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23. GLOBAL SIGNIFICANCE OF AN ISOTOPIC RECORD FROM THE NEW JERSEY COASTAL PLAIN: LINKAGE BETWEEN THE SHELF AND DEEP SEA IN THE LATE PALEOCENE TO EARLY EOCENE[1]

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ABSTRACT

Stratigraphic correlation between shallow-water and deep-sea sections has proven notoriously difficult because of hiatuses, diachrony of marker species, and diagenesis on the shelf. Isotope stratigraphy, biostratigraphy, and magnetostratigraphy reveal that sedimentation on the New Jersey Margin (Island Beach borehole) was relatively continuous during the late Paleocene and early Eocene (~58–52.5 Ma). All planktonic foraminiferal and calcareous nannofossil zones are represented at Island Beach. However, two disconformities are recognized in the upper Paleocene to lower Eocene section: a physical surface (lithologic change) at the Vincentown/Manasquan contact (uppermost Paleocene), which has a hiatus of ~0.3 m.y., and a ~0.4-m.y. gap associated with a paraconformity in the lower Eocene section.

Stable isotopic data from the New Jersey Margin indicate that this neritic section can be successfully correlated to the deep sea using $\delta^{13}C$ and $\delta^{18}O$ of benthic foraminiferal calcite. Comparison between the Island Beach and global isotopic records (as represented by deep Pacific Site 577) shows that Island Beach parallels the global trend in both $\delta^{18}O$ and $\delta^{13}C$. All major features of the late Paleocene to early Eocene global isotopic record are preserved, including general $\delta^{18}O$ decrease, step-like $\delta^{13}C$ decrease, and the well-known latest Paleocene $\delta^{13}C$ excursion. We recognize three 1- to 1.5-m.y. $\delta^{13}C$ steps over our interval of study at both Island Beach and the deep Pacific (~56.6–55.8 Ma; ~55.5–54 Ma; ~53.6–52.6 Ma). These steps are correlative with intervals of increased paleodepth, as indicated by benthic foraminiferal biofacies studies, and decreased $\delta^{18}O$ values. We suggest a link between increased temperature and sea level, and reduced organic carbon burial in the deep sea.

Previous workers identified a latest Paleocene benthic foraminiferal faunal change on the New Jersey Margin (Clayton borehole). They suggested that this faunal turnover was the neritic correlative of the well-known latest Paleocene benthic extinction event. Our data indicate that at Island Beach, uppermost Paleocene $\delta^{13}C$ and $\delta^{18}O$ excursions occur above the disconformity and the associated shallow-water benthic foraminiferal faunal change. This isotopic excursion may be synchronous with the deep-sea extinction event or with a younger $\delta^{13}C$ decrease. We suggest that the benthic foraminiferal event on the New Jersey Margin was the result of a dramatic water-depth increase on the shelf and was unrelated to the deep-sea extinction.

INTRODUCTION

Shallow-water (<200 m depth) sedimentary sequences provide information regarding sea-level changes, as well as information about local hydrography and the neritic environment. Although changes in global sea level can dramatically affect ocean chemistry and circulation, it is often difficult to identify direct causal links between sea level and open-ocean changes. Direct responses to sea-level change are recorded on continental margins, whereas the deep-sea only records indirect responses (e.g., Tucholke, 1982). However, correlation between shallow and deep-sea environments is notoriously difficult. Biostratigraphy is often complicated by diachronous changes resulting from facies control in shallow environments, and isotope stratigraphy has rarely been applied to shallow-water sections, primarily because of the discontinuous nature of shelf sections and complication by local isotopic effects. Because few successful attempts have been made to correlate between shelf and deep-sea sequences, causal relationships between global sea level and climate change remain uncertain for the Paleocene and Eocene.

In this contribution, we show that selected shelf sections can be correlated to the deep sea using standard stratigraphic techniques. We have obtained a late Paleocene to early Eocene benthic foraminiferal stable isotopic ($\delta^{13}C$ and $\delta^{18}O$) record from Island Beach, NJ. We show that this record can be used to place late Paleocene and early Eocene (~58–52.5 Ma on the Berggren et al., 1995, time scale) climatic events on the New Jersey Margin within a global framework. In particular, we describe distinctive latest Paleocene isotopic events that have previously been identified only in deep-sea sections. Finally, we show that sea-level events identified on the New Jersey Margin can provide clues to the mechanisms of climate and ocean-chemistry changes during this critical interval of time.

Late Paleocene to Early Eocene (58–52 Ma) Climate

Over the past decade, much interest has been focused on Paleogene climate change. This is in part because the Eocene has been extensively cited as an example of a climate system operating under conditions of extreme warmth, and therefore as a possible analog of a "greenhouse" world. There is abundant floral, faunal, and isotopic evidence for Paleocene and Eocene warm climates. Paleontological evidence (e.g., Wolfe, 1978; Estes and Hutchinson, 1980) indicates that high-latitude terrestrial environments experienced subtropical temperatures during the Eocene. In addition, oxygen isotopes of foraminiferal calcite indicate that the deep oceans and high-latitude surface oceans warmed throughout the Paleocene, reaching maximum Cenozoic temperatures of 15°–20°C by the early Eocene (54 Ma on the Berggren et al. (1995) time scale; Miller et al., 1987a; Kennett and Stott, 1990; Zachos et al., 1994). Deep-ocean cooling began abruptly near the early/middle Eocene boundary and continued in a series of steps until the earliest Oligocene (Savin et al., 1975; Shackleton and Kennett, 1975; Miller et al., 1987a).

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In addition to warm climates, the Paleocene and early Eocene were characterized by relatively high sea levels (Haq et al., 1987). The scarcity of early Eocene hiatuses and an elevated calcite compensation depth (van Andel et al., 1975) are consistent with sluggish ocean circulation (Moore et al., 1978). Dust records indicate that atmospheric circulation was sluggish as well (Janecek and Rea, 1983; Miller et al., 1987b). Low global carbon isotopic values have been interpreted as reflecting low early Eocene productivity (Shackleton and Hall, 1984; Corfield and Shackleton, 1988). Evidence of decreased productivity during the late Paleocene and early Eocene is also indicated by oligotropic patterns of planktonic foraminiferal abundance and diversity (Hallock et al., 1991). All of these observations combine to form a picture of Paleocene and Eocene climate as a time of stability and gradual change.

However, recent high-resolution isotopic studies have shown that the Paleogene isotopic record of gradual (million year) change was punctuated by a number of abrupt isotopic events reflecting rapid (thousand year) change. The most prominent of these events occurred in the latest Paleocene (~55.5 Ma). The Carbon Isotope Excursion (CIE) was first identified at Southern Ocean Site 690 (Kennett and Stott, 1990, 1991), where it was characterized by an abrupt decrease in surface- and deep-water carbon isotopes of 5.0‰ and 3.0‰, respectively. At the same time, benthic and planktonic $\delta^{18}O$ values decreased, indicating a warming of deep waters by 4°C and of surface waters by 5°–6°C. Within ~10,000 yr, $\delta^{18}O$ and $\delta^{13}C$ values recovered, although not quite to pre-CIE values (Kennett and Stott, 1991).

The isotopic events of the CIE (Kennett and Stott, 1990) correlate precisely with a well-known latest Paleocene benthic foraminiferal extinction event first identified by Beckmann (1960) in Paleocene–Eocene sediments from Trinidad, and subsequently described in detail by numerous workers (e.g., von Hillebrandt, 1962; Schnitker, 1979; Tjalsma and Lohman; 1983). The synchrony of the events not only suggests that they were linked, but also provides a distinctive and precise stratigraphic datum level. The CIE has been readily identified in bathyal and abyssal sections from the Pacific (Pak and Miller, 1992; Bralower et al., 1995), Atlantic (Pak and Miller, 1992; Thomas and Shackleton, 1996) and Indian Oceans (Lu and Keller, 1993), where it was also precisely synchronous with the benthic foraminiferal extinction. The CIE has also been reported from shallow-water sections in the Tethyan region (Charisi and Schmitz, 1995; Schmitz et al., 1996). On the North American Margin, Gibson et al. (1993), reported a latest Paleocene benthic foraminiferal turnover (on the New Jersey Coastal Plain, Clayton borehole), as well as clay mineralogic evidence for climatic warming and lithofacies changes indicative of sea-level rise. Biostratigraphic control suggests that this event took place within Biochron NP9, and thus was concurrent with the deep-sea benthic foraminiferal turnover. Isotopic data are not available for the Clayton borehole; however, the New Jersey Coastal Plain evidence suggests that there were intriguing connections between late Paleocene to early Eocene shelfal/onshore and deep-sea events. In this contribution, we explore these connections by comparison of a new benthic foraminiferal isotopic ($\delta^{13}C$ and $\delta^{18}O$) record from Island Beach (New Jersey) with a published record from the Pacific (Site 577; Pak and Miller, 1992).

METHODS

The Island Beach borehole was drilled near Island Beach, NJ (Fig. 1) in March–May 1993 as part of the New Jersey Coastal Plain Drilling Project (Leg 150X of the Ocean Drilling Program [ODP]; Miller et al., 1994). This project was designed as the onshore component of the New Jersey Sea-level Transect, which drilled offshore sites on the slope and rise (ODP Leg 150), as well as additional onshore boreholes (Atlantic City, Cape May). The upper Paleocene and lower Eocene section at Island Beach comprises a thick (226 ft [68.9 m]), continuously cored sequence of sands, silts, and clays. This fossiliferous sequence provides a good record of shallow-water (middle–outer neritic, 30–200 m; Liu et al., Chapter 19, this volume; Browning et al., Chapter 16, this volume) Paleocene and Eocene deposition.

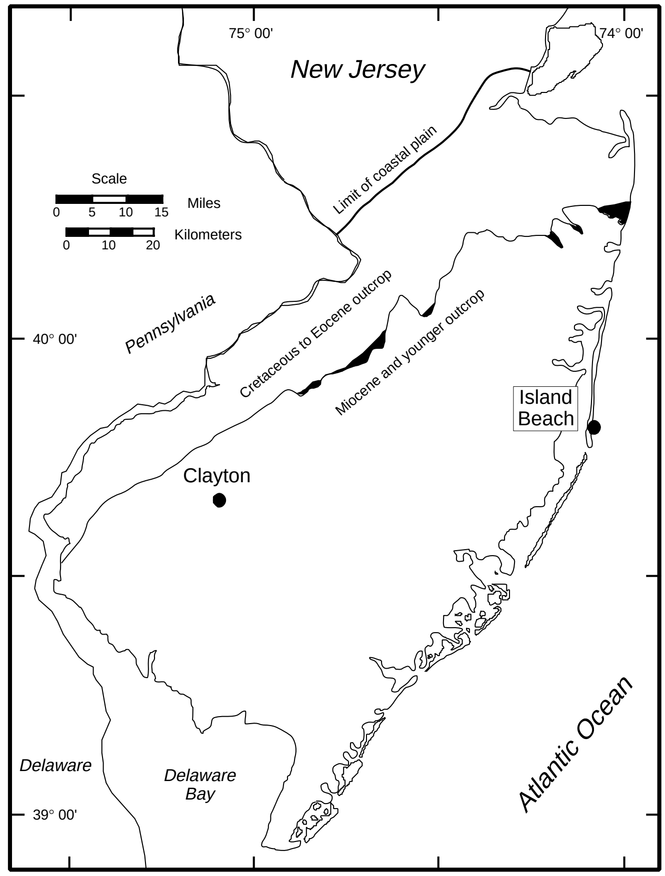

Figure 1. Location map of Island Beach.

Isotopic records are presented for the Paleocene and Eocene section of the Island Beach borehole. Every 1–2 ft (0.3–0.6 m), 20-cm^3 samples were taken from the upper Paleocene and lower Eocene sections (upper Vincentown and Manasquan Formations, 980–1160 ft [299–354 m]), corresponding to a sampling interval of ~20–50 k.y. Samples were disaggregated in a solution of tap water and sodium hexametaphosphate, washed through a 63-µm sieve, and oven dried. Carbon and oxygen isotopic analyses were conducted on several different species of *Cibicides,* primarily *C. eocaena* and *C. cocoaensis,* which were picked from the >150-µm fraction. The foraminifers were ultrasonically cleaned for 2 s and roasted under vacuum at 375°C for 1 hr. All isotopic analyses (Table 1; Fig. 2) were conducted at Lamont-Doherty Earth Observatory using a Carousel-48 automatic carbonate preparation device attached to a Finnigan MAT 251 mass spectrometer. Analytical error (1 σ) was 0.06‰ and 0.04‰ for $\delta^{18}O$ and $\delta^{13}C$, based on 35 analyses of the carbonate Standard NBS20. Reproducibility was 0.17‰ and 0.30‰ for $\delta^{18}O$ and $\delta^{13}C$, based on 15 replicate analyses.

Because diagenesis is often a problem in onshore sections, we carefully selected specimens for isotopic analyses. Specimens with pyritic infillings were discarded, as were those that were obviously recrystallized. Visual examination with the light microscope indicated that preservation of foraminifers was generally good, with the exception of a dissolution zone between 1089 and 1107 feet (332 and 337.5 m), which was barren of calcareous foraminifers.

Paleoenvironmental (paleodepth) interpretations are based on lithology and sedimentary structures (Miller et al., 1994) and benthic foraminiferal biofacies analysis (Browning et al., Chapter 16, this volume; Liu et al., Chapter 19, this volume). Briefly, these methods pro-

Table 1. *Cibicides* spp. isotopic data from the Island Beach, NJ, borehole.

Depth (ft)	*Cibicides* spp. $\delta^{18}O$	*Cibicides* spp. $\delta^{13}C$
980.00	–1.88	–0.65
982.00	–2.98	–1.46
982.00	–2.65	–1.28
984.00	–1.97	–0.48
984.00	–2.20	–0.70
986.20	–1.76	–0.34
986.20	–1.51	–0.16
988.00	–1.91	–0.69
990.00	–2.06	–0.59
992.00	–1.34	–0.35
995.00	–1.69	–0.17
998.00	–1.47	–0.41
1001.00	–1.66	–0.41
1002.00	–1.61	–0.42
1005.00	–1.35	–0.16
1007.50	–1.99	–0.70
1008.00	–2.12	–1.07
1010.00	–1.43	–0.21
1012.20	–1.33	–0.54
1012.20	–1.40	–0.33
1015.00	–2.05	–0.90
1015.00	–2.00	–0.84
1017.00	–1.49	–0.45
1022.00	–1.48	–0.10
1024.00	–1.27	0.37
1024.00	–1.21	0.35
1026.00	–1.25	0.21
1026.00	–1.29	0.43
1028.00	–1.10	0.33
1030.00	–1.40	0.10
1033.00	–1.39	0.25
1033.00	–1.35	–0.36
1034.00	–1.30	–0.21
1038.00	–1.06	0.14
1041.10	–1.50	–0.26
1041.10	–1.33	–0.54
1042.00	–1.40	–0.54
1044.50	–1.24	–0.28
1056.70	–1.22	–0.16
1057.20	–1.56	–0.46
1058.00	–1.10	–0.32
1059.00	–1.20	–0.23
1061.00	–1.24	–0.14
1061.00	–1.34	0.03
1063.00	–0.89	0.35
1063.00	–1.09	0.01
1064.00	–1.58	–0.21
1066.00	–1.79	–0.86
1066.00	–1.22	–0.15
1067.00	–1.31	–0.34
1068.00	–1.22	–0.34
1071.00	–1.18	0.00
1072.10	–1.80	–0.46
1072.10	–1.81	–0.50
1073.80	–2.17	–1.05
1075.00	–1.66	–0.83
1075.00	–1.21	0.38
1076.00	–1.22	0.91
1078.00	–1.24	1.22
1081.00	–1.08	1.02
1087.50	–1.07	1.19
1108.00	–1.18	1.60
1117.50	–1.11	1.50
1119.50	–1.78	1.03
1121.50	–0.56	1.52
1123.60	–1.06	1.91
1125.50	–1.21	2.12
1127.50	–1.18	1.80
1129.25	–1.27	1.79
1131.00	–1.15	2.08
1138.10	–0.91	2.16
1140.20	–0.83	1.53
1142.00	–0.70	1.74
1148.30	–0.66	1.68
1148.30	–0.72	1.57
1150.00	–0.68	1.95
1152.15	–0.57	1.26
1152.15	–0.59	1.29
1153.00	–0.63	1.19
1155.10	–0.56	1.32
1157.00	–0.78	1.11
1158.00	–0.79	1.02
1159.80	–0.85	1.18
1161.80	–0.83	1.21

duce complementary results, indicating that the Vincentown Formation (upper Paleocene) was deposited at middle neritic water depths (50–100 m), whereas the Manasquan Formation (lower Eocene) was deposited in outer neritic (100–200 m) water depths. This is consistent with previous water-depth estimates from slightly updip boreholes on the New Jersey Margin (Olsson and Wise, 1987).

All of the samples were analyzed for organic carbon content. Samples were analyzed at Woods Hole Oceanographic Institution after combustion at 900°C on a Model 5011 Coulometer with a precision of 1%. Samples were first acidified with 5% phosphoric acid and filtered onto precombusted glass microfiber filters.

STRATIGRAPHY

Stratigraphic control is provided by integrated planktonic foraminiferal and calcareous nannofossil stratigraphy and magnetostratigraphy (Miller et al., 1994; Browning et al., Chapter 16, this volume). Numerical ages are provided by the Berggren et al. (1995) time scale. Datum levels used for the Island Beach age model are given in Table 2.

All of the late Paleocene and early Eocene planktonic foraminiferal and calcareous nannofossil zones (P6a–P9; NP9–NP14) are present at Island Beach, indicating relatively continuous deposition. However, integrated stratigraphy (Browning et al., Chapter 16, this volume) indicates that there are two significant hiatuses in the upper Paleocene to the lower part of the lower Eocene section. The younger hiatus is recognized by the lowest occurrence (LO) of *Morozovella formosa formosa* and *Tribrachiatus orthostylus* at 1019 ft (310.6 m). A physical surface and an increase in glauconite are recognized at this level; we estimate a hiatus of ~0.4 m.y. based on an age/depth plot (Fig. 3). The second hiatus occurs at the lithologic contact between the Vincentown and Manasquan Formations (1075.5 ft [327.9 m]). An erosional disconformity occurs at this level associated with a gamma-ray log peak (Miller et al., 1994). A single occurrence of the planktonic foraminifer *Morozovella acuta* (considered to be equivalent to the highest occurrence (HO) of *Morozovella velascoensis*; Berggren et al., 1995) is recognized within the basal Manasquan Formation (between 1074 and 1069 ft [327.4 and 326 m]). We suggest that a distinctive carbon and oxygen isotopic excursion in the basal Manasquan (at 1073.8 ft [327.4 m]) at Island Beach is correlative with the latest Paleocene CIE. Based on paleomagnetics, planktonic foraminiferal biostratigraphy, and isotopic correlation, we estimate the duration of the hiatus to be ~0.3 m.y. However, we note that correlation of the Island Beach isotopic excursion with the CIE is in direct contradiction with the calcareous nannofossil stratigraphy (M.-P. Aubry, pers. comm., 1995). At Southern Ocean and North Atlantic sites (Aubry et al., 1996), the CIE occurs prior to the LO of *T. bramlettei* (within nannofossil Zone NP9). At Island Beach, *T. bramlettei* first occurs in the basalmost sediments of the Manasquan Formation (Aubry, pers. comm., 1995), placing the isotopic excursion within Zone NP10. Aubry (pers. comm., 1995) suggests that the isotopic event at Island Beach is not correlative with the CIE, but is in fact a much younger event. In addition to *T. bramlettei*, a single specimen of *Pseudohastigerina* spp. occurs at 1074 ft (327.4 m). Although the range of this planktonic foraminiferal genus is diachronous, the LO of *Pseudohastigerina* spp. approximates the Paleocene/Eocene boundary in the tropics (Berggren et al., 1995). The presence of *Pseudohastigerina* and *T. bramlettei* suggests that the basal sediments of the Manasquan Formation are Eocene, whereas the presence of *M. acuta* and isotopic correlation suggest that they are Paleocene. Although we cannot resolve the discrepancy between the two stratigraphic interpretations, we point out that both interpretations are consistent with the magnetostratigraphy, which indicates that the Chronozone C25n/C24r boundary occurs between 1070 and 1090 ft (326.2 and 332.3 m; M. van Fossen, pers. comm., 1995). Furthermore, we

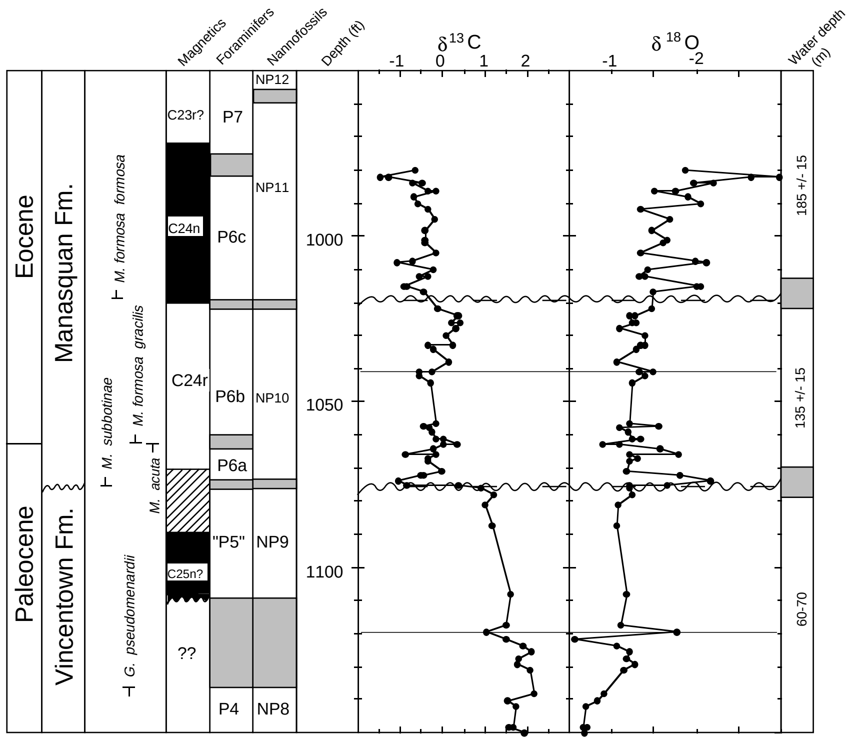

Figure 2. Stratigraphy and stable isotopes of the Island Beach, NJ, borehole. Stable isotopic analyses were performed on *Cibicides* spp. Water-depth estimates are based on benthic foraminiferal biofacies analysis and lithology. Wavy lines indicate unconformities in the Island Beach section. Dashed lines indicate boundaries between inferred δ^{13}C cycles.

Table 2. Age-model parameters, Island Beach borehole.

Level	Age (Ma)	Depth (ft)
Top of C24n	52.4	973.0
FO *Morozovella formosa*	54.0	1019.0
FO *Tribrachiatus orthostylus*	53.6	1019.0
CIE	55.5*	1073.8
Sediment missing, equivalent to base of C24r	55.8	1076.0
Top of C25n	55.9	1080.0
LO *G. pseudomenardii*	59.2	1161.7

Note: * = age of CIE from Aubry et al. (1996).

note that at the Clayton borehole the LO *T. bramlettei* is at 93.4 m, 4.25 m above the Vincentown/Manasquan Formation contact (Gibson et al., 1993). Similarly, the HO of *M. velascoensis* occurs at 96.4 m, 1.25 m above the contact (R. Olsson and J. Browning, pers. comm., 1995), indicating that sediments of the basal Manasquan at the Clayton borehole are Paleocene in age.

We also observe occurrences of the benthic foraminifer *Stensioina beccariiformis* in samples from both the Vincentown and Manasquan Formations at Island Beach. At deep-sea sites, the HO of this species is indicative of the latest Paleocene benthic extinction (e.g., Tjalsma and Lohmann, 1983) and correlative with the CIE (Kennett and Stott, 1990; Thomas, 1990; Pak and Miller, 1992). At Island Beach, *S. beccariiformis* is abundant below 1073.8 ft (327.4 m), but occurs sporadically to 1055 ft (321.6 m; Browning et al., Chapter 16, this volume) in samples that are otherwise clearly Eocene according to both the planktonic foraminifer and nannofossil stratigraphies. We consider the presence of *S. beccariiformis* in Eocene sediments to be anomalous and suggest that this taxon may have a diachronous range in shallow water or that specimens may have been reworked from older material. Bioturbation and reworking can be significant in shallow-water sediments; both burrows and macrofossils are common in the lower 34 ft (10.4 m) of the Vincentown Formation (Owens et al., Chapter 2, this volume). However, macrofossils are absent from the interval of study (980–1160 ft [299–354 m]), and the presence of fine laminations in the upper part of the Vincentown Formation and the lower part of the Manasquan Formation (Owens et al., Chapter 2, this volume) indicate that bioturbation was not severe.

RESULTS

We compare our benthic foraminiferal isotopic record from Island Beach with the published record (Pak and Miller, 1992) from ODP Site 577 (32°26.15′N, 157°43.40′E; 2675-m present depth; ~1500-m Eocene paleodepth). Site 577 was selected for comparison, because it is located in the deep Pacific, removed from the dominant sources of Paleogene deepwater formation (Katz and Miller, 1991; Pak and Miller, 1992, 1995) and thus approximated global average isotopic values. We employ the published (Pak and Miller, 1992) stratigraphy for Site 577, with a revised age of the CIE of 55.09 Ma on the Berggren et al. (1995) time scale. This revision reflects recent work on the chronology of the CIE (Aubry et al., 1996).

We make our interpretations based on our preferred isotopic and *Morozovella acuta*-based Island Beach stratigraphy (Table 2; Figs. 4, 5). However, we also present isotopic figures based on the nannofossil stratigraphy (Figs. 6, 7). With the nannofossil stratigraphy, few high-resolution comparisons can be made between the Island Beach and global isotopic records. However, inferred relationships between the isotopic record and the record of water-depth changes at Island Beach are unaffected by stratigraphic correlations. Similarly, general comparisons between the Island Beach and global isotopic records are unaffected by minor changes in correlation.

Carbon Isotopes

The Island Beach isotopic record indicates that there were three late Paleocene–early Eocene cycles in benthic foraminiferal δ^{13}C (Fig. 2; cycle = a periodic or aperiodic interval in which δ^{13}C values are similar). Carbon-isotope values were relatively high in the upper Paleocene (1150–1074 ft [350.6–327.4 m]), dropped abruptly in the uppermost Paleocene to lowermost Eocene (1074–1019 ft [327.4–310.7 m]), and dropped to still lower values in the lower Eocene (1019–980 ft [310.7–298.8 m]). Each step comprised a decrease in average δ^{13}C values of ~0.75‰–1.0‰. At Island Beach the major

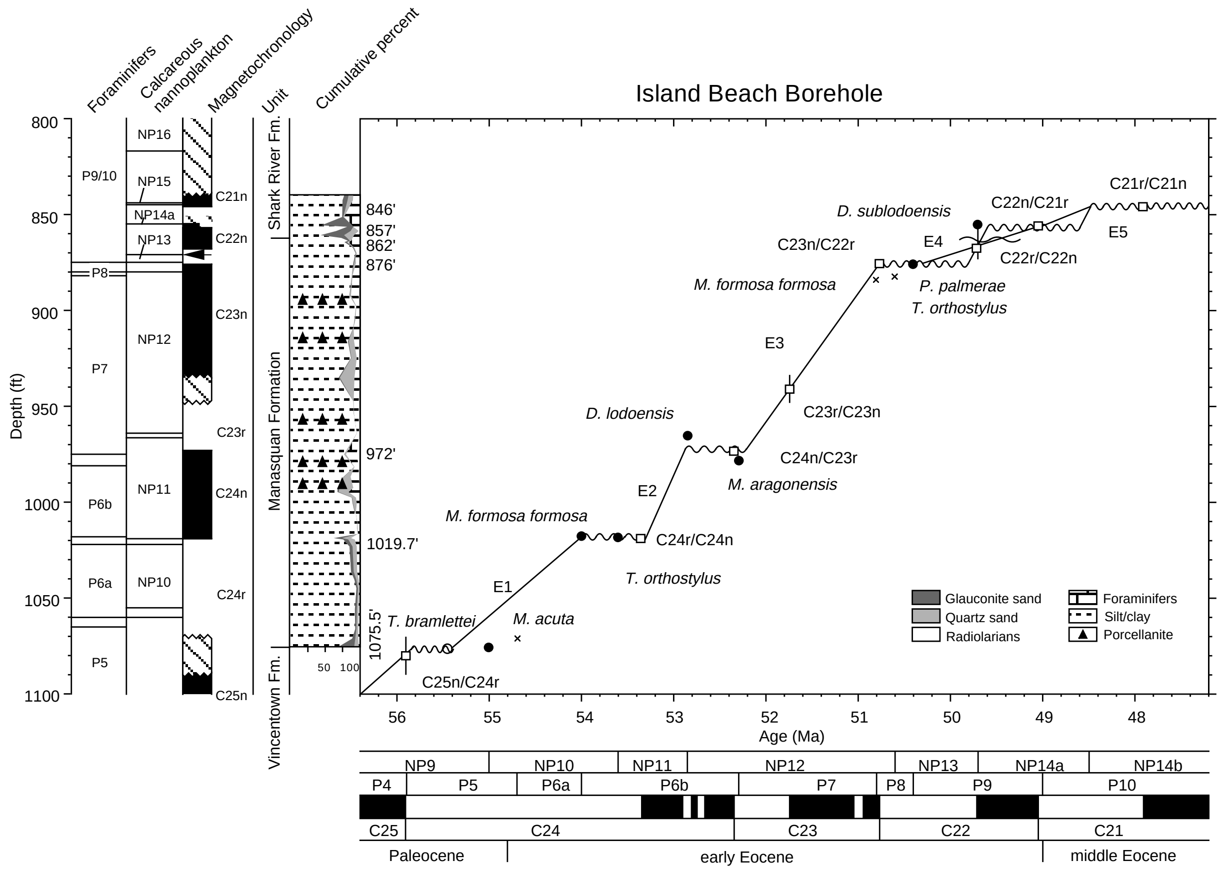

Figure 3. Age vs. depth plot of biostratigraphic and magnetic datum levels in the Island Beach borehole, modified after Browning et al. (Chapter 16, this volume). Crosses are faunal highest occurrences. Solid circles are faunal lowest occurrences. Open squares are magnetic reversals.

steps are separated by unconformities representing hiatuses of 0.3–0.4 m.y. (see “Stratigraphy” section). Within the first (upper Paleocene) and second (uppermost Paleocene/lowermost Eocene) steps there were two additional minor changes: a small decrease at 1120 ft (341.5 m) and a small increase at 1040 ft (317.1 m).

Comparison between the Island Beach and Pacific (Site 577) benthic isotopic records indicates that the $\delta^{13}C$ cycles recognized at Island Beach were global (Fig. 4). The first extended from ~56.6 to 55.8 Ma on the Berggren et al. (1995) time scale. This interval of late Paleocene high $\delta^{13}C$ values has been widely recognized in both benthic and planktonic foraminiferal $\delta^{13}C$ records and represents the highest $\delta^{13}C$ values of the Cenozoic (Douglas and Savin, 1971; Shackleton and Kennett, 1975; Shackleton and Hall, 1984; Shackleton, 1986, 1987; Corfield and Cartlidge, 1992). The long-term drop in foraminiferal $\delta^{13}C$ across the Paleocene/Eocene boundary has been equally well documented (Douglas and Savin, 1971; Shackleton and Hall, 1984; Shackleton, 1986, 1987; Miller et al., 1987a; Corfield and Cartlidge, 1992). We recognize the interval from ~55.5 to 53.9 Ma as the second Paleocene–Eocene $\delta^{13}C$ cycle. The small $\delta^{13}C$ increase from 54.4 to 54.1 Ma at Island Beach is not well represented at Site 577.

The final $\delta^{13}C$ cycle within our interval of study extends from ~53.6 to 52.6 Ma. Although the interval comprises a relatively gradual drop from the higher values of the previous step, these early Eocene $\delta^{13}C$ values were among the lowest of the Cenozoic (Douglas and Savin, 1971; Shackleton and Hall, 1984; Shackleton, 1986, 1987; Corfield and Cartlidge, 1992). Thus, the three late Paleocene to early Eocene benthic $\delta^{13}C$ cycles that we recognize at Island Beach not only mirror the global record (here represented by Pacific Site 577), but also span the largest change in the Cenozoic $\delta^{13}C$ record.

The primary difference between the records from Site 577 and Island Beach is that the Island Beach record is ~0.5–1.0‰ depleted relative to Site 577. We attribute the low-$\delta^{13}C$ values at Island Beach to the influence of relatively nutrient-enriched waters on the shelf that result from local effects. Assuming that Pacific deep water reflects the global average $\delta^{13}C$ (because it represents the largest volume of deep water in the oceans and is far removed from deep-water sources), we can “back out” mean deep-water values by subtracting the Island Beach benthic foraminiferal $\delta^{13}C$ record from the Pacific $\delta^{13}C$ record (Fig. 8). This comparison indicates that from 57.8 to 55.8 Ma $\Delta\delta^{13}C$ was 0.2‰–0.79‰, from 55.5 to 54 Ma $\Delta\delta^{13}C$ was 0.85‰–1.2‰, and from 53.6 to 52.5 Ma $\Delta\delta^{13}C$ was 0.3‰–0.89‰.

It is unexpected that the Island Beach $\delta^{13}C$ should be depleted relative to the deep Pacific throughout the interval of comparison. Today, biological activity leaves shallow (<50–100 m) waters enriched in ^{13}C (Kroopnick, 1980). As a result, shelfal benthic foraminiferal calcite is enriched in ^{13}C relative to deep water. The small $\delta^{13}C$ difference from 57.8 to 56 Ma at Island Beach probably reflects this biological enrichment of ^{13}C, because this section was deposited in very shallow water (60–70 m).

However, the modern New York Bight/New Jersey shelf is a special situation, and may be analogous to the New Jersey Paleogene shelf. The bathymetry of the shelf encourages strong seasonal stratification because of spring runoff and summer warming, leading to seasonally low in situ oxygen (Seger and Berberian, 1976). Winter storms disrupt the stratification, and deep mixing resumes (e.g., Seger and Berberian, 1976; Fairbanks, 1982). During the Paleocene and Eocene, warmer winters and fewer storms may have led to longer term stratification of shelf waters, and persistent low oxygen conditions on the shelf. Low oxygen conditions at Island Beach are indi-

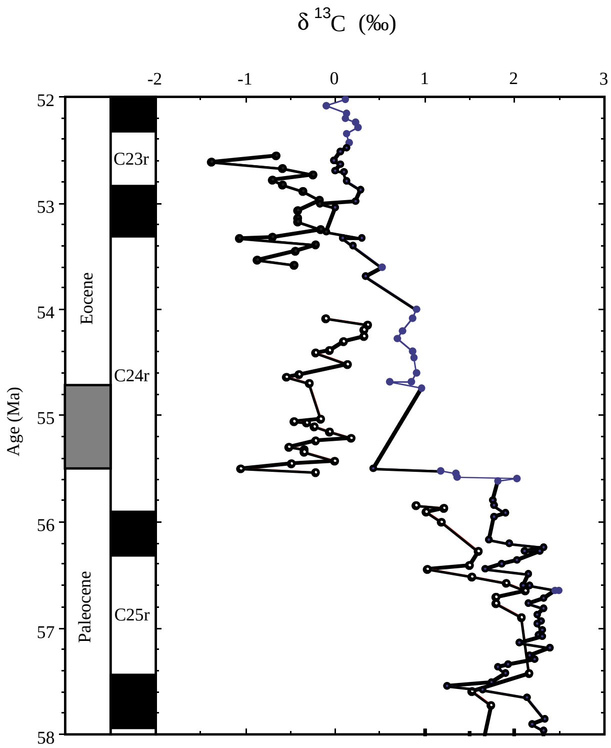

Figure 4. Comparison between carbon isotopic records from Island Beach (open circles; *Cibicides* spp. data; duplicates averaged) and Pacific Site 577 (solid circles; *Nuttallides truempyi* data corrected by 0.27‰). Island Beach stratigraphy based on paleomagnetics, planktonic foraminifers, and isotopic correlation.

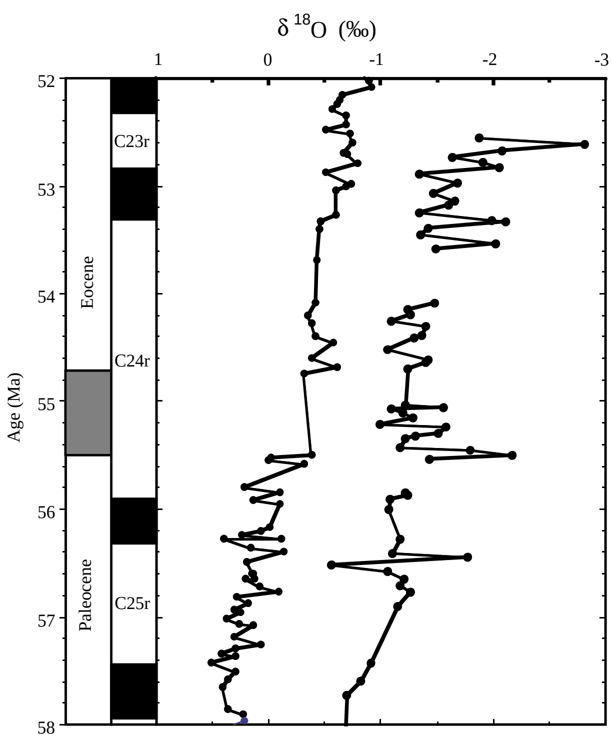

Figure 5. Comparison between oxygen isotopic records from Island Beach (open circles; *Cibicides* spp. data; duplicates averaged) and Pacific Site 577 (solid circles; *Nuttallides truempyi* data). Island Beach stratigraphy based on paleomagnetics, planktonic foraminifers, and isotopic correlation.

cated by the presence of glauconite, which forms under suboxic conditions (McRae, 1972). At Island Beach, glauconite is common from 1019 ft to 1071 ft (310.7–326.5 m; 54–55.4 Ma) and abundant from 1071 ft to 1075.5 ft (326.5–327.9 m; 55.4–55.5 Ma; Miller et al., 1994). In addition, we measured sedimentary organic carbon in each of our samples. The results indicate that percent organic carbon was slightly elevated in the region of the greatest $\delta^{13}C$ difference (Fig. 8), consistent with lower oxygen. Finally, benthic foraminiferal biofacies of the lower Manasquan Formation are dominated by species and genera indicative of low-oxygen bottom conditions (Browning et al., Chapter 16, this volume; Gibson et al., 1993). We interpret the low-$\delta^{13}C$ values at Island Beach as representative of locally low-oxygen conditions, resulting in high in situ nutrients.

Oxygen Isotopes

The $\delta^{18}O$ record from Island Beach shows a general decrease of ~1.0‰ $\delta^{18}O$ from the late Paleocene to early Eocene (Fig. 5; 58−52.5 Ma). This decrease reflects the well-known Paleocene warming of ocean deep waters, which culminated in deep-ocean temperatures of 15°C in the early Eocene. Although the amplitude of the $\delta^{18}O$ decrease is very similar between the Pacific and New Jersey records, the New Jersey $\delta^{18}O$ record is depleted relative to that from Site 577 by approximately −1.0‰ (Fig. 5). We attribute this depletion to the influence of local temperature and salinity in the shelfal environment. Fresh water runoff and relatively warm temperatures at shallow depth combine to form a low-$\delta^{18}O$ water mass on the shelves. In the modern ocean, shelfal $\delta^{18}O$ ranges from –0.75‰ to –2.2‰ (Fairbanks, 1982), which is ~0.6‰–2.05‰ depleted relative to the deep Pacific (Craig and Gordon, 1965). The $\delta^{18}O$ values we report for Island Beach are consistent with modern differences.

There is a strong positive covariance between $\delta^{13}C$ and $\delta^{18}O$ within both the Vincentown and Manasquan Formations of the Island Beach isotopic record (Fig. 2). Each of the $\delta^{13}C$ cycles previously described is matched by a $\delta^{18}O$ decrease. In particular, the prominent $\delta^{13}C$ decreases at the beginning of each step (e.g., at 1073.8 and 1019 ft [327.4 and 310.7 m]) correspond with large $\delta^{18}O$ decreases. Covariance between $\delta^{18}O$ and $\delta^{13}C$ is also apparent in the early Paleogene global isotopic record. The large late Paleocene to early Eocene global decrease in $\delta^{13}C$ is represented by a smaller amplitude (~0.75‰) decrease in $\delta^{18}O$. As with $\delta^{13}C$, the lowest $\delta^{18}O$ values of the Cenozoic occurred in the early Eocene (Emiliani, 1955; Douglas and Savin, 1971; Shackleton and Kennett, 1975; Shackleton, 1986; Miller et al., 1987a).

Within the Manasquan Formation of Island Beach, $\delta^{18}O$ and $\delta^{13}C$ show a strong positive correlation (Fig. 9, $r^2 = 0.7$). Although recrystallization can alter the isotopic composition of carbonates, we do not think that our record is the result of diagenesis. In the marine environment, diagenesis is the result of recrystallization of foraminiferal calcite within the microenvironment of pore waters. Pore-water $\delta^{18}O$ becomes depleted relative to ocean water because of increased temperature with increased burial depth and/or interaction with basaltic basement (which has an $\delta^{18}O$ value of –7‰ to –15‰), leading to anomalously light $\delta^{18}O$ values. Although the $\delta^{18}O$ values at Island Beach are ~1.0‰ depleted relative to Site 577, such values are reasonable for a near-shore site. Because $\delta^{13}C$ is not controlled by temperature, it is more difficult to alter in pore waters unless there is a $\delta^{13}C$-depleted source, such as methane or organic carbon, nearby. Thus, the similar changes in both $\delta^{18}O$ and $\delta^{13}C$ argue against diagenetic obliteration of the signal.

Because Island Beach is an onshore section, it is also possible that diagenesis took place in meteoric water. This would lead to a positive covariance, because ground waters are depleted in $\delta^{13}C$ because of interaction with soils, as well as depleted in $\delta^{18}O$. However, we would expect to see a correlation between lithology and $\delta^{18}O/\delta^{13}C$ peaks, with more porous sandy layers being more affected by the groundwater signal than the clay-rich layers. We do not see such a pattern; high-amplitude $\delta^{18}O/\delta^{13}C$ peaks are present in both the sandy basal

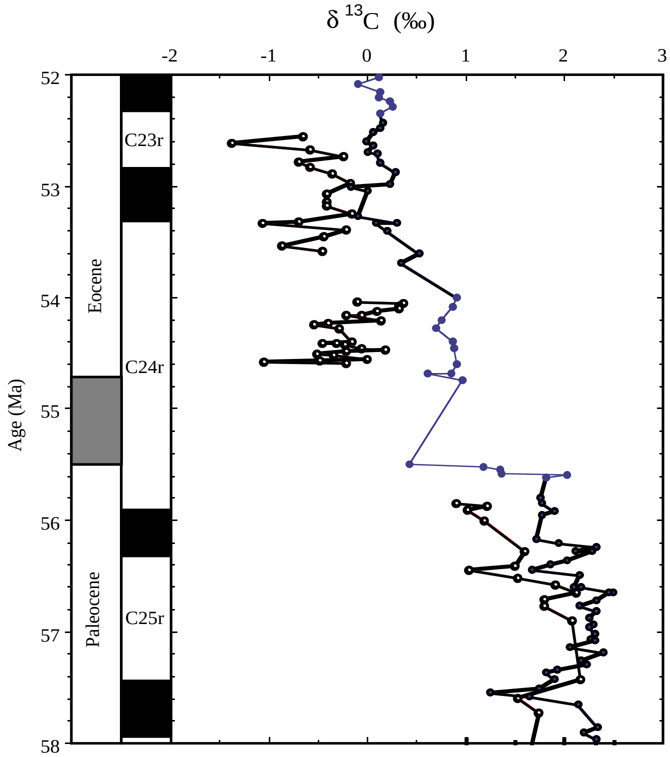

Figure 6. Same as Figure 4, except with Island Beach stratigraphy based on nannofossils (after M.-P. Aubry, pers. comm., 1995).

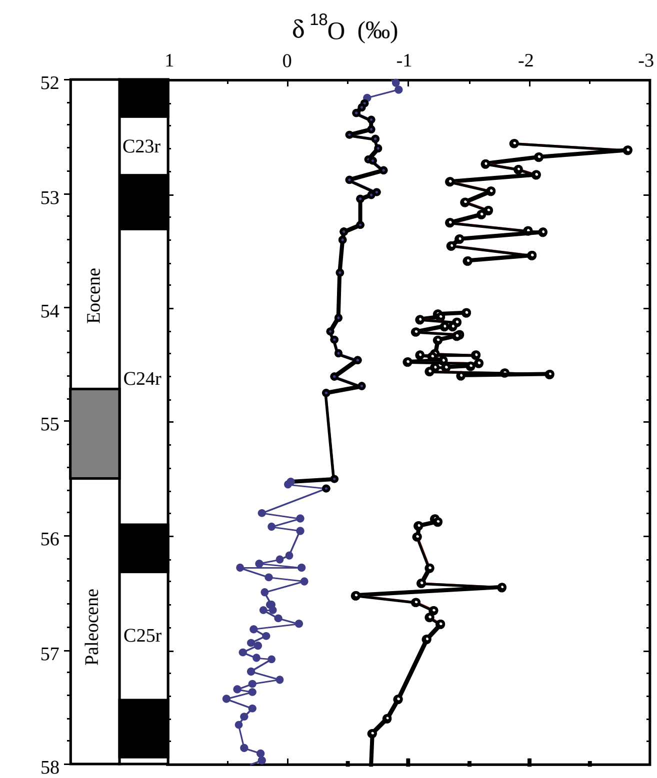

Figure 7. Same as Figure 5, except with Island Beach stratigraphy based on nannofossils (after M.-P. Aubry, pers. comm., 1995).

Manasquan (1070–1075 ft [326.2–327.7 m]) and the relatively homogenous massive silty clays of the upper part of the unit (980–1020 ft [298.8–311 m]).

Finally, we note that the preservation of the global trend in both oxygen and carbon at Island Beach argues against a significant diagenetic signal, as does the high-amplitude nature of the record. In general, diagenesis tends to damp the amplitude of high-frequency variations, rather than create spikes (Schrag et al., 1992). We maintain that the high-frequency isotopic covariance is the result of high-amplitude variations in the local environment of Island Beach. We suggest that strong stratification would lead to a low-δ^{18}O, low-δ^{13}C shelf water.

The Island Beach δ^{18}O record is more variable than the deep-water record (Fig. 2). The higher amplitude signal does not simply represent intrasample variability, because reproducibility is generally good (15 duplicate analyses yielded a reproducibility of 0.17‰). Instead, we believe that the intersample variability reflects the variable nature of near-shore waters. Coastal waters are subject to variations in regional environmental conditions, as well as global climate change. Therefore, we interpret the Island Beach δ^{18}O record as reflecting local variations in shelfal δ^{18}O, superimposed on the global record of Paleocene–earliest Eocene δ^{18}O decrease.

Covariance Between Water-Depth Changes and the Isotopic Record

The late Paleocene–Eocene water-depth history of the New Jersey shelf (Fig. 2) was identified on the basis of benthic foraminiferal biofacies studies and lithology (Browning et al., Chapter 16, this volume; Liu et al., Chapter 19, this volume). At Island Beach, sediments of the Vincentown Formation (1168–1075.5 ft [356.1–327.9 m]) indicate deposition at shallow neritic depths (60–70 m; Browning et al., Chapter 16, this volume; Liu et al., Chapter 10, this volume), although the upper part of the Vincentown Formation (1175.5–1120 ft [358.4–341.5 m]) may have been deposited in slightly deeper water (Liu et al., Chapter 10, this volume). A major change in benthic foraminiferal biofacies occurs at the Vincentown/Manasquan contact; an *Osangularia expansa* assemblage dominates from the base of the Manasquan to 1040 ft (317 m; Browning et al., Chapter 16, this volume). There was a large, correlative increase in water depth at 1075.5 ft (327.9 m) from middle neritic to outer neritic depths (60–70 m to ~135 m ± 25 m; Browning et al., Chapter 16, this volume). Lithologic and biofacies analyses indicate a minor shallowing at 1040 ft and an increase in water depth at 1019 ft (Browning et al., Chapter 16, this volume).

The major water-depth changes (at 1075.5 and 1019 ft [327.9 and 310.7 m]) correspond well with the isotopic steps we have identified in the Island Beach record (Fig. 2). The first interval (1140–1075.5 ft [347.6–327.9 m]), representing the highest Paleocene–Eocene δ^{13}C and δ^{18}O values, corresponds with the shallowest Paleocene–Eocene water depths at Island Beach. Similarly, the two successive steps (from 1075.5 to 1019 ft [327.9–310.7 m] and from 1019 to 980 ft [310.7–298.8 m], respectively) correspond with increasing water depth at Island Beach. In addition, minor δ^{13}C changes at 1120 and 1040 ft (341.5 and 317.1 m) correlate with lithologic and foraminiferal indicators of increasing and decreasing water depths.

Comparison with the Haq et al. (1987) cycle chart indicates that the water-depth changes identified at Island Beach are similar in scale to proposed eustatic changes. Haq et al. (1987) predicted latest Paleocene to earliest Eocene sea-level rise, with the highest sea levels of the Cenozoic occurring in the early Eocene. In addition, Browning et al. (Chapter 16, this volume) noted that third-order sea-level events predicted by the Haq et al. (1987) cycle chart correspond with the two prominent unconformities in the Island Beach record (at 1075.5 and 1019 ft; 327.9 and 310.7 m). Finally, we note that the isotopic steps identified in the Island Beach δ^{13}C record mirror the global record.

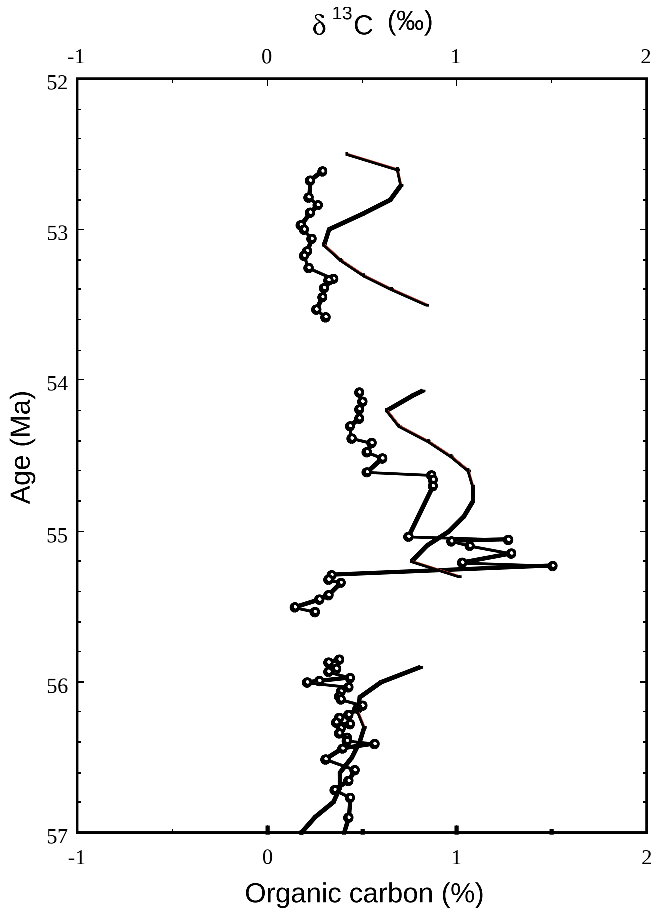

Figure 8. Comparison of $\delta^{13}C$ difference between Pacific Site 577 and Island Beach (solid line) and percent organic carbon at Island Beach (open circles).

We suggest that global changes in oceanic $\delta^{13}C$ were linked to late Paleocene–early Eocene sea-level changes.

DISCUSSION

Our benthic foraminiferal carbon and oxygen isotopic record from Island Beach, NJ, indicates that global isotopic signals were recorded on the New Jersey Margin during the late Paleocene and early Eocene, and can thus be used to correlate to the deep sea. This observation confirms the results of recent studies (Gibson et al., 1993; Miller et al., 1994; Browning et al., Chapter 16, this volume), suggesting that Paleocene and Eocene sedimentation was relatively complete on the New Jersey Coastal Plain in spite of the shallow-water environment and several unconformities. Although shallow-water sections may be very discontinuous, and therefore provide less useful stratigraphic information than deep-sea sections, there are several features of the New Jersey Margin that make it an ideal candidate for a relatively complete stratigraphic record. First, sediments of the Paleogene New Jersey Margin were deposited on a gently sloping carbonate ramp. The geometry of the margin discouraged vigorous erosion and encouraged pelagic deposition. Second, the Paleocene and Eocene record of eustasy is primarily one of gradual sea-level rise (Haq et al., 1987). Third, there are few early Eocene erosional unconformities in the deep-sea record, indicating generally sluggish ocean circulation. Therefore, early Eocene sections may be relatively more complete than those of other ages. Finally, we note that the deep sea is not the quiet depositional basin as once thought (e.g., Aubry, 1991; Aubry et al., 1996), and that deep-sea sections are not necessarily more complete than shallow-water sections. We suggest that other carefully selected shelf sections may also provide relatively complete stratigraphic records.

The preservation of global isotopic changes at Island Beach indicates that direct comparisons between the shelf and deep sea can be accomplished with stable isotopic and stratigraphic correlations. This observation has important paleoceanographic implications. Because direct evidence of sea-level change is recorded on the continental margin, we are able to examine Paleogene isotopic events in the context of sea-level changes.

Linkage Between $\delta^{18}O$, $\delta^{13}C$, Sea Level, and Climate

Comparison among the Island Beach isotopic record, the deep-sea isotopic record, and the record of New Jersey Margin sea-level events leads to several intriguing correlations.

1. From the latest Paleocene to the early Eocene, three intervals of change, defined by step-like decreases in $\delta^{18}O$ and $\delta^{13}C$, can be identified in both the Island Beach and Site 577 (Pacific) isotopic records (~56.6–55.8 Ma; ~55.5–54 Ma; ~53.6–52.6 Ma).
2. The steps are separated by prominent unconformities in the Island Beach record.
3. Each of the decreases in the isotopic record corresponds with benthic foraminiferal biofacies and lithologic changes that indicate water-depth increase on the New Jersey Coastal Plain.

We note the correspondence between decreasing $\delta^{18}O$ and $\delta^{13}C$ and increasing sea level, and suggest a linkage between global climate, sea level, and organic carbon accumulation.

We suggest that intervals of warmer temperatures and higher sea levels were characterized by generally low oceanic productivity. Decreased organic carbon burial rates have been cited previously as a cause of the long-term (3 m.y.) $\delta^{13}C$ decrease spanning the Paleocene/Eocene boundary (Shackleton and Hall, 1984; Shackleton, 1987). Our study provides new evidence indicating that the long-term decrease occurred in a step-like manner and was associated with sea-level increase. We suggest that warm temperatures and sluggish ocean circulation (Moore et al., 1978) associated with high sea levels may have damped upwelling of nutrient-enriched waters, leading to low oceanic productivity. This mechanism has also been proposed to explain similar covariance among $\delta^{18}O$, $\delta^{13}C$, and sea level in the Miocene (Flower and Kennett, 1993) and late Eocene–early Oligocene (Zachos et al., 1995). However, it is opposite in sense to models proposed to explain late Pleistocene glacial/interglacial $\delta^{13}C$ changes (Broecker, 1982), which suggest that deep-ocean $\delta^{13}C$ decreases are the result of sea-level decreases and the resultant erosion of isotopically light organic matter from exposed shelves. The deep-ocean $\delta^{13}C$ record does not help us distinguish between increased erosion of old organic deposits and decreased deposition of fresh organic matter. However, the shelf record at Island Beach indicates that periods of decreased $\delta^{13}C$ in the late Paleocene and early Eocene were not the result of increased supply of shelf carbon because of erosion, but were instead correlative with times of sediment deposition and water-depth increase on the New Jersey shelf.

Benthic foraminiferal $\delta^{13}C$ values on the shelf followed the global (deep sea) pattern, but remained very low relative to deep-sea $\delta^{13}C$. We attribute low benthic $\delta^{13}C$ at Island Beach to increased stratification of shelf waters leading to low oxygen conditions below a shallow mixed layer, and resultant low benthic $\delta^{13}C$ values at Island Beach. We suggest that warm Paleogene temperatures and high sea levels encouraged stratification of shelfal waters and led to low in situ oxygen on the deep shelf. Low oxygen conditions on the Paleocene and Eocene New Jersey shelf are supported by the presence of glauconite

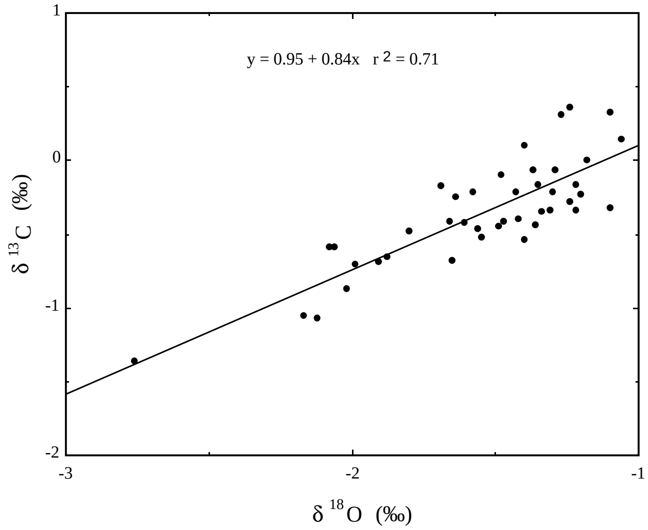

Figure 9. Covariance between *Cibicides* spp. $\delta^{18}O$ and $\delta^{13}C$ within the Manasquan Formation at Island Beach.

(Miller et al., 1994), relatively high organic carbon (Fig. 8), and benthic foraminiferal assemblages presumed to be characteristic of low oxygen conditions (Gibson et al., 1993; Browning et al., Chapter 16, this volume; Liu et al., Chapter 10, this volume).

Low benthic $\delta^{13}C$ and dissolved oxygen may also have been the result of locally high productivity on the shelf. It is possible that nutrients derived from riverine input became trapped on the shelves during sea-level rise. This would result in decreased productivity in the oceans and increased productivity on the shelves. However, we note that although organic carbon at Island Beach was slightly elevated in the early Eocene, there is little evidence of widespread organic-rich deposits on the New Jersey Margin (Owens et al., Chapter 2, this volume).

Latest Paleocene Shallow-Water Environmental Changes

Until recently (Gibson et al., 1993), rapid environmental changes associated with the CIE had been reported only from bathyal and abyssal sites (e.g., Kennett and Stott, 1990; 1991; Thomas 1990; Pak and Miller, 1992, Lu and Keller, 1993; Thomas and Shackleton, 1996). However, Gibson et al. (1993) reported a benthic foraminiferal faunal turnover event within the Manasquan Formation in the Clayton, NJ, borehole. The timing of the Clayton event (uppermost Paleocene; within faunal Zone NP9) led Gibson et al. (1993) to suggest that it was correlative with the well-known latest Paleocene benthic foraminiferal extinction event (Tjalsma and Lohmann, 1983; Thomas, 1990; Kennett and Stott, 1990), and thus with the CIE. Identification of the extinction and CIE in neritic depths has serious implications for proposed explanations of the event, many of which point to temporary instability of deep-water source areas as a possible cause (e.g., Kennett and Stott, 1990; 1991; Thomas, 1990; Pak and Miller, 1992; Kennett and Stott, 1995; Thomas and Shackleton, 1996).

A benthic foraminiferal turnover occurred at the Vincentown/Manasquan contact in the Island Beach section. Foraminifers commonly occurring in the upper part of the Vincentown are *Alabamina midwayensis, Anomalinoides welleri, Bulimina hornerstownensis, B. midwayensis, Cibicides mortoni, Cibicidoides hilgardi, Gyroidinoides subangulata, Lenticulina midwayensis, Nodosaria paleocenica, Osangularia convexa, Stilostomella paleocenica, Tappanina selmensis,* and *Tritaxia midwayensis* (Liu et al., Chapter 10, this volume). This assemblage changes to an *Osangularia*-dominated biofacies in the lower Manasquan Formation (Browning et al., Chapter 16, this volume). A ~0.7-m.y. hiatus at the contact precludes precise identification of the timing of the turnover, although its position (within C24r, and at the NP9/NP10 and P5/P6a zonal boundaries) is consistent with that of the deep-sea extinction event.

Our isotopic record indicates a prominent decrease in $\delta^{13}C$ and $\delta^{18}O$ at 1073.8 ft (327.4 m) at Island Beach. The magnitude of the isotopic excursion ($\delta^{13}C$ decreased by ~2.0‰, whereas $\delta^{18}O$ decreased by ~1.0‰) is somewhat less than has been recorded in the Southern Ocean (Kennett and Stott, 1991; Site 690; benthic foraminiferal $\delta^{13}C$ decreased by 3.0‰ and $\delta^{18}O$ by 2.0‰), but is equivalent to that recorded in mid-latitude Atlantic sections (e.g., Thomas and Shackleton, 1996; Site 524; $\delta^{13}C$ decreased by 2.0‰ and $\delta^{18}O$ by 1.5‰). We correlate the isotopic excursion at Island Beach with the deep-sea excursion, although M.-P. Aubry (pers. comm., 1995) suggests that it corresponds to a much younger $\delta^{13}C$ decrease (see "Stratigraphy" section for further discussion). The position of the isotopic excursion ~1.5 ft above the Vincentown/Manasquan contact suggests that the benthic foraminiferal turnover at Island Beach was not the neritic equivalent of the deep-sea extinction, which was precisely coeval with the isotope event in bathyal and abyssal sections. We suggest that the benthic foraminiferal event on the New Jersey Margin was the result of dramatic water-depth increase and facies change on the shelf and was unrelated to the deep-sea extinction.

CONCLUSIONS

1. Isotopic, magnetostratigraphic, and biostratigraphic correlations indicate that the upper Paleocene and lower Eocene section of the Island Beach, NJ, borehole can be correlated to the deep-sea record. This result contradicts previous assumptions of highly discontinuous sedimentary sections and sparse calcareous microfossils on the continental shelves, and indicates that at least some shelfal sequences can be directly correlated with deep-sea sequences using integrated techniques.
2. Benthic foraminiferal oxygen and carbon isotopic records indicate that the late Paleocene–early Eocene global isotopic signal was recorded and preserved at Island Beach. However, the neritic isotopic record is characterized by high-amplitude variations and a depleted $\delta^{18}O$ and $\delta^{13}C$ signal relative to the deep-sea record. We attribute these differences to the more variable shelfal conditions superimposed on the global record.
3. A latest Paleocene benthic foraminiferal turnover occurs ~1.5 ft below a prominent $\delta^{18}O$ and $\delta^{13}C$ excursion at Island Beach. We suggest that the foraminiferal turnover was the result of water-depth increase and facies change on the New Jersey shelf and was not correlative with the well-known latest Paleocene deep-sea extinction event.
4. Steps of decreasing $\delta^{13}C$ and $\delta^{18}O$ correlate with increasing water depth on the New Jersey shelf. The covariance between isotopic steps and water-depth change suggests a linkage between sea level, global climate, and carbon cycling. We suggest that globally warm temperatures and high sea levels led to low oceanic productivity and $\delta^{13}C$ decrease in the late Paleocene and early Eocene.

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