichtian section is nearly complete, but even here the nannoplankton succession indicates a short hiatus at the Cretaceous–Tertiary contact (Fig. 9). At Site 105, there are no calcareous microfossils in the Maestrichtian interval, but an undifferentiated Maestrichtian–Danian icthyolith assemblage is present, succeeded by an undifferentiated Tertiary assemblage, including dinoflagellates (Fig. 25, back pocket; Kaneps et al., 1981). At Site 603, upper Paleocene radiolarian assemblages unconformably overlie an unfossiliferous, presumably Upper Cretaceous, turbiditic sandstone.

The Maestrichtian sequence displays chiefly onlap-fill and chaotic-fill seismic facies within the prism of slope-front fill, which is a typical result of the downslope mass transport of sediment.

Paleocene (Sequence 10) Depositional History

The two striking features of the Paleocene distribution pattern (Sequence 10) are its widespread absence and its thinness elsewhere, compared to the two Late Cretaceous sequences (Figs. 12; 20, back pocket). The general pattern of a broad, thinly covered continental shelf, whose shelf break is marked by a thickened prism of slope-front fill, persisted during Paleocene deposition. The position of the shelf break remained about the same as during the Maestrichtian, being near Site 605 on Profile 25 (Fig. 20, back pocket). On the inner to middle shelf, northeast of line 6 (Fig. 12), a northward-thickening deltalike wedge of sediments built out, extending a few broad lobes onto the outer shelf; the se-

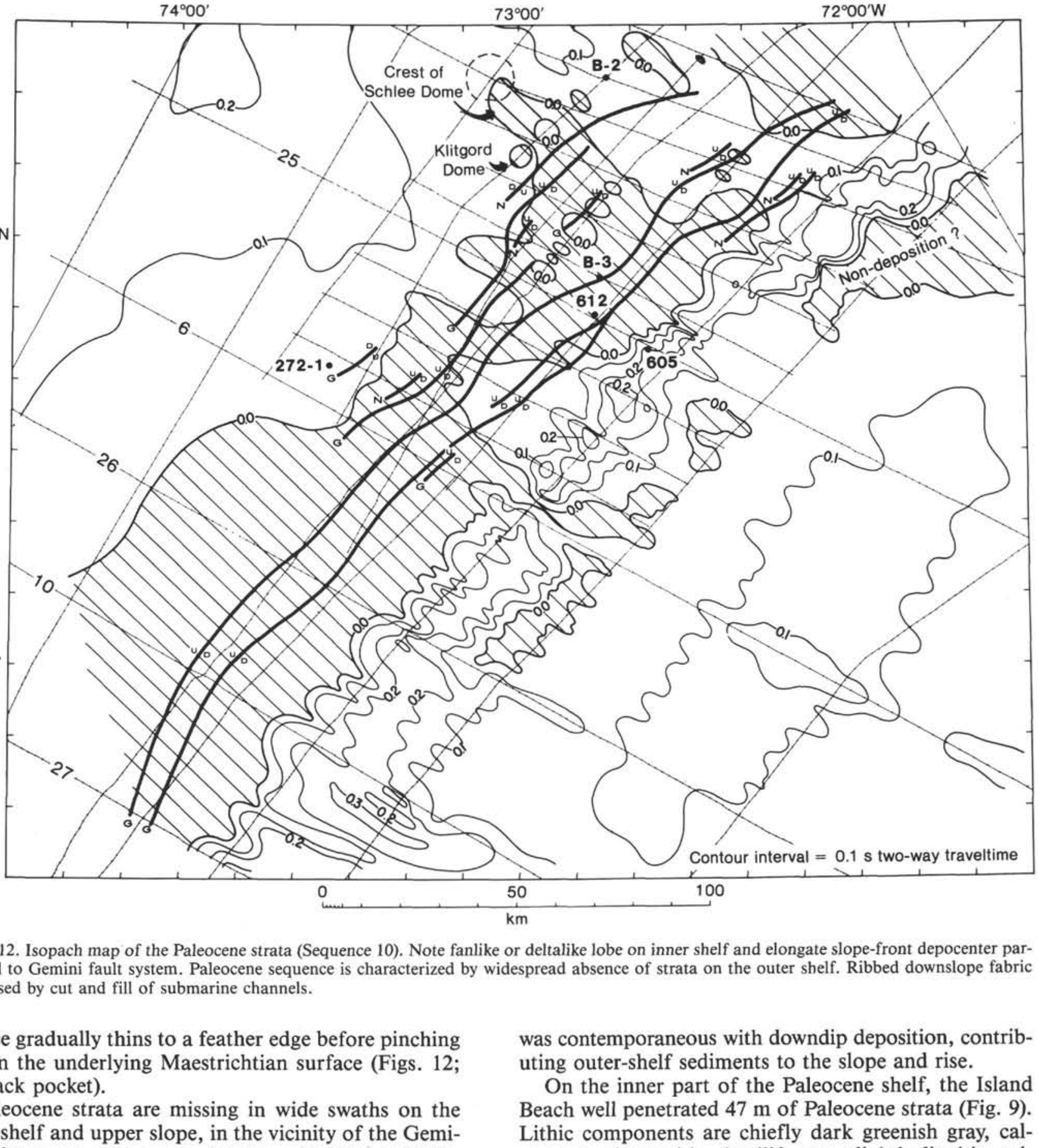

Figure 12. Isopach map of the Paleocene strata (Sequence 10). Note fanlike or deltalike lobe on inner shelf and elongate slope-front depocenter parallel to Gemini fault system. Paleocene sequence is characterized by widespread absence of strata on the outer shelf. Ribbed downslope fabric caused by cut and fill of submarine channels.

quence gradually thins to a feather edge before pinching out on the underlying Maestrichtian surface (Figs. 12; 20, back pocket).

Paleocene strata are missing in wide swaths on the outer shelf and upper slope, in the vicinity of the Gemini fault system, and across the tops of Schlee and Klitgord domes (Fig. 12). Sequence 10 can not be traced onto the shelf segments of Profiles 10 and 27 (lower left corner of Fig. 12).

The Paleocene sequence thickens to form a slope-front fill along strike Profile 35 (Fig. 24, back pocket) and its southwestward extension, Line 79-202. In this vicinity it fills downslope-trending channels, and its surface is channeled in turn, to produce the familiar downslope ribbed depositional fabric. The thickness of the slope-front prism and the obvious upslope origin of its sedimentary components (channel fill, chaotic reflections, terrigenous detritus at Site 605) suggest that some of the updip erosion was contemporaneous with downdip deposition, contributing outer-shelf sediments to the slope and rise.

On the inner part of the Paleocene shelf, the Island Beach well penetrated 47 m of Paleocene strata (Fig. 9). Lithic components are chiefly dark greenish gray, calcareous, glauconitic, fossiliferous, slightly lignitic, micaceous clay, interbedded with olive to greenish gray, calcareous lignitic, micaceous, pyritic, glauconitic, sandy silt (Seaber and Vecchioli, 1963; Brown et al., 1972). Microfaunal assemblages indicate middle to outer sublittoral paleoenvironments (100–150 m). Inner sublittoral assemblages are present in outcropping beds of the Paleocene Hornerstown and Vincentown formations of the New Jersey Coastal Plain (Olsson, 1964; Youssefnia, 1978).

Paleocene strata are absent at the two COST wells, but at the Shell 272-1, located on the outer Paleocene shelf (Fig. 12), 61 m of calcareous mudstones represent

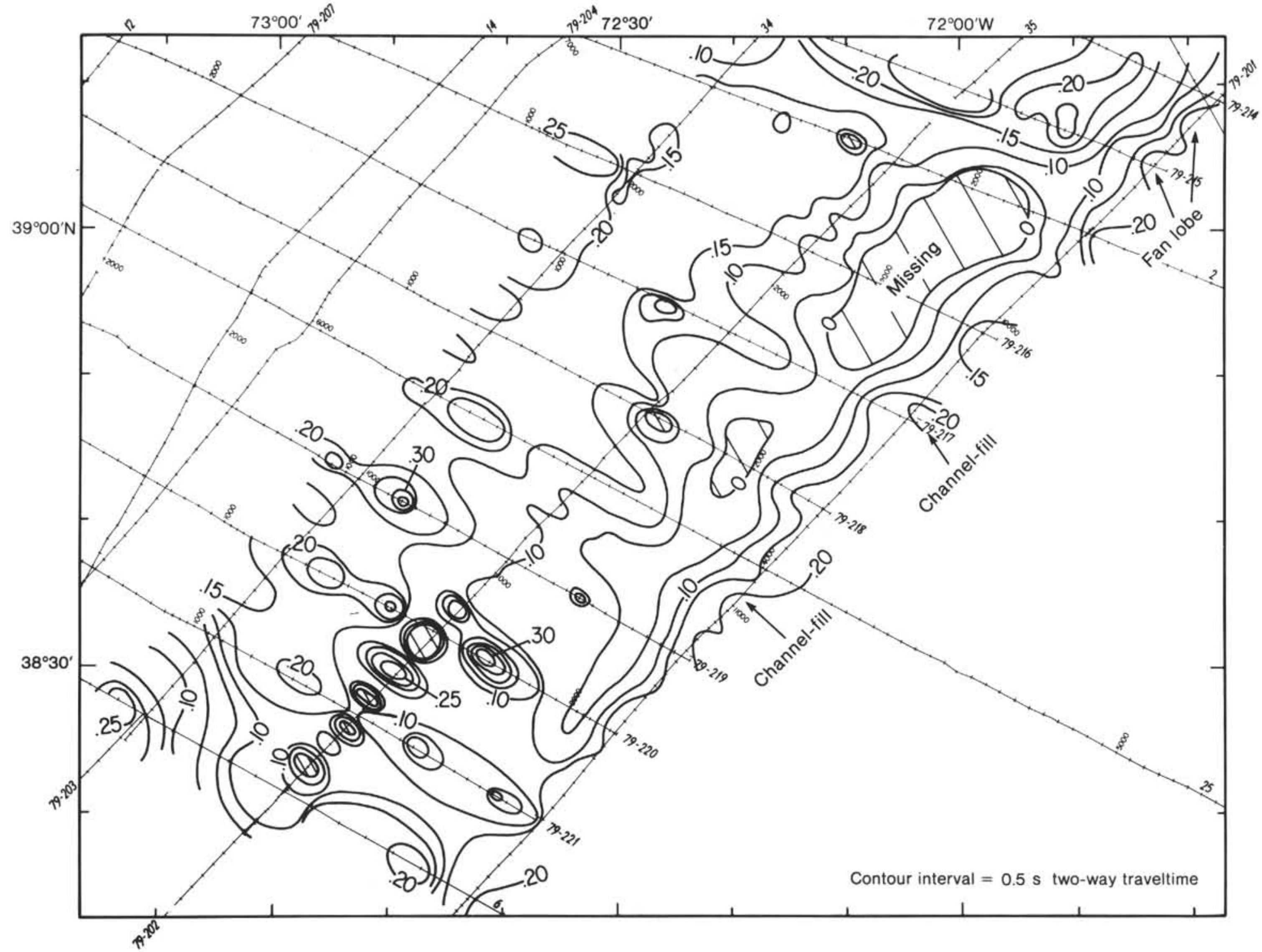

Figure 13. Isopach map of lower Eocene strata (Sequence 9). This map is taken, unchanged, from Poag and Mountain (this volume); it does not include as complete an analysis of the continental shelf as included in most of the other isopach maps. Note downslope fabric caused by cut and fill of submarine channels. Note thickening along Profile 34, and along upper right margin of figure. The sequence is thin or missing in an elongate swath that parallels the shelf edge, suggesting erosion by longslope currents.

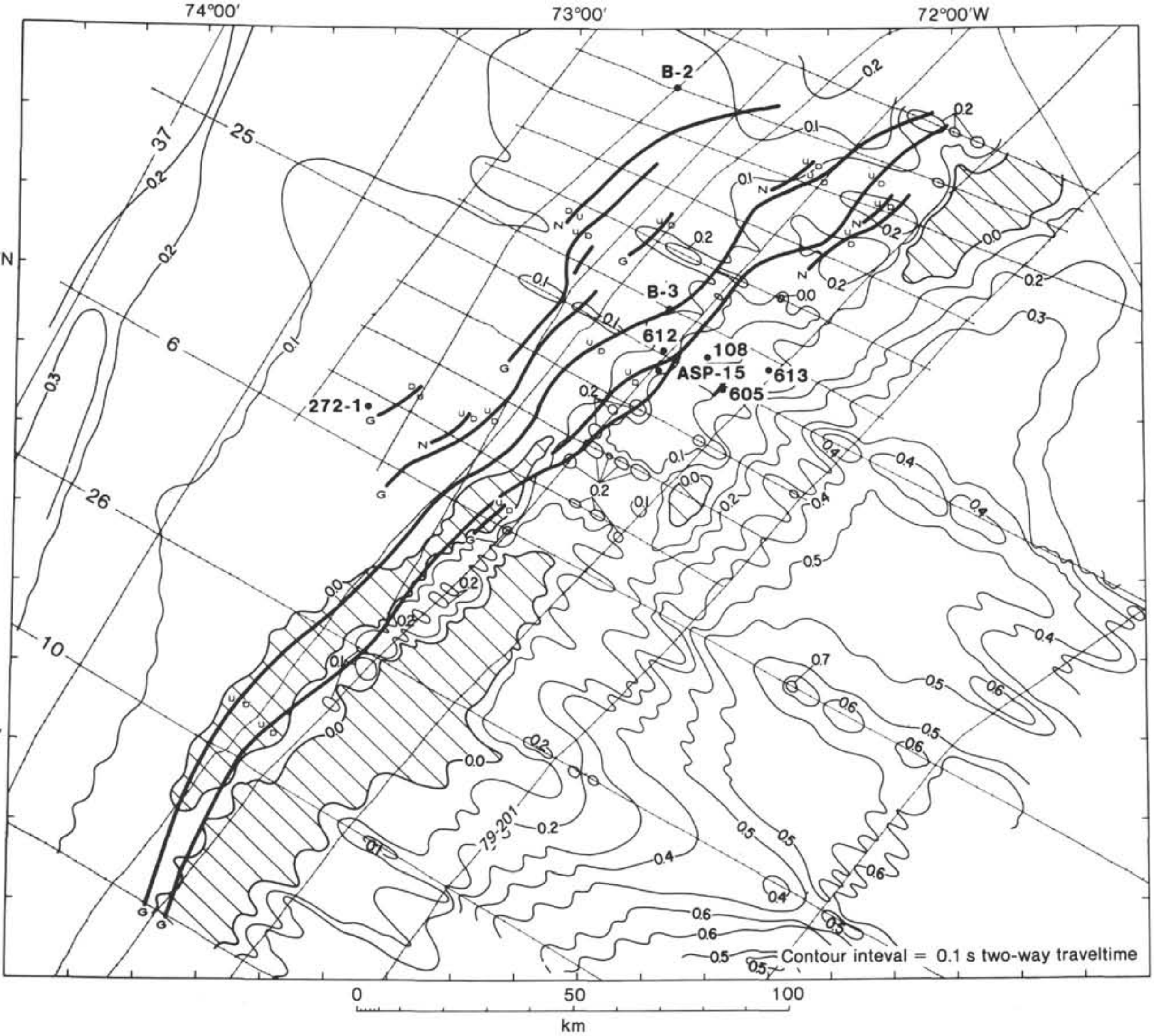

Figure 14. Isopach map of middle Eocene strata (Sequence 8). Note landward position of northeast-trending depocenter (>0.3 s) that represents thickening at hinter-shelf edge. Section thins to <0.1 s across fore shelf, is eroded in elongate swaths parallel to Gemini fault system, and thickens again downdip in slope-front and upper-rise depocenters. Downslope ribbed fabric caused by cut and fill of submarine channels. Thickened lobes (>0.6) at lower right may represent submarine fan deposits.

Paleocene deposition. At Site 612 no Paleocene rocks were recovered, but a 9-m interval of significantly increased clay or glauconite content (according to the gamma-ray log) suggests that Paleocene sediments are present, though too thin to be resolved on the seismic profile.

At Site 605 (Figs. 5, 9), however, the Paleocene is well represented by a 196-m section of silty limestone, claystone, and mudstone recovered from the upper part of the Paleocene slope-front prism. The muddy, often quartz-bearing limestones reflect terrigenous contributions to a deep-water pelagic setting.

Several elongate patches of very thin or missing Paleocene deposits parallel the base of the slope-front prism northeast of Profile 26 (Fig. 12). Those patches between Profiles 26 and 25 appear to be erosional swaths created by downslope channeling, as seen along strike Profile 79-201. In contrast to this erosional setting, a thickened ridge of Paleocene sediments trends perpendicular to the continental slope southwest of Profile 26. The most seaward broad swath of thinning (<0.1) may have been caused, in part, by longslope bottom currents, but modification by sediment-laden downslope currents is indicated by channeling along Profile 13.

At Site 603, the seaward terminus of the New Jersey Transect—a 20-m section of late Paleocene, dark greenish gray, zeolitic, silt-bearing, radiolarian-rich claystones—contains minor amounts of quartz and mica (Figs. 9; 25, back pocket). Thus long-distance dispersal of shelf-derived detritus continued to take place in the North Atlantic Basin.

On the continental shelf and at Site 603, the thin Paleocene section contains chiefly upper Paleocene fossils, indicating that erosion was a prominent element in the

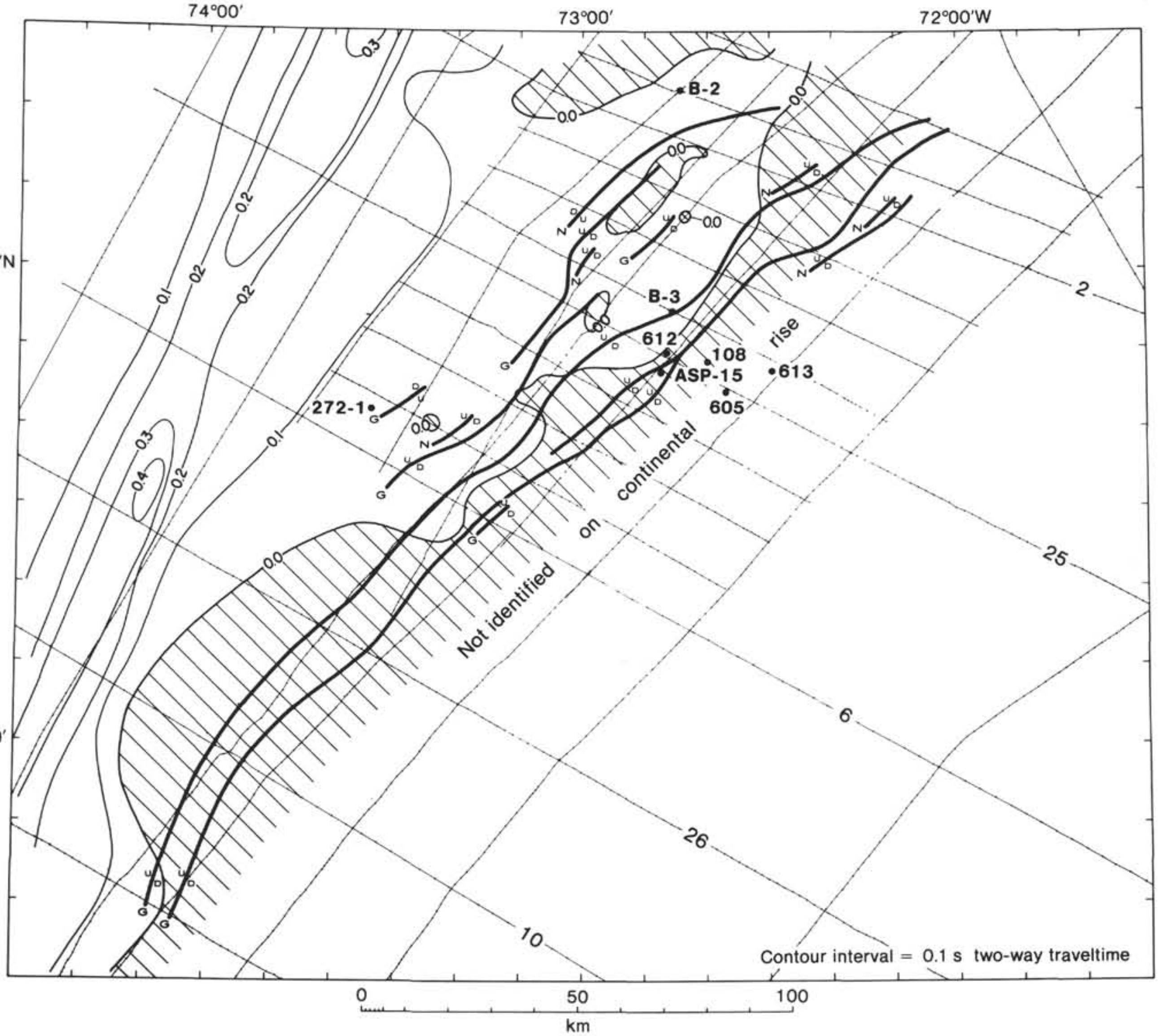

Figure 15. Isopach map of upper Oligocene strata (sequence not numbered because not identified on upper and middle continental rise). Note thickened pod of the hinter-shelf edge (>0.4 s). Section is thin (<0.1 s) on hinter shelf and fore shelf; missing on outer part of fore shelf and across edge of fore shelf; not yet identified on continental rise.

early Paleocene history of this region. At Site 605, the thicker Paleocene section is more complete, but the sharp contrast between the glauconitic silty strata of the lower Paleocene section (605-64-1, 53 cm) and the overlying argillaceous nannofossil limestone may represent the main early Paleocene erosional event.

The top of the Paleocene sequence is, in many places, an erosional unconformity that separates upper Paleocene from lower Eocene strata. This contact is manifest at Site 605 (Fig. 9) by a distinct lithologic change upward from dark greenish gray, foraminiferal, clayey, nannofossil limestone to a section of alternating dark and light gray clayey limestone. The biostratigraphic gap is probably less than 1 m.y., as indicated by the juxtaposition of consecutive nannofossil and planktonic foraminiferal zones at 605-44-5, 33 cm. At Site 603, the Paleocene–Eocene contact is marked by a 4-cm zone of olive yellow, radiolarian-, mica-, and zeolite-bearing claystone (603-19-2, 138–142 cm) sandwiched between dark gray to red brown claystones. A hiatus of less than ca. 2 m.y. is indicated by the succession of radiolarian biozones.

Chaotic-fill seismic facies are commonly associated with the downslope channels of the Paleocene sequence, but nonchanneled regions basinward of the slope-front contain primarily hummocky and subparallel reflections that suggest more uniform depositional styles.

Early Eocene (Sequence 9) Depositional History

The lower Eocene sequence, deposited under elevated sea levels, is generally present over the entire study area, except for a broad longslope erosional swath between Profiles 35 and 79-201, and a few small erosional patches along Profile 35 (Figs. 13; 20 and 24, back pocket). It

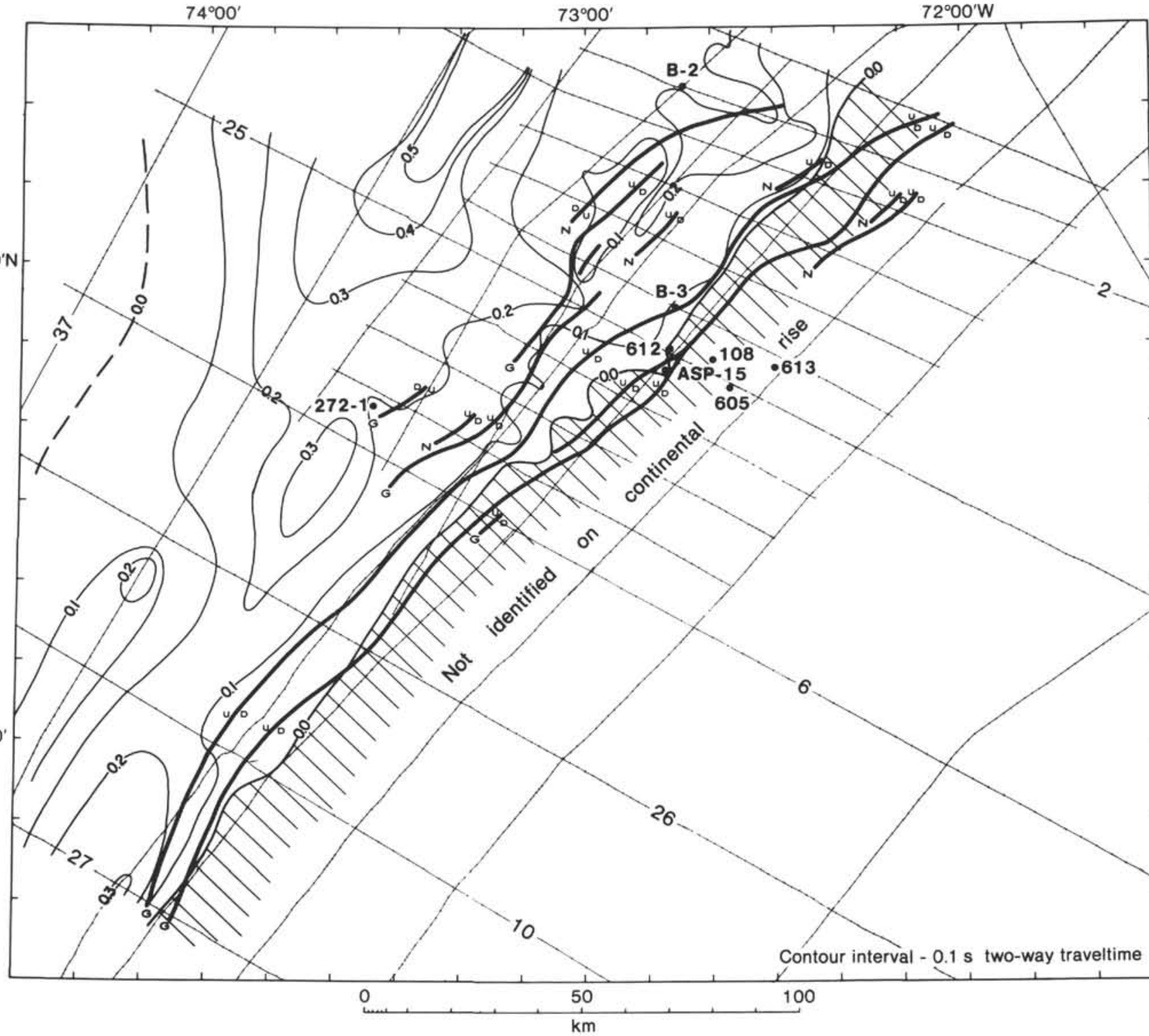

Figure 16. Isopach map of lower Miocene strata (sequence not numbered because not identified on upper and middle continental rise). Note thickened (>0.5 s) hinter shelf edge has prograded seaward compared to middle Eocene and late Oligocene positions (Figs. 14, 15). Section thins on hinter shelf and fore shelf and is truncated along outer part of fore shelf parallel to Gemini fault system. Equivalent strata have been identified at only scattered locations on the continental rise seaward of the mapped area.

has been thinned, presumably by longslope bottom currents, along a broad central erosional swath.

Along the middle shelf, the lower Eocene sequence is generally 2 or 3 times as thick as the Paleocene sequence. The landward margin of a seaward thickening slope front is seen on Profile 25 about 25 km updip from its Paleocene position (Fig. 20, back pocket), indicating a shoreward shift in the early Eocene shelf break.

The slope-front prism is generally thickest along Profile 34 and northeast of Profile 2 (Fig. 13). Downslope cutting, filling, and slumping have produced a ribbed depositional fabric, which is especially prominent along Profile 35 (Fig. 24, back pocket). The most prominent component of the fabric in this vicinity is a series of deep channels cut into the upper surface of the lower Eocene sequence. Farther downdip, most of the thickened pods are caused by filling of channels in the underlying surface.

Shoreward, at the Island Beach well (Fig. 9), 67 m of lower Eocene strata are composed of light to dark greenish gray, calcareous, glauconitic clay and fragmental limestone of the Manasquan Formation (Olsson, 1978). The outer sublittoral (100–200 m) microfossil assemblages at this location are rich in species and specimens (Charletta [1980] inferred upper bathyal depths for part of the early Eocene deposition). The outcropping lower Eocene Manasquan and Shark River formations in New Jersey represent deposition in inner to middle sublittoral environments (Olsson, 1978).

The COST B-2 well encountered a 150-m section of lower Eocene strata (Fig. 9), consisting of sandy limestone and gray to black calcareous claystones and chalks,

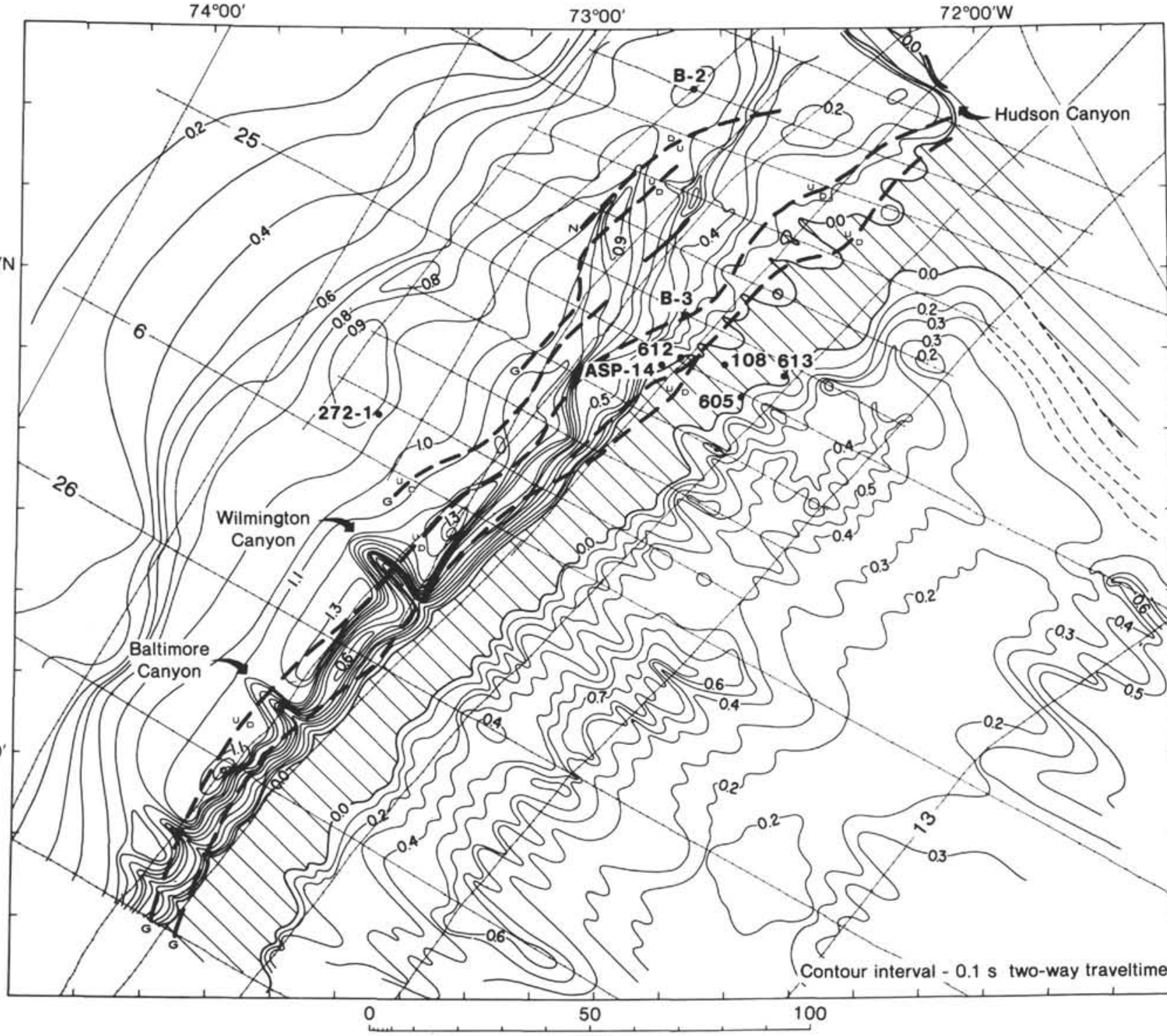

Figure 17. Isopach map of middle Miocene strata (Sequences 7, 6, 5). Rapid progradation of thick deltaic wedges (>1.3 s) has moved hinter-shelf edge seaward to coincide with fore shelf edge near modern position of shelf break. Maximum depocenter on upper rise (>0.7 s) is opposite shelf-edge depocenter between Profiles 6 and 26. Downslope ribbed fabric is caused by cut and fill of submarine channels and by submarine fan lobes. Middle Miocene strata are missing along base of the continental slope where middle Eocene strata crop out at seafloor.

overlying a thin basal quartzose sandstone. Upper bathyal paleoenvironments (200–500 m) are indicated by the microfossil assemblages of the limestones and chalks.

At the COST B-3 site, terrigenous components decrease as the 160-m lower Eocene section becomes chiefly white biomicritic limestone and light gray calcareous claystone and chalk containing mixed microfossil assemblages of outer sublittoral (100–200 m) and upper bathyal (200–1000 m) origin (Fig. 9; Poag, 1980). The most shoreward evidence of silicification due to conversion of radiolarian skeletons to siliceous cements shows up in the lower Eocene section of the COST B-3 well. There a 30-m interval (1768 m–1798 m below the kelly bushing) contains almost no foraminifers, and they are poorly preserved throughout the lower Eocene interval (Poag, 1980).

The DSDP 612 borehole was drilled through the thickest part of the lower Eocene slope-front fill, encountering 220 m of bathyal, light gray, biosiliceous, nannofossil and foraminiferal chalk and limestones that have been partly silicified during diagenesis (conversion of radiolarian skeletons to silica cements).

Downdip at Sites 605 and 613 (Figs. 9; 20, back pocket), the section begins to thin (218 m at 605; ~150 m at 613), but lithic and paleontologic characteristics are similar. However, the depositional regime at Site 613 included a considerable increase in downslope slumping on the flank of an erosional channel.

At Site 603 the lower Eocene strata are only 36 m thick (Figs. 6; 25, back pocket), consisting of multicolored radiolarian claystones in which the clay has retard-

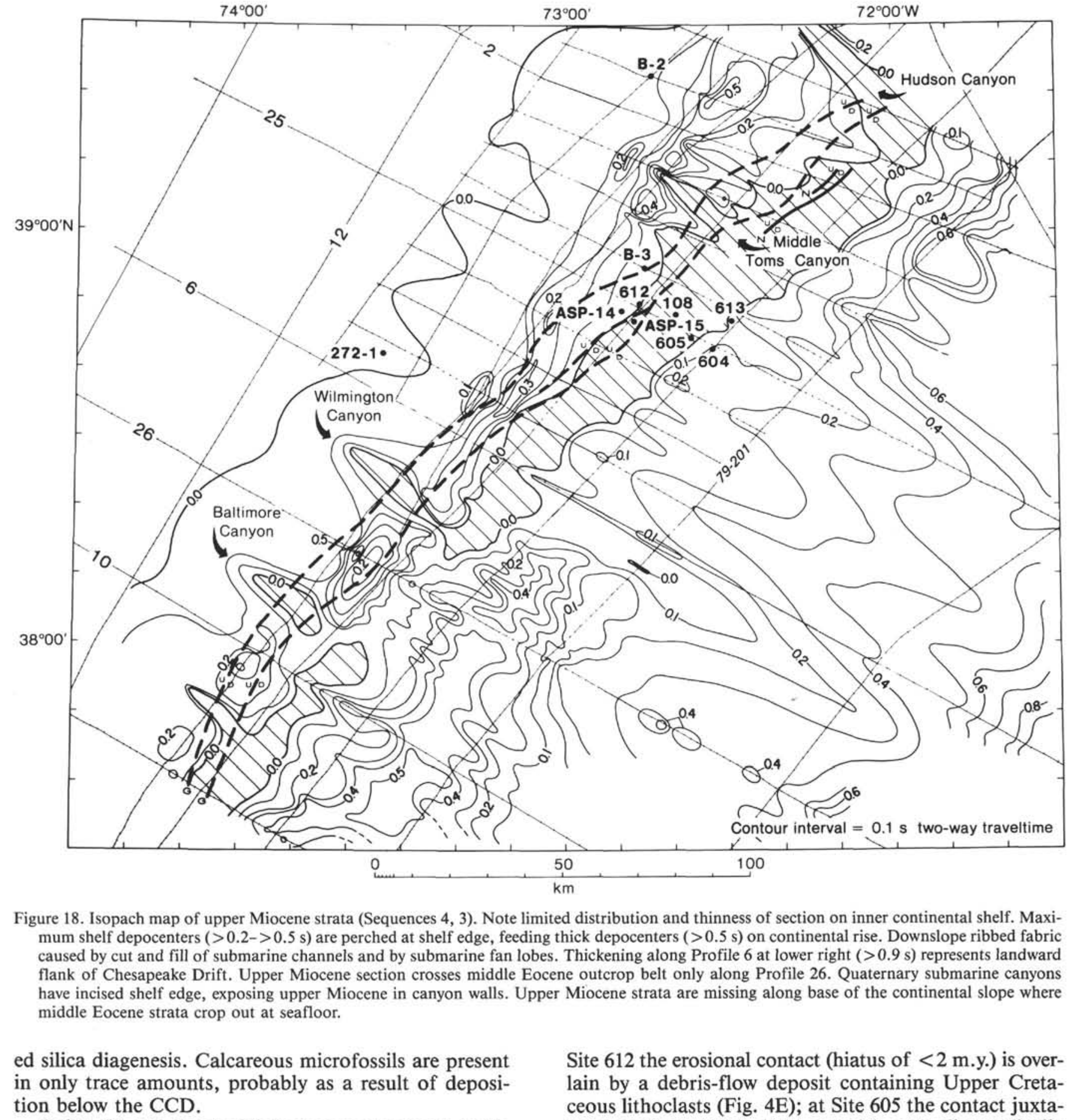

Figure 18. Isopach map of upper Miocene strata (Sequences 4, 3). Note limited distribution and thinness of section on inner continental shelf. Maximum shelf depocenters (>0.2–>0.5 s) are perched at shelf edge, feeding thick depocenters (>0.5 s) on continental rise. Downslope ribbed fabric caused by cut and fill of submarine channels and by submarine fan lobes. Thickening along Profile 6 at lower right (>0.9 s) represents landward flank of Chesapeake Drift. Upper Miocene section crosses middle Eocene outcrop belt only along Profile 26. Quaternary submarine canyons have incised shelf edge, exposing upper Miocene in canyon walls. Upper Miocene strata are missing along base of the continental slope where middle Eocene strata crop out at seafloor.

ed silica diagenesis. Calcareous microfossils are present in only trace amounts, probably as a result of deposition below the CCD.

Onlap-fill and chaotic-fill facies are prominent in the lower part of the lower Eocene slope-front prism (Site 613), but updip at Sites 612 and 605, reflections are chiefly subparallel and subcontinuous, or the section is reflection free, indicating more uniform deposition.

The top of the lower Eocene sequence is an erosional surface that can be traced from the coastal plain outcrops (Ward and Strickland, 1985) to the lower continental rise, and is reported widely outside the western North Atlantic as well (Steele, 1976; McGowran, 1979; Quilty, 1980; Barr and Berggren, 1981; Loutit and Kennett, 1981; Berggren and Aubert, 1983; Aubry, 1985). At Site 612 the erosional contact (hiatus of <2 m.y.) is overlain by a debris-flow deposit containing Upper Cretaceous lithoclasts (Fig. 4E); at Site 605 the contact juxtaposes a 60-cm thick, light greenish gray, diagenetically altered (lithified), middle Eocene porcellanite above a soft, dark greenish gray, clay-rich, lower Eocene nannofossil chalk (Fig. 4H). The hiatus is ca. 2 m.y. according to nannofossil biozonation.

Middle Eocene (Sequence 8) Depositional History

The middle Eocene was a time of considerable change in the depositional patterns of the Baltimore Canyon Trough and environs as sea level reached maximum heights for the Cenozoic. The most notable change is the development of a shelf break far updip near seismic Profile

Upper-rise sequences No.	Symbol	Age	Upper-rise equivalents (Mountain & Tucholke)	Characteristics of upper-rise sequences
1		Quaternary	Pleistocene	Widespread; chiefly terrigenous; displaced shelf faunas; reworked Eocene clasts, slope-front onlap- and chaotic-fill; sampled at DSDP 604, 605, 612, 613; ASP 14, 15; AMCOR 6021; COST B-3; DSDP 603, 105.
2		Pliocene	—Blue—	Widespread; chiefly terrigenous; reworked Eocene microfossils; upper surface channeled; fills upper Miocene channels; onlap- and chaotic-fill; sampled at DSDP 604, 605, 612, 613, 603, 105.
3		late Miocene		Widespread; chiefly terrigenous; reworked Eocene clasts, mildly channeled; fills channels on several older surfaces; slope-front, onlap- and chaotic fill, sampled at DSDP 604, 612, 613, 603.
4		Not known (?middle Miocene?)	late Miocene?	Limited to NE study area; chiefly terrigenous ?; fills channels on several underlying sequences; severely eroded; onlap- and chaotic-fill; includes submarine fan facies; not sampled in upper rise DSDP sites, and possible updip equivalent (upper Miocene) not sampled at DSDP 612; COST B-3; ASP 14-15.
5		Not known (?middle Miocene?)		Limited to SW study area; chiefly terrigenous ?; thin sequence; severely eroded; slope-front fill, onlap-fill and submarine fan facies; not sampled in upper rise DSDP sites, but possible updip equivalent (middle Miocene) sampled at COST B-3, ASP 14, 15.
6		middle Miocene		Limited to SW study area; chiefly terrigenous ? fills Eocene channels; severely eroded; onlap-, mounded-onlap-, chaotic-fill and submarine fan facies; not sampled in upper rise DSDP sites, but equivalent (middle Miocene) sections sampled at COST B-3; ASP 14, 15; DSDP 603.
7		middle Miocene	—Merlin— middle and early Miocene?	Limited to SW study area; patchy distribution; chiefly terrigenous ? severely eroded; fills middle Eocene channels; onlap- and chaotic-fill; not sampled in upper rise DSDP sites, but equivalent (middle Miocene) sections sampled at COST B-3; ASP 14, 15, DSDP 603.
8		middle Eocene	late Oligocene ?	Continuous from slope to rise; chiefly biogenous; broad seafloor exposure; channeled, very thick downdip; onlapped by several younger sequences; chiefly onlap-fill; subordinate slope-front and chaotic-fill; sampled at DSDP 605, 612, 613; COST B-3; ASP 15.
9		early Eocene		Continuous from slope to rise; chiefly biogenous; porcellanite and very deep channels associated with upper surface; slumps observed in cores; onlap- and chaotic-fill; slumps observed in cores; sampled at DSDP 605, 612, 613; COST B-3; DSDP 603, 105.
10		Paleocene	early Oligocene ? —A^u—	Limited to upper rise and lower slope, chiefly biogenous; fills channels on Cretaceous surface; upper surface channeled; sampled at DSDP 605, 603, 105; cored but not recovered at DSDP 612.
11		Maestrichtian	Eocene	Continuous from slope to rise; mixed terrigenous and biogenous; upper surface channeled; onlap- and chaotic-fill; sampled at DSDP 605, 612, 603?, 105?; COST B-3.
12		Campanian	Maestrichtian	Continuous from slope to rise; chiefly terrigenous; upper surface channeled; onlap- and chaotic-fill; sampled at DSDP 612, 603; COST B-3.

Figure 19. Summary chart of ages and depositional characteristics for sequences of the upper-rise segment of the New Jersey Transect (modified from Poag and Mountain, this volume). Sequences 7 and 6 have been traced (along Profile *Conrad* 21) to Site 603 on the lower rise, where microfossils show that they are of middle Miocene age. Sequences 5 and 4 do not extend to Site 603 and have not been drilled elsewhere. The upper-rise equivalent stratigraphy (column 4) is from Mountain and Tucholke (1985), as interpreted on Profile 25 at shot point 4000 (see Fig. 20, back pocket; and Poag [1985b]). Blue, Merlin and A^u are regional seismic horizons of the North American Basin.

37, close to the present shoreline (Figs. 14; 20, back pocket). This "hinter" shelf break is marked by a relatively thick prograded wedge of reflections along the inshore strike profiles (Figs. 13, 19). The thickest part of this wedge (ca. 200 m thick) developed southwest of Profile 6. From this hinter shelf break, the middle Eocene sequence thins significantly (to <50 m) seaward across a broad "fore shelf," before thickening again (>200 m thick) in a slope-front prism that built out in the vicinity of the earlier Paleocene and Late Cretaceous shelf break, near the Gemini fault system (i.e., near the COST B-3 well projection on Profile 25; Fig. 20, back pocket). To the southwest of Profile 6, however, an elongate narrow erosional swath is present on the outer fore shelf, and another parallel swath was formed on the middle to lower continental slope by postdepositional erosion.

The results of lower slope erosion are also seen to the northeast of Profile 6, where an elongate thinned area is offset in a downdip direction; here the middle Eocene section was not as completely removed as in the southwest (Fig. 14). A thick prism (>0.5–0.7 s) accumulated seaward (southeast) of seismic Profile 79-201. The downslope ribbed depositional fabric is obvious along all the strike profiles southeast of the fore-shelf edge.

Middle Eocene strata throughout the Baltimore Canyon Trough and vicinity are characterized by an abundance of carbonate components, which accumulated in a warm, moist, tropical maritime climate (Frederiksen, 1984). At the Island Beach well, located 40 km shoreward from the edge of the middle Eocene hinter shelf (Figs. 9, 14), 34 m of sandy, shelly, calcareous clay is topped by a 9-m gypsiferous section, the latter indicating shoaling in a relatively arid local climate. At the outcrop, glauconitic sands and clays of the Manasquan Formation (Farmingdale Member) and Shark River Formation (Squankum Member), contain inner to middle sublittoral (10–50 m) microfossil assemblages (Charletta, 1980).

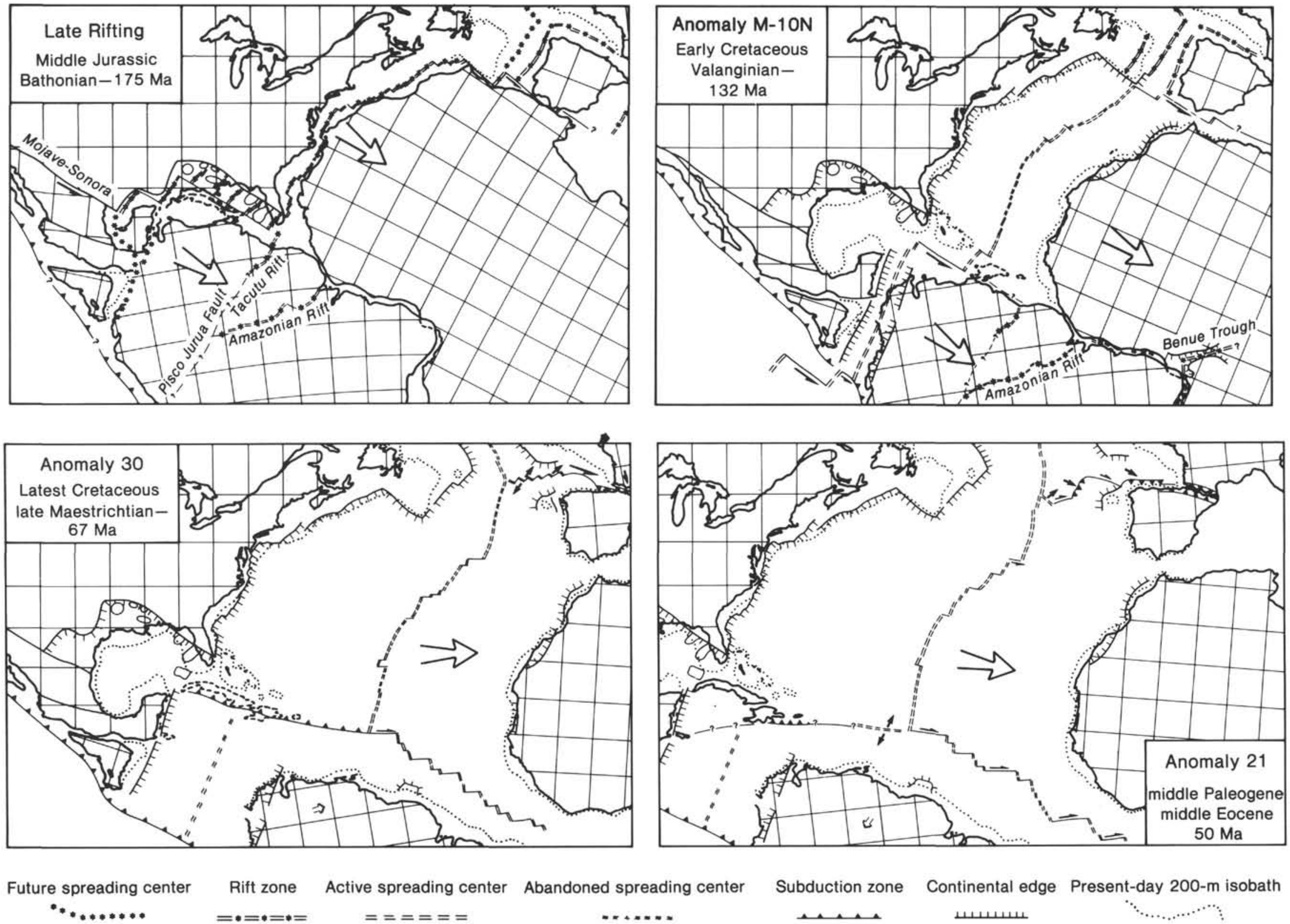

Figure 21. Reconstruction of continental positions around the North Atlantic at four selected time intervals (from Klitgord and Schouten, 1986). Large arrows indicate plate motions relative to North America.

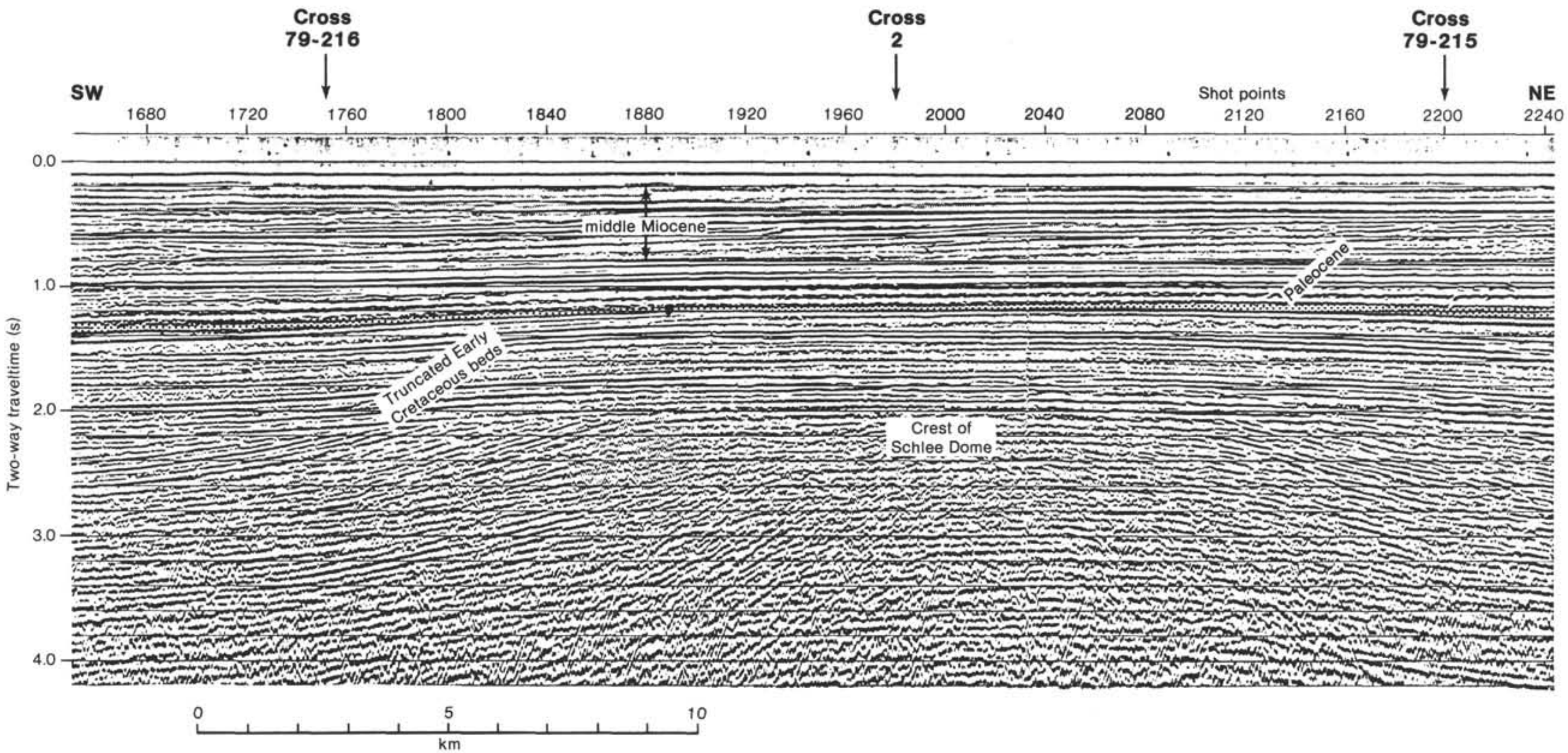

Figure 22. Segment of multichannel seismic Profile 79-207 showing the stratigraphic and structural relationships of the Schlee Dome, a mafic intrusion of Early Cretaceous age. Line 79-207 crosses the dome in a southwest-northeast direction. This feature has been previously known informally as the "Great Stone Dome" (Schlee et al., 1976; Grow, 1980). Seafloor relief over Schlee Dome persisted into the Cenozoic, causing significant erosion of the Paleocene sequence across its elevated crest (see isopach map, Fig. 12). This feature is named in honor of John S. Schlee, who has pioneered the stratigraphic investigations of Baltimore Canyon Trough.

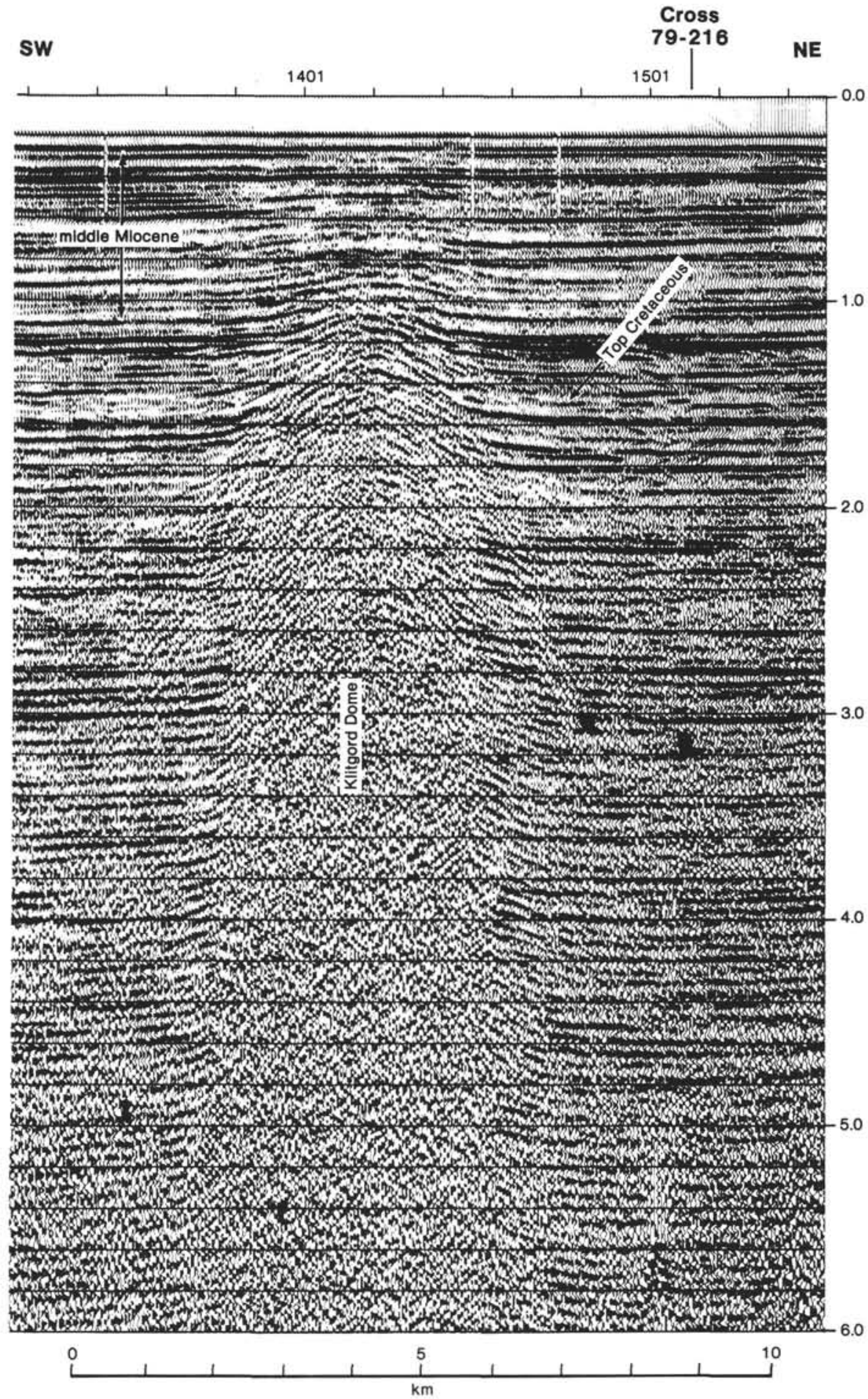

Figure 23. Segment of multichannel seismic Profile 14, showing the narrow piercement structure of Klitgord Dome, which is presumed to be a salt diapir (Grow, 1980). The salt is inferred to be of Early Jurassic age, having intruded well into the Cenozoic section. This feature is named in honor of Kim D. Klitgord, who has contributed immensely to our understanding of the structural development of the North Atlantic Basin.

At the COST B-2 well, located on the outer part of the gently sloping middle Eocene fore shelf (Figs. 14; 20, back pocket), 135 m of buff to light gray, dense, argillaceous micrite (Fig. 9) contains microfossil assemblages indicating bathyal paleodepths of 500–600 m. Radiolarians become noticeably more abundant at this location than updip, and increase even more at downdip sites.

At the COST B-3 site, the middle Eocene section is 90 m thick (Fig. 9), comprising light gray to white cal-

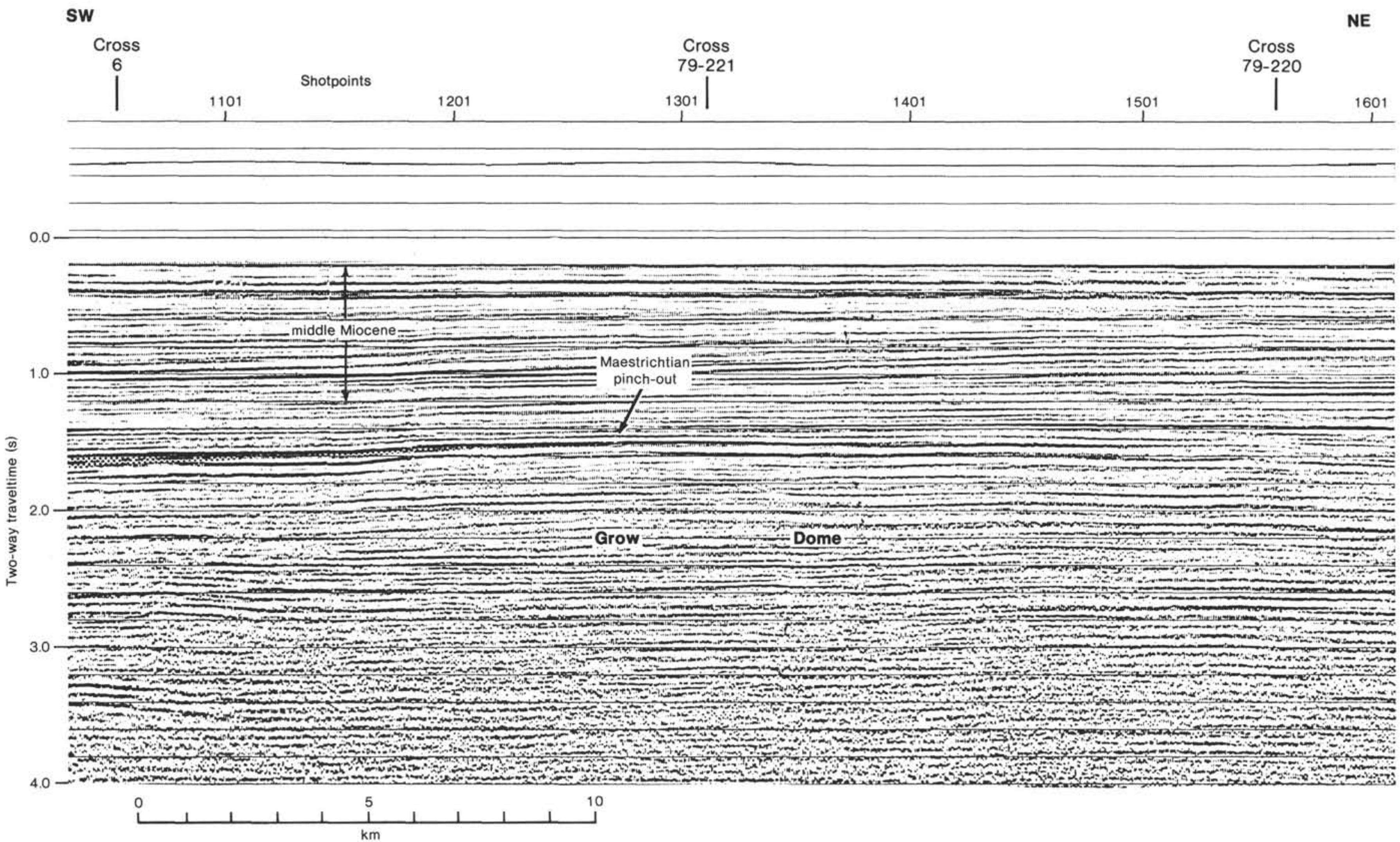

Figure 26. Segment of USGS multichannel Profile 14 crossing the broad, gently arched crest of Grow Dome. Apparently, seafloor relief over this structure caused significant erosion of the Maestrichtian sequence from its crest (see isopach map Fig. 11). This feature is named in honor of John A. Grow, whose geological and geophysical investigations of the U.S. Atlantic margin have been germinal to our present understanding of its evolution.

careous claystone and fossiliferous limestone. Rich microfossil assemblages, which include abundant radiolarians, indicate bathyal paleodepths of ca. 1000 m.

At Site 612, the middle Eocene section thickens to 151.6 m and changes to light greenish gray, biosiliceous, nannofossil chalk; the radiolarian and diatom assemblages continue to increase and terrigenous lithic components drop out. The upper 42 m of the section is noticeably least indurated, constituting a soft ooze, but the constituents remain the same as those of the lower section. The porcellanitic interval of the diagenetic "front" comprises the basal 8 m of the middle Eocene section.

The middle Eocene section changes little in composition downdip at Sites 605 and 613 (Fig. 9), but thickens gradually (145 and 173 m, respectively). Considerably thicker sections are present in some of the channel-fill deposits along Profile 35 (Fig. 24, back pocket). One notable lithologic change is the presence of a thin (2–5 cm) layer of unaltered rhyodacitic ash, 9 m above the base of the middle Eocene section at Site 605 and 37 m above the base of the middle Eocene section at Site 613. Although von Rad and Kreuzer (in press) assumed that these ash layers were deposited simultaneously, the higher relative stratigraphic position and the younger K/Ar age of ash at Site 613 (40 Ma vs. 45 Ma at Site 605) suggest that they represent two different events. Schlee (1977) reported as many as nine different ash layers in the Eocene–Oligocene sections of JOIDES Coreholes 3, 4, and 6 on the continental margin of Florida. Presumably wind and/or surface currents (e.g., the proto-Gulf Stream) transported the ash to the New Jersey margin from active centers of volcanism in the Caribbean Island Arc.

No middle Eocene strata were identified at Sites 603 and 105 (Figs. 9; 25, back pocket). These results confirm the distribution of Sequence 8 (middle Eocene), which pinches out (is truncated) ca. 25 km from the seaward end of Profile 25 (shot point 6100; Fig. 20, back pocket), and at 1300 hrs. on the *Conrad* 21 profile (MCS-75A). The closest deep-sea site that contains middle Eocene sediments is DSDP Site 8 on the Bermuda Rise (~250 km northeast of Site 603); there a discontinuously cored section of at least 30 m of multicolored, clayey, silty, radiolarian ooze overlies 10 m (or more—hole bottomed in this unit) of hard, cherty, radiolarian mudstone and silty clay. Comparison of early radiolarian data (Cita et al., 1970) with an up-to-date radiolarian biozonation (Sanfilippo et al., 1985) indicates that Core 2 in Hole 8 and 1 in Hole 8A (the noncherty sections) are of middle Eocene age. The samples from the cherty section contain sparse, long-ranging radiolarian species, which yield an age of undifferentiated early-to-middle Eocene. A strong acoustic impedance contrast at the top of the cherts in Core 8A-2 produces the seismic reflector known widely in the North American Basin as Horizon A^c (Tucholke, 1979; Tucholke and Mountain, 1979). Several authors have suggested that Horizon A^c can be traced into the New Jersey margin and correlated with the porcellanites at Sites 612, 605, and 613. Further discussion of this topic is presented in a later section of this chapter.

The seismic reflection characteristics of the middle Eocene sequence indicate that onlap-fill, slope-front-fill, and chaotic-fill facies are prominent in the thickened prism of sediments constituting the slope front, especially near Site 613. Updip from Profile 34 (Site 612) and downdip from Profile 79-201, however, broad reflection-free intervals (on multichannel profiles) and parallel, subcontinuous, high-amplitude reflections (on single-channel profiles) suggest more uniform, lower-energy depositional environments. Coring these varied seismic facies revealed similar variation among the lithofacies. Updip at Sites 612 and 605 the strata are rather uniform in lithology and sedimentary structures. Erosional unconformities at the sequence boundaries were the principal deviations from a steady rain of pelagic carbonate particles to the upper bathyal seafloor. However, downdip at Site 613 sedimentary deformation is more notable, especially in the lower 10 m of the sequence, where faulting, slumping, and folding are prominent, attesting to the importance of downslope mass sediment transport.

The top of the middle Eocene sequence is an erosional surface that can be traced widely across the U.S. Atlantic margin from coastal plain outcrops (Ward, 1984; Ward and Strickland, 1985) to the continental rise where it coalesces with the unconformable lower Eocene–middle Miocene contact (Fig. 20, back pocket; Poag, 1985b). The middle Eocene erosional surface is now exposed on the seafloor at the base of the continental slope (between Sites 612 and 605 on Profile 25; Fig. 20, back pocket; Robb et al., 1983; Hampson and Robb, 1984; Farre, 1985; Farre and Ryan, 1985; Poag, 1985a) where it was drilled during DSDP Leg 11 (Site 108; Hollister, Ewing, et al., 1972). Farther seaward, at Sites 605, 613, and vicinity, the middle Eocene erosional surface is onlapped by Tertiary and Quaternary sequences of the continental rise (Fig. 20, back pocket; Tucholke and Mountain, 1979, 1986; Mountain and Tucholke, 1985; Poag, 1985b). Some authors have correlated this erosion surface with Horizon A^u, a prominent unconformable seismic reflector of the North American Basin (Klitgord and Grow, 1980; Emery and Uchupi, 1984; Mountain and Tucholke, 1985; Poag, 1985b). Further discussion of Horizon A^u and its relationship to reflectors of the New Jersey margin is presented later in this chapter.

The middle to upper Eocene erosional contact as expressed at Site 612 is an irregular scour surface that separates medium gray, biosiliceous, sparsely burrowed, nannofossil ooze (below) from a dark greenish gray, glauconitic, quartzose, microtektite-bearing sand, 1.5 cm thick (above; Fig. 4D). A hiatus of ca. 5 m.y. is represented by the unconformable contact at the base of the sand. A significant positive deflection in the gamma-ray log is associated with the basal upper Eocene sand; sparse amounts of glauconite and volcanic glass keep the gamma-ray values consistently higher in the upper Eocene than in the middle Eocene section. This gamma-ray characteristic is also seen on the B-3 well log (Poag, 1985b), which suggests a similar change in lithology at the middle-to-upper Eocene contact there. Sediments from the B-3 well have not yet been studied in enough detail (Pollack, 1980) to determine whether a basal glauconite sand is present there.

The presence of the microtektite-bearing sand is significant for its presence within a 420-m section of bathyal pelagic carbonates. The terrigenous contents suggest derivation from a debris-flow deposit that crossed Site 612 during a major regression (sea-level fall) in the early part of the late Eocene, as suggested by Vail and Mitchum (1979). On the New Jersey Coastal Plain, the middle Eocene erosion surface is exposed at the outcrop, directly overlain by Miocene strata.

The age and location of the original microtektite-bearing beds, from which those at Site 612 were derived, is not yet known. However, as reworked constituents of a debris-flow unit, they do not necessarily signal the impact of an extraterrestrial body near Site 612 during the earliest late Eocene.

Late Eocene (unnumbered sequence) Depositional History

The known distribution of the upper Eocene sequence of the New Jersey Transect is so limited that it is difficult to prepare a meaningful isopach map, and I have not numbered this sequence. It has been sampled at Site 612, in the Anchor-Dickinson No. 1 well on Cape May, New Jersey, and at the COST B-2 and B-3 wells (Figs. 2, 9). It is missing at the outcrop in New Jersey and in the subsurface of the New Jersey Coastal Plain (except for the center of the Salisbury Embayment). It is relatively thin at most sites (45–55 m at COST B-2 and B-3 wells and DSDP 612), but thickens in the Anchor-Dickinson well to ca. 120 m (Fig. 9; Poag, 1985a). It is either missing or too thin to be traced over much of the Eocene shelf on seismic profiles (e.g., Profile 25; Fig. 20, back pocket), but a small prograded wedge of late Eocene strata appears to have created a local depocenter seaward of the Anchor-Dickinson well along the inner-shelf part of Profiles 6 and 26 (Fig. 2). Upper Eocene sediments have not yet been identified from the lower continental margin between Sites 612 and 603 (Figs. 9; 25, back pocket).

At Site 612, the 45 m of upper Eocene sediments are principally light greenish gray, bathyal, biosiliceous, nannofossil oozes, similar to the softer upper strata of the middle Eocene, but containing small percentages of terrigenous components, such as quartz and glauconite, along with trace amounts of volcanic glass shards. Calcareous clays at the B-2 and B-3 wells give way shoreward to thick sands and glauconitic, thin, calcareous clays at the Anchor-Dickinson well. Inner to middle sublittoral paleodepths are estimated for this New Jersey location.

The upper surface of the upper Eocene sequence is an unconformity on most seismic profiles, having been deeply eroded over most of its extent. This presence of an unconformity at Site 612, however, is equivocal. The uppermost Eocene strata appear to be missing according to the planktonic foraminiferal and nannofossil zonations, but that may be due to a small loss of section between 612-16-7 and 612-16,CC. The lithologies and fossil contents of these two core sections are quite different, but no contact was recovered.

Late Oligocene (unnumbered sequence) Depositional History

The Oligocene sequence, as presently known, is chiefly a shelf sequence of late Oligocene age (Fig. 15). Lower Oligocene strata have been identified at Site 612 (Figs. 2; 20, back pocket) and ASP 15, and at scattered locations beneath the New Jersey Coastal Plain (e.g., Olsson et al., 1980; Bybell and Poore, 1986). No Oligocene beds have been documented from the upper continental rise (Sites 605, 613) or at Site 603 on the lower rise, thus no sequence number has been assigned to this unit. However, an ichthyolith assemblage from Site 105 may be of late Oligocene age (Figs. 9; 25, back pocket; Kaneps et al., 1981).

Like the preceding middle Eocene sequence, upper Oligocene strata accumulated on a double shelf. The hinter shelf was built by a series of seaward prograding strata, which are thickest (0.3–0.4 s = 200–300 m) along Profile 26 off the present entrance of Delaware Bay (Figs. 15; 27, back pocket) and 50 km seaward of the Island Beach well along Profile 2.

The presence and thickness of Oligocene strata at the Island Beach well are equivocal. Brown et al. (1972) and previous authors recognized no Oligocene rocks in the well. Olsson et al. (1980) assigned 84 m of silty calcareous clay, glauconitic, quartzose sands, and greensands to the upper and lower Oligocene. I (Poag, 1985b) assigned a 15-m greensand to the upper Oligocene, concluding that lower Oligocene strata are missing there. Microfossil assemblages in the Island Beach section indicate inner to middle sublittoral paleoenvironments, and similar paleoenvironments are inferred from other subsurface localities in New Jersey (Olsson et al., 1980).

The AMCOR 6011 core hole penetrated the upper 9 m of the upper Oligocene section on the middle part of the hinter shelf, 12 km southeast of the Island Beach well on Profile 2 (Fig. 2). Gray green, micaceous, shelly, silty clay contains late Oligocene microfossils deposited in middle sublittoral environments (Olsson et al., 1980; Poag, 1985a).

On the middle part of the Oligocene fore shelf, the COST B-2 well (Figs. 9; 20, back pocket) penetrated 150 m of upper Oligocene, gray brown, calcareous claystones, siltstones, and silty sands, having thin, dark brown, limestone interbeds. Foraminiferal and radiolarian assemblages are generally well-developed, although often poorly preserved. Outer sublittoral and upper bathyal paleoenvironments are inferred for most of the strata at this site. At the top of the section, however, a marked reduction in benthic foraminiferal diversity suggests shoaling to outer or middle sublittoral depths (Poag, 1985a).

At the COST B-3 well, located on the outer part of the Oligocene foreshelf (Fig. 20, back pocket), 91 m of light olive-gray, glauconitic clays represent late Oligocene deposition. Rich foraminiferal and radiolarian assemblages here indicate mid-bathyal (~1000-m) paleoenvironments.

Along Profile 25, upper Oligocene strata extend downdip to within a few hundred meters of Site 612, before the section is truncated (Figs. 3; 20, back pocket). A thin unit (< 1 m) of lower Oligocene, white, foraminiferal, radiolarian, and nannofossil ooze, containing abundant volcanic glass shards and tests of the chrysophyte(?) alga *Bolboforma*, is present, however, at Site 612; 10 m of similar strata was cored at the ASP 15 site (Fig. 2). Mid-bathyal paleoenvironments are also indicated by the microfossils of these lower Oligocene beds.

The lower Oligocene section is, in turn, truncated a few hundred meters southeast of Sites 612 and ASP 15 and is missing across the seafloor exposure of middle Eocene rocks (Figs. 15; 20, back pocket). Even broader erosional embayments extend into the middle part of the Oligocene fore shelf along Profiles 10, 26, and 2, and several isolated, elongate, erosional patches are present north of the COST B-3 site (Fig. 15). Thus the edge of the Oligocene fore shelf appears to have been completely eroded in the study area, and its former position can only be grossly estimated to have been somewhere near the edge of the middle Eocene fore shelf. Oligocene strata may be present within Sequence 7 (described below) of the upper rise wedge (e.g., Mountain and Tucholke, 1985; Poag, 1985a), but they have not yet been identified by drilling.

The only Oligocene strata drilled near the outer end of the New Jersey Transect are at Site 105 (Figs. 9; 25, back pocket). There, a 4-m interval in Core 105-5 contains noncalcareous, multicolored, zeolitic clays and silts and an upper Oligocene ichthyolith assemblage (Kaneps et al., 1981).

As indicated in part by the broad patches where Oligocene strata are missing, the upper surface of the Oligocene sequence is an erosional unconformity, which is overlain by lower or middle Miocene strata over most of the New Jersey margin. At Site 612, however, an atypical section was cored within a small channel, where *late* Miocene strata have buried the lower Oligocene section (Fig. 3). The 25-m.y. hiatus represented by this locally channeled unconformity encompasses three regional erosional events, which can be documented from nearby drill sites (ASP 15, ASP 14, COST B-2, and B-3) and traced on seismic profiles.

Early Miocene (unnumbered sequence) Depositional History

During the early Miocene, the double shelf system of the New Jersey margin was maintained (Figs. 16; 27, back pocket), but the edge of the hinter shelf prograded ca. 40–60 km to the southeast as the basin entered a phase of accelerated terrigenous deposition. The main source of clastic detritus appears to have been north or northwest of the study area, as the thickest accumulation (> 0.5 s) lies between Profile 25 and the northern margin of Figure 16.

Landward of Profile 37, the lower Miocene section is missing, or is too thin to resolve on the seismic profiles. Lower Miocene strata may include most of the Kirkwood Formation in New Jersey, and sandy paralic and inner sublittoral beds of early Miocene age are present in Virginia, Maryland, and Delaware, along the southwestern flank the Salisbury Embayment (Benson et al., 1985; Ward and Strickland, 1985). Thickening of the lower Miocene section near the edge of the hinter shelf on Profile 27, offshore Maryland, may be a reflection of this southwestward distribution.

To the southeast, lower Miocene strata on the fore shelf thin to less than 0.1 s (64 m at the COST B-3 well), and are truncated ca. 2 km updip from Site 612 (Fig. 20, back pocket) and at equivalent locations all along the margin (Fig. 16). The former edge of the early Miocene fore shelf has been eroded, and the lower Miocene strata do not cross the exposure of middle Eocene carbonates along the base of the continental slope, thus I have not numbered the lower Miocene section as a separate sequence. However, lower Miocene strata appear to have been cored at Site 603 at the outer end of the New Jersey Transect (Figs. 9; 25, back pocket) and may be included within the lower part of Sequence 7 on the continental rise.

The best documentation of lower Miocene strata on the fore shelf comes from the ASP 14 and 15 coreholes and the COST B-3 well (Figs. 2, 9; 20, back pocket). At the ASP sites, the section is ca. 15–20 m thick (too thin to detect on multichannel seismic profiles, but clearly shown on high-resolution single-channel profiles), comprising dark silty clays and glauconitic sands. Middle to lower bathyal (800–1200 m) microfossil assemblages are rich in planktonic foraminifers, radiolarians, and diatoms. The section thickens to 64 m at the COST B-3 well, where similar litho- and biofacies are developed. Lower Miocene microfaunas were not identified at the COST B-2 and Shell 272-1 wells, although seismic profiles indicate that a thin section is probably present at each site. These wells recovered sparse foraminiferal assemblages of low diversity, dominated by inner to middle sublittoral, delta-margin benthic species and abundant diatoms. Planktonic foraminifers are rare in the silty, micaceous, organic-rich, sands, sandy silts, and silty clays at these sites.

At Site 603 (Fig. 6), a 14-m section of gray, brown, and yellow, silty, sideritic, gassy claystones contains lower to middle Miocene ichthyoliths in an otherwise nonfossiliferous interval, resting on lower Eocene radiolarian claystones. Seismic extrapolation of this lower(?) Miocene unit toward the upper rise suggests that it pinches out before reaching the seaward end of Profile 25.

Middle Miocene (Sequences 7, 6, 5) Depositional History

During the middle Miocene, deposition of prograding deltaic detritus accelerated to ~240 m/m.y., a maximum for Tertiary deposition in the Baltimore Canyon Trough. Presumably deep weathering of humid subtropical soils (Frederiksen, 1984) and uplift of the Appalachian highlands (Hack, 1982) contributed to this rapid accumulation. The main middle Miocene depocenter off the present mouth of Delaware Bay collected more than 1200 m of terrigenous detritus (Figs. 17; 20, 27, back pocket). Garrison (1970), writing before borehole data were available, speculated that this prograded wedge was of Oligocene age. At least three major pulses of seaward progradation took place during the middle Miocene, as shown by the three distinct subsequences of prograding reflections on the dip profiles (Fig. 20, back pocket). These subsequences form the bulk of Schlee's (1981) prograded Unit G.

The middle Miocene section thins to the northeast and shoreward from the depocenter, and its slope-face margin has been deeply incised by shelf-edge submarine canyons that developed during the Pleistocene (Fig. 17). By the end of the middle Miocene, the shelf edge had moved seaward ca. 30–60 km from its early Miocene position and formed the relatively steep slope-face that is the foundation of today's continental slope (Fig. 20, back pocket). By this time, the New Jersey margin was again characterized by a single shelf break. The edge of the middle Miocene section has been truncated by erosion where it borders the middle Eocene outcrop belt (Fig. 20, back pocket), suggesting that middle Miocene strata originally extended across the outcrop here to join the upper rise prism, as they do along USGS multichannel Profile 11, 70 km southwest of Profile 27 (Fig. 2). On the continental rise, three sequences, numbered 7, 6, and 5 (from oldest to youngest) appear to represent downdip equivalents of the three shelf subsequences of the middle Miocene. Sequences 7 and 6 can be traced all the way to Site 603 along seismic Profile *Conrad* 21 (Fig. 24, back pocket) where microfossil dating shows they are indeed of middle Miocene age. Sequence 7 reaches Site 105, but Sequence 6 does not. Sequence 7 encompasses accretionary Sequences 1 and 2 of Tucholke and Laine (1982); Sequence 6 encompasses their accretionary Sequence 3. The distribution of sequences 7, 6, and 5 combined (Fig. 17) shows that they are thickest (0.6–0.7 s) opposite the shelf-edge depocenter and thin northeastward in concert with the middle Miocene shelf sequences. They also thin basinward in the direction of Site 603, although a secondary thickening takes place along Profile 13, where the underlying middle Eocene section thins (Figs. 17; 20, back pocket). The downslope ribbed fabric characteristic of older sequences of the upper-rise prism was maintained in the middle Miocene as frequent turbidity currents and debris flows cut and filled downslope channels.

The middle Miocene sequence is notable on the coastal plain as quartzose, shelly, diatomaceous, sandy beds and gray green clay of the upper Calvert, Choptank, and St. Marys formations in Virginia, Maryland, and Delaware, and include the upper part of the Kirkwood Formation, the Cohansey Sand, and perhaps the Bridgeton Formation in New Jersey (Owens and Minard, 1979; Ward and Strickland, 1985). A plot of paleocurrent directions derived from extensive cross-bedding in the fluviatile sands of the Bridgeton Formation (Owens and Minard, 1979) shows a major middle Miocene drainage system paralleling the present Delaware River southwestward across New Jersey and turning sharply eastward directly updip from the offshore depocenter.

In the Island Beach well, 100 m of glauconitic, micaceous, shelly, medium to coarse, quartzose sand and several beds of gray, micaceous, lignitic, silty clay represent middle Miocene deposition (Fig. 9). Most samples are barren of microfossils, but diatoms and a few middle Miocene radiolarians have been identified (Poag, 1985a). Olsson et al. (1980) assigned this section to the Kirkwood Formation, which extends westward to the outcrop in western New Jersey (Fig. 1). Paralic and inner and middle sublittoral paleoenvironments are inferred from the litho- and biofacies of these strata.

At the B-2 well (Figs. 9; 20, back pocket), the middle Miocene section thickens to 600 m along the northeast margin of the depocenter. Here silty, micaceous, organic-rich sands, sandy silts, and silty clays contain abundant diatoms. Foraminifers are sparse and poorly preserved, and radiolarians are few. Middle sublittoral paleoenvironments are inferred from these constituents. Three AMCOR boreholes (6009, 6010, 6011; Fig. 2) penetrated part of the middle Miocene section in the vicinity of the COST B-2 well, revealing similar lithofacies and microfaunal assemblages.

At the COST B-3 well, the middle Miocene section thins to 200 m on the lower part of the mid-Miocene continental slope (Figs. 9; 20, back pocket). Glauconitic, micaceous, organic-rich, silty clays dominate here and contain lower bathyal (1000–1500 m) microfossil assemblages. Radiolarians and diatoms are especially prominent constituents. At nearby ASP 14, 240 m of similar strata were cored, and an abbreviated 24-m section was sampled at ASP 15 (Fig. 2). The middle Miocene section at Site 612 has been completely removed by local downslope channeling (Fig. 3).

Within the upper-rise prism, the middle Miocene seismic facies include onlap and chaotic fill, which are especially common near the base of the prominent downslope channels. Several mounded sedimentary sections are interpreted to represent submarine fan lobes.

At Site 603, middle Miocene deposition (Sequences 7 and 6) is well represented by 325 m of dark greenish gray, silty, micaceous, often sideritic, claystones of the Blake Ridge Formation (Figs. 9; 25, back pocket). This is the thickest of the Cenozoic sequences cored at Site 603. Foraminifers are sparse or missing throughout this section, but nannofossils are common, especially in the upper half of the section, and radiolarians are prominent in the lower two-thirds. Turbidites characterize this sequence, and the emission of gas from many of the cores indicates a relative abundance of organic matter (as much as 1.32% TOC).

Middle Miocene strata of the continental shelf and slope also are enriched in organic matter (both marine and terrigenous). Palmer (1986) and I (Poag, 1985a) concluded that upwelling combined with the accumulation of organic-rich deltaic sediments produced a highly productive coastal environment in the middle Miocene (see also Snyder, 1982; Riggs, 1984), which accounts for the prominence of diatoms and radiolarians in the shelf sequences. Rapid dumping of middle Miocene detritus into the North American Basin supplied abundant terrigenous inorganic and organic constituents to Site 603 and vicinity, and a relatively high CCD further reduced carbonate accumulation there.

The contact between the middle Miocene and overlying sections has not been cored in the offshore region of New Jersey, but the extensive grid of seismic reflection profiles (Figs. 2; 20, back pocket) indicates that it is a widespread erosional surface (Horizon Merlin of Mountain and Tucholke, 1985). On the coastal plain, part of the upper Miocene is missing at the most complete stratigraphic sections in Virginia and Maryland (Ward and Strickland 1985). An even longer hiatus seems to be represented in New Jersey and Delaware, where Pleistocene strata often rest on the middle Miocene surface (Owens and Minard, 1979; Benson et al., 1985; Ward and Strickland, 1985). The paralic nature of many of the post-middle Miocene formations of the coastal plain, however, reduces the accuracy of fossil dating techniques so that age relationships are often imprecisely known.

The most severe erosion on the middle Miocene surface took place on the continental slope, as expressed by abrupt truncation of seismic reflections along all the dip profiles (e.g., Fig. 20, back pocket). Clearly large volumes of sediment were removed from what is now the middle Eocene submarine outcrop belt and transferred to the upper-rise wedge by downslope gravity flows and longslope bottom currents. The Gemini fault system, which presumably often triggered downslope mass movement, appears to have become dormant during the late middle Miocene, as seismic reflections offset along the fault traces extend only about half-way up through the thick middle Miocene sequence (Fig. 20, back pocket).

Late Miocene (Sequences 4, 3) Depositional History

The late Miocene was a time of chiefly deep-water deposition along the New Jersey margin, as the shelf break migrated still farther seaward and principal depocenters were established on the continental rise (0.6–0.8 s; Figs. 18; 20, back pocket). Shelf deposition was minimal (mostly 0.1 s or less). The zero isopach contour (as defined on multichannel seismic profiles) does not reach updip to Profile 12 at any point, but an upper Miocene section, too thin to be resolved on the seismic profiles, may extend shoreward of Profile 12 in some places (Fig. 18). This is suggested by the presence of possibly upper Miocene strata in the New Jersey Coastal Plain (Pensauken Formation; Owens and Minard, 1979). Farther south in the Delaware, Maryland, and Virginia segments of the Salisbury Embayment, the presence of an upper Miocene section (Eastover Formation) is well established by its content of marine fossils (Ward and Strickland, 1985).

On the upper continental slope, the main late Miocene depocenter shifted 150 km northeastward from the middle Miocene depocenter off Delaware Bay (Fig. 18), and maximum thicknesses (0.4–0.5 s) developed off central New Jersey. A corresponding depocenter (0.6 s thickness) on the upper rise developed near the intersection of Profiles 2 and 79-201 (Fig. 18). Apparently the supply of terrigenous sediment continued to be voluminous, but instead of accumulating mainly on the outer shelf and slope, as in the middle Miocene, these late Miocene sediments were channelled to the lower continental rise, where vigorous longslope bottom currents swept them into the thick elongate mounds of the Chesapeake Drift and Hatteras Outer Ridge (Figs. 20 and 25, back pocket; Tucholke and Laine, 1982; Mountain and Tucholke, 1985; Tucholke and Mountain, 1986).

The upper and middle continental rise are crossed by numerous, broad to narrow, downslope channels, filled with chaotic upper Miocene seismic facies. At Site 604 on the upper rise (Figs. 9; 20B, back pocket), the upper part of the upper Miocene channel-fill yielded coarse conglomeratic sands containing large quartz pebbles, igneous and metamorphic lithoclasts, and white chunks of reworked Eocene chalk (Fig. 4P, Q). Site 613 (Fig. 7) was located over an upper Miocene interchannel ridge, where the section is much thinner than at Site 604 (Fig. 8), but even there the upper Miocene strata are coarse to fine, glauconitic, quartzose sands and conglomeratic sands (Fig. 9).

Upper Miocene channel fill was recovered also at Site 612 (Fig. 4B, C). The section there is partly finer grained, chiefly dark gray, micaceous mud, but chert pebbles, glauconitic quartz sand, and a vertebrate fossil are also included. Upper Miocene sediments have not been recovered from any other drill site on the New Jersey margin. Although several exploration wells and the COST B-2 and B-3 wells penetrated the upper Miocene section, few samples were collected at these shallow drill depths.

The downslope ribbed fabric of the upper Miocene sequence is due mainly to filling channels in the underlying surface. The upper surface is not as extensively channeled as older sequences, although deep channels are cut into it on the uppermost rise (Figs. 18; 24, back pocket). Downdip from Profile 35, the upper Miocene surface is relatively smooth over broad areas. On the continental slope, the upper Miocene sequence is truncated along the edge of the middle Eocene outcrop belt, but along Profile 26 upper Miocene strata cross the middle Eocene erosional surface and are continuous with Sequence 3 on the rise. Several of the major submarine canyons that developed during the Pleistocene have cut deeply into the upper Miocene section, exposing it in some canyon walls (e.g., Hudson, Wilmington, and Baltimore canyons; Hampson and Robb, 1984; Fig. 18).

At the seaward end of the New Jersey Transect (Site 603), 311 m of upper Miocene strata constitute the major component of the Hatteras Outer Ridge (Figs. 9; 25, back pocket) and include chiefly dark greenish gray, micaceous, sideritic claystone. A much thinner section of similar lithology was cored at Site 388, 95 km to the northeast. These distal upper Miocene sections can be traced updip along the *Conrad* 21 profile to Profile 25, where they are correlative with Sequence 3.

Pliocene (Sequence 2) Depositional History

During the Pliocene, deposition was concentrated even farther seaward than during the late Miocene. Accumulation rates slowed and maritime climates cooled (Frederiksen, 1984). The main depocenter was again in the North American Basin, while a relatively thin wedge of slope-front fill formed at the shelf break (Figs. 28; 20, back pocket) and thinned rapidly shoreward. Pliocene strata are missing or are too thin to resolve on most multichannel seismic profiles of the continental shelf. Northeast of Profile 2, the Pliocene section thickens and extends seaward in a broad lobe, suggesting that deltaic progradation took place in this region (Fig. 28). A corre-

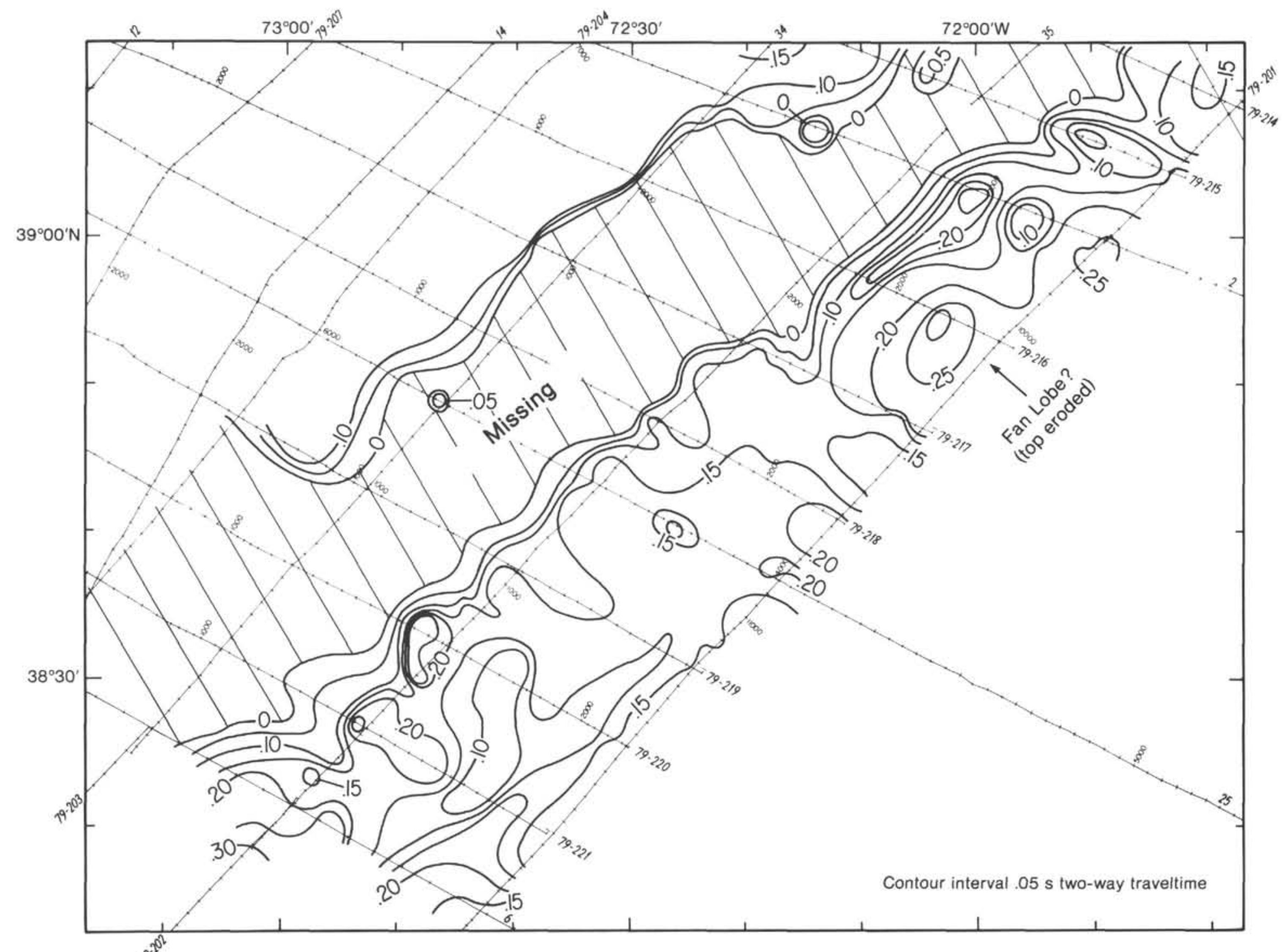

Figure 28. Isopach map of Pliocene strata (Sequence 2). This map is taken, unchanged, from Poag and Mountain (this volume); it does not include as complete an analysis of the continental shelf as included in the maps of most older sequences. Note the lack of Pliocene strata on the middle Eocene outcrop belt and the presence of opposing depocenters (shelf and rise) at upper right.

sponding depocenter on the upper continental rise appears to represent part of an eroded fan lobe. No Pliocene beds have been unequivocally recognized in New Jersey, Maryland, or Delaware (Owens and Minard, 1979; Ward and Strickland, 1985) but they are known in Virginia as the Yorktown and Chowan River formations. These deposits contain shelly, phosphatic, and glauconitic sands of paralic to inner sublittoral origin, along with lagoonal clays and lag deposits of coarse sand, gravel, and cobbles (Blackwelder, 1981).

At Site 612, sediments of the Pliocene continental slope comprise 51 m of channel fill (Fig. 3), including dark gray glauconitic mud with distinctive interbeds of glauconitic sand. The thin, presumably Pliocene sections of the COST B-2 and B-3 wells have not been sampled.

The Pliocene sequence was sampled in an upper-rise setting at Sites 604 (67 m) and 613 (81 m), revealing dark greenish gray, glauconitic muds, often with layers of glauconitic sand and conglomeratic sand and intervals of biosiliceous, nannofossil-rich clay (Fig. 9). Reworked Eocene microfossils are common in these sections, but no large chunks of displaced Eocene chalk, like those in the upper Miocene section, were observed.

The Pliocene sequence thickens on the middle part of the continental rise to form part of the current-controlled, mounded sediments of the Chesapeake Drift (Fig. 20, back pocket; Mountain and Tucholke, 1985). Farther seaward, Sites 105, 106, 388, and 603 have yielded Pliocene strata from the flanks of the Hatteras Outer Ridge (Fig. 25, back pocket). The most complete and thickest Pliocene section (319 m) was cored at Site 603, where turbidites consist of greenish gray, quartzose, micaceous muds, grading downward to micaceous, silty claystone (Fig. 6).

The downslope cut-and-fill depositional fabric of the Pliocene sequence is seen along Profiles 35 and 79-201 (Fig. 24, back pocket), but the channeling is not as extensive as in most older sequences. Superimposed on the downslope fabric is a longslope fabric, created by contour-following bottom currents. Seismic reflections from the upper-rise Pliocene sequence are generally parallel and subcontinuous, except where they form chaotic channel fill.

The upper surface of the Pliocene sequence is a marked unconformity on seismic profiles. Its erosional nature has been substantiated by drilling at Sites 612, 604, and 613. At Site 612 a glauconitic, muddy sand incorporates shelf-derived microfossils and detrital gypsum at the upper Pliocene–upper Pleistocene contact (Fig. 4A), which suggests that a sea-level fall was associated with this erosion.

Quaternary (Sequence 1) Depositional History

The Quaternary sequence, like the Pliocene and upper Miocene, is thickest on the continental rise (Figs. 20, 25, and 27, back pocket; 29 as a consequence of continued seaward progradation of the shelf break and a relatively steep bathymetric gradient ($\sim 6°$) on the continental slope.

The updip prism of Pleistocene sediments (includes thin Holocene veneer) is thickest on the upper continental slope, except where the shelf edge has been incised by deep submarine canyons, which have channeled terrigenous detritus to the continental rise depocenter (Figs. 20, 27, back pocket; 29). The formation of these large canyons intensified downslope depositional processes during the Quaternary and shifted the locus of the most extensive cut-and-fill landward by 20 to 40 km (to the vicinity of Profile 34) from its previous position on the upper rise (vicinity of Profile 35; Fig. 29).

A thickened, prograded depositional lobe extends seaward across the continental slope northeast of Profile 2 (Fig. 29), suggesting that the Pliocene sediment source in this area was maintained during the Pleistocene. Analysis of grain shapes (Mazzullo, this volume) suggests that a major change in sediment provenance took place in the early Pleistocene as proximal coastal plain sources began to dominate over those of the distant Appalachian Highlands. As in the Pliocene, a corresponding depocenter on the upper rise appears to be part of a large fan lobe associated with the slope-front progradation (Fig. 29). In fact, the sediments are thick enough in this region to have completely buried the middle Eocene outcrop belt, and did likewise to the southwest of Profile 6. Nevertheless, the post-Eocene sediment cover is generally thin along the base of the continental slope, and the middle Eocene surface is still exposed between Profiles 2 and 6 and in the walls of some of the submarine canyons (Hampson and Robb, 1984). The maintenance of this exposure and the thinned Pleistocene section across it suggest that the southwestward-flowing Western Boundary Undercurrent has been an effective sediment disperser in this region during the Quaternary. The stratigraphic and physiographic relationships along Profile 26 (Fig. 30) illustrate an abruptly truncated, thick, Quaternary section, which presumably was eroded by longslope currents during the late Quaternary or Holocene.

The Quaternary section thickens seaward in two elongate, subparallel, longslope prisms, separated by a narrow exposure of the Pliocene sequence (Fig. 29; Mountain and Tucholke, 1985). The outer prism constitutes the Hudson Fan, ponded behind the Hatteras Outer Ridge, the latter of which has minor topographic relief on the modern seafloor.

Quaternary gravels and paralic terrigenous strata are known in the New Jersey Coastal Plain and have been assigned by various authors to the Bridgeton, Pensauken, and Cape May Formations. However, such assignments are equivocal (Minard and Rhodehamel, 1969; Owens and Minard, 1979). At the Island Beach well (Fig. 9), beds of gravelly, micaceous, lignitic, often shelly sands at the top and bottom of the Quaternary section encompass a middle interval of silty, micaceous, glauconitic, lignitic clays, containing thin sand interbeds (total thickness = 72 m). These lithic characteristics and a sparse fossil assemblage suggest paralic environments of deposition (e.g., estuaries and coastal lagoons). At the COST B-2 well (Fig. 9), the Quaternary section is thicker (130 m) and slightly more marine in part (inner to middle sublittoral), but lithologies are similar to those of the Island Beach section.

The AMCOR 6021 borehole, located near the upper-slope Quaternary depocenter (Fig. 2), penetrated 305 m

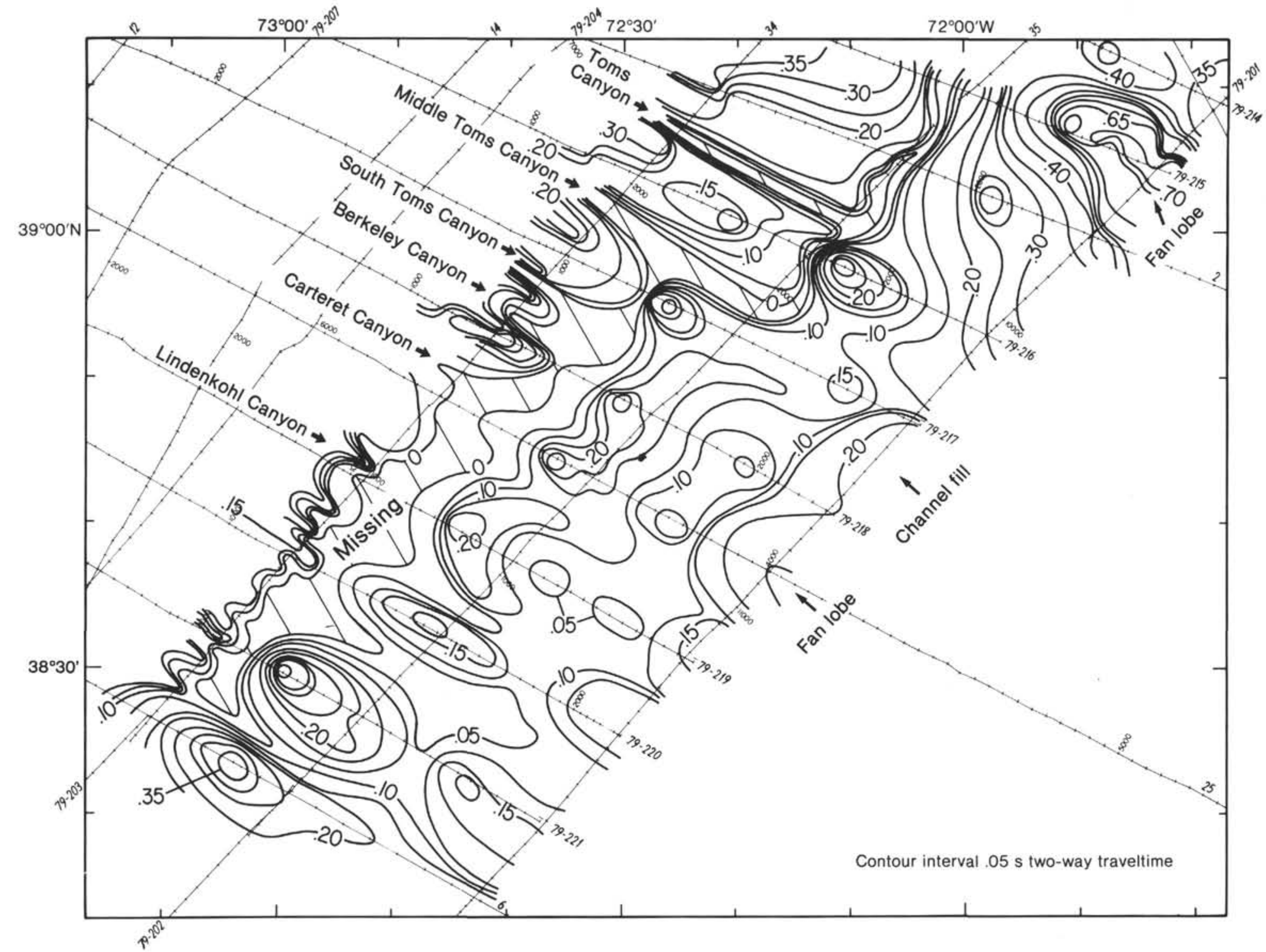

Figure 29. Isopach map of Pleistocene strata (Sequence 1; includes negligible thickness of Holocene blanket). Note deep incision of shelf edge by submarine canyons and exposure of older strata in the canyon floors and walls. This map is taken unchanged from Poag and Mountain (this volume); it does not include as complete an analysis of the continental shelf as included in the maps of most older sequences. Opposing shelf and upper-rise depocenters are shown at upper right. These are apparently products of a deltaic lobe that prograded across the middle Eocene outcrop in this area.

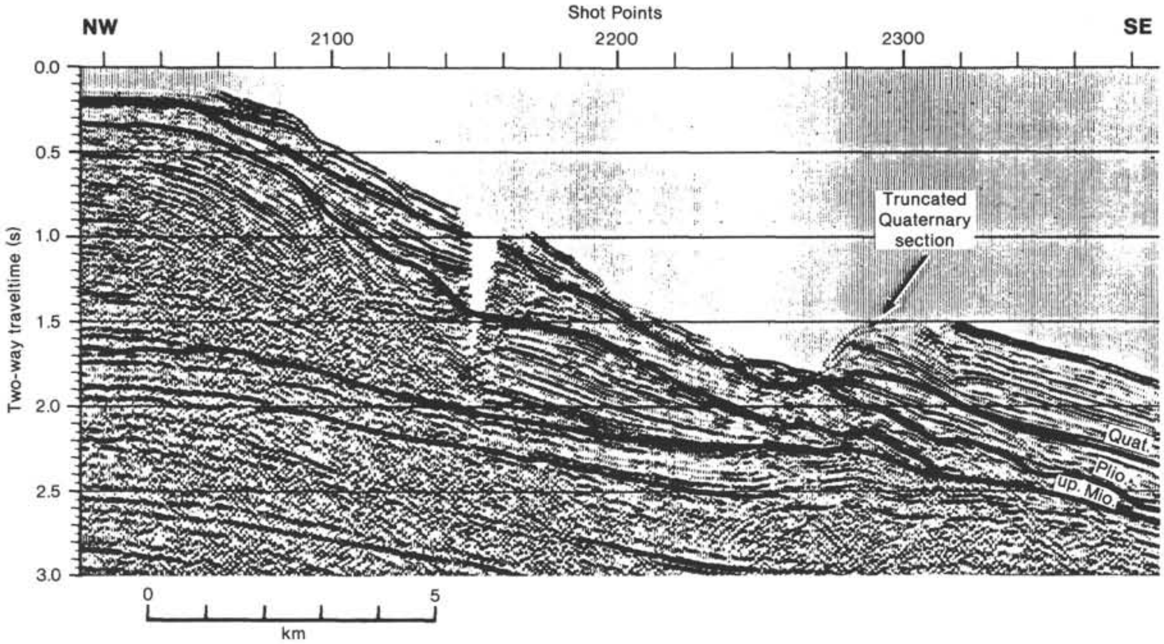

Figure 30. Segment of USGS multichannel seismic Profile 26 showing the seafloor topography and stratigraphic relationships of the continental slope and upper rise in an area where middle Eocene beds do not crop out on the lower slope. The truncated Quaternary strata attest to erosion by longslope currents.

of dark gray, gassy, organic-rich, silty and sandy clays, containing thin shell beds. Several organic-rich layers contain abundant diatoms and associations of benthic foraminifers that indicate oxygen-depleted bottom waters (oxygen-minimum zone). A mixture of inner sublittoral and bathyal foraminifers attests to cross-shelf transport of shallow-water detritus.

At ASP 14, ASP 15, and DSDP 612, the lower (thinner) flank of the slope-front Quaternary prism was sampled. Maximum thickness cored was 36 m at Site 612 (Fig. 3). The sediments are chiefly dark gray, homogeneous, organic-rich muds containing mixed microfossil assemblages of inner to middle sublittoral and bathyal species.

Downdip on the thicker upper continental rise section, DSDP Sites 604, 605, and 613 provided cores of Quaternary sediments. Approximately 185 m of dark greenish gray, homogeneous, gassy, organic-rich, often diatomaceous mud, with interbeds of quartzose, glauconitic sand, and occasional conglomeratic zones, were cored at Site 613, and are characteristic of the upper rise section (Fig. 7). The lithic and microfossil evidence (coarse sands, conglomerates, chunks of white Eocene chalk, displaced shelf species) confirms the importance of downslope depositional processes (turbidity currents, debris flows) inferred from the sediment-distribution pattern and isopach maps. Faunal characteristics further indicate that a major hydrographic boundary separated Sites 612 and 613 during the Quaternary (Scott, this volume).

At Site 603, approximately 31 m of lower Quaternary strata are draped over the Hatteras Outer Ridge (Figs. 6; 25, back pocket). Here the sediments are mainly greenish gray, nannofossil-rich clay and claystone, which emitted hydrogen sulfide gas. At Site 106, drilled on the lower continental rise terrace (Fig. 2), the ponded, turbiditic Quaternary section is 360 m thick, consisting of gray to brown terrigenous mud, with glauconitic, quartzose sand interbeds. Mica, wood, and plant fragments are common in some sandy layers, and siliceous microfossils are especially notable in the lower Pleistocene sediments.

Seismic profiles crossing the continental rise show that the Quaternary section can be divided into two subsequences; drilling shows that these represent the lower Pleistocene and upper Pleistocene/Holocene. In the upper-rise prism, lower Pleistocene sediments fill downslope-trending channels cut into the upper surface of the Pliocene sequence. The contact between the lower and upper Pleistocene subsequences is, in contrast, a rather smooth surface (Figs. 20, 24, back pocket). On the other hand, the upper Pleistocene/Holocene subsequence displays a marked sea-floor relief, caused by differential downslope erosion and deposition. Farther downdip, ponding behind the Hatteras Outer Ridge has smoothed the seafloor topography.

SUMMARY OF PRINCIPAL OBJECTIVES ACHIEVED

The preceding data and their interpretation provide the means of answering the seven principal questions set out as the objectives for DSDP drilling along the New Jersey Transect (see Objectives section of this chapter).

1. The detailed relationships between unconformities seen on seismic reflection profiles and unconformities identified in boreholes were established most thoroughly at Site 612. Here, close correspondence among sonic log and gamma-ray log signatures, lithic and biostratigraphic discontinuities, and unconformable seismic sequence boundaries clearly supports the validity of seismostratigraphic interpretation methods touted by Vail et al. (1977) and many subsequent authors, despite disclaimers by

Thorne and Watts (1984). Similar data from Site 613 corroborate this conclusion. In fact, the records at Sites 603, 604, and 605 also support this conclusion, although no geophysical logging was carried out at those sites. These results strengthen the basis of prior interpretations derived from seismic and borehole data collected on the coastal plain and continental shelf (e.g., Schlee, 1981; Poag and Schlee, 1984; Poag, 1985a).

2. The drilling at Sites 603, 604, 605, 612, and 613, combined with previous drilling on the continental shelf, shows that 12 major Upper Cretaceous and Cenozoic sequence boundaries on the New Jersey Transect are formed by the unconformities listed in Table 1 and illustrated schematically in Figure 9 and in column 5 of Figure 31.

In addition, unconformities at the lower-upper Paleocene contact, the lower-upper Oligocene contact, and the Tortonian-Messinian contact are recognizable in scattered locations. Several unconformities in the older Cretaceous and Jurassic sections are also indicated (Fig. 9), but are less well documented.

The presence of sand layers, exotic lithoclasts and conglomeratic zones, immediately above scour surfaces, and faults or contorted bedding within sequences indicates that erosion by downslope mass sediment displacement (turbidity currents, debris flows, slumps) was the chief agent in forming the unconformities on the continental slope and upper continental rise. These relationships are similar to those noted for several equivalent sequence boundaries on the opposite margin of the North Atlantic, off Ireland (Goban Spur, DSDP Leg 80: Poag et al., 1985).

The source of sand at the Cretaceous, Neogene, and Quaternary unconformities could have been almost anywhere on the adjacent shelf and slope, as the sedimentary sections there are chiefly terrigenous detritus (Poag, 1985a). It is more difficult, however, to identify the source of a quartz sand layer in the midst of the thick Paleogene carbonate section, seen at Site 612 (middle Eocene-upper Eocene contact). Presumably this sand was emplaced during a rapid sea-level fall, which brought a shallow-water siliciclastic section (as at the Island Beach and Anchor-Dickinson sites) much closer to Site 612 than during the preceding and subsequent highstands.

Table 1. Summary chart of 12 major Upper Cretaceous and Cenozoic unconformities documented on the continental shelf, slope, and rise of New Jersey.

Unconformable contact	Estimated hiatus (m.y.) (Site location)
lower Pleistocene-upper Pleistocene	<0.5 (613)
upper Pliocene-lower Pleistocene	<0.5 (613)
upper Miocene-lower Pliocene	<0.5-2.0 (612, 604, 603)
middle Miocene-upper Miocene	<0.2 (603)
lower Miocene-middle Miocene	3.0-5.0 (COST B-3, 603)
upper Oligocene-lower Miocene	<0.5 (COST B-3)
upper Eocene-upper Oligocene	8 (COST B-2, B-3)
middle Eocene-upper Eocene	2.0-5.0 (612, COST B-2, B-3)
lower Eocene-middle Eocene	<2.0 (612)
Paleocene-lower Eocene	<0.1 (605)
Maestrichtian-Paleocene	<0.5-6 (605, Island Beach No. 1)
Campanian-Maestrichtian	ca. 1 m.y. (612)

3 and 4. The location of the New Jersey Transect drill sites within a grid of single-channel and multichannel seismic reflection profiles, coupled with downhole logging and detailed lithostratigraphic and biostratigraphic studies, has shown that the principal depositional sequences and unconformities can be traced over most of the continental slope and rise and are correlative with those of the adjacent shelf and other nearby shelf basins (Poag, 1982; and Schlee, 1984; Poag, 1985a; Popenoe, 1985), of the coastal plain (Owens and Gohn, 1985; Ward and Strickland, 1985; Poag and Ward, in press), and of the margins of several other continents (Steele, 1976; McGowran, 1979; Quilty, 1980; Barr and Berggren, 1981; Loutit and Kennett, 1981; Zeigler, 1982; von Rad and Exon, 1982; Riggs, 1984; Schlee, 1984; Seiglie and Baker, 1984; Seiglie and Moussa, 1984; Aubry, 1985; Poag et al., 1985).

The persistence of gravity-flow deposits at the unconformable sequence boundaries of the continental slope and upper rise of both New Jersey *and* Ireland, and their correlation with paleobathymetric cycles derived from sites on the coastal plain and continental shelf (column 3 of Fig. 31; Poag and Schlee, 1984; Ward and Strickland, 1985; Poag and Ward, in press), link these erosional episodes with sea-level falls. Moreover, the stratigraphic positions of the boundaries of the eight major Cenozoic supersequences (= global unconformities) of the Vail depositional model (Vail et al., 1977) are correlative with the principal stratigraphic gaps of the New Jersey *and* Irish continental margins (Figs. 9, and 1, columns 5, 6). The inescapable conclusion is that sea-level change has been a major factor in controlling Late Cretaceous and Cenozoic deposition and erosion on the margins of the North Atlantic.

Systematic changes in paleoclimate, seawater temperature, and global ice volumes, derived from extensive analyses of oxygen and carbon isotopes, provide an independent means of identifying major sea-level changes. A clear link between widespread sublittoral and bathyal (and even abyssal) erosion, increased global ice volumes, cooler global climates, and lowered sea levels has been established for the Cenozoic as far back as the late Eocene (Fig. 31, column 8: Vail et al., 1977; Frakes, 1979; Miller and Fairbanks, 1983; Keigwin and Keller, 1984; Aubry, 1985; Miller et al., 1985; Poag and Schlee, 1984; Poag, 1985a; Poag et al., 1985; Poag and Low, 1985; Woodruff and Savin, 1985). Some authors have interpreted the oxygen-isotope record as an indication that significant global ice volumes were present into the Late Cretaceous (Matthews and Poore, 1980; Matthews, 1984). The stratigraphic positions of major inflections in the oxygen-isotope curves (indicating increased ice volumes) correlate well with several of the principal stratigraphic gaps of the New Jersey Transect (Fig. 1, column 8).

A recent study of plate kinematics of the North Atlantic has provided an updated interpretation of plate motion changes (Fig. 31, column 10; Klitgord and Schouten, 1986), which presumably would cause sea-level fluctuations (Hays and Pitman, 1973; Cloetingh, 1986). The timing of these plate motion shifts is remarkably coinci-

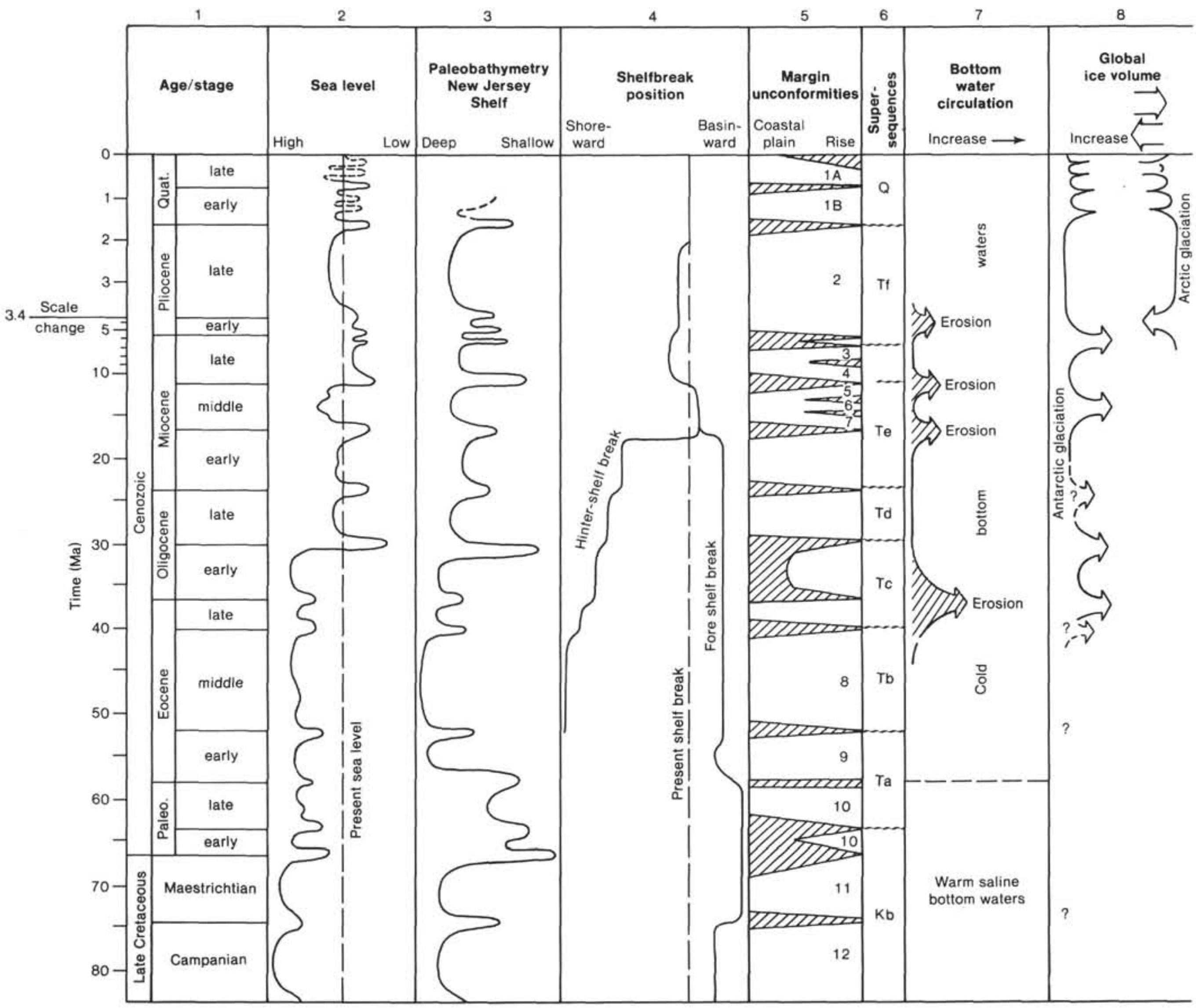

Figure 31. Schematic summary of the important geological, paleobiological, and paleoceanographical events affecting the New Jersey margin and their relationships during the last 84 m.y. (Campanian to Holocene). Data are from the following sources: Column 1—Berggren et al. (1985), Kent and Gradstein (1985); Column 2—Vail and Hardenbol (1979), Poag (1985a); Column 3—Poag and Schlee (1984), Poag (1985a); Column 4—this volume; Column 5—Poag and Schlee (1984), Poag (1985a, 1985b), Ward and Strickland (1985), Poag and Ward (in press); Column 6—Vail and Mitchum (1979); Column 7—Tucholke and Mountain (1986), Berggren and Olsson (1986); Column 8—Kennett and von der Borch (1986), Tucholke and Mountain (1986); Column 9—Emery and Uchupi (1984), Popenoe (1985), Tucholke and Mountain (1986); Column 10—numbered ticks are dates (Ma) of major changes in plate motions identified by Klitgord and Schouten (1986), other data from Tucholke and Mountain (1986); Column 11—this volume; Column 12—this volume, and Tucholke and Mountain (1986); Column 13—Tucholke (1979); Column 14—Berggren and Olsson (1986); Column 16—Haq et al. (in press).

dent with supercycle boundaries and other regional unconformities of the Paleogene and early Neogene, and may explain the major preglacial sea-level changes.

5. Sediment dispersal on the outer continental shelf, the continental slope, and the continental rise has involved a varied and complex series of processes during the past 160 m.y. (Oxfordian to Holocene). Processes such as downslope mass gravity flows, shallow-flowing surface currents (and associated gyres), deep-flowing boundary currents (and associated shear zones), shifting water-mass boundaries, storms, fronts, tides and internal waves dominated different segments of the margin. Some of these processes may have often interacted to accelerate or dampen each other and their relative effectiveness was inconstant, varying temporally and spatially.

The continental slope, both now, and in its earlier manifestations, has been a zone of transition between sublittoral (0–200 m) shelf processes and abyssal (>2000 m) processes of the continental rise. The development of a shelf-edge reefal system during the Late Jurassic, its subsequent burial in the Early Cretaceous, the appearance of a dual shelf-break system (hinter shelf–fore shelf) during the middle Eocene to middle Miocene, rapid progradation of massive, organic-rich delta systems during

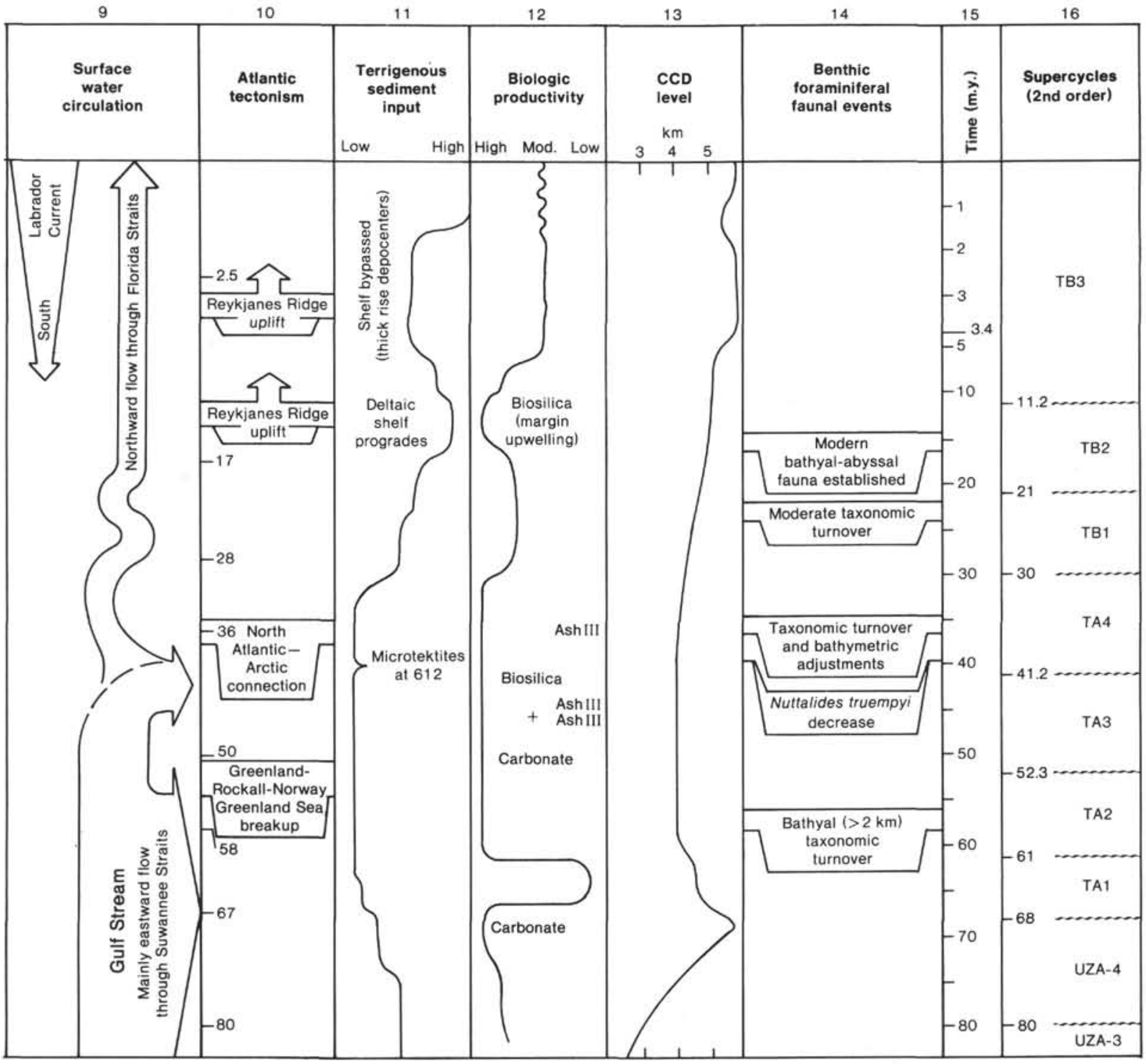

Figure 31 (continued).

the middle Miocene, and deep incision of shelf-edge submarine canyons during the Pleistocene complicated sediment dispersal routes and processes even more.

The Late Jurassic shelf edge was a carbonate regime, along which grew a series of pinnacle reefs (Fig. 20, back pocket; Poag, 1985a; Edson, 1986; Eliuk et al., 1986; Karlo, 1986; Meyer, 1986; Ringer and Patten, 1986). This reef system served as a partial barrier to the movement of siliciclastic detritus into the bathyal depths seaward of a precipitous reef front. The abyssal sediments of the Upper Jurassic Cat Gap Formation, sampled at DSDP Site 105, are chiefly light gray limestones, reddish brown clayey limestones, and reddish brown calcareous claystones, which reflect long-distance transport of only the fine fraction of terrigenous clastics. The presence at Site 105 of flow structures and graded beds containing rounded pebbles of carbonate ooze ("pelagic turbidites") has been interpreted as evidence of local transport (by gravity and weak currents) from nearby abyssal topographic highs (Lancelot et al., 1972). No evidence of silt- or sand-size terrigenous detritus has been documented in that Jurassic section. The deep-sea Jurassic data base is sparse, however, in the vicinity of the New Jersey Transect, consisting of only a single borehole (Site 105).

Carbonate deposition continued during the earliest Cretaceous (Berriasian–early Valanginian) on the outer shelf (Poag, 1985a; Ringer and Patten, 1986) and in the North American Basin (Lancelot et al., 1972; von Rad, 1984; Mountain and Tucholke, 1985; van Hinte, Wise, et al., in press) with presumably little shallow-water contribution to the abyssal sedimentary record. However, in the upper part of the Valanginian section at Site 603, the presence of large wood fragments and plant fragments in an interval of interbedded pelagic limestone and nannofossil claystone signals the onset of a significant dissemination of shelf-derived clastics into the deep-sea, as the shelf-edge reef system was buried. Thick terrigenous turbidites dominate the subsequent Early Cretaceous abyssal deposits, fed by thick siliciclastic wedges that advanced to the distant shelf break.

As the Cretaceous drew to a close (Campanian and Maestrichtian), the position of the shelf edge was still controlled in large part by the position of buried Jurassic reef structures. Erosional channels (canyons?) at the base of the Late Cretaceous continental slope provided numerous conduits for shelf- and slope-derived siliciclastics to reach the continental rise, but rising sea levels allowed principally clay-size particles to reach the North American Basin, forming the multicolored pelagic shales of the Plantagenet Formation. The supply of siliciclastic components to the lower rise dwindled in the Maestrichtian, and the dominant lithofacies there became chalk and limestone (Mountain and Tucholke, 1985). However, chaotic seismic facies filling Maestrichtian channels suggest that the upper rise continued to receive considerable amounts of terrigenous gravity-flow deposits.

A major shift in depositional regime took place in the Paleocene, as carbonate accumulation dominated on the shelf as well as at deep-water sites above the CCD. The systems of downslope-trending channels continued into the Eocene to play a major role in distributing these carbonate sediments on the upper rise. For example, an increase in the number of slumps and microfaults is a notable characteristic of the Eocene section at Site 613.

During the middle Eocene, another major shift in depositional regime occurred as a second shelf break (hinter shelf) developed (Figs. 25, back pocket; 31, column 4) 120 km landward of the buried Late Jurassic reef system, which still controlled the position of the seaward shelf edge (fore shelf). Thus middle Eocene deposition was greatest on the hinter shelf and continental slope; the fore shelf was a bypass area of relatively thin accumulation. Gravity-flow mechanisms continued to be important in dispersing sediments on the upper continental rise.

The hinter-shelf edge prograded progressively seaward following the middle Eocene (Figs. 25, back pocket; 31, column 4), and the progradation culminated in the middle Miocene with the development of a complex system of shelf-edge deltas. Terrigenous detritus was pumped across the fore shelf in huge volumes, until by the end of the middle Miocene the major shelf depocenter was near the fore-shelf break, giving the continental slope a modern aspect with its relatively steep declivity. Having this major detrital source at the shelf edge significantly increased the volume of sediment reaching the continental rise. These sediments were distributed by gravity-flow mechanisms through upper-rise channels onto the lower rise.

Similar sedimentary processes dominated the late Miocene through Pliocene, but depocenters on the continental rise received the largest volumes of sediment, fed from shelf depocenters that continued to perch at the shelf break. On the middle and lower rise, contour-following bottom currents shaped fine-grained hemipelagic sediments into elongate, mounded, drift deposits. Continental rise depocenters dominated margin accumulation in the Quaternary as well, but conduits across the continental slope became more localized as large submarine canyons incised its surface and created some channel systems that reached the lower rise, building large submarine fans (e.g., Hudson Fan; Tucholke and Laine, 1982).

Superimposed on these depositional processes and providing large volumes of sediment to the slope (and rise) throughout its history were periodic intervals of erosion. These erosion-dominant intervals are attributable to cyclical eustatic lowering of sea levels (Fig. 31, column 2). Subaerial erosion was widespread on the continental shelf, and submarine erosion dominated deeper-water locations. Of special significance is the fact that many of the resultant unconformities can be traced from coastal plain outcrops to the continental rise over distances of 700 km. It is easy to envision such erosive processes at work on a shallow continental shelf; but it is more difficult to understand how erosion on the continental slope and rise, which are covered by thousands of meters of water, could be induced by a sea-level fall.

Several possible mechanisms have been suggested. Sarnthein et al. (1982) suggested that internal waves and turbulence, caused by density differences at water-mass boundaries, could cause significant erosion where a boundary intersects the seafloor. Where such a boundary intersects the continental slope, it would be depressed or elevated in unison with sea-level change or other major changes in circulation, creating a broad erosional swath. Poag et al. (1985) suggested that evidence of such a process could be found in the sedimentary and microfossil record of the Goban Spur. Stanley et al. (1983) discussed similar relationships for water-mass boundaries on the New Jersey margin. They showed that the mudline on the modern New Jersey margin can range from 200 to 1000 m, depending on several variables. Beneath the shelf water mass (shoreline to the shelf break—0–200 m) erosion takes place continually from the interplay of storms, fronts, tides, and internal waves. The upper few hundred to 1000 m below the intersection of the shelf and slope water masses is a transitional zone in which sediments are periodically resuspended by surface waves, tidal currents, wind-stress currents, internal waves, and shear forces between major water masses and oceanic fronts. This alternation of deposition and resuspension triggers sediment flow down the middle and lower slope. A falling sea level would depress this transitional zone of erosion even farther down the slope. The benthic microfossil record along the New Jersey Transect shows that one or more hydrographic boundaries have separated Site 612 (mid-slope) from Sites 613, 604, and 605 (upper rise) during much of the Late Cretaceous and Cenozoic.

Deep flowing boundary currents such as the Gulf Stream and the Western Boundary Undercurrent also are effective agents for eroding the continental slope and rise (e.g., Tucholke and Mountain, 1979; Vail et al., 1980; Tucholke, 1981; Pinet and Popenoe, 1982; Ledbetter and Balsam, 1985; Mountain and Tucholke, 1985; Popenoe, 1985). Geographic and bathymetric shifts of such currents, coincident with sea-level changes, have been demonstrated (e.g., Tucholke and Laine, 1982; Ledbetter and Balsam, 1985; Popenoe, 1985). For example, the high-velocity core of the Western Boundary Undercurrent off New Jersey, accelerated, moved shoreward by 150 km, and shoaled by 1000 m (relative to its modern velocity and position) during the last glacial maximum (Ledbetter and Balsam, 1985).

Seismicity is another mechanism that may have accelerated erosion on the slope and rise in unison with sea-level falls. The growth faults of the Gemini fault system have been active along the outer shelf and upper-to-middle continental slope of New Jersey from at least the Late Jurassic until well into the middle Miocene (Figs. 10–17; 20, back pocket). Shelf-edge and upper-slope depocenters have been associated with this fault system since the Campanian, and broad erosional swaths have paralleled it at varying positions since the Paleocene (Figs. 12–17). Presumably, sea level falls, which reduce the hydrostatic pressure, could thereby create excessive sedimentary pore pressures and trigger periodic movements along these faults, displacing large volumes of sediment from the shelf edge and slope to cut erosional swaths across the continental rise (Booth, 1979).

The presence of a broad, elongate outcrop of middle Eocene chalk along the base of the New Jersey Continental Slope has raised the question of whether downslope or longslope erosional processes have dominated its excavation. It has been suggested that a repetitious two-step combination of these processes has taken place: (1) the lower slope was undercut by longslope boundary currents (perhaps aided by submarine ground-water discharge [Robb, 1984]); and (2) pervasive downslope mass wasting took place as the margin sought a new equilibrium profile (Farre, 1985; Mountain and Tucholke, 1985). Data from the New Jersey Transect give evidence of both processes. First, chunks of middle Eocene chalk were incorporated into debris-flow deposits of the upper rise during the late Miocene and Quaternary (sampled at Sites 604, 605, 613). Thus it is certain that downslope erosion has helped excavate the middle Eocene surface at least since the late Miocene. Second, extensive systems of downslope-trending erosional channels are present within each of the 12 Late Cretaceous and Cenozoic depositional sequences mapped on the upper rise. Thus downslope erosion was significant in this region for at least the last 84 m.y. Furthermore, the presence of a marked shelf-edge declivity, coupled with the sedimentary record at Site 603 and the regional depositional patterns mapped by Tucholke and Mountain (1979), Ewing and Rabinowitz (1984), Mountain and Tucholke (1985), and Schlee and Hinz (in press), attests to almost continuous passage of erosive turbidity currents and debris flows across the continental slope since the late Valanginian (135 Ma). Third, during the late Miocene and Quaternary, downslope deposition has covered parts of the Eocene outcrop belt, attesting to the preeminence of gravity-flow processes. Fourth, the Quaternary section has been truncated on both the updip and downdip edges of the Eocene outcrop belt, forming a longslope channel, several kilometers wide, which is interpreted to result from late Quaternary longslope bottom currents. These data suggest that downslope sediment dispersal has been the principal agent of both deposition and erosion along the continental slope and *upper* rise of New Jersey since the Valanginian overtopping of the Late Jurassic–Early Cretaceous shelf-edge reefs.

There is little doubt that longslope boundary currents and other vigorous bottom currents have modified downslope depositional patterns on the *middle* to *lower* rise since the early Miocene, when elongate, mounded, drift deposits began to build up (Tucholke and Mountain, 1979, 1986; Tucholke and Laine, 1982; Miller and Tucholke, 1983; Emery and Uchupi, 1984; Mountain and Tucholke, 1985). Off New Jersey, however, in the bathyal transitional zone from continental slope to continental rise (200–2000 m), mass gravity flows appear to have dominated both deposition and erosion.

Comprehensive summaries of the Mesozoic and Cenozoic paleoceanographic history of the North American Basin have recently been compiled by Emery and Uchupi (1984), Mountain and Tucholke (1985), Berggren and Olsson (1986), and Tucholke and Mountain (1986). However the paleoceanographic scenarios proposed to date are based on a complex framework of rather speculative seismostratigraphic interpretations, for which there are few supporting geological data. The New Jersey Transect data help to constrain some of the interpretations. The main features of the Late Cretaceous to Holocene paleoceanographic history, as presently inferred, are shown in Figure 31.

6. During the Late Cretaceous and Paleocene, there appear to have been no suitable sources of cold bottom water in high latitudes like those of the later Cenozoic. Instead, bottom waters may have been formed in low-latitude marginal seas where high evaporation rates produced dense, saline, warm waters (Berger, 1979; Kitchell and Clark, 1982; Berggren and Olsson, 1986). The first Cenozoic evidence of a change to thermohaline bottom-water circulation is thought to have been a pulse of abyssal erosion and significant faunal turnover among bathyal benthic foraminifers near the Paleocene–Eocene transition (Fig. 31, column 14). This change is ascribed to the initial formation of cold surface waters (and their subsequent sinking) during the tectonic breakup of the Greenland, Rockall, Norwegian-Greenland Sea region. During this interval, widespread erosion took place on the New Jersey margin, removing all Paleocene strata from a broad area of the middle and outer shelf.

Surface current systems of the western North Atlantic were somewhat different during this Early Cretaceous–Paleocene interval than at later times during the Cenozoic. The proto-Gulf Stream, instead of flowing northward from the Straits of Florida, entered the Atlantic from the west, crossing northern Florida and southern Georgia through the Suwannee Straits (Figs. 1; 31, column 9).

The Campanian–Maestrichtian, Maestrichtian–Danian, and early Paleocene erosional episodes seen on the New Jersey margin have not been noted at abyssal drill sites where the sparse carbonate record retards precise biozonation, nor is there a coincident tectonic episode of note for the older event. However a change in plate motion in the mid-Paleocene, which may have affected sea levels, is correlative with the younger of these two events (Fig. 31, column 10).

Olsson and Wise (1985) have attributed the widespread absence of Paleocene strata to vigorous currents flowing across the Paleocene shelf. Since the late Miocene, the cold Labrador Current has flowed southward across the New Jersey Shelf (Figs. 1, 31 [column 9]), but the history of possible southward flowing predecessors to the Labrador Current is not known at present. There is reason to suspect, however, that such currents may have developed in the early Eocene, initiated by the same paleogeographic rearrangements in the Greenland-Rockall region that produced cold bottom waters. The early Eocene is the period when biosilica production accelerated in the North American Basin, which may have been associated, in part, with increased coastal upwelling (Emery and Uchupi, 1984; Tucholke and Mountain, 1986). Upwelling fronts presumably were much more prominent along the fore-shelf edge off New Jersey during the high sea-level stands of the early and middle Eocene and the middle Miocene than they are today (Pietrafesa, 1983).

The next major change in Cenozoic bottom-water circulation of the North American Basin is postulated to have taken place near the Eocene–Oligocene transition, when erosion became widespread at abyssal depths and mounded drifts of abyssal hemipelagic sediments started to form (Fig. 31, column 7). Thermohaline circulation dominated the North Atlantic at this time, North Atlantic Deep Water intensified, precursors to the Western Boundary Undercurrent began a southwestward trending circulation pattern, and the CCD was depressed compared to middle Eocene levels (Fig. 31, column 13). These phenomena were accompanied by a faunal turnover and adjustment of bathymetric ranges among benthic foraminifers (Fig. 31, column 14). Agglutinated foraminiferal assemblages of the North Sea (bathyal) and Labrador Sea (abyssal) were replaced by calcareous assemblages. These events are attributed to a pulse of seafloor spreading (a change in plate motion) that opened a connection between the North Atlantic and the Arctic, via the Norwegian-Greenland Sea (Fig. 31, column 10).

On the New Jersey margin also, widespread erosion was characteristic of the Eocene–Oligocene transition (Olsson et al., 1980; Uchupi et al., 1982; Miller et al., 1985), and, in common with the Paleocene–Eocene transition, the underlying section (in this case, the upper Eocene) is missing or too thin to identify over most of the shelf. The two intra-Eocene erosional intervals of the New Jersey margin appear to be unrelated to known changes in bottom-water circulation, but a change in plate motion is correlative with the lower–middle Eocene contact (Fig. 31, column 10).

Three additional pulses of increased abyssal erosion are cited by Tucholke and Mountain (1986): (1) at the early/late Miocene boundary; 2) at the middle/late Miocene boundary; and (3) during the late Pliocene (Fig. 31, column 8); no clear explanation is offered for these pulses, but they do not appear to be related to the episodes of tectonic reorganization of the ocean basins listed by Tucholke and Mountain. In fact, Tucholke and Mountain (1986) suggest a reverse relationship for the last two events, calling upon tectonic uplift of the Reykjanes Ridge to curtail the flow of cold northern waters and end the abyssal erosion. However, Klitgord and Schouten (in press) have noted a significant change in plate motions at the early/middle Miocene boundary and in the late Pliocene, which could affect sea levels at these times (Fig. 31, column 10).

It appears that most of the 12 regional unconformities and their associated depositional sequences of the New Jersey shelf, slope, and upper rise have counterparts (either dated by boreholes or observed on seismic profiles) in the abyssal sediments of the outer North American Basin (see also Vail et al., 1980). However, although the observed stratigraphic framework fits the supercycle framework of the Vail model quite well, there are major differences between the observed and predicted distributions of highstand versus lowstand deposits.

The Vail model predicts that during a highstand of sea level, "along the margins of ocean basins, highstand deposits commonly consist of sediments that have prograded across the shelf into deeper water. In the basins highstand deposits are typically hemipelagic and characteristically drape over the underlying topography. Lowstand deposits commonly occur as marine fans" (Vail et al., 1980, p. 114). However, highstand deposits of the New Jersey margin display quite different (and sometimes opposite characteristics). For example, during the middle Miocene highstand, the shelf deposits did, indeed, prograde across the shelf into deeper water. But the equivalent strata in the deep sea are thick turbidites and debris-flow deposits that formed large submarine fans.

During the middle Eocene, the depositional patterns were even more complex, as we have seen earlier. The hinter shelf was characterized by a prograded series of deposits, but the broad fore shelf was a starved bypass region. Deposition increased significantly seaward of the fore-shelf edge, where almost pure biosiliceous, carbonate ooze accumulated.

7. The DSDP drilling on the New Jersey margin has provided new perspectives regarding correlation of key seismic horizons of the abyssal realm with possible equivalents on the upper rise and continental slope (Klitgord and Grow, 1980; Emery and Uchupi, 1984; Ewing and Rabinowitz, 1984; Mountain and Tucholke, 1985; Poag, 1985b).

The deep-sea seismic horizons in question fall into three categories: (1) depositional features (A*); (2) diagenetic features (A^c) and (3) erosional features (A^u, Merlin, Blue). Klitgord and Grow (1980), Mountain and Tucholke (1985), and Ewing and Rabinowitz (1984) used the traditional method of tracing a major reflector (or set of reflectors) from an abyssal type area (where it could be dated, with variable accuracy) to adjacent continental slopes as much as 400 km away.

I (Poag, 1985b) have worked in the opposite direction, identifying seismic sequences (Vail et al., 1977) on the continental slope and upper rise, (where several have been drilled), and tracing them (as seismic sequences) to the lower continental rise. These two different methodologies have yielded, in some cases, disparate correlations and different inferred depositional histories. Further drilling into some of the undated sequences will no doubt resolve some of the minor differences, but others appear to be more substantial, caused by: (1) the subjective nature of seismostratigraphy (i.e., there are many opportunities to choose between reflections that may be closely spaced on the lower rise, but which either diverge widely or coalesce toward the margin); (2) the variable signature of some reflections; (3) gaps between segments of seismic profiles; (4) the fundamental difference between tracing seismic "horizons" and tracing sequences; and (5) the limited resolution of multichannel seismic reflection techniques.

The minor differences apply, for example, to correlating Horizon A*. In the deep-sea type area, this horizon is derived from a calcareous bed in the upper Maestrichtian section at Sites 386 and 387 on the Bermuda Rise. Its extrapolated position on the outer end of Profile 25 (s.p. [shot point] 6600), as correlated by Mountain and Tucholke (1985), places it at the base of the Maestrichtian, as interpreted by me (Fig. 20, back pocket). At s.p. 4600, Mountain and Tucholke's (1985) A* marks the base of the Campanian (according to Poag's stratigraphy; Fig. 20, back pocket). At s.p. 3500 (on strike with Site 613), A* rises back up to the upper Maestrichtian. These positions are vertically very close together (0.2–0.4 s) along the outer end of Profile 25 and seaward of it, and a slight adjustment could easily eliminate the correlation differences. On the other hand, the signature of a depositional feature such as this can change significantly away from its type section as its lithofacies change, and Tucholke and Mountain (1986) admit that A* is difficult to trace on the North American margin.

The most contentious deep-sea horizon is A^u, defined on the lower rise, at Site 603, as an unconformity (hiatus of ca. 35 m.y.) between poorly dated middle to early Miocene and early Eocene sections. (Both sections contain sparse calcareous fossils due to deposition beneath the CCD). A similar situation is present at Site 105, where A^u lies between a probable late Oligocene section (above) and a section containing ichthyoliths of undifferentiated Tertiary age (below). Hiatuses of such long duration suggest that A^u may be the product (in this area) of several episodes of erosion; perpetuation of the concept of a single erosional episode may be detrimental to understanding this phenomenon. Strata stratigraphically lower than the middle Miocene (but undated) lie above the A^u unconformity at DSDP Site 104 on the Blake Outer Ridge (400 km away from the type area). Tucholke and Mountain (1986) estimated that the oldest strata above Horizon A^u at Site 104 are early late Oligocene. This estimate is based on extrapolating the high middle Miocene accumulation rates of the borehole (190 m/m.y.) downward (through 2 km of sediment) to the A^u unconformity. However, it is clear from foregoing discussion of the Miocene depositional record (see also Poag, 1985a) that middle Miocene accumulation rates are higher by an order of magnitude than any other Tertiary depositional rates, and are inappropriate for extrapolating rates in any other part of the stratigraphic column. Using a lower accumulation rate for the pre-middle Miocene section would make A^u older than early late Oligocene. Thus the oldest sediments above A^u at Site 104 are pre-late Oligocene, but how much older they are cannot be determined with confidence.

Even more perplexing than these relationships are the disparate correlations of A^u along Profile 25 (Fig. 20, back pocket). Beginning at s.p. 6600, the position at which Mountain and Tucholke (1985) place Horizon A^u is the unconformable contact between Poag's Paleocene and lower Eocene sequences. Moving updip along Profile 25, however, the position of Mountain and Tucholke's A^u shifts down to the Maestrichtian–Paleocene contact (Fig. 20, back pocket; s.p. 4600 to 3900), then up again to the Paleocene–lower Eocene contact (s.p. 3700), then up to the lower Eocene–middle Eocene contact (s.p. 3600), and finally to the erosional surface at the top of the middle Eocene section (s.p. 3300). My tracing of the lower Eocene sequence (Sequence 9) from this position to Site 603 (along Profile *Conrad* 21) shows that it is continuous from the shelf to the lower rise, and its upper surface coincides with A^u; but this surface also coincides with Horizon A^c (see below).

Horizon A^c, in its type area (western flank of the Bermuda Rise, Site 387), is an irregularly silicified, cherty, or porcellanitic zone approximately at the lower Eocene–middle Eocene contact. Drilling at Sites 612, 605, and 613 found nearly identical relationships, showing that Horizon A^c can be easily recognized on the New Jersey margin. In fact, intense silicification in the upper part of the lower Eocene section can be recognized as far updip as the COST B-3 well, located on the outer part of the lower Eocene shelf (Figs. 9, 20, back pocket; Poag, 1985a).

Horizon Merlin was defined on the North American continental rise by Mountain and Tucholke (1985) as a reflector of varying characteristics. In seaward areas it marks the top of hummocky seismic facies, but closer to the continental margin it is an unconformity separating middle Miocene from upper Miocene strata. These relationships can be traced along the New Jersey Transect from Sites 604, 605, and 613 (where Horizon Merlin forms the contact between the upper Miocene Sequence 3 and undrilled Sequence 4; Fig. 20, back pocket) to Site 603 (where Merlin separates upper Miocene Sequence 3 from middle Miocene Sequence 6; Fig. 25, back pocket; [sequences 4 and 5 do not extend this far downdip]).

Seismic Horizon Blue is recognized by Mountain and Tucholke (1985) as chiefly an unconformable surface along the U.S. Atlantic margin at approximately the lower Pliocene–upper Pliocene contact. The erosion is attributed to strong bottom currents developed in conjunction with the beginning of North American glaciation. On Profile 25, however, Horizon Blue, as identified by Mountain and Tucholke (1985), is the unconformable contact between the Pliocene and Pleistocene (Quaternary) sequences. The dichotomous origin of the two erosional surfaces (downslope mass sediment movement on the upper rise versus accelerated bottom currents on the middle and lower rise) suggest that Horizon Blue does not have an exact equivalent on Profile 25.

It appears then, that of the five seismic horizons discussed, A^c and Merlin can be successfully traced from their deep-sea type areas into the upper-rise region of the New Jersey Transect (Fig. 32). The unusual lithic

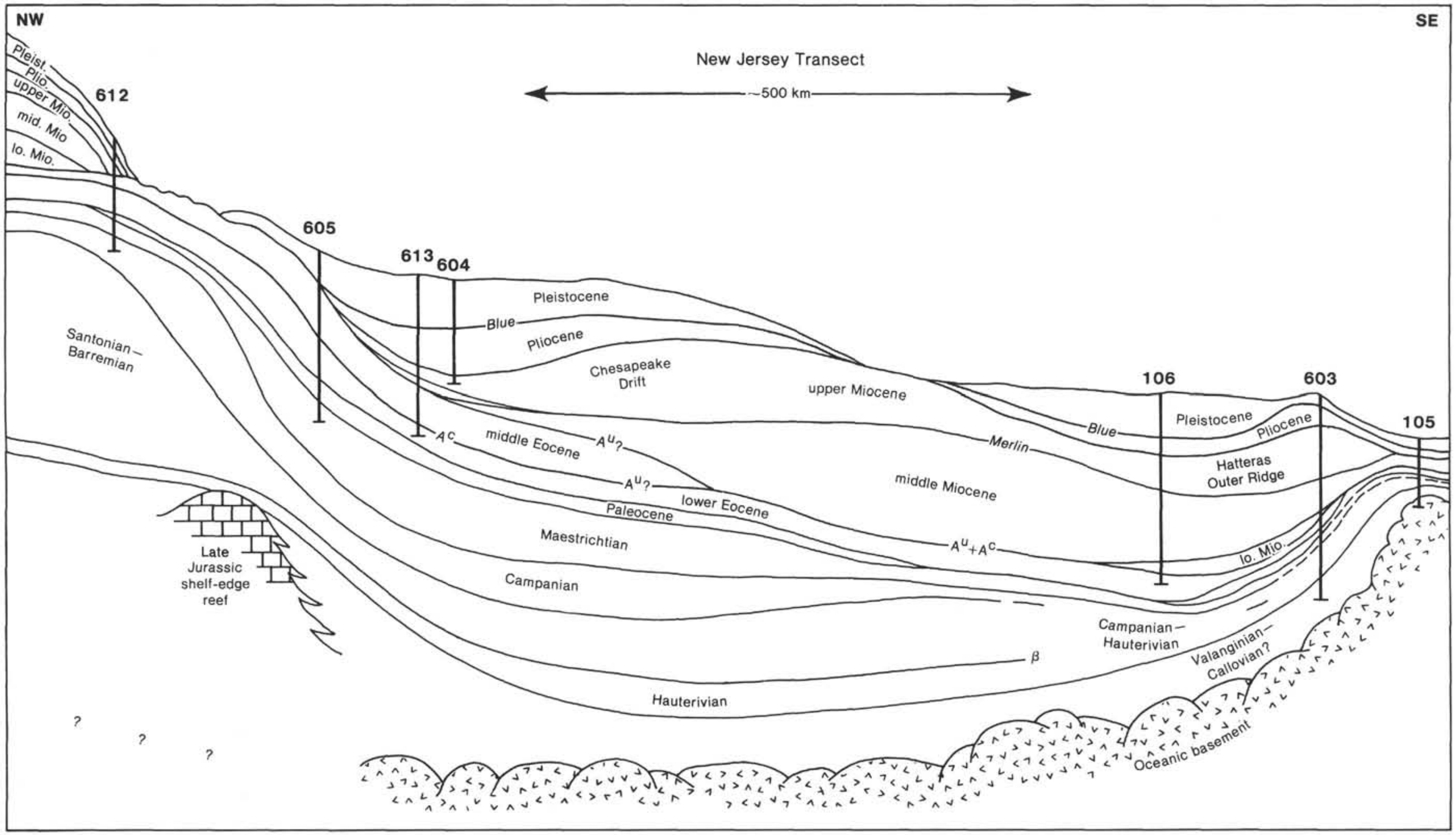

Figure 32. Exaggerated schematic section of the slope and rise segments of the New Jersey Transect (not to scale), showing general relationships of depositional sequences and regional seismic horizons.

characteristics of Horizon A^c (postdepositional transformation of siliceous microfossil skeletons to siliceous cements), seem to have formed almost simultaneously over the entire North American Basin and even within the outer parts of the Baltimore Canyon Trough and in the Gulf of Maine (Schlee and Cheetham, 1967), affecting sediments near the lower Eocene–middle Eocene contact. On the other hand, Horizon A*, which represents a primary lithic change in the type area, is difficult to trace through lateral lithofacies changes. The unconformable Horizon A^u and Horizon Blue were formed by vigorous bottom currents in their type areas, whereas the sequence boundaries of the upper rise are largely the result of downslope sediment movement. There is no a priori reason to expect that seismic horizons of such disparate origin should be exactly correlative (see Tucholke, 1981).

FINAL THOUGHTS

The coring at Site 613 on the New Jersey Transect completed 15 years of DSDP drilling into the sedimentary prism that forms the eastern margin of North America. The scientific expectations of the early shipboard investigators and of the larger earth-science community that planned, funded, guided, and carried out the Deep Sea Drilling Project have been realized severalfold. In conjunction with drilling and seismic exploration of the adjacent continental shelf, and renewed investigations of coastal plain geology, the major (and many of the minor) elements of the depositional–erosional system that built this imposing sedimentary edifice have come to light.

We have documented the pervasive role of sea-level change and regional erosional events in punctuating the seaward progression of terrigenous detritus that filled the Baltimore Canyon Trough and spilled over into the North American Basin, creating a complex framework of depositional sequences. The rain of siliciclastic debris was briefly halted during the Late Jurassic and Paleogene by widespread deposition of carbonate sediments, but following each interruption a renewed pulse of rapidly accumulating detritus filled major depocenters on the continental shelf and rise.

The biosiliceous carbonates of the late Paleocene and early and middle Eocene signal an unusual basin wide (or ocean-wide) productivity bloom that provided siliceous constituents for subsequent chert and porcellanite diagenesis that is responsible for the interregional seismic Horizon A^c.

Of course, we have not solved all the problems posed by this complex history. For example, some abyssal unconformities have different origins from those of the slope and upper rise, and precise intercorrelation of certain key seismic horizons (unconformities) between the two regions is difficult. We still do not know whether Oligocene and lower Miocene sections are present on the upper and middle continental rise. Nor have we documented places where the interregional unconformities become conformable. To solve such problems it will require a number of additional core sites in order to construct a composite stratigraphy from the incomplete record left by multiple erosional episodes. Most of all it will require much deeper penetration of the thick mid-rise depocenters to sample lithofacies and sequence boundaries within the wide geographic gap between the core sites of the upper rise and those of the lower rise.

To those predecessors whose foresight and determination provided the early deep-sea data from the New Jersey margin, the scientific party of Leg 95 gives much-deserved thanks. To those who have followed in the ODP research program and those yet to enter the arena, we give the encouragement of our enthusiasm and the results of our best efforts at providing a comprehensive historical framework in which to formulate future research.

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Date of Initial Receipt: 5 September 1986
Date of Acceptance: 5 September 1986