1. BASS RIVER SITE[1]

Kenneth G. Miller,[2, 3] Peter J. Sugarman,[2,4] James V. Browning,[2] Richard K. Olsson,[2] Stephen F. Pekar,[2] Timothy J. Reilly,[2] Benjamin S. Cramer,[2] Marie-Pierre Aubry,[5] Roland P. Lawrence,[6] John Curran,[4] Michael Stewart,[2] John M. Metzger,[7] Jane Uptegrove,[4] David Bukry,[8] Lloyd H. Burckle,[3] James D. Wright,[9] Mark D. Feigenson,[2] Gilbert J. Brenner,[10] and Richard F. Dalton[4]

AUTHORSHIP OF SITE SECTIONS

The following, who are listed in alphabetic order, are responsible for the given section:

Operations: Lawrence
Lithostratigraphy: Browning, Cramer, Dalton, Metzger, Olsson, Pekar, Reilly, Stewart, Uptegrove
Biostratigraphy:
Foraminifers: Browning, Olsson, Pekar
Calcareous nannofossils: Aubry (Cenozoic), Bukry (Cretaceous)
Diatoms: Burckle
Pollen: Brenner
Isotope stratigraphy: Feigenson, Pekar, Wright

BASS RIVER SITE SUMMARY

Background and Operations

The Bass River Site was the fourth borehole drilled as part of the New Jersey Coastal Plain Drilling Project, which began with Ocean Drilling Program (ODP) Leg 150X drilling at Island Beach, Atlantic City, and Cape May (Miller et al., 1994a, 1994b, 1996). Bass River was drilled by the New Jersey Geological Survey (NJGS) and Rutgers University and is the first site drilled as part of ODP Leg 174AX, complementing shelf drilling by Leg 174A; future Leg 174AX drilling is planned for 1998 near Corson's Inlet and Ancora, NJ. Funding for Bass River was provided by the NJGS for direct drilling expenses and the National Science Foundation (Earth Sciences Division, Continental Dynamics Program and Ocean Science Division, ODP) for science support.

Drilling at Bass River targeted middle Miocene and older sequences, with the primary focus on Upper Cretaceous (Cenomanian-Maastrichtian) to Paleocene strata that previously were poorly sampled. The drilling contractor, Boart Longyear, Inc., continuously cored 1956.5 ft (596.34 m) in October and November 1996 in Bass River State Forest, NJ (39°36′42″N, 74°26′12″W; elevation 28 ft [8.53 m]; New Gretna, NJ, 7.5-min quadrangle); drilling operations were superintended by the Continental Scientific Drilling Office of Texas A&M University. Recovery was excellent (mean recovery = 86.2%; median recovery = 99%), and a gamma log was obtained to total depth (TD). The on-site scientific team provided preliminary descriptions of sedimentary textures, structures, colors, fossil content, identification of lithostratigraphic units, lithologic contacts, and sequences (unconformity-bounded units).

Neogene Sequences

The Cape May Formation consists of ?Pleistocene–Holocene unconsolidated gravels, gravelly sands, and sandy clays (3–19.7 ft [0.91–6.00 m]). These overlie quartz sands and sandy clays assigned to the ?upper or ?middle Miocene Cohansey Formation (19.7–132.9 ft [6.0–40.5 m]). Three or four sequences were identified in the Cohansey Formation, but their ages are not known because of the absence of calcareous fossils. The lower middle to lower Miocene Kirkwood Formation (132.9–555.3 ft [40.51–169.26 m]) can be divided into four coarsening-upward (shallowing) sequences (Kw2b, Kw2a, Kw1b, Kw1a). These sequences consist of thin to absent basal sands (Transgressive Systems Tracts [TST]) overlain by prodelta clayey silts (lower Highstand Systems Tracts [HST]) that grade upsection to delta front medium-coarse sands (upper HST). Age control on these sequences consist of limited diatom biostratigraphy and Sr-isotopic analyses on the lower sequence (21.4–20.8 Ma).

Paleogene Sequences

The Oligocene/Miocene boundary is marked by a sharp unconformity separating the Kw1a and O1 sequences at 555.3 ft (169.26 m). The Oligocene section (555.3–675.5 ft [169.26–205.89 m]) is predominantly a clayey quartzose glauconite sand (>50% glauconite); it becomes glauconitic clay below 670 ft (204.22 m). The entire Oligocene section is lower Oligocene (33.7–32.0 Ma) and is assigned to sequence O1. Benthic foraminifers indicate deposition in inner to middle neritic (0–100 m) paleodepths. A sharp unconformity (675.4 ft [205.9 m]) separates Oligocene from Eocene strata.

The Eocene section at Bass River consists primarily of clays deposited in middle to outer neritic (30–200 m) paleodepths. Uniform shelly glauconitic brown clays of the upper Eocene Absecon Inlet Formation (675.4–846.6 ft [205.86–258.04 m]) are divided into at least two sequences (E10 and E11). These unonformably overlie the fossiliferous glauconitic clay of the upper middle Eocene upper Shark River Formation (846.6–885.8 ft [258.04–269.99 m]), which comprises two sequences (E8 and E9). An unconformity at 885.8 ft (269.99 m) separates the upper Shark River Formation from the bioturbated marls of the lower middle Eocene lower Shark River Formation; this formation is divided into three sequences (E5, E6, and E7). The lower Shark River Formation is separated from the lower Eocene Manasquan Formation by a distinct unconformity at 959.9 ft (292.58

[1]Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX: College Station, TX (Ocean Drilling Program).

[2]Department of Geological Sciences, Rutgers University, Piscataway, NJ 08855, U.S.A.
[3]Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, U.S.A.
[4]New Jersey Geological Survey, PO Box 427, Trenton, NJ 08625, U.S.A.
[5]Institute des Sciences de l'evolution, Universite Montpellier II, Place Eughne Bataillon, 37095, Montpellier, cedex 05, France, and Woods Hole Oceanographic Institution, Woods Hole, MA 02543, U.S.A.
[6]Continental Scientific Drilling, Texas A&M University, College Station, TX 77843, U.S.A.
[7]Department of Geosciences, Pennsylvania State University, State College, PA 16802, U.S.A.
[8]Scripps Institution of Oceanography, University of California, San Diego, A-008, La Jolla, CA 92093-2015, U.S.A.
[9]Department of Geological Sciences, University of Maine at Orono, Orono, ME 04469, U.S.A.
[10]Department of Geological Sciences, State University of New York at New Paltz, New Paltz, NY 12561, U.S.A.

m). The Manasquan Formation is divided into four sequences (E1, E2, E3, and E4).

A distinct unconformity (1138.6 ft [347.05 m]) separates the Manasquan Formation from slightly micaceous clays of the upper Paleocene Vincentown Formation. The expanded upper Paleocene section, deposited at an estimated rate of 24 cm/k.y., provides a rare opportunity to document evolutionary changes and climatic and oceanographic events of the late Paleocene on the U.S. Atlantic Coastal Plain. The upper Paleocene Vincentown Formation is divided into three sequences (1138.6–1178 ft [347.05–359.6 m], 1240.8–1256.5 ft [378.20–382.98 m], and 1256.5–1258.7 ft [382.98–383.66 m]). The contact of the Vincentown Formation with the underlying Hornerstown Formation at 1248.9 ft (380.66 m) is gradational and occurs within a sequence. There are two thin lower Paleocene sequences assigned to Subzones P1c (1256.5–1258.7 ft [382.89–383.65 m]) and P1a (1258.7–1260.25 ft [383.65–384.12 m]) within the Hornerstown Formation.

Cretaceous/Tertiary Boundary

The Bass River borehole recovered a remarkable Cretaceous/Tertiary (K/T) boundary succession. We identified a ~6-cm-thick spherule layer overlying the K/T boundary (1260.25 ft [384.12 m]) presumably resulting from fallout of ballistic ejecta from the Chicxulub Crater in Yucatan, Mexico. This layer represents extremely rapid deposition (with settling though the water column of 100 m beginning at ~10 min after impact). This is the farthest site from the impact where a distinct spherule layer has been identified (~2500 km from the crater). It is also the first confirmed nonturbidite spherule bed (i.e., >1 cm) outside of the Gulf of Mexico. This discovery constrains the amount and direction of ejecta derived from the impact and the size and direction of the impactor. Because the K/T boundary in New Jersey is far enough from “ground zero,” it allows clear identification of the K/T boundary and its relationship to the effects of the impact.

Initial biostratigraphic studies confirm that deposition was continuous at Bass River across the K/T boundary. Uppermost Cretaceous strata (*Micula prinsii* Zone) are overlain by lowermost Paleocene Zone P0, indicating that deposition was continuous on a scale of tens of thousands of years. Continuous deposition was interrupted by the abrupt fallout of the ejecta. An abrupt extinction of marine planktonic organisms subsequently occurred, indicating a major environmental disruption.

Upper Cretaceous Sequences

The Campanian–Maastrichtian section consists of at least four to five shallowing-upward marine (neritic) sequences:

1. The Maastrichtian Navesink Formation glauconite sands (TST; 1270.0–1294.5 ft [387.10–394.56 m]) are overlain by the New Egypt/Red Bank Formation glauconitic clays (HST; 1260.24–1270.0 ft [384.12–387.10 m]).
2. The Marshalltown Formation glauconite sands (TST; 1429.0–1440.5 ft [435.56–439.06 m]) are overlain by Wenonah Formation silts (lower HST; 1391.0–1429.0 ft [423.98–435.56 m]), and Mount Laurel Formation sands (upper HST; 1294.5–1391.0 ft [394.56–423.98 m]). This sequence is upper Campanian to lowermost Maastrichtian. Both the Wenonah and Mount Laurel Formations are fossiliferous at Bass River (in contrast with outcrops and previous wells).
3. The Englishtown Formation (1440.5–1488 ft [439.06–453.54 m]) is Campanian. An upper Englishtown sequence (1440.5–1472.6 ft [439.06–448.85 m]), including the unconformity separating the upper from the lower Englishtown, was recovered for the first time.
4. The Campanian Merchantville Formation (TST; 1654.0–1683.2 ft [504.14–513.04 m]) glauconite sands are overlain by thick, very micaceous, fossiliferous silty clays of the Woodbury Formation (lower HST; 1492–1654.0 ft [504.14–504.44 m]) and micaceous silty fine sands of the lower Englishtown Formation (upper HST; 1472.6–1488 ft [448.85–453.54 m]).
5. A thin lithologic unit (1683.2–1709 ft [513.04–520.90 m]) may represent a separate sequence correlative to the Cheesequake Formation in outcrop. The age of this sequence is Santonian (CC15) at Bass River.

The nonmarine ?Turonian–?Santonian Magothy Formation (1709.2–1806.4 ft [520.96–550.59 m]) contains diverse facies that appear to represent two sequences: (1) an upper sequence consists of a marginal marine interbedded coarse sand and clay, overlying a delta front fine sand and a terrestrial white kaolinitic clay; and (2) a lower sequence consists of a fluvial sand overlying a prodelta micaceous silty clay. A major ?mid-Turonian unconformity separates the Magothy Formation from the underlying Bass River Formation.

The outer? neritic Cenomanian–Turonian Bass River Formation (1806.4–1956.5 ft [550.59–596.34 m]) consists of fossiliferous, micaceous (chloritic), clayey silts and silty clays with occasional sandy silts. The Cenomanian/Turonian boundary was recovered in an apparently continuous succession, and a $\delta^{13}C$ decrease noted in other Cenomanian/Turonian boundary sections is documented at Bass River. The base of the Bass River Formation was not penetrated, and the 150.1 ft (45.75 m) of the formation we recovered appears to represent at least two sequences.

Significance of the Bass River Site

The thick section recovered at Bass River has provided cores that address various aspects of global change, regional tectonics, and local hydrogeology. The Bass River borehole is the first fossiliferous continuously cored Upper Cretaceous (Cenomanian–Maastrichtian) section in New Jersey. Recovery was excellent and the sequence stratigraphic successions are clear. The borehole provides the requisite material for a detailed, integrated stratigraphic study of Cretaceous sequences in New Jersey and comparison of these sequences to other proxies of global sea-level change.

The Bass River borehole also provides material needed to evaluate aquifer-confining unit relationships and local hydrogeology. In particular, the Cohansey–Kirkwood aquifer is unconfined; the “Atlantic City 800-ft sand” (Zapecza, 1989) aquifer (Kw1a) is unexpectedly thick; the thick Oligocene sands contain indurated zones that may limit permeability; the lower and upper Englishtown Formation sands are too thin and silty for water supply at this location; and the thick Mount Laurel sands and the coarse Magothy sand are potential undiscovered sources of water for this region.

BACKGROUND AND OBJECTIVES

This chapter is the site report for the fourth continuously cored and logged borehole drilled onshore as part of the New Jersey Sea-level Transect. The transect involves both offshore drilling, begun by ODP Leg 150 (Mountain, Miller, Blum, et al., 1994), and onshore drilling. The first three onshore sites (Fig. 1) were drilled at Island Beach (March–April 1993), Atlantic City (June–August 1993), and Cape May (March–April 1994) as ODP Leg 150X (Miller et al., 1994a, 1994b, 1996). ODP Leg 174A has continued the transect by drilling on the shelf (Austin, Christie-Blick, Malone, et al., 1998), whereas drilling at Bass River continues the onshore transect by drilling deeper into Upper Cretaceous strata. PCOM endorsed the onshore drilling as an ODP-related activity and designated drilling at Bass River and proposed boreholes at Corson’s Inlet/Ocean City and Ancora (Fig. 1) as ODP Leg 174AX.

The geological background and scientific justification for the New Jersey Sea-level Transect are provided by Miller and Mountain

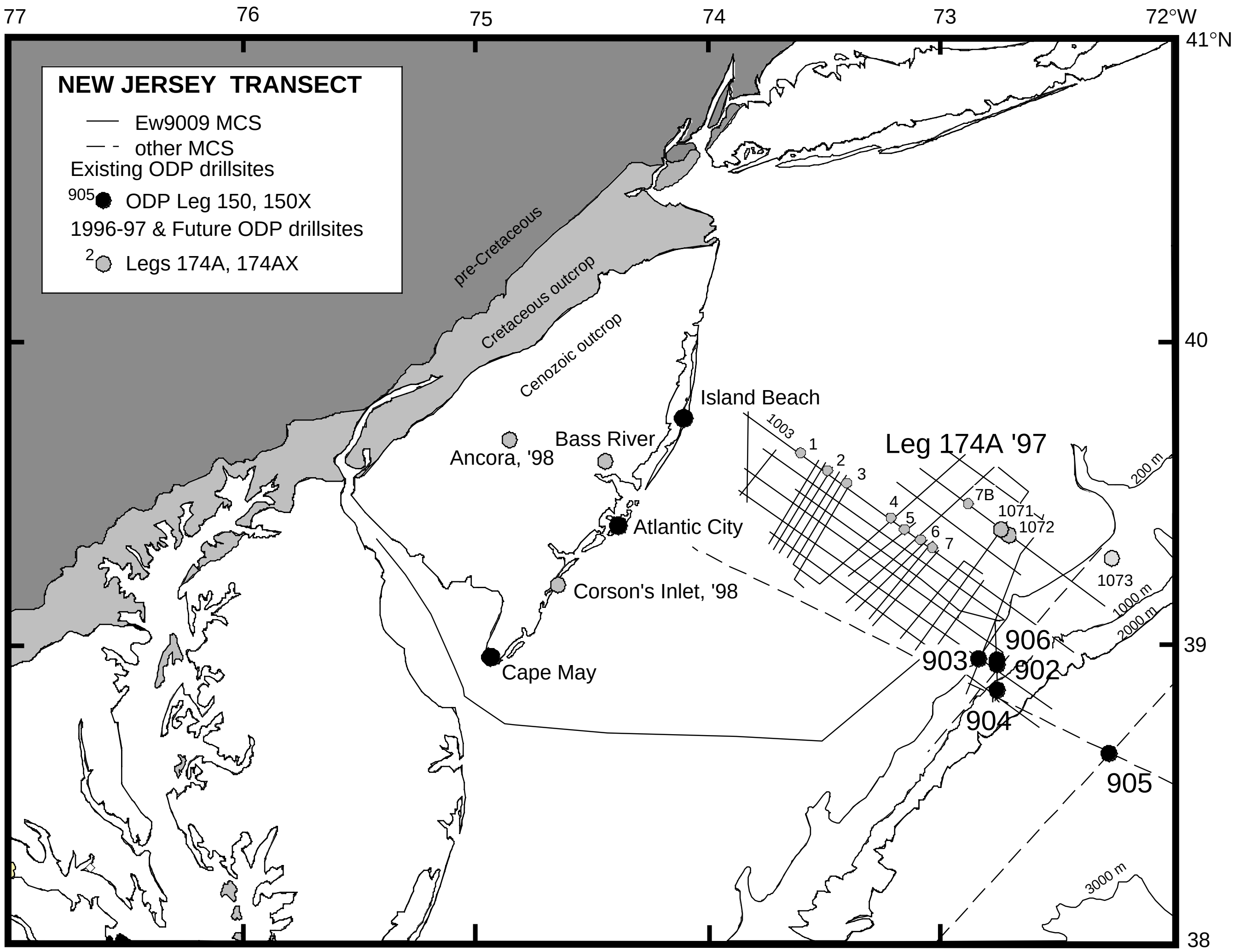

Figure 1. Location map showing existing ODP boreholes analyzed as a part of the New Jersey transect and proposed sites for boreholes at Ancora and Corson's Inlet. Also shown are multichannel seismic data (MCS) from Ew9009 and other sources.

(1994). The Transect is intended to document the response of passive continental margin sedimentation to glacioeustatic changes during the Oligocene to recent "Icehouse World," a time when glacioeustasy was clearly operating, and to document the ages and nature of Eocene and older "Doubthouse" and "Greenhouse" sequences, a time when mechanisms for sea-level change are poorly understood (Miller et al., 1991).

The Bass River borehole had one other major objective: to evaluate the stratigraphic continuity and hydrogeological potential of aquifers and confining units, particularly those in the Cretaceous. The NJGS funded all direct drilling costs for this borehole, targeting Cretaceous aquifers in the Englishtown and Potomac-Raritan-Magothy (PRM) Formations (see Zapecza [1989] for discussion of these aquifers). Onshore drilling of the Leg 150X and 174AX boreholes was sponsored by the National Science Foundation, Earth Science Division, Continental Dynamics and Ocean Drilling Programs.

OPERATIONS

Drilling began 18 October 1996 at Bass River State Forest, NJ (39°36′42″N, 74°26′12″W; elevation 28 ft (8.53 m); New Gretna, NJ, 7.5-min quadrangle). Drilling operations were superintended by Roland Lawrence; John Curran was the New Jersey licensed driller onsite. Site preparations included drilling a 73-ft water well by Kaye Well Drilling and digging a $3 \times 4 \times 4$ ft cellar, three reserve mud pits, and area for steel tanks. On 17 October 1996, a crew from Boart Longyear, Inc. (Trice McDonald, foreman; Curtis Mitchell, day driller; Raymond Quesenberry, night driller; Shannon Hart, day helper; and Bradie Horton, night helper) began setting up. Space and electricity for core description were provided by the park superintendent, Dennis C. Fox. A field lab was set up onsite in a garage.

All cores were measured in feet (all depths are given in feet below land surface), and all operations are described in feet only. We continue to adopt ODP convention of top justifying depths for intervals with incomplete recovery for all field notes and photos.

The first core was obtained on 18 October 1996. Coring began at 4 ft using a Longyear Geo-barrel (HQ) system, 3.96-in hole diameter, and 2 1/8-in core diameter. The first core from 4 to 9 ft had no recovery. We changed the core barrel extension to 4 in below bit, coring predominantly gravelly sands and sandy clays. A total of 64 ft (19.51 m) was penetrated on 18 October, and 35.7 ft (10.88 m) was recovered from 60 ft (18.29 m) cored (59.5% recovery).

Drilling was halted at 0304 on 19 October to set 5 1/2-in PW steel casing into a silty clay layer penetrated between 66 and 74 ft (20.12 and 22.56 m). Coring resumed at 1642. Heavy rains on 19 and 20 October thinned the drilling mud, resulting in delays because of caving and poor recovery. After thickening the mud and washing the hole, coring resumed at 1425 on 20 October with excellent recovery (91% from 129 to 144.5 ft [39.32–44.04 m]). The day ended at 171 ft (52.12 m) with 43.6 ft recovered (65%).

On 21 October, poor recovery continued to be a problem while drilling through medium- to coarse-grained sands. Caving sands required extensive washing and redrilling between runs. Mud circulation was momentarily lost at one point in the night. Three feet of the core run between 187 and 192 ft (57.00 and 58.52 m) was recovered on the next core run (192–194 ft [58.52–59.13 m]); this core should be bottom justified. Three feet (0.91 m) was lost between 187 and 192 ft (57.00 and 58.52 m) but was picked up on the next core run (192–194 ft [58.52–59.13 m]); this core should be bottom justified. Sands caving in the hole required extensive washing and redrilling between runs and hindered recovery. Drillers continued to mix heavy muds, and hole conditions improved later in the day as the heavy mud appeared to hold back the caving sands. Recovery was good in interbedded clays and sands (214–219 ft [65.23–66.75 m]) and moderate (219–224 ft [66.75–68.28 m]) to excellent (224–229 ft [68.28–69.80 m]) in sands. Recovery improved as the lithology switched from a medium- to coarse-grained sand (at 234 ft [71.32 m]) to clays and silts. The day ended at 257 ft (78.33 m; 81 ft [24.69 m] cored, 63.1 ft [19.23 m] recovered; 78% recovery).

On 22 October, coring proceeded smoothly, and we enjoyed excellent recovery (90% between 257 and 314 ft [78.33 and 95.71 m]). Coring was suspended from 1030 to 1430 hr to clean tanks and mix new mud. Recovery on two runs between 314 and 324 ft (95.71 and 98.76 m) was hampered by clays that blocked the core catcher, resulting in washing away of the coarse interbedded sands. Caving of the "Atlantic City 800-ft sand" began to hamper operations. Circulation was lost after dropping the inner core barrel. The rods were pulled between 1900 and 2100 hr. We found 6 ft (1.83 m) of caved sand on top of the inner core. The hole was reentered with no problems in the first 90 ft (27.43 m) below casing. We reamed the hole from 160 to 324 ft (48.77–98.76 m).

Coring resumed on 23 October, recovering 6.3 ft (1.92 m) from 324 to 329 ft (98.76–100.28 m; 1.3 ft [0.40 m] is probably from the run above). We lost circulation after emplacing the inner core barrel. The rods were pulled, cleaned, and run back into the hole. We cored from 329 to 364 ft (100.28–110.95 m) until further caving required flushing the hole until 1800 hr. Once drilling resumed, we enjoyed excellent recovery. The day ended at 364 ft (110.95 m; 33.3 ft [10.15 m] recovered; 83%).

On 24 October, we cored from 364 to 449 ft (110.95–136.86 m) with excellent recovery in sands above 400 ft (121.92 m) and moderate recovery in sands from 400 to 449 ft (121.92–136.86 m). The rods periodically became stuck while trying to pump down the inner core barrel, and sand became packed off in the rods at 429 ft (130.76 m). The sand was flushed out by working the rods. At 449 ft (136.86 m), sand again packed into the rods and would not dislodge. We pulled the rods. At the end of the day, we had recovered 64.9 ft (19.78 m) from 85 ft (25.91 m) drilled (76% recovery).

On 25 October, we finished pulling rods out of the hole, cleaned 15 ft (4.57 m) of sand from the bottom of hole (BOH), began running rods back in the hole, and reamed from 85 ft (25.91 m) to BOH (449 ft [136.86 m]). The hole was flushed, pulling 30 ft (9.14 m) of cavings from the BOH. The mud tanks were half filled with sand; they were cleaned, and the drilling mud was thickened in an attempt to make the mud cake on the walls to prevent caving. Coring began at 2040 hr between 449 and 454 ft (136.86 and 138.38 m), after which 20 ft (6.10 m) of caving sand was removed.

On 26 October, we reamed to BOH and had full recovery between 454 and 458 ft (138.38 and 139.60 m). Coring proceeded to 471 ft (143.56 m), and the hole was reamed to BOH. Sand began to cave while retrieving the inner core barrel, and the rods were pulled to 40 ft (12.19 m). We decided to core 8 ft (2.44 m), or until the inner core barrel again became blocked. We cored to 479 ft (146.00 m) and cleaned 40 ft (12.19 m) of caving sands. The next core (479–489 ft [146.00–1419.05 m]) contained clay in the bottom 2 ft (0.61 m), indicating we had penetrated the composite confining unit in which we intended to set casing. Two 5-ft (1.52 m) runs made were made to 499 ft (152.10 m), recovering tight clays. We pulled rods, ran single-shot surveys at 255 and 95 ft (77.72 and 28.96 m), and began to case the hole with HW steel casing. The day ended at 499 ft (152.10 m; 28.4 ft [8.66 m] recovered from 45 ft [13.72 m] drilled; 63% recovery).

On 27 October, we continued to run HW casing. We began reaming at 90 ft (27.43 m), but it became difficult to advance casing between 420 and 430 ft (128.02 and 131.06 m). On 28 October, casing was set to 450 ft (137.16 m) by 0500 hr. We were unable to advance casing further and could not rotate the casing. Casing operations were ended, and the rig shutdown until 0800 hr on 29 October.

We began using Benseal during coring operations between 469 and 499 ft (142.95 and 152.10 m), and it appeared to stop the sand from caving. Before using Benseal, the hole required reaming each time the rods were raised. We pumped Benseal downhole after each core run and the rods made it back to bottom without having to ream. We hoped that Benseal would prevent caving of the "Atlantic City 800-ft sand" below casing (i.e., between 450 and 483.5 ft [137.16 and 147.37 m]) and planned to use it periodically when going through some of the lower sands.

On 29 October, John Curran of the NJGS obtained a gamma-ray log through steel casing from land's surface to 449 ft (136.86 m). The tool would not penetrate below this level. We began to run rods in the hole, but were delayed by break downs of the transmission and water swivel. We reamed from 446 to 499 ft (135.94–152.10 m) and resumed coring at 1830 hr. By the end of the day, we cored from 499 to 534 ft (152.10–162.76 m), recovering 35.9 ft (10.94 m; 103% recovery).

Smooth coring and excellent recovery continued on 30 October despite coring interbeds of indurated and soft sediments. We decided to continue 5 ft (1.52 m) runs to maximize recovery. We cored from 534 to 664 ft (162.76–202.39 m) and recovered 119.5 ft (36.42 m; 92% recovery).

On 31 October, drilling rates slowed slightly in clays with excellent recovery. We cleaned the tanks and mixed more mud. The clays began to slip out of the inner core barrel, and we made several short runs to recover slipped core. We cored from 664 to 744 ft (202.39–226.77 m) and recovered 70.7 ft (21.55 m; 88% recovery).

On 1 November, recovery was excellent (100% from 744 to 789 ft [226.77–240.49 m]). We stopped at 1030 hr to survey the hole and found a 1° deviation as noted in the previous survey. Excellent recovery continued from 789 to 794 ft (240.49–242.01 m) with 5 ft (1.52 m) recovered. Although recovery was excellent, the drillers were having trouble getting the cores out of the ground. The clays tended to stretch instead of breaking off cleanly, causing the core to fall out of the catcher. To prevent this we changed to a metal finger shoe and recovery dropped for the next two cores (794–804 ft [242.01–245.06 m]; 1.55 ft [0.47 m] recovered). We resumed using the collet core catcher and needed to go down into the hole several times on each run to retrieve entire core run, sometimes unsuccessfully. The day ended with 60.6 ft (18.47 m) recovered between 744 and 814 ft (226.77 and 248.11 m; 86% recovery).

On 2 November, progress slowed because of problems retrieving the core. We thinned the mud and began to overdrill, making each run slightly longer (e.g., running 5.4 ft [1.65 m] on a 5-ft [1.52 m] barrel) and jamming the core into the barrel. Good retrieval, full recovery, and rapid coring resumed. We recovered 59.9 ft (18.26 m) between 814 and 878.4 ft (248.11 and 267.74 m; 93% recovery).

Smooth coring continued on 3 November despite freezing temperatures overnight. Coring in harder clay helped with the slippage problem. We recovered 98.1 ft (29.90 m) between 878.4 and 978.3 ft (267.74 and 298.19 m; 98% recovery).

On 4 November, we had difficulties breaking the cores off in the hole. It took several runs to pack the inner core barrel off and recover the core. Hard porcellanitic layers were encountered that helped to break the core. We recovered 50.3 ft (16.33 m) between 978.3 and 1032 ft (298.19 and 314.55 m; 94% recovery).

On 5 November, slow coring continued because of slipping of the cores out of the barrel. We repaired the water swivel and took a survey. We recovered 86.4 ft (26.33 m) between 1032 and 1119 ft (314.55 and 341.07 m; 99% recovery).

On 6 November, short runs were made from 1124 to 1142 ft (342.6–348.08 m) because of core slippage. Below 1142 ft (348.08 m), core runs of 5 ft (1.52 m) were achieved. We recovered 83.5 ft (25.45 m) between 1119 and 1202.5 ft (341.07 and 366.52 m; 100% recovery).

On 7 November, smooth coring continued with slow drilling through clays and silts, although occasional slippage still occurred. Drilling rates increased as we penetrated glauconite sand, and Benseal was pumped into the hole on every other run. We recovered 99.1 ft (30.21 m) between 1202.5 and 1304.3 ft (366.52 and 397.55 m; 97% recovery).

On 8 November, smooth coring continued until 1316–1327 ft (401.12–404.47 m), when we penetrated very soft sand and found 5 ft (1.52 m) of fill. We began to use Benseal on every core. We lost circulation and the rods almost became stuck in these Mount Laurel Formation sands. We regained circulation and full unobstructed rotation and circulated batch mud from the reserve tank. The hole appeared to stabilize, and coring continued with the 4-in extension. We recovered 71.3 ft (21.73 m) between 1304.3 and 1391 ft (397.55 and 423.98 m; 82% recovery).

Rapid coring ensued on 9 November until ~2200 hr at 1497 ft (456.29 m), when pump pressure increased and we lost circulation. We spent the rest of the day working at regaining circulation. We recovered 97.5 ft (29.72 m) between 1391 and 1497 ft (423.98 and 456.29 m; 92% recovery).

We regained circulation and resumed coring on 10 November. We cleaned out the mud tanks at 1524 ft (464.52 m). While pulling the core out at 1550 ft (472.44 m), the chain came off of the sprocket. The pipe became stuck during the shutdown. We worked the stuck pipe and regained circulation and rotation. We recovered 67 ft (20.42 m) between 1497 and 1564 ft (456.29 and 476.71 m; 100% recovery).

On 11 November, drilling slowed in tight clays. Several sections broke off in the hole requiring additional runs to recover the core. We recovered 57.1 ft (17.4 m) between 1564 and 1623 ft (476.71 and 494.69 m; 97% recovery).

Slow coring continued on 12 November in clays requiring additional trips for each core. Coring began to improve in slightly sandy clays at 1650 ft (502.92 m), although the cores still continued to slip. Penetration rate went from under 4 ft/hr to ~9 ft/hr. We recovered 59.5 ft (18.14 m) between 1623 and 1684 ft (494.69 and 513.28 m; 98% recovery).

On 13 November, drilling was quick through the night as we penetrated glauconite sands. The hydraulic oil was low, and transmission fluid was substituted until daylight. The shims on the chuck and the pop-off valve were repaired. We crossed over into Magothy Formation interbedded clays and sands and changed to the 4-in (10 cm) extension, resulting in no recovery. We changed back to the regular core catcher, but still had poor to no recovery below 1728 ft (526.69 m). From 1728 to 1749 ft (526.68–533.10 m), only a combined total of 2.3 ft (0.70 m) was recovered. Overall, we recovered 53.3 ft (16.25 m) between 1684 and 1768 ft (513.28 and 538.89 m; 63% recovery).

On 14 November, we received and repaired the pop-off valve and chuck jaws. Recovery improved as we penetrated silts and clays (63.5 ft [19.35 m] between 1768 and 1839 ft [538.89 and 560.53 m; 89% recovery]).

On 15 November, slow drilling with excellent recovery continued. We recovered 7.4 ft (2.26 m) between 1873.8 and 1879 ft (571.13 and 572.72 m). Trice McDonald noted that the base of the hole was at 1879 ft (527.72 m); the over-recovery of 142% may be attributed to expansion of the sediments. Alternatively, assuming that the base of the hole is at 1881.3 ft (573.42 m), mean recovery for this interval is 104%. We recovered 71.4 ft (21.76 m) between 1839 and 1904 ft (560.53 and 580.34 m; 110% recovery).

Smooth coring continued on 16 November until 1924 ft (586.44 m). While getting ready to core to 1929 ft (587.96 m), the pump pressure increased, requiring the pipe to be pulled back up 10–15 ft (3.05–4.57 m). The hole was reamed slowly before coring continued, and the chuck in head was repaired. We recovered 49.5 ft (15.09 m) between 1904 and 1956.5 ft (580.34 and 596.34 m; 94% recovery). After coring to 1956.5 ft (596.34 m), the inner core barrel was pulled. Upon retrieving the inner core barrel, it was found the core lifter case had backed off in the pipe. We made several attempts to retrieve the case. While pulling the rods up 10 ft (3.05 m), the main hoist cable broke due to strain, and the hook fell to the rig floor. We began to repair the main hoist.

On 17 November, we made several more attempts to retrieve the core lifter case, including dropping a 10-ft (3.05 m) inner barrel with a modified shoe. The temperature during the night went down to 15°F, and the water lines froze. We determined that it might be necessary to pull the rods and that several days might ensue before reaching bottom again. Because the major scientific objectives were already attained, the hole was within 43.5 ft (13.26 m) of the intended bottom, and we had expended budgeted funds, we decided to run a gamma-ray log through the rods and to stop coring. John Curran obtained a gamma-ray log from 1930 to 1000 ft (588.26–304.80 m). We checked the rods during logging and discovered that they were stuck. Problems occurred with the logging tool, and we relogged the interval from 1930 ft (588.26 m) to surface. We ran the overshot and attached it to the inner core barrel, but could not pull it free. We pulled the wireline with the main hoist; it broke off 300 ft (91.44 m) above tool. We pulled on the pipe, left it in strain, and shutdown operations for the night.

On 18 November, we noted that no log data were recorded above 1500 ft (457.20 m) because of a computer problem; we relogged the hole from 1515 ft (461.77 m) to the surface. The digital log data from 1570 to 1650 ft were lost because of a computer virus. A field record of the analog gamma log was spliced into the digital gamma log in this missing interval. We shut down on 19 November waiting for tools. On 20 November, we recovered rods and casing, mixed and pumped cement to bottom, and capped the hole. The rig was released at 1700 hr, 20 November, and moved out 21 November. The location was restored to its original condition on 21 and 22 November.

At Bass River, we recovered 1685.9 ft (513.86 m) from a total hole of 1956.5 ft (596.34 m; mean recovery = 86.2%; median recovery = 99%; Table 1; Fig. 2). Cores were photographed onsite in color using Tungsten lighting and 160T film. Lithologies were described onsite and subsequently at the Rutgers core facility; these descriptions form the basis for the preliminary lithologic descriptions. Samples were obtained at ~5-ft (1.52 m) intervals for planktonic foraminiferal, calcareous nannofossil, and diatom biostratigraphy and coarse-fraction lithologic studies. Cores were cut into 2-ft sections, labeled at top and bottom of each section, placed into split PVC pipe (3-in diameter), wrapped in plastic sheeting, and stored in 2-ft wax boxes. Two hundred and six core boxes were moved to permanent storage at the Rutgers University core library for further study.

Despite various problems encountered during the 31 days of drilling and logging operations, the Bass River borehole was the most successful one drilled by the New Jersey Coastal Plain Drilling Project for recovery (both percentage and footage; Fig. 2), depth of penetration (1956.5 ft [596.34 m]), and rapidity of drilling operations (Fig. 3). It represents the deepest continuously cored borehole in the New Jersey Coastal Plain and recovered the first continuously cored record of the Upper Cretaceous.

LITHOSTRATIGRAPHY

Introduction

The on-site scientific team provided preliminary descriptions of sedimentary textures, structures, colors, fossil content, identification of lithostratigraphic units (NJGS Information Circular 1, 1990), and

Table 1. Core description, Bass River borehole.

Core	Depth (ft)	Recovery (ft)	Description	Color	Formation
1	4-9	0.0 (0%)	No recovery		Surficial
2	9-14	1.0 (20%)	Gravelly coarse sand	10YR 6/6 brownish yellow	Surficial
3	14-19	1.1 (22%)	Gravel, sandy clay at bottom	10YR 7/6 yellow	Surficial
			Lithologic contact at 19.7 ft		
4	19-20	2.8 (280%)	Gravel (caved), brown and dark gray clays, coarse quartz sands at base	7.5 6/6 reddish brown	Surficial/Cohansey
5	20-24	4.0 (100%)	Coarse quartz sand	5Y 7/1 gray	Cohansey
6	24-29	3.5 (70%)	Predominantly medium sand interbedded clays	5Y 7/2 light gray	Cohansey
7	29-34	2.0 (40%)	Medium quartz sand, not well sorted	5Y 5/1 gray	Cohansey
8	34-39	4.4 (88%)	Silty clay; quartz sand	10YR 5/3 brown	Cohansey
9	39-44	3.5 (70%)	Quartz sand; clay–sandy clay; may be caved	2.5YR 2.5/2 very dusky red	Cohansey
10	44-49	4.25 (85%)	Sandy clay; poorly sorted sand	10YR 6/6 brownish yellow	Cohansey
11	49-54	1.4 (28%)	Sandy clay grading in and out with poorly sorted sand, nodules of black clay	10YR 6/6 brownish yellow	Cohansey
12	54-59	5.3 (106%)	Sandy-brown to light gray clayey sand	10YR 6/6 brownish yellow	Cohansey
13	59-64	2.45 (49%)	Clayey sand yellow	7.5 YR 5/6 strong brown	Cohansey
14	64-65	1.0 (100%)	Coarse grading to very coarse sand; contact with silty clay	10YR 6/6 brownish yellow	Cohansey
15	65-69	1.1 (28%)	Poorly sorted sand; silty to sandy clay	10YR 5/8 yellowish brown	Cohansey
16	69-71	1.2 (60%)	Olive yellow silty clay	2.5Y 6/6 olive yellow	Cohansey
17	71-74	3.5 (117%)	Silty clays white with some yellow and red	10YR 7/1 light gray	Cohansey
18	74-75	1.2 (120%)	Fine sandy clay	10YR 7/1 light gray	Cohansey
19	75-79	1.0 (25%)	Fine sandy clay and clayey sand	10YR 6/6 brownish yellow	Cohansey
20	79-84	1.1 (22%)	Sandy clay	10YR 6/6 brownish yellow	Cohansey
21	84-89	0.3 (6%)	Coarse sand	10YR 6/6 brownish yellow	Cohansey
22	89-94	0.75 (15%)	Coarse sand	10YR 6/6 brownish yellow	Cohansey
23	94-96	0.3 (15%)	Medium sand	10YR 6/6 brownish yellow	Cohansey
24	96-99	2.15 (72%)	Four-color clays	10YR 3/1 very dark gray	Cohansey
25	99-104	5.05 (101%)	Clay grading to coarse sand	10YR 7/6 yellow	Cohansey
26	104-109	0.0 (0%)	?		Cohansey
27	109-114	5.3 (106%)	Coarse and medium sand, basal clay	10YR6/8 brownish yellow	Cohansey
28	114-119	1.75 (35%)	Medium sand	10YR 7/1 light gray	Cohansey
29	119-124	4.0 (80%)	Fine sand	7.5YR 6/8 reddish brown	Cohansey
30	124-129	3.55 (71%)	Very coarse sand	10YR 6/6 brownish yellow	Cohansey
			Lithologic contact at 132.9 ft		
31	129-134	4.7 (94%)	Medium sand with lower clay	10YR 7/8 yellow	Cohansey/Kirkwood
32	134-139	3.9 (78%)	Interbedded sand and clay	5Y 3/1 very dark gray	Kirkwood-Kw2b
33	139-144.5	5.5 (100%)	Interbedded sand and clay	10YR 4/1 dark gray	Kirkwood-Kw2b
34	144.5-149	2.9 (64%)	Medium sand	10YR 4/1 dark gray	Kirkwood-Kw2b
35	149-154	3.5 (70%)	Clay with minor sand beds	10YR 4/1 dark gray	Kirkwood-Kw2b
36	154-159	0.0 (0%)	?		Kirkwood-Kw2b
37	159-164	2.1 (42%)	Fine grained silty sand and silty clay	10YR 3/1 very dark gray	Kirkwood-Kw2b
38	164-169	1.35 (27%)	Very dark gray clay	2.5YR 3/1 very dark gray	Kirkwood-Kw2b
39	169-171	4.4 (220%)	Very dark gray clay	7.5YR 3/1 very dark gray	Kirkwood-Kw2b
40	171-172	1.9 (190%)	Silty sand	7.5YR 3/1 very dark gray	Kirkwood-Kw2b
41	172-177	4.4 (88%)	Clay to clayey fine sand	5YR 5/1 gray	Kirkwood-Kw2b
42	177-182	1.45 (29%)	Fine sandy clay/clayey fine sand	2.5Y 4/1 dark gray	Kirkwood-Kw2b
43	182-187	1.3 (26%)	Silty clay	10 YR 3/1 very dark gray	Kirkwood-Kw2b
44	187-192	2.0 (40%)	Clay to clayey fine sand	10YR 3/1 very dark gray	Kirkwood-Kw2b
45	192-194	4.7 (235%)	Interbedded sand and clay	5Y 4/1 dark gray	Kirkwood-Kw2b
46	194-199	2.3 (46%)	Very fine sandy silt	5Y 4/1 dark gray	Kirkwood-Kw2b
47	199-204	3.7 (74%)	Very fine sandy silt, lignite	5Y 4/1 dark gray	Kirkwood-Kw2b
			Lithologic contact at 205 ft		
48	204-209	0.0 (0%)	?		Kirkwood-Kw2a
49	209-214	2.0 (40%)	Medium sand	5Y 4/1 dark gray	Kirkwood-Kw2a
50	214-219	5.1 (102%)	Medium sand and chocolate clays	5Y 4/1 dark gray	Kirkwood-Kw2a
51	219-224	2.6 (52%)	Medium sand	5Y 4/1 dark gray	Kirkwood-Kw2a
52	224-229	5.05 (101%)	Medium-coarse sand	5Y 4/1 dark gray	Kirkwood-Kw2a
53	229-232	3.0 (100%)	Medium sand, coarse sand, ind zone	5Y 4/1 dark gray	Kirkwood-Kw2a
54	232-234	1.0 (50%)	Medium-coarse sand	5Y 4/1 dark gray	Kirkwood-Kw2a
55	234-237	3.5 (117%)	Top 0.3 ft medium-coarse sands; remainder = clays and silts	2.5Y 4/1 dark gray	Kirkwood-Kw2a
56	237-242	4.3 (86%)	Clays with fine-medium sand lenses	7.5YR 3/1 very dark gray	Kirkwood-Kw2a
57	242-247	5.4 (108%)	Clays with occasional silty fine sand beds	7.5YR 3/1 very dark gray	Kirkwood-Kw2a
58	247-252	4.7 (94%)	Micaceous clays	7.5YR 3/1 very dark gray	Kirkwood-Kw2a
59	252-257	4.7 (94%)	Micaceous clays, occasional clayey fine sand	7.5YR 3/1very dark gray	Kirkwood-Kw2a
60	257-262	3.0 (60%)	Same as above	7.5YR 3/1 very dark gray	Kirkwood-Kw2a
61	262-264	2.6 (130%)	Clayey silty sands	2.5Y 3/1 very dark gray	Kirkwood-Kw2a
62	264-269	3.5 (70%)	Silty clays, clayey sands	2.5Y 3/1 very dark gray	Kirkwood-Kw2a
63	269-274	4.7 (94%)	Clays	2.5Y 3/1 very dark gray	Kirkwood-Kw2a
64	274-279	5.25 (105%)	Clays and silty clays	2.5Y 3/1 very dark gray	Kirkwood-Kw2a
65	279-284	5.3 (106%)	Sandy silts and silts	10YR 4/1 very dark gray	Kirkwood-Kw2a
66	284-289	5.0 (100%)	Clay-silt interbedded with micaceous silty fine sand	7.5YR 3/2 dark brown	Kirkwood-Kw2a
67	289-294	1.6 (32%)	Silty sand	10YR 3/2 very dark grayish brown	Kirkwood-Kw2a
68	294-299	5.1 (102%)	Silty fine sand	10YR 4/1 dark gray	Kirkwood-Kw2a
69	299-304	5.0 (100%)	Silty micaceous fine sand	10YR 3/2 very dark grayish brown	Kirkwood-Kw2a
70	304-309	5.1 (102%)	Micaceous silty fine sand	5Y4/2 olive gray	Kirkwood-Kw2a
71	309-314	5.0 (100%)	Fine sand, sandy silt grading down to coarse sand	5Y4/2 olive gray	Kirkwood-Kw2a
72	314-319	1.5 (30%)	Medium-coarse sand, chocolate clay, and coarse sand	10YR 3/2 very dark grayish brown	Kirkwood-Kw2a
73	319-324	1.6 (32%)	Chocolate clay, occasional sands	10YR 3/2 very dark grayish brown	Kirkwood-Kw2a
			Lithologic contact at 329 ft		
74	324-329	6.3 (126%)	Chocolate clays and clayey fine sands	10YR 3/2 very dark grayish brown	Kirkwood-Kw1b
75	329-334	4.5 (90%)	Medium-coarse sands	2.5Y 5/1 gray	Kirkwood-Kw1b
76	334-339	3.0 (60%)	Medium- coarse sands with pebbles	2.5Y 5/1 gray	Kirkwood-Kw1b
77	339-344	0.0 (0%)			Kirkwood-Kw1b
78	344-349	4.2 (84%)	Clayey medium sands with pebbles	2.5Y 3/1 very dark gray	Kirkwood-Kw1b
79	349-354	4.7 (94%)	Medium-coarse sands to sandy clays	2.5Y 3/1 very dark gray	Kirkwood-Kw1b
80	354-359	5.5 (110%)	Medium-coarse sands top clays bottom	2.5Y 5/3 light olive brown	Kirkwood-Kw1b

Table 1 (continued).

Core	Depth (ft)	Recovery (ft)	Description	Color	Formation
81	359-364	5.1 (102%)	Clays to clayey sands	2.5Y 5/1 gray	Kirkwood-Kw1b
82	364-369	5.2 (104%)	Clays top, fine-medium sands, frequent lignite	2.5Y 3/1 very dark gray	Kirkwood-Kw1b
83	369-374	4.3 (86%)	Medium top, clays below	2.5Y 3/1 very dark gray	Kirkwood-Kw1b
84	374-379	5.3 (106%)	Sands above, clays below	2.5Y 5/1 gray	Kirkwood-Kw1b
85	379-384	5.5 (110%)	Medium sands, interbedded salts and clays	2.5Y 4/1 dark gray	Kirkwood-Kw1b
			Lithologic contact at 329 ft		
86	384-389	4.9 (98%)	Muddy medium sand	5Y 4/1 dark gray	Kirkwood-Kw1a
87	389-394	5.2 (104%)	Muddy medium sand	5Y 4/1 dark gray	Kirkwood-Kw1a
88	394-399	4.9 (98%)	Medium sand, very coarse sand, muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
89	399-404	3.0 (60%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
90	404-407	3.9 (130%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
91	407-412	0.6 (12%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
92	412-414	1.1 (55%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
93	414-419	1.4 (28%)	Muddy medium sand, coarse sand	5Y 5/1 gray	Kirkwood-Kw1a
94	419-423	4.1 (103%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
95	423-425	1.8 (45%)	Muddy medium sand	5Y 4/1 dark gray	Kirkwood-Kw1a
96	424-429	1.8 (90%)	Muddy medium sand	5Y 4/1 dark gray	Kirkwood-Kw1a
97	429-434	3.8 (76%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
98	434-439	1.0 (20%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
99	438-444	2.0 (40%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
100	444-449	5.3 (106%)	Muddy medium sand	5Y 5/1 gray	Kirkwood-Kw1a
101	449-454	5.4 (108%)	Medium sand	10YR 5/1 gray	Kirkwood-Kw1a
102	454-459	0.45 (9%)	Medium sand	10YR 5/1 gray	Kirkwood-Kw1a
103	459-464	5.85 (117%)	Medium-coarse sand	10YR 5/1 gray	Kirkwood-Kw1a
104	464-469	0.5 (10%)	Coarse sand	10YR 5/1 gray	Kirkwood-Kw1a
105	469-471	2.2 (110%)	Coarse sand	5Y 5/1 gray	Kirkwood-Kw1a
106	471-479	3.2 (40%)	Medium-coarse sand	5Y 5/1 gray	Kirkwood-Kw1a
107	479-489	5.5 (55%)	Medium sand and laminated clays	7.5YR 5/1 gray	Kirkwood-Kw1a
108	489-494	5.3 (106%)	Laminated silts and clays	7.5YR 2.5/3 very dark brown	Kirkwood-Kw1a
109	494-499	5.4 (108%)	Laminated silts and clays	7.5YR 3/1 very dark gray	Kirkwood-Kw1a
110	499-504	5.5 (110%)	Laminated micaceous silts and clays	2.5YR 3/1 reddish brown	Kirkwood-Kw1a
111	504-509	5.3 (106%)	Laminated micaceous silts and clays	2.5YR 3/1 reddish brown	Kirkwood-Kw1a
112	509-514	3.4 (68%)	Laminated micaceous silts and clays	2.5YR 3/1 reddish brown	Kirkwood-Kw1a
113	514-516	3.2 (160%)	Laminated micaceous silts and clays	2.5YR 3/1 reddish brown	Kirkwood-Kw1a
114	516-519	3.9 (130%)	Muddy fine grained sand	10 YR 3/2 very dark grayish brown	Kirkwood-Kw1a
115	519-524	4.9 (98%)	Clayey silt to sandy silt; individual nodules	10 YR 3/2 very dark grayish brown	Kirkwood-Kw1a
116	524-529	5.2 (104%)	Clays coarsen up to fine sands	10 YR 3/2 very dark grayish brown	Kirkwood-Kw1a
117	529-534	4.5 (90%)	Micaceous clayey sandy silts	2.5Y 3/2 very dark grayish brown	Kirkwood-Kw1a
118	534-539	5.0 (100%)	Micaceous clayey sandy silts	2.5YR 3/1 reddish brown	Kirkwood-Kw1a
119	539-544	5.1 (102%)	Micaceous clayey sandy silts	2.5YR 3/1 reddish brown	Kirkwood-Kw1a
120	544-549	1.0 (20%)	Micaceous clayey sandy silts	5Y 3/1 very dark gray	Kirkwood-Kw1a
121	549-554	5.0 (100%)	Shelly glauconitic clays and fine- medium quatz sands	5Y 3/1 very dark gray	Kirkwood-Kw1a
			Lithologic contact at 555.3 ft		
122	554-559	3.6 (72%)	Glauconite shelly clays/indurated glauconite sands	5Y 3/1 very dark gray/10YR 2/1 black	Kirkwood/Atlantic City
123	559-564	5.1 (102%)	Shelly clayey glauconitic sand	5Y 2.5/2 black	Atlantic City
124	564-569	5.1 (102%)	Muddy shelly quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
125	569-574	5.0 (100%)	Muddy shelly quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
126	574-579	5.4 (108%)	Muddy shelly quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
127	579-584	5.0 (100%)	Muddy shelly quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
128	584-589	5.2 (104%)	Muddy quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
129	589-594	4.9 (98%)	Muddy quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
130	594-599	4.5 (90%)	Muddy quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
131	599-604	4.75 (95%)	Muddy quartzose shelly glauconite sand; indurated	5Y 3/2 dark olive gray	Atlantic City
132	604-609	5.1 (102%)	Muddy shelly quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
133	609-614	5.1 (102%)	Muddy shelly quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
134	614-619	0.3 (6%)	Muddy quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
135	619-624	5.3 (106%)	Muddy very coarse quartzose glauconite sand	5Y 3/2 dark olive gray	Atlantic City
136	624-629	4.6 (92%)	Coarse quartzose medium glauconite	5Y 3/2 dark olive gray	Atlantic City
137	629-634	5.1 (102%)	Medium-coarse quartzose fine-medium glauconite sand	5Y 3/2 dark olive gray	Atlantic City
138	634-639	4.4 (88%)	Medium-coarse quartzose fine-medium glauconite sand	5Y 3/2 dark olive gray	Atlantic City
139	639-644	5.0 (100%)	Medium-coarse quartzose fine-medium glauconite sand	5Y 3/2 dark olive gray	Atlantic City
140	644-649	5.0 (100%)	Medium-coarse quartzose fine-medium glauconite sand	5Y 3/2 dark olive gray	Atlantic City
141	649-654	5.0 (100%)	Medium-coarse quartzose fine-medium glauconite sand	5Y 3/2 dark olive gray	Atlantic City
			Lithologic contact at 655.3 ft		
142	654-659	4.9 (98%)	Medium-coarse quartzose fine-medium glauconite sand	5Y 3/2 dark olive gray	Sewell Pt
143	659-664	5.0 (100%)	Medium quartzose clayey fine-medium glauconite sand	5Y 3/2 dark olive gray	Sewell Pt
144	664-669	4.9 (98%)	Fine-medium quartzose clayey glauconite sand	5Y 3/2 dark olive gray	Sewell Pt
145	669-674	1.5 (30%)	Fine quartzose clayey glauconite sand	2.5YR 3/2 dark olive gray	Sewell Pt
			Lithologic contact at 675.4 ft		
146	674-679	5.3 (106%)	Lithologic break:clayey glauconite above, brown clays below	2.5Y 5/2 grayish brown	Sewell Point/Absecon Inlet
147	679-684	0.5 (10%)	Brown clays	2.5Y 3/2 dark olive gray	Absecon Inlet
148	684-686	3.4 (170%)	Brown clays; contact at 684.9 ft	2.5Y 3/2 dark olive gray	Absecon Inlet
149	686-689	3.3 (110%)	Fossiliferous silty clay	5Y 3/2 dark olive gray	Absecon Inlet
150	689-694	5.1 (102%)	Fossiliferous silty clay	5Y 3/2 dark olive gray	Absecon Inlet
151	694-699	3.7 (74%)	Fossiliferous silty clay	5Y 3/1 very dark gray	Absecon Inlet
152	699-701	1.3 (65%)	Fossiliferous glauconitic silty clay	5Y 3/1 very dark gray	Absecon Inlet
153	701-704	3.2 (107%)	Glauconitic silty clay	5Y 3/2 very dark gray	Absecon Inlet
154	704-709	5.3 (106%)	Fossiliferous silty clay	2.5Y 3/1 very dark gray	Absecon Inlet
155	709-710	1.2 (120%)	Fossiliferous glauconitic silty clay	2.5Y 3/1 very dark gray	Absecon Inlet
156	710-715	5.9 (118%)	Fossiliferous silty clay; 2 shell beds	5Y 2.5/2 black	Absecon Inlet
157	715-719	3.3 (83%)	Fossiliferous silty clay	3/N 3/ very dark gray	Absecon Inlet
158	719-724	6.0 (120%)	Fossiliferous silty clay; 4 shell beds	3/N 3/ very dark gray	Absecon Inlet
159	724-729	2.05 (41%)	Fossiliferous silty clay	3/N 3/ very dark gray	Absecon Inlet
160	729-734	5.45 (109%)	Fossiliferous silty clay	5Y 2.5/2 black	Absecon Inlet
161	734-739	5.3 (106%)	Fossiliferous silty clay; shell bed	2.5Y 2/1 black	Absecon Inlet

Table 1 (continued).

Core	Depth (ft)	Recovery (ft)	Description	Color	Formation
162	739-744	4.95 (99%)	Glauconitic fossiliferous silty clay	2.5Y 3/1 very dark gray	Absecon Inlet
163	744-749	4.7 (94%)	Glauconitic fossiliferous silty clay	2.5Y 3/1 very dark gray	Absecon Inlet
164	749-754	5.05 (101%)	Glauconitic fossiliferous silty clay	2.5Y 3/1 very dark gray	Absecon Inlet
165	754-760.5	6.4 (98%)	Glauconitic fossiliferous silty clay	2.5Y 3/1 very dark gray	Absecon Inlet
166	760.5-764	4.7 (134%)	Glauconitic fossiliferous silty clay; sandy clay; 3 shell beds	2.5Y 3/1 very dark gray	Absecon Inlet
167	764-769	4.5 (90%)	Glauconitic fossiliferous silty clay	10YR 2/2 very dark brown	Absecon Inlet
168	769-774	5.0 (100%)	Glauconitic fossiliferous silty clay	10YR 3/1 very dark gray	Absecon Inlet
169	774-779	4.4 (88%)	Glauconitic fossiliferous silty clay	10YR 3/1 very dark gray	Absecon Inlet
170	779-784	5.5 (110%)	Glauconitic fossiliferous silty clay	10YR 3/1 very dark gray	Absecon Inlet
171	784-789	4.7 (94%)	Glauconitic fossiliferous silty clay	10YR 3/1 very dark gray	Absecon Inlet
172	789-794	5.0 (100%)	Interbedded fossiliferous glauconitic clays and glauconitic silts	10YR 3/1 very dark gray	Absecon Inlet
173	794-799	1.25 (25%)	Interbedded fossiliferous glauconitic clays and glauconitic silts	5Y 3/1 very dark gray	Absecon Inlet
174	799-804	0.3 (6%)	Interbedded fossiliferous glauconitic clays and glauconitic silts	5Y 3/1 very dark gray	Absecon Inlet
175	804-809	3.95 (79%)	Interbedded fossiliferous glauconitic clays and glauconitic silts	5Y 3/1 very dark gray	Absecon Inlet
176	809-814	5.1 (102%)	Silty clay, very clayey, corals	2.5Y 3/2 very dark gray	Absecon inlet
177	814-819	3.3 (66%)	Glauconitic fossiliferous sandy clay; interbed fossiliferous glauconitic clays and silts	5Y 3/1 very dark gray	Absecon Inlet
178	819-824	3.8 (76%)	Interbedded fossiliferous glauconitic clays and gl silts	5Y 3/1 very dark gray	Absecon Inlet
179	824-829	5.0 (100%)	Glauconitic sandy silty clay	5Y 3/1 very dark gray	Absecon Inlet
180	829-836	7.0 (100%)	Glauconitic sandy silty clay, glauconitic clay; clayey glauconitic sand at base	2.5 YR 3/2 very dark grayish brown	Absecon Inlet
181	836-841.4	5.4 (100%)	Clayey glauconitic sand; fossiliferous glauconitic sandy clay; contact at 840.5 ft	2.5Y 3/2 very dark grayish brown	Absecon Inlet
182	841.4-845.9	4.6 (102%)	Fossiliferous glauconitic sandy clay	2.5Y 3/2 very dark grayish brown	Absecon Inlet
			Lithologic contact at 846.6 ft		
183	845.9-851.4	5.5 (100%)	Fossiliferous glauconitic sandy clay	5Y 3/2 dark olive gray	Absecon Inlet/upper Shark River
184	852-857.3	5.3 (90%)	Glauconitic slightly sandy clay	5Y 3/2 dark olive gray	Upper Shark River
185	857.3-862.6	5.3 (100%)	Fossiliferous glauconitic clay	5Y 3/2 dark olive gray	Upper Shark River
186	862.6-867.9	5.3 (100%)	Fossiliferous glauconitic clay; slightly glauconitic clay	5GY 4/1 dark greenish fray	Upper Shark River
187	867.9-873.2	3.7 (70%)	Fossiliferous glauconitic silty clay	5GY 4/1 dark greenish fray	Upper Shark River
188	873.2-877	1.8 (47%)	Fossiliferous glauconitic clay	5GR 4/2 dark greenish gray	Upper Shark River
189	877-878.4	3.9 (279%)	Fossiliferous glauconitic clay	5GR 5/1 greensih gray	Upper Shark River
190	878.4-883.7	5.45 (103%)	Fossiliferous glauconitic clay	5Y 3/2 dark olive gray	Upper Shark River
			Lithologic contact at 885.8 ft		
191	883.7-889	5.3 (100%)	Slightly glauconitic clay/clay	5GY 7/1 light greenish gray	Upper Shark River/lower Shark River
192	889-894	4.35 (87%)	Bioturbated clay	5GY 7/1 light greenish gray	Lower Shark River
193	894-899	4.9 (98%)	Bioturbated clay	5GY 6/1 greenish gray	Lower Shark River
194	899-904	5.3 (106%)	Slightly glauconitic burrowed clay	5GY 6/1 greenish gray	Lower Shark River
195	904-909	5.0 (100%)	Slightly glauconitic burrowed clay	5GY 6/1 greenish gray	Lower Shark River
196	909-914.2	5.2 (100%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
197	914.2-919	4.6 (96%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
198	919-922	2.9 (97%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
199	922-927.7	5.8 (102%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
200	927.7-932.9	5.2 (100%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
201/202	932.9-939	5.4 (89%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
203	939-944.3	5.7 (108%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
204	944.3-950	5.7 (100%)	Slightly glauconitic burrowed silty clay	5GY 6/1 greenish gray	Lower Shark River
205	950-954	2.4 (60%)	Glauconitic burrowed silty clay	2.5Y 6/2 light brownish gray	Lower Shark River
206	954-959	5.25 (105%)	Glauconitic burrowed silty clay; sequence boundary 954.3 ft	5GY 6/1 greenish gray	Lower Shark River
			Lithologic contact at 959.85 ft		
207	959-964	5.2 (104%)	Glauconitic burrowed silty clay	5GY 6/1 greenish gray	Shark River/Manasquan
208	964-969	5.3 (106%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
209	969-974	3.8 (76%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
210	974-978.3	5.3 (123%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
211	978.3-983.6	5.3 (100%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
212	983.6-988.9	3.8 (72%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
213	988.9-994	5.3 (104%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
214/215	994-997.5	3.5 (100%)	Bioturbated silty clay	5GY 4/1 dark greenish gray	Manasquan
216/217	997.5-1003	5.5 (100%)	Bioturbated silty clay	5GY 4/1 dark greenish gray	Manasquan
218	1003-1009	5.4 (90%)	Bioturbated silty clay	5GY 4/1 dark greenish gray	Manasquan
219	1009-1114	5.3 (106%)	Bioturbated silty clay	5GY 4/1 dark greenish gray	Manasquan
220	1014-1019	5.5 (100%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
221	1019.5-1026	5.2 (80%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
222	1026-1032	5.5 (92%)	Bioturbated silty clay	5GY 5/1 greenish gray	Manasquan
223-225	1032-1040.5	8.9 (105%)	Bioturbated silty clay	5GY 5/1 greenish gray	Manasquan
226	1040.8-1045.8	5.2 (98%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
227	1045.5-1051	6.4 (123%)	Bioturbated silty clay	5GY 6/1 greenish gray	Manasquan
228-229	1051-1057.6	5.2 (79%)	Bioturbated silty clay	5GY 5/1 greenish gray	Manasquan
230	1057.6-1063	5.3 (98%)	Bioturbated silty clay	5GY 5/1 greenish gray	Manasquan
231	1063-1069	5.6 (93%)	Bioturbated silty clay; sequence boundary at 1063.3 ft	5GY 5/1 greenish gray	Manasquan
232	1069-1074.2	5.2 (100%)	Alternating porcellantic silty clay and silty clay	5GY 5/1 greenish gray	Manasquan
233	1074.2-1079.2	5.2 (104%)	Alternating porcellantic silty clay and silty clay	5GY 5/1 greenish gray	Manasquan
234	1079.2-1084.7	5.6 (102%)	Alternating porcellantic silty clay and silty clay	5GY 4/1 dark greenish gray	Manasquan
235	1084.7-1088	3.4 (103%)	Alternating porcellantic silty clay and silty clay; shelly bed 1185.5 ft	5GY 4/1 dark greenish gray	Manasquan
236	1088-1093.3	5.3 (100%)	Alternating porcellantic silty clay and silty clay	5GY 4/1 dark greenish gray	Manasquan
237	1093.3-1099	5.3 (93%)	Alternating porcellantic silty clay and silty clay	5GY 4/1 dark greenish gray	Manasquan
238	1099-1104	4.4 (88%)	Alternating porcellantic silty clay and silty clay	5GY 4/1 dark greenish gray	Manasquan
239	1104-1109	5.4 (108%)	Alternating porcellantic silty clay and silty clay	5G 5/2 grayish green	Manasquan
240	1109-1114.3	4.5 (85%)	Alternating porcellantic silty clay and silty clay	5G 5/2 grayish green	Manasquan

Table 1 (continued).

Core	Depth (ft)	Recovery (ft)	Description	Color	Formation
241	1114.3-1119	5.1 (109%)	Alternating porcellantic silty clay and silty clay	5G 5/2 grayish green	Manasquan
242-243	1119-1124.5	5.0 (91%)	Alternating clay and silty clay	5G 5/2 grayish green	Manasquan
244	1124.5-1129	3.1 (69%)	Alternating clay and silty clay	5G 5/2 grayish green	Manasquan
245	1129-1132	3.2 (107%)	Clay	5G 5/2 grayish green	Manasquan
246	1132-1136	3.1 (78%)	Clay to 1134 ft; glauconitic clays below	5GY 4/1 dark greenish gray	Manasquan
			Lithologic contact at 1138.6 ft		
247	1136-1139	2.7 (90%)	Glauconitic clays	5GY 4/1 dark greenish gray	Manasquan/Vincentown
248-249	1139-1142.5	3.6 (103%)	Clay	5G 4/1 dark greenish gray	Vincentown
250	1142.6-1148	5.4 (98%)	Clay	5G 4/1 dark greenish gray	Vincentown
251	1148-1153.5	5.5 (100%)	Clay	5G 4/1 dark greenish gray	Vincentown
252	1153.5-1160	5.7 (88%)	Clay	5G 4/1 dark greenish gray	Vincentown
253	1160-1164	4.0 (100%)	Clay	5Y 5/1 gray	Vincentown
254	1164-1170	5.5 (92%)	Clay	5G 4/1 dark greenish gray	Vincentown
255	1170-1176	5.6 (93%)	Clay	5G 4/1 dark greenish gray	Vincentown
256	1176-1181.5	5.1 (93%)	Glauconitic silty micaceous clay	5G 4/1 dark greenish gray	Vincentown
257	1181.5-1186.5	5.6 (112%)	Glauconitic silty micaceous clay	5G 4/1 dark greenish gray	Vincentown
258-259	1186.5-1192.5	5.3 (88%)	Glauconitic silty micaceous clay	5Y 3/1 very dark gray	Vincentown
260	1192.5-1197.5	4.9 (98%)	Glauconitic silty micaceous clay	5Y 3/1 very dark gray	Vincentown
261	1197.5-1202.5	5.1 (102%)	Slightly silty micaceous glauconitic clay	5Y 3/1 very dark gray	Vincentown
262	1202.5-1208	0.4 (7%)	Very hard, silty, micaceous glauconitic clay	5Y 3/1 very dark gray	Vincentown
263	1208-1209	5.0 (500%)	Very hard, silty, micaceous glauconitic clay	5Y 3/1 very dark gray	Vincentown
264	1209-1214.3	5.5 (104%)	Very hard, silty, micaceous clay	5Y 3/1 very dark gray	Vincentown
265	1214.3-1219.6	5.1 (96%)	Indurated silty, slightly glauconitic micaceous clay	5GY 4/1 dark greenish gray	Vincentown
266	1219.6-1224.9	5.3 (100%)	Indurated silty, slightly glauconitic micaceous clay	5Y 3/1 very dark gray	Vincentown
267	1224.9-1230.2	5.4 (102%)	Indurated silty, slightly glauconitic micaceous clay	5Y 3/1 very dark gray	Vincentown
268	1230.2-1236	5.3 (91%)	Indurated silty, slightly glauconitic micaceous clay	5Y 3/1 very dark gray	Vincentown
269	1236-1241.4	5.4 (100%)	Slightly glauconitic micaceous clayey silt	5Y 3/1 very dark gray	Vincentown
270	1241.4-1246.2	5.2 (108%)	Glaucontic silt; contact	5Y 4/1 dark gray	Vincentown
			Lithologic contact at 1248.9 ft		
271	1246.2-1251.6	5.4 (100%)	Clayey micaceous glauconite sand	5Y 4/1 dark gray	Vincentown/Hornerstown
272	1251.6-1257	5.2 (96%)	Glauconite sand; gryphae shells 1251.9-1252.8 ft	5Y 4/1 dark gray	Hornerstown
273	1257-1259.5	2.5 (100%)	Clayey glauconite sand, clasts, sequence boundary 1258.7 ft; glauconitic clay below	5Y 4/1 dark gray	Hornerstown
			Lithologic contact at 1260.25 ft		
274	1259.5-1266	5.6 (86%)	Clayey glauconite sand contact 1260.2 ft spherule layer, glauconitic clay	5Y 3/1 very dark gray	Hornerstown/New Egypt
			Lithologic contact at 1260.25 ft		
275	1266-1271.3	5.4 (102%)	Glauconitic clay	2.5 Y 3/1 very dark gray	New Egypt/Navesink
276	1271.3-1277.5	5.7 (92%)	Bioturbated silty glauconitic clay	5Y 4/1 dark gray	Navesink
277	1277.5-1282.5	5.3 (106%)	Bioturbated clayey glauconite sand	2.5Y 5/1 gray	Navesink
278	1282.5-1288	5.4 (98%)	Bioturbated clayey glauconite sand	2.5Y 5/1 gray	Navesink
279	1288-1293.5	5.4 (98%)	Bioturbated clayey glauconite sand	2.5Y 5/1 gray	Navesink
			Lithologic contact at 1294.5 ft		
280	1293.5-1299	5.2 (95%)	Silty glauconite/quartz sand	5Y 6/2 light olive gray	Navesink/Mount Laurel
281	1299-1304.3	5.4 (102%)	Silty glauconitic quartz sand	5Y 6/2 light olive gray	Mount Laurel
282	1304.3-1309.6	5.3 (100%)	Silty glauconitic quartz sand	5Y 6/2 light olive gray	Mount Laurel
283	1309.6-1316	5.1 (80%)	Silty glauconite/quartz sand	5Y 6/2 light olive gray	Mount Laurel
284-286	1316-1327	3.2 (29%)	Fossiliferous glauconite/quartz sand	5Y 6/2 light olive gray	Mount Laurel
287	1327-1332	5.0 (100%)	Burrowed glauconitic quartz sand	5Y 4/1 dark gray	Mount Laurel
288	1332-1337	3.3 (66%)	Glauconitic quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
289-290	1337-1342	2.3 (46%)	Glauconitic micaceous quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
290-291	1342-1349	5.5 (79%)	Glauconitic micaceous quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
291	1349-1354	5.2 (104%)	Glauconitic slightly micaceous quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
292	1354-1359	5.0 (100%)	Silty micaceous glauconitic quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
293	1359-1364	4.7 (94%)	Silty micaceous glauconitic quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
294	1364-1369	5.3 (106%)	Silty micaceous glauconitic quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
295	1369-1374	5.2 (104%)	Silty micaceous glauconitic quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
296	1374-1379	5.3 (106%)	Glauconitic micaceous silty fine sand; clayey at base	5GY 4/1 dark greenish gray	Mount Laurel
297	1379-1384	5.4 (108%)	Silty clayey micaceous glauconitic fine quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
298	1384-1389	1.2 (24%)	Silty clayey micaceous glauconitic fine quartz sand	5GY 4/1 dark greenish gray	Mount Laurel
299	1389-1391	4.3 (215%)	Slightly clayey glauconitic silty fine sand	5GY 4/1 dark greenish gray	Mount Laurel
			Lithologic contact at 1391 ft		
300	1391-1397.5	5.6 (86%)	Slightly glauconitic micaceous silt	5GY 4/1 dark greenish gray	Wenonah
301	1397.5-1403	5.6 (102%)	Slightly glauconitic micaceous silt	5GY 4/1 dark greenish gray	Wenonah
302	1403-1409	5.5 (92%)	Slightly glauconitic micaceous silt	5GY 4/1 dark greenish gray	Wenonah
303	1409-1414	5.5 (110%)	Slightly glauconitic micaceous silt	5GY 4/1 dark greenish gray	Wenonah
304	1414-1419	5.5 (110%)	Micaceous very fine sandy silt with silty sand	10YR 4/1 dark gray	Wenonah
305	1419-1424	5.05 (101%)	Slighlty glauconitic clayey micaceous silt	10YR 4/1 dark gray	Wenonah
306	1424-1429	5.3 (106%)	Micaceous glauconitic silt	5Y 3/1 very dark gray	Wenonah
			Lithologic contact at 1429 ft		
307	1429-1435	4.4 (73%)	Clayey glauconite sand	5GY 4/1 dark greenish gray	Marshalltown
			Lithologic contact at 1440.5 ft		
308	1435-1440.5	5.5 (100%)	Indurated clayey glauconite sand; micaceous glauconitic clayey fine sand below. sequence boundary at base	5GY 4/1 dark greenish gray	Marshalltown/upper? Englishtown
309	1440.5-1446.5	5.3 (88%)	Micaceous clayey fine sand; slighlty glauconitic	5Y 3/1 very dark gray	Upper? Englishtown
310	1446.5-1451.8	5.3 (100%)	Very micaceous silty fine sand with clay interbeds	5Y 3/1 very dark gray	Upper? Englishtown
311	1451.8-1459	5.1 (67%)	Micaceous silty very fine sand to clay silt; slightly glauconitic	5Y 3/1 very dark gray	Upper? Englishtown
312	1459-1464	5.4 (108%)	Bioturbated, shelly, micaceous, slightly glaucontic, silty clay; more clayey and glauconitic at base	5Y 3/1 very dark gray	Upper? Englishtown
313	1464.4-1469	5.4 (117%)	Glauconitic silty clay; glauconitic clay at base	5Y 3/1 very dark gray	Upper? Englishtown
			Lithologic contact at 1472.6 ft		

Table 1 (continued).

Core	Depth (ft)	Recovery (ft)	Description	Color	Formation
314	1469-1474.5	5.4 (98%)	Glauconitic silty clay/micaceous silty fine sand	5Y 3/1 very dark gray	Upper Englishtown/lower Englishtown
315	1474.5-1480	5.4 (98%)	Micaceous silty fine sand	5Y 3/1 very dark gray	Lower Englishtown
316	1480-1487	5.4 (77%)	Micaceous silty fine sand	5Y 3/1 very dark gray	Lower Englishtown
			Lithologic contact at 1488 ft		
317	1487-1492	2.9 (58%)	Micaceous silty fine sand	5Y 3/1 very dark gray	Lower Englishtown/ Woodbury
318	1492-1497	3.95 (79%)	Micaceous silty clay	5Y 2.5/1 black	Woodbury
319	1497-1498	1.85 (185%)	Micaceous silty clay	5Y 2.5/1 black	Woodbury
320	1498-1503	5.4 (108%)	Micaceous silty clay	5Y 2.5/1 black	Woodbury
321	1503-1509	5.7 (95%)	Micaceous silty clay	5Y 2.5/1 black	Woodbury
322	1509-1514	5.8 (116%)	Micaceous silty clay	5Y 2.5/1 black	Woodbury
323	1514-1519	4.9 (98%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
324	1519-1524.5	5.4 (98%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
325	1524.5-1529.6	5.1 (100%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
326	1529.6-1534.2	4.8 (104%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
327	1534.2-1539	4.7 (98%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
328	1539-1543	3.9 (98%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
329	1543-1550	4.25 (61%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
330	1550-1554	5.3 (133%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
331	1554-1559	4.8 (96%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
332	1559-1564	5.3 (106%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
333	1564-1569	5.0 (100%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
334	1569-1574	5.2 (104%)	Micaceous silty clay	N 3/ very dark gray	Woodbury
335	1574-1577	3.0 (100%)	Slightly silty clay	N 2.5/ black	Woodbury
336	1577-1582.5	5.5 (100%)	Slightly silty clay	N 2.5/ black	Woodbury
337	1582.5-1588	5.5 (100%)	Slightly silty clay	N 2.5/ black	Woodbury
338	1588-1593.7	5.7 (100%)	Slightly silty clay	N 3/ very dark gray	Woodbury
339	1593.7-1597.7	4.0 (100%)	Very slightly silty clay	N 3/ very dark gray	Woodbury
340	1597.7-1603	5.3 (100%)	Clay	N 3/ very dark gray	Woodbury
341	1603-1609	5.6 (93%)	Clay	N 3/ very dark gray	Woodbury
342	1609-1614	4.5 (90%)	Clay	N 3/ very dark gray	Woodbury
343	1614-1619	2.4 (48%)	Micaceous clay	N 3/ very dark gray	Woodbury
344	1619-1623	5.4 (135%)	Micaceous clay	N 3/ very dark gray	Woodbury
345	1623-1628	4.5 (90%)	Micaceous clay	N 3/ very dark gray	Woodbury
346	1628-1633	4.9 (98%)	Glauconitic clays	N 3/ very dark gray	Woodbury
347	1633-1638	4.7 (94%)	Slightly silty clay	N 3/ very dark gray	Woodbury
348	1638-1642	4.7 (118%)	Slightly silty clay	N 3/ very dark gray	Woodbury
349	1642-1647.4	5.3 (98%)	Slightly silty clay	N 3/ very dark gray	Woodbury
350	1647.4-1652.4	5.0 (100%)	Slightly silty clay	N 3/ very dark gray	Woodbury
			Lithologic contact at 1655 ft		
351	1652.4-1656.8	4.4 (100%)	Slightly silty clay/foraminiferal clay	N 4/ dark gray	Woodbury/Merchantville
352	1656.8-1661.9	5.1 (100%)	Glauconitic foraminiferal silty clay	N 4/1 dark gray	Merchantville
353	1661.9-1667.1	5.2 (100%)	Glauconitic foraminiferal silty clay	N 4/ dark gray	Merchantville
354	1667.1-1672.8	5.6 (98%)	Glauconitic foraminiferal silty clay	N 3/ very dark gray	Merchantville
355	1672.8-1678.5	4.8 (84%)	Glauconitic silty clay	N 3/ very dark gray	Merchantville
			Lithologic contact at 1683.2 ft		
356	1678.5-1684	5.3 (96%)	Glauconitic silty clay	N 3/ very dark gray	Merchantville/Cheesequake
357	1684-1689	5.4 (108%)	Clayey glauconitic sand	N 3/ very dark gray	Cheesequake
358	1689-1694	5.5 (110%)	Clayey glauconitic sand	N 3/ very dark gray	Cheesequake
359	1694-1699	4.8 (96%)	Clayey glauconitic sand	N 3/ very dark gray	Cheesequake
360	1699-1704	5.2 (104%)	Clayey glauconitic sand	N 3/ very dark gray	Cheesequake
361	1704-1709	4.8 (96%)	Clayey glauconitic sand; sb at 1704	N 3/ very dark gray	Cheesequake
			Lithologic contact at 1709.2 ft		
362	1709-1714	4.6 (92%)	Clay and medium to coarse sand	5YR 2.5/1 black	Cheesequake/Magothy
363	1714-1722	3.4 (43%)	Lignitic medium sand	2.5Y 6/1 gray	Magothy
364	1722-1728	4.9 (82%)	Lignitic, silty, very fine sand, silty clay	2.5Y 5/1 gray	Magothy
365	1728-1733	0.0 (0%)	No recovery		Magothy
366	1733-1739	1.5 (25%)	Clay	10YR 6/1 gray	Magothy
367	1739-1744	0.0 (0%)	No recovery		Magothy
368	1744-1749	0.8 (16%)	Clay	10YR 6/1 gray	Magothy
369	1749-1755	1.9 (32%)	Medium-coarse sand with pebbles	10YR 6/1 gray	Magothy
370	1755-1759	0.6 (15%)	Medium-coarse sand with pebbles	10YR 6/1 gray	Magothy
371	1759-1768	4.6 (51%)	Clayey fine gray sand, mica	10YR 6/1 gray	Magothy
372	1768-1774	4.7 (78%)	Clay to clayey fine gray sand, mica	10YR 6/1 gray	Magothy
373	1774-1779	5.0 (100%)	Clayey fine sand to sandy clays	2.5Y 6/1 gray	Magothy
374	1779-1784	1.1 (22%)	Clayey fine sand to sandy clays	2.5Y 6/1 gray	Magothy
375	1784-1789	5.4 (108%)	Silty lignitic micaceous clay; lithified zone1788.2-1788.5 ft	5Y 2.5/1 black	Magothy
376	1789-1795	5.4 (90%)	Indurated zone at top; silty micaceous clay	5Y 2.5/1 black	Magothy
377	1795-1798	0.25 (8%)	Indurated sand	5Y 2.5/1 black	Magothy
378	1798-1803	5.4 (108%)	Lignitic, micaceous silty clay	5Y 2.5/1 black	Magothy
			Lithologic contact at 1806.4 ft		
379	1803-1809	5.4 (90%)	Lignitic, micaceous silty clay/ fossiliferous micaceous silt	5Y 3/1 very dark gray	Magothy/Bass River
380	1809-1814.4	5.4 (100%)	Micaceous silt and sandy micaceous clay	5Y 3/1 very dark gray	Bass River
381	1814.4-1818.8	5.1 (116%)	Shelly indurated zone; sandy micaceous silt	5Y 3/1 very dark gray	Bass River
382	1818.8-1824	4.7 (90%)	Sandy micaceous silt and indurated clay	5Y 3/1 very dark gray	Bass River
383	1824-1829	5.3 (106%)	Micaceous silts and silty calys	5Y 3/1 very dark gray	Bass River
384	1829-1834	4.85 (97%)	Micaceous silts to clayey silts	5Y 3/1 very dark gray	Bass River
385	1834-1839	5.5 (110%)	Micaceous silts to clayey silts and silty clays	5Y 3/1 very dark gray	Bass River
386	1839-1844	5.0 (100%)	Micaceous silts to clayey silts and silty clays	5Y 3/1 very dark gray	Bass River
387	1844-1849	5.6 (112%)	Interbedded silty fine sand and shelly clays	5GY 4/1 d. greenish gray	Bass River
388	1849-1854	5.3 (106%)	Interbedded silty fine sand and shelly clays	5GY 4/1 d. greenish gray	Bass River
389	1854-1859	3.9 (78%)	Shelly silty fine sand- sandy silt	5Y 3/2 d. olive gray	Bass River
390	1859-1864.4	5.3 (98%)	Fossiliferous silty clay and very fossiliferous sandy silt	N3/ very dark gray	Bass River
391	1864.4-1869	5.1 (111%)	Fossiliferous interbeds of silty clay and clays	N3/ very dark gray	Bass River
392	1869-1873.8	4.8 (100%)	Fossiliferous very fine sandy silt with clay interbeds	N3/ very dark gray	Bass River

Table 1 (continued).

Core	Depth (ft)	Recovery (ft)	Description	Color	Formation
393	1873.8-1879	7.4 (40%)	Fossiliferous silty very fine sand	N3/ very dark gray	Bass River
394	1879-1886.7	5.4 (100%)	Fossiliferous sandy silt to silt	N3/ very dark gray	Bass River
395	1886.7-1891.3	4.65 (108%)	Fossiliferous sandy silt to silt	N3/ very dark gray	Bass River
396	1891.3-1896	2.5 (72%)	Fossiliferous sandy silt to clay	N3/ very dark gray	Bass River
397	1896-1899	4.55 (100%)	Fossiliferous sandy silt to clay	N3/ very dark gray	Bass River
398	1899-1902.6	3.6 (100%)	Fossiliferous silty clay	N3/ very dark gray	Bass River
399	1902.6-1904	3.1 (221%)	Fossiliferous silty clay	N3/ very dark gray	Bass River
400	1904-1909	5.2 (104%)	Fossiliferous silty clay	N3/ very dark gray	Bass River
401	1909-1914	4.0 (80%)	Fossiliferous sandy silt	N3/ very dark gray	Bass River
402	1914-1919	4.95 (99%)	Laminated fossiliferous slightly silty clay	N3/ very dark gray	Bass River
403	1919-1924	4.9 (98%)	Laminated fossiliferous slightly silty clay	N3/ very dark gray	Bass River
404	1924-1929	5.1 (102%)	Laminated fossiliferous slightly silty clay	N3/ very dark gray	Bass River
405	1929-1934	5.0 (100%)	Laminated fossiliferous slightly silty clay	5Y 3/1 very dark gray	Bass River
406	1934-1939.4	5.4 (100%)	Laminated fossiliferous slightly silty clay	5Y 3/1 very dark gray	Bass River
407	1939.4-1940.7	1.3 (100%)	Laminated fossiliferous slightly silty clay	5Y 2.5/1 black	Bass River
408	1940.7-1946.1	5.4 (100%)	Laminated fossiliferous slightly silty clay	5Y 2.5/1 black	Bass River
409	1946.1-1951.0	4.7 (96%)	Laminated fossiliferous slightly silty clay	2.5Y 3/1 very dark gray	Bass River
410	1951-1956.5	3.5 (64%)	Laminated fossiliferous slightly silty clay	2.5Y 4/1 dark gray	Bass River

Notes: Total depth = 1956.5 ft; mean recovery = 86.2%; median recovery = 99%.

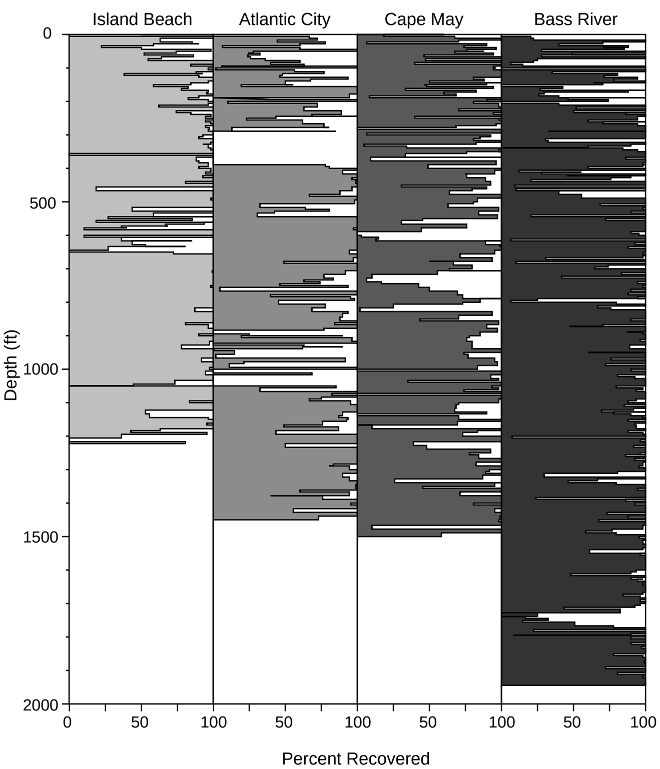

Figure 2. Percent core recovery from each core run from the ODP 150X and 174AX boreholes drilled to date.

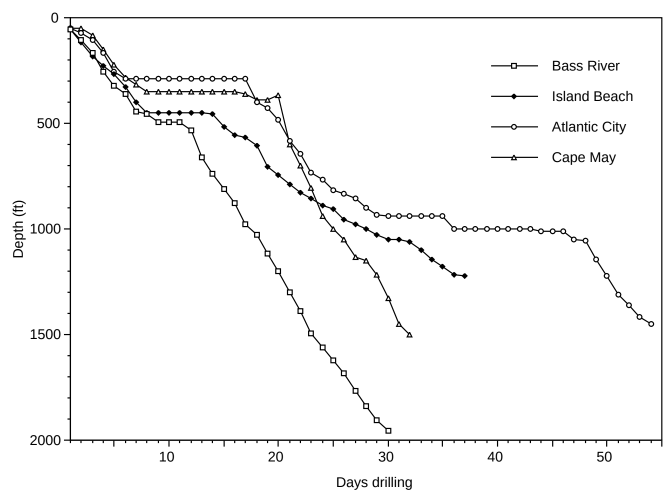

Figure 3. Comparison of days drilled vs. depth among the onshore boreholes drilled to date in ODP Legs 150X and 174AX.

lithologic contacts (Table 1; Figs. 4–14). Subsequent studies integrated preliminary descriptions with additional descriptions, biostratigraphy, biofacies studies, isotopic stratigraphy, and geophysical well logs. Unconformities were identified on the basis of physical stratigraphy, including irregular contacts, reworking, bioturbation, major facies changes, gamma-ray peaks, and paraconformities inferred from biostratigraphic breaks. For the nonmarine and nearshore sections (primarily the Miocene and younger section), lithofacies interpretations provide the primary means of recognizing unconformities and interpreting paleoenvironments. For the neritic sections (primarily the Paleogene), biostratigraphic and biofacies studies provide an additional means of recognizing unconformities and the primary means of interpreting paleoenvironments. Recognition of these surfaces allows identification of depositional sequences at the Bass River borehole. Benthic foraminiferal biofacies were used to recognize inner (0–30 m), middle (30–100 m), and outer (100–200 m) neritic, and upper bathyal (200–600 m) paleodepths.

Cape May Formation

Age: ?Pleistocene–Holocene
Interval: ~19.7 ft (6.00 m)

Below surface fill (determined as ~2–3 ft [0.61–0.91 m] in the mud pit) are the unconsolidated gravels, gravelly sands, and sandy clays of the Cape May Formation (3–19.7 ft [0.91–6.00 m]). Recovery of this interval was poor (21% between 9 and 19.7 ft [2.74 and 6.00 m]), and the age and facies interpretation of this section are uncertain. The dominance of poorly stratified gravels and gravelly sands is consistent with a braided stream paleoenvironment.

Cohansey Formation

Age: ?late and/or ?middle Miocene
Interval: 19.7–132.9 ft (6.00–40.51 m)

We assign gravelly yellow to brownish yellow medium sands with occasional clays to the Cohansey Formation (Fig. 4). The inter-

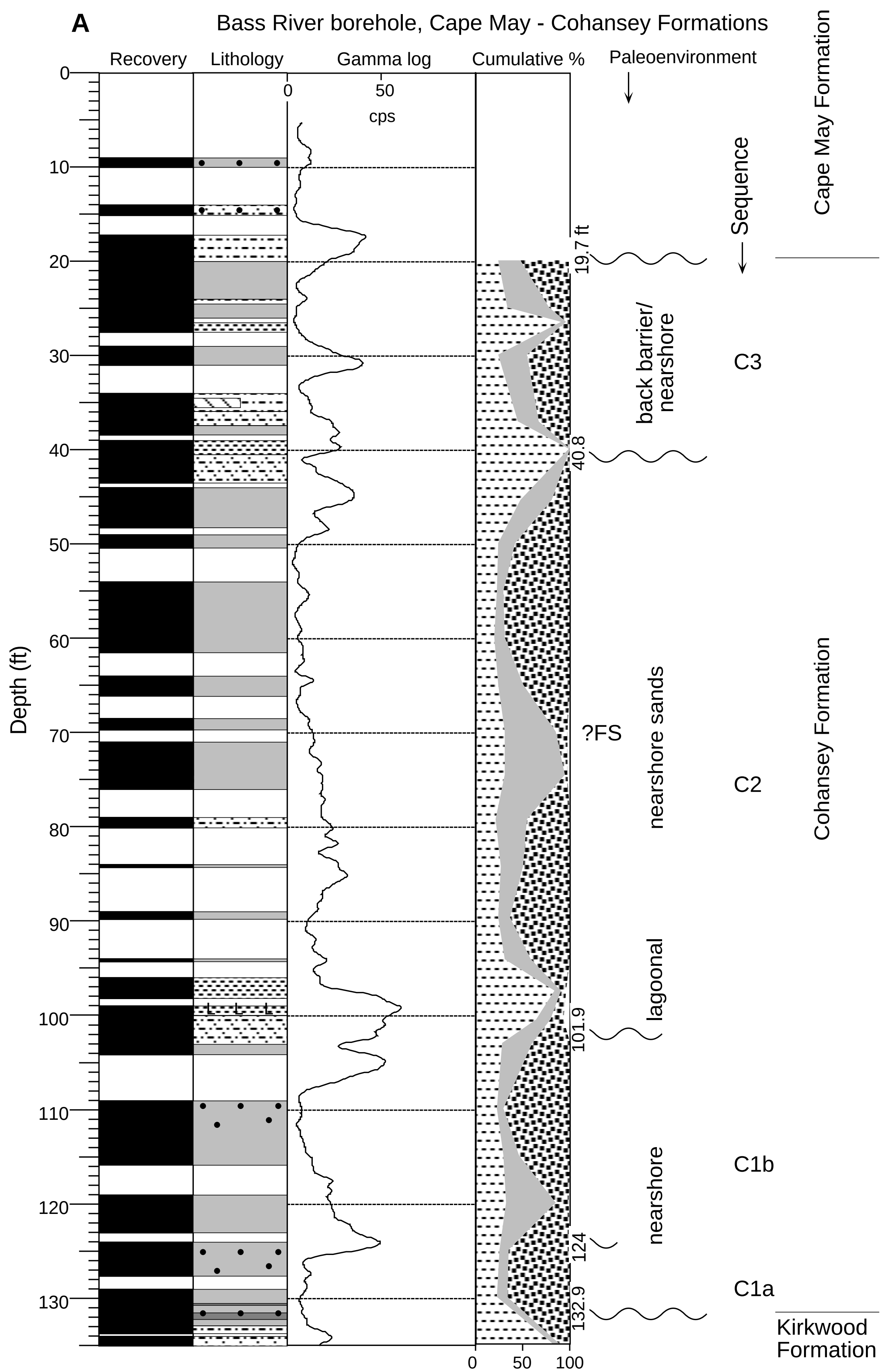

Figure 4. **A.** Cape May (?Pleistocene–Holocene) and Cohansey Formations (?upper and/or ?middle Miocene) from the Bass River borehole. C1a through C3 are sequences recognized in the Cohansey Formation. See Figure 4B for key to symbols. (Continued next page.)

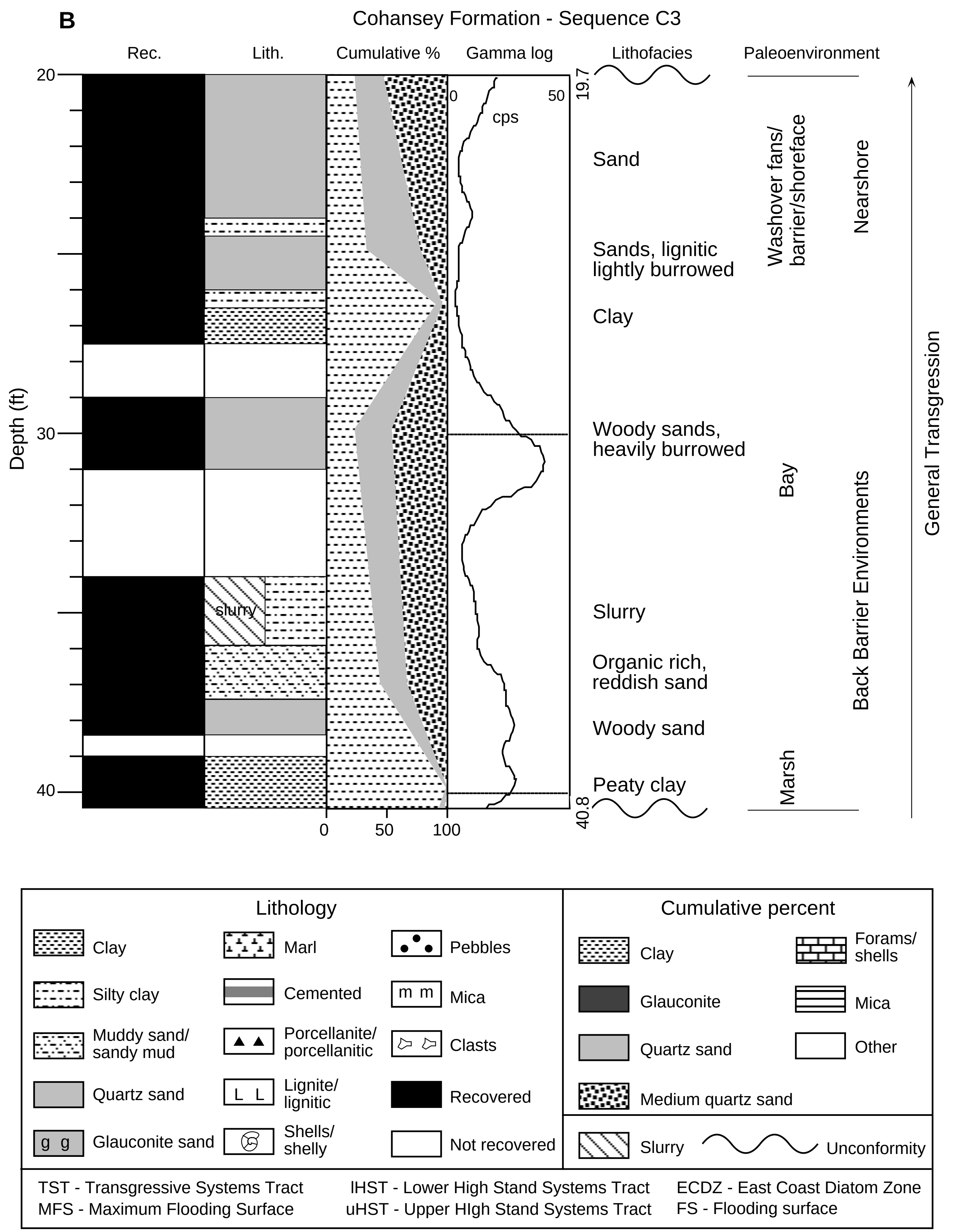

Figure 4 (continued). **B.** Cohansey Formation Sequence C3 from the Bass River borehole showing details of the lithofacies and environmental interpretations. See key for description of symbols.

val from 19.7 to 40.8 ft (6.00–12.44 m) is a transgressive sequence (C3) with basal marsh clays, medial lagoonal/bay sands and clays, and upper nearshore sands (Fig. 4). A sharp contact at 40.8 ft (12.44 m) separates clays above from yellow laminated (?cross bedded) sands below. A 5-cm weathered zone above the contact is overlain by (Fig. 4A): (1) very dusky red to reddish black peaty clay (39.5–40.5 ft [12.04–12.34 m]) interpreted as a marsh deposit; (2) light gray fine quartz sand (37.6–39.5 ft [11.46–12.04 m]) interpreted as an open lagoon/bay deposit; (3) pinkish brown organic-rich very slightly sandy silty clay (36–37.6 ft [10.97–11.46 m]), interpreted as a marsh deposit; (4) an interval between 36 and 31 ft (10.97 and 9.45 m) consisting of a slurry of sand and (drilling?) mud; (5) organic-rich, woody, gravelly medium sand (29–31 ft [8.84–9.45 m]), interpreted as representing lagoon/bay deposition; (6) interbedded clay (27.0–26.0 ft; 24.4–24.0 ft [8.23–7.92 m; 7.44–7.32 m]) and slightly bioturbated sands (26.0–24.4 ft [7.92–7.44 m]), interpreted as indicative of interfingering marsh/lagoon/bay; and (7) yellowish to gray moderately sorted quartz sand (24.0–19.7 ft [7.32–6.00 m]), interpreted as a washover/barrier/nearshore deposit.

Sands of the underlying Cohansey sequence (C2) continue from 40.8 to 101.9 ft (12.44–31.06 m; Fig. 4). These sands contain little clay except for two intervals of slightly sandy silty clay (44–46.8 ft, 69.0–80.1 ft [13.41–14.26 m; 21.03–24.41 m]). The sand ranges from moderately sorted to poorly sorted coarse sand; we interpret these sands to be nearshore deposits. There may be a parasequence with deeper water fine sands (69–76 ft [21.03–23.16 m]) bracketed by shallower water medium-coarse sands (48–69 and 79–94 ft [14.63–21.03 and 24.08–28.65 m]). Laminated, dark gray, very slightly sandy, lignitic clays from 96.4 to 102.15 ft (29.38–31.14 m) containing interbedded sand (fine burrowed sand, 100.2–100.5 ft [30.54–30.63 m] and coarse sand, 99.8–100.1 ft [30.42–30.51 m]) are interpreted as lagoonal deposits. A sharp contact at 101.9 ft (31.06 m) contains a reworked zone of fine sands and brown clays below (101.9–102.15 ft [31.06–31.14 m]). This surface separates lagoonal clays below from nearshore sands above and is interpreted as a sequence boundary separating C2 from C1.

Brownish yellow to pale yellow medium sand occurs below the 101.9 ft (31.06 m) contact. The sands are well sorted; cross bedding is clearly delineated by heavy mineral laminae. These sands are nearshore marine deposits (shoreface/offshore bar). The section fines downsection to fine sand and then silty sand at 119–123 ft (36.27–37.49 m); coarse sand returns at 124 ft (37.8 m) below an interval of no recovery. The gamma log shows a sharp increase in the interval of no recovery; it appears that we missed a basal clay and sequence boundary (124 ft [37.80 m]; C1b on Fig. 4).

Gravelly, very coarse to coarse sands (124–129.75 ft [37.8–39.55 m]) grade downsection to fine-medium sand (129.75–130.7 ft [39.55–39.84 m]); the section from 124.0 to 132.9 ft (37.8–40.51 m) is tentatively identified as a separate sequence (C1a; Fig. 4). At the base of the formation are three iron-cemented zones (130.7–130.8, 131.7–131.8, and 131.9–132.6 ft [39.84–39.87, 40.14–40.17, and 40.2–40.42 m]) composed of pebbly coarse sand. The interval from 131.9 to 132.9 ft (40.2–40.51 m) is a reworked zone, containing pebbles up to 1.5 cm in diameter at the top of the zone. A sharp, slightly irregular surface at 132.9 ft (40.51 m) separates sand from a slightly silty organic-rich clay.

Kirkwood Formation

Age: early middle to middle Miocene
Interval: 132.9–555.3 ft (40.51–169.26 m)

Kw2b Sequence

The Kirkwood Formation was first encountered below the unconformity at 132.9 ft (40.51 m), where it consists of gray clays and interbedded sands and clays (Fig. 5). These interbeds continue to 149.4 ft (45.54 m). Bedding thickness varies from less than 0.1 ft (3.0 cm) to over 2 ft (0.61 m). The section contains marine diatoms and lignite. It is possible to interpret the interfingering clay-sand facies as subaqueous delta-front deposits, although delta-front environments generally contain more mica. It is more likely that these facies represent deposition on an inner neritic, storm-dominated shelf. If so they would constitute the upper HST of this Kirkwood Formation sequence.

A dark gray micaceous clay unit (149.4–199.0 ft [45.5–60.7 m]) was deposited on a shallow shelf. This unit is primarily very dark gray clay from 149 to 187 ft (45.42–57.00 m), with interbedded fine-grained silty sand (159.0–160.0, 171.3–172, 173.5–177, 187–189, and 194–196 ft [48.46–48.77, 52.21–52.43, 52.88–53.95, 57.00–57.61, and 59.13–59.74 m]). This section was disturbed by drilling, and the following intervals are mostly drilling slurry: 169–171, 172–173.5, 192.9–193.6, and 199.0–201.0 ft (51.51–52.12, 52.43–52.88, 58.8–59.01, and 60.66–61.26 m). Micaceous clay from 149.4 to 199.0 ft (45.54–60.66 m) contains marine diatoms and is interpreted as a shallow shelf deposit marking the lower HST of the sequence. The environment of deposition of these shelf clays contrasts with other Kirkwood sequences in which the medial and lower clays are prodelta deposits. We tentatively place a maximum flooding surface (MFS) at ~185 ft (56.39 m) at a gamma-log peak (Fig. 5).

From 201.0 to 201.7 ft (61.26–61.48 m), the section consists of clayey medium sand grading down to a pebbly coarse sand. This overlies a lignite (log) layer at 201.7–202.2 ft (61.48–61.63 m) and a return to a well-sorted medium sand (202.2–202.7 ft [61.63–61.78 m]). These are interpreted as shallower water (lagoonal/tidal inlet and marsh) environments and may represent the TST at the base of the sequence. Alternatively, the sequence boundary may be at the base of the pebble layer at 201.7 ft (61.48 m). The juxtaposition of these diverse facies is consistent with a TST interpretation and placement of the lower sequence boundary in a coring gap (202.7–209 ft [61.78–63.7 m]; 205 ft [62.48 m] on Fig. 5). We interpret the following succession within the 132.9–205 ft (40.51–62.48 m) sequence from base to top: (1) lower lagoonal/nearshore sediments; (2) medial shallow shelf (inner neritic) sands; and (3) upper nearshore-shelf sands and clays. The section from 224.0 to 325.0 ft (68.28–99.06 m) is assigned to East Coast Diatom Zone (ECDZ) 2, which includes the Kw2b and 2a sequences of Sugarman et al. (1993). Thus, the interval from 132.9 to 205 ft (40.5–62.48 m) probably corresponds to the Kw2b sequence (Sugarman et al., 1993; Miller et al., 1997) and to the Wildwood Member of Owens et al. (1995).

Kw2a Sequence

The Kw2a sequence is tentatively identified from 205 to 329 ft (62.48–100.28 m; Fig. 5). Below a coring gap, dark gray medium to coarse quartz sands occur from 209 to 216.2 ft (63.7–66.05 m). The sands are poorly sorted with mud, fine sand, coarse sand, very coarse sand, and pebbles to 7 mm in diameter. The presence of diatoms (*Paralia sulcata*) at 210 ft (64.01 m) indicates that the section is shallow marine. Bedding is massive, perhaps due to bioturbation and repeated reworking. Below the sand is a very dark brown “chocolate” clay (216.2–217.8 ft [65.9–66.39 m]). We interpret the clay as a deeper shelf deposit that shallows to sands (Fig. 5).

A contact zone is present between 217.6 and 217.8 ft (66.32 and 66.39 m), with clays above and sands below (Fig. 5). In the contact zone, sands interfinger with the clays; although this may be a sequence boundary, we conservatively interpret it as a parasequence boundary (i.e., bounded by flooding surfaces). Medium-coarse sands return from 217.8 to 232.4 ft (66.39–70.84 m). Grain size varies from moderately sorted medium to poorly sorted medium-coarse sands. These sands are similar to facies interpreted by Owens and Sohl (1969) as nearshore; they represent part of the upper HST. An indurated pebbly sand is present at 232.4 ft (70.84 m). From 234.3 to 289 ft (71.41–88.09 m), the section consists primarily of micaceous silty clays, with occasional micaceous, silty fine quartz sand beds. The clays contain fine laminations of sand and are slightly bioturbated.

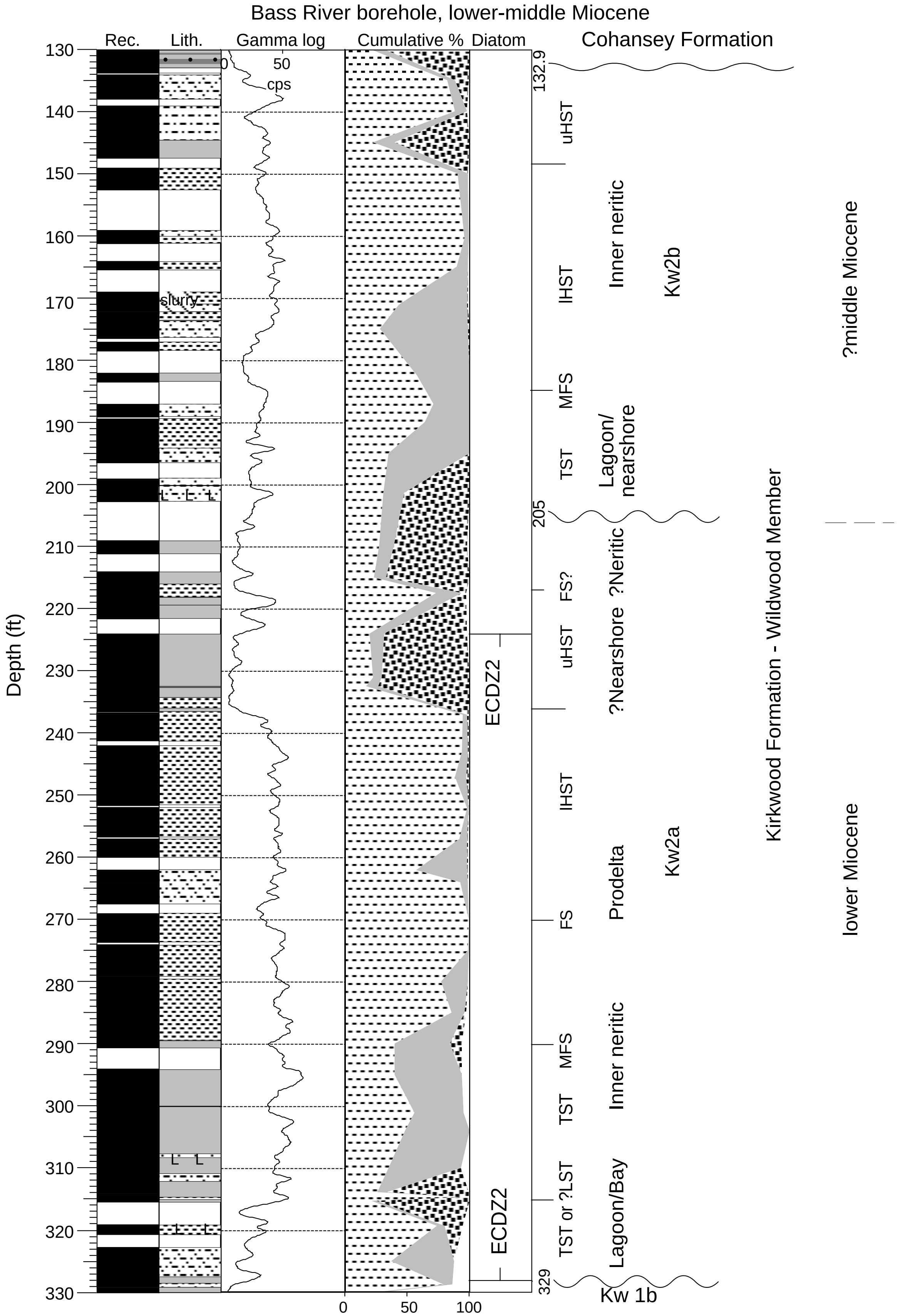

Figure 5. Wildwood Member (lower to middle Miocene) of the Kirkwood Formation from the Bass River borehole. Kw2a and Kw2b are sequences defined by Sugarman et al. (1993). See Figure 4 for key to symbols.

We interpret these as prodelta, as supported by the presence of mica and diatoms and the laminated bedding. The interval from 262.0 to 263.1 ft (79.86–80.19 m) is clayey sand to sandy clay, returning to clay below. We interpret a possible flooding surface in the interval 270–275 ft (82.3–83.82 m), based on the lowest amounts of sand, the presence of echinoid spines and foraminifers, and the top of a fining-upward succession (Fig. 5). Slightly sandy clays continue to 288.9 ft (88.06 m), with fine sand increasing downsection.

A facies contact at 288.9 ft (88.06 m) separates the prodelta clays above and shelf sands below (Fig. 5). Dark gray, micaceous, burrowed to laminated, silty fine-grained sand occurs from 288.9 to 307 ft (88.06–93.57 m); burrowing tends to obscure cross lamination. We interpret these sands as shelf sands (inner neritic zone), with cross bedding developed above wave base. The sands yield high gamma-ray log values (Fig. 5), and no gamma kick is associated with the 288.9 ft (88.06 m) MFS that we interpret as the boundary between the TST and HST. From 311 to 312.2 ft (94.79–95.16 m), sandy silts overlie an fining-upward succession from pebbly coarse sand to sandy silt; this section overlies a dirty, poorly sorted medium to coarse sand.

Sands with interbedded clays comprise the interval between 312.6 and 329.0 ft (95.28 and 100.28 m; Fig. 5). Lithologies include coarse sand at 314 ft (95.71 m); organic-rich slightly sandy clay (314.3–314.8 ft [95.8–95.95 m]); dark brown "chocolate clay" (319–321 ft [97.23–97.84 m]); and interbedded clays and clayey fine sands (324–329 ft [98.76–100.28 m]). The sands are occasionally clayey and organic rich. The section generally fines upward from 329 to 314 ft (100.28–95.71 m). We interpret these complex sand-clay facies to represent lagoonal-bay environment and a generally shallowing-upsection succession. These facies (312.6–329.0 ft [95.28–100.28 m) are interpreted as part of a TST or possibly a Lowstand Systems Tract (LST). We tentatively place the sequence boundary at the base of these sands at 329.0 ft (100.28 m) and assign the entire succession between 288.9 and 329.0 ft (88.06 and 100.28 m) as the TST of the Kw2a sequence of Sugarman et al. (1993). Alternatively, the section from 288.9 to 314 ft (88.06–95.71 m) could be the Kw1c sequence of Miller and Sugarman (1995). This sequence is part of the Wildwood Member of Owens et al. (1995).

Kw1b Sequence

A sequence boundary at 329 ft (100.28 m) is associated with a facies change between interbedded sand and clay above and medium to coarse sand below (Fig. 6). Medium-coarse sand with occasional pebbles occurs from 329 to 354 ft (100.28–107.9 m); these facies may represent deposition in a tidal-delta paleoenvironment. The interval from 355 to 359 ft (108.2–109.42 m) is a lignitic clay that yields a high gamma-log signature (Fig. 6), comprises a confining unit, and is interpreted as a marsh deposit. Below this, lignitic sands with clay interbeds, interpreted as tidal delta/lagoon, extend to 376.3 ft (114.70 m). A burrowed clayey sand from 376.3 to 379.2 ft (114.70–115.58 m) is interpreted as a delta front, perhaps also reflecting a lagoonal/back barrier setting. Thus, the section from 329 to 379.3 ft (100.28–115.61 m) is a shallowing-upward succession. Log characteristics indicate that this unit may be further subdivided into several parasequences. From 379.3 to 383 ft (115.61–116.74 m), a laminated, pyritic clay with interbedded sands is interpreted as proximal prodelta representing the TST of this sequence. The age and correlation of the sequence is uncertain; we tentatively assign it to the Kw1b sequence of Sugarman et al. (1993) and to the Shiloh Marl Member of Owens et al. (1995).

Kw1a Sequence

The Kw1a sequence is identified from 383.0 to 555.3 ft (116.74–169.26 m; Fig. 6). From 383.0 to 486.5 ft (116.74–148.29 m), the section consists of muddy medium sand (Fig. 6) with only minor interbeds of coarse sand (395.8–397.0 ft [120.64–121.01 m] and 414.3–419 ft [126.28–127.71 m]). These "dirty" sands are massive and micaceous, contain marine diatoms, occasionally have high organic content, and are interpreted as delta front sands. The section above 419 ft (127.71 m) is somewhat coarser (Fig. 6) and less organic rich than below and may reflect slightly shallower environments. The sands from 383.0 to 486.5 ft (116.74–148.29 m) constitute the main part of the "Atlantic City 800-ft sand" aquifer unit (Fig. 6) of Zapecza (1989).

Very dark gray and brown, micaceous clays with thin interbeds of silty fine sand appear at 486.5 ft (148.29 m) and continue down to 493.4 ft (150.39 m; Fig. 6). These fine-grained beds comprise the composite confining unit (Fig. 6) of Zapecza (1989). From 493.4 to 516 ft (150.39–157.28 m), interbeds of very dark grayish brown silty clay and clayey silts dominate; they are generally very micaceous and laminated with occasional cross laminations. The clays and silts from 486.5 to 516 ft (148.29–157.28 m) are interpreted as a prodelta deposit and the lower HST of the Kw1a sequence (Fig. 6).

Brown, burrowed, micaceous, silty sand occurs from 516 to 526 ft (157.28–160.32 m; Fig. 6); we interpret these as a (?inner) neritic deposit (Fig. 6). From 526 to 529 ft (160.32–161.24 m), a kaolinitic, greenish gray clay is interpreted as a deeper (?middle) neritic deposit; this may represent a flooding event (Fig. 6). Brown, burrowed, micaceous, sandy silts occur from 529 to 545 ft, (161.24–166.12 m), with less mica below about 538 ft (163.98 m); these were deposited in shallower (?inner) neritic environments. The silt contains shell beds at 540.2, 542.0, and 544.0 ft (164.65, 165.20, and 165.81 m). Interbedded glauconitic clays with fine to medium quartz sands occur from 549.0 to 555.3 ft (167.34–169.26 m), with shell beds at 549.6–549.9, 550.9–551.3, and 553.6–553.9 ft (167.52–167.61, 167.91–168.04, and 168.74–168.83 m). These glauconitic, shelly, sands represent the TST of the sequence; we place the MFS at ~547 ft (166.73 m) based on a major gamma-log increase within a coring gap separating glauconite facies below from shelly sands above (Fig. 6). We assign the sequence between 289 and 555.3 ft (88.09 and 169.26 m) to the Kw1a sequence of Sugarman et al. (1993) and to the Brigantine Member of Miller et al. (1997). The shelly glauconite sands from 549 to 555.3 ft (167.34–169.26 m) are lithologically similar to the Kw0 sequence at Atlantic City (Miller et al., 1997), and it is possible that this interval may represent a thin Kw0 sequence, although Sr-isotopic ages of 20.8–21.4 Ma (Table 2; see "Isotopic Stratigraphy" section, this chapter) indicate correlation to the Kw1a sequence at Island Beach (Miller et al., 1997).

Atlantic City Formation

Age: early Oligocene
Interval: 555.3–655.3 ft (169.26–199.74 m)

A sharp sequence boundary at 555.3 ft (169.26 m) separates shelly, dark grayish-brown, glauconitic, silty clays with quartz pebbles above from medium glauconite sands below (Fig. 7). The contact spans ~0.5 ft (0.15 m; 555.3–554.8 ft [169.26–169.10 m]), with reworked inner neritic glauconite sand incorporated into the inner to middle neritic Kirkwood Formation clays. Shells in the contact zone are similar to those below and are probably reworked, whereas the large shells in the base of the Kirkwood Formation above the contact zone (549.6–554.8 ft [167.52–169.10 m]) are apparently in situ. From 555.3 to 669.9 ft (169.26–204.19 m), the lithology consists of quartzose glauconite sand (Fig. 7). The cause of a general upsection increase in gamma radiation at 588 ft (179.22 m; Fig. 7) is unknown, although it may be caused by either the presence of more weathered, brown glauconite or greater lithification in the upper section. The quartz sand is medium to coarse grained; the glauconite sand is fine to medium grained. Shells (pectinids, mytiloids) and shell fragments occur from 555.3 to 619.0 ft (169.26–188.67 m). The section is indurated in many places. The uniform lithology is consistent with our interpretation of this interval as one sequence (Sr-isotopes indicate cor-

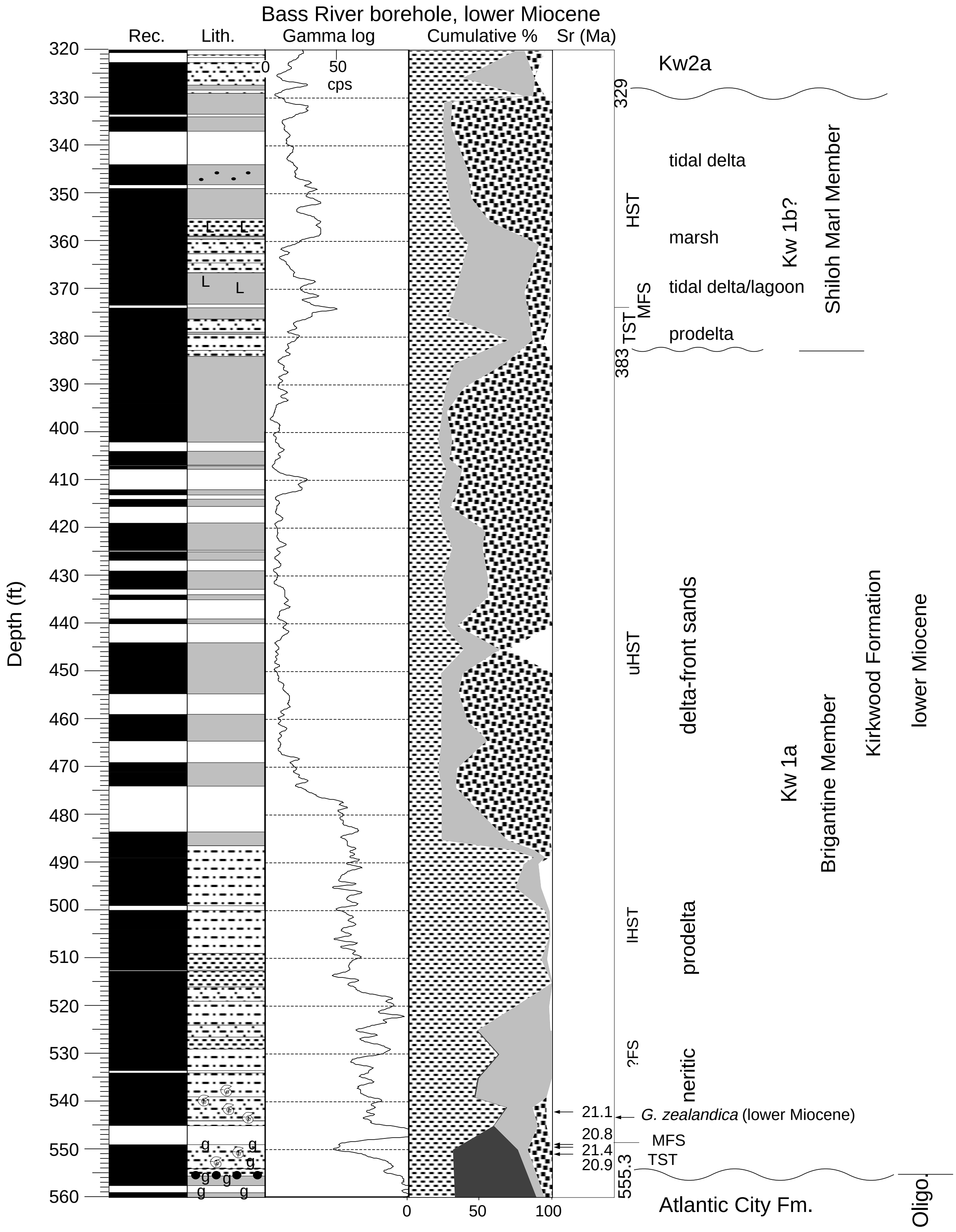

Figure 6. Brigantine and Shiloh Marl Members (lower Miocene) of the Kirkwood Formation from the Bass River borehole. Kw1a and Kw2a are sequences defined by Sugarman et al. (1993). See Figure 4 for key to symbols.

relation to Sequence O1 of Pekar et al. [1997]; see "Isotopic Stratigraphy" section, this chapter). Thin (<0.1 ft [3 cm]) very dark grayish brown clay beds appear at 655.3 ft (199.74 m), although the section remains primarily quartzose glauconitic sand. The quartz sand component decreases in grain size and abundance downsection from pebbly coarse-grained sand at ~660 ft (201.17 m) to fine-grained sand by 669 ft (203.91 m).

Sewell Point Formation

Age: early Oligocene
Interval: 669.0–675.4 ft (203.91–205.86 m)

From 669.0 to 675.4 ft (203.91–205.86 m), the section consists mainly of glauconitic clays (Fig. 7). We tentatively place this section

Table 2. Sr-isotopic data, Bass River borehole.

Depth (ft)	Depth (m)	Material	$^{87}Sr/^{86}Sr$	Error (±)	Age (Ma)
542.1	165.2	Shell	0.708410	0.000029	21.1
549.1	167.4	Shell	0.708426	0.000034	20.8
549.6	167.5	Shell	0.708396	0.000010	21.4
550.9	167.9	Shell	0.708420	0.000021	20.9
560.7	170.9	Shell	0.707921	0.000027	32.0
561.5	171.1	Shell	0.707903	0.000022	32.5
565.0	172.2	Shell	0.707891	0.000020	32.8
577.4	176.0	Shell	0.707895	0.000005	32.7
577.4	176.0	Shell	0.707872	0.000031	33.3
602.5	183.6	Shell	0.707859	0.000022	33.7
611.3	186.3	Shell	0.707833	0.000021	34.3
611.3	186.3	Shell	0.707872	0.000011	33.3

in the Sewell Point Formation. These finer grained beds constitute the lower part (TST) of Sequence O1 of Pekar et al. (1997).

Absecon Inlet Formation

Age: late Eocene
Interval: 675.4–846.6 ft (205.86–258.04 m)

A major lithologic break and sequence boundary is present at 675.4 ft (205.86 m; Fig. 8), where glauconitic clays (with quartz pebbles) overlie uniform brown clays of the Absecon Inlet Formation. The contact spans ~1.2 ft (0.37 m; to 674.2 ft [205.50 m]) and is characterized by brown clay rip-up clasts of the underlying Absecon Inlet Formation. The mottled brown clays are fossiliferous, bioturbated, and contain glauconitic beds.

An unconformity in the core corresponding to a change in lithology from brown clays above to grayish brown silty clays below occurs at 684.6 ft (208.67 m; Fig. 8). The thin sequence from 684.6 to 675.5 ft (208.67–205.89 m) may be equivalent to Sequence E11 of Browning et al. (1997a).

The grayish brown silty clay from 684.9 to 824.0 ft (208.76–251.16 m) is slightly micaceous and glauconitic and contains abundant macrofossils (including corals, scaphopods, and nuculids) and mollusk shell fragments. In places it is laminated, particularly above 700 ft (213.36 m), but it is generally bioturbated and massive. The lithology from 684.9 to 770.7 ft (208.76–234.91 m) is relatively uniform, although pyrite concretions become common below 734 ft (223.72 m) and glauconite generally increases downsection, reaching a distinct peak at 760.0–766.7 ft (321.65–233.69 m; Fig. 8). A distinct erosional surface at 770.7 ft (234.91 m) may be a sequence boundary that splits Sequence E10 of Browning et al. (1997a) into two possible sequences.

The section from 770.7 to 840.1 ft (234.91–256.06 m) may be a separate sequence or part of the sequence to 684.9 ft (208.76 m). Glauconite is common from 784 to 809 ft (238.96–246.58 m) and less common from 809 to 824 ft (246.58–251.16 m); this may reflect reworking of glauconite in the HST. Mollusk shells are concentrated in several layers that may represent storm deposits (e.g., 766.8, 785.2, and 788.3 ft [233.72, 239.33, and 240.27 m]). The section from 824 to 829 ft (251.16–252.68 m) is an intensely bioturbated glauconitic clay with small amounts of silt and glauconite; it probably represents the deepest paleowater depths of the sequence (condensed interval/MFS). Between 829 and 836 ft (252.68 and 254.81 m), the amount of glauconite in the clays increases, and the section grades downsection to clayey glauconite sand (836–837 ft [254.81–255.12 m]). Interbedded glauconitic sands and green glauconitic clays continue downsection (837–840.1 ft [255.12–256.06 m]). There is an erosional surface at 840.1 ft (256.06 m; 840.5 ft on figure) separating glauconite clay above from brown clay below. The sequence between 840.1 and 684.9 ft (256.06 and 208.76 m) is probably Sequence E10 of Browning et al. (1997a); the possible subdivision of E10 into two sequences by a surface at 770.7 ft (234.91 m) is consistent with results at Leg 150X boreholes (Browning et al., 1997a).

It is difficult to identify the lower boundary of the Absecon Inlet Formation. It could be at either 840.1 or 846.6 ft (256.06 or 258.04 m; Fig. 8). The lower level is probably a sequence boundary separating darker glauconitic sandy clays burrowed down into lighter green clays; the contact is heavily burrowed. Above this is a shelly, glauconitic clay with coarse glauconite sand; the sequence fines at the top (840.1–840.6 ft [256.06–256.21 m]) to a brown clay. The sequence between 846.6 and 840.1 (258.04 and 256.02 m) has not been previously recognized.

Shark River Formation

Age: early late and middle Eocene
Interval: 846.6–959.85 ft (258.04–292.56 m)

The contact between the Absecon Inlet Formation and the Shark River Formation is tentatively placed at 846.6 ft (258.04 m; Fig. 8). The Shark River Formation has been informally divided into a coarser grained, more glauconitic upper unit and a more carbonate-rich (marly) lower unit (Miller et al., 1990). In this borehole, the upper unit is found between 846.6 and 885.8 ft (258.04 and 269.9 m). It consists of bioturbated fossiliferous glauconitic sandy clay to clayey glauconite sand.

The upper Shark River Formation apparently consists of two sequences at Bass River (Fig. 8), as it does at Island Beach and Atlantic City (Browning et al., 1997b). Glauconite is common at the base of the upper Shark River Formation (885.8 to ~880 ft [269.99–268.22 m]), decreases between ~880 and 863.6 ft (268.22 and 263.23 m) and increases upsection in conjunction with increased quartz sand from 863.6–860 ft (263.23–262.13 m). A faint surface at 863.6 ft (263.23 m) with clay rip-up clasts above, separates more glauconitic, sandier clays above from less glauconitic, clayier sediments below. We interpret this as a sequence boundary; it probably separates Browning et al.'s (1997a) Sequence E8 below from E9 above. The section above 868.9 ft (264.84 m) contains heavily bioturbated, occasionally cross bedded(?) glauconite-quartz sand. These upper sands are stratigraphically equivalent to intervals with pervasive biostratigraphic reworking noted at Atlantic City and Island Beach boreholes (Miller et al., 1994a, 1994b). The lower sequence (E8, 868.9–885.8 ft [264.84–269.99 m]) is a typical Eocene sequence with glauconite at the base (TST), medial clays (lower HST), and a slightly sandier upper section (upper HST; Fig. 8).

The contact at 885.8 ft (269.99 m) separates the glauconitic clays of the upper Shark River Formation and the bioturbated, greenish gray colored, carbonate-rich, slightly glauconitic, silty clay (marls) of the lower Shark River Formation (Figs. 8, 9). This is also the contact between Sequences E8 above and E7 below of Browning et al. (1997c). Lithologic variation in this unit is subdued, although inspection of washed residues (Fig. 9) from the E7 sequence (885.6–932 ft [269.99–284.07 m]) shows that glauconite is most abundant at the base (TST), clay dominates the medial section (lower HST), and traces of quartz and ?reworked glauconite sand occur in the upper part (upper HST). There is a faint gamma-log expression of this cyclicity.

A surface at 932 ft (284.07 m) separates glauconitic silty clay above from silty clays below. This may be the boundary separating sequence E7 above from E6 below (Fig. 9; Browning et al., 1997c). The interval below the sequence boundary is well indurated and slightly porcellanitic. The interval between 932.0 and 959.85 ft (284.07 and 292.56 m) is a slightly glauconitic, carbonate-rich, silty clay. There are two surfaces in the core at 954.35 and 959.85 ft (290.89 and 292.56 m). In both instances, slightly glauconitic silty clays grade down into clayey glauconite sand that abruptly overlies slightly glauconitic silty clay. A porcellanite bed (954.35–955.35 ft [290.89–291.19 m]) underlies the upper surface. These surfaces are tentatively identified as sequence boundaries separating E6 (932–954.35 ft [284.07–290.89 m]) from E5 (954.35–959.85 ft) and E5

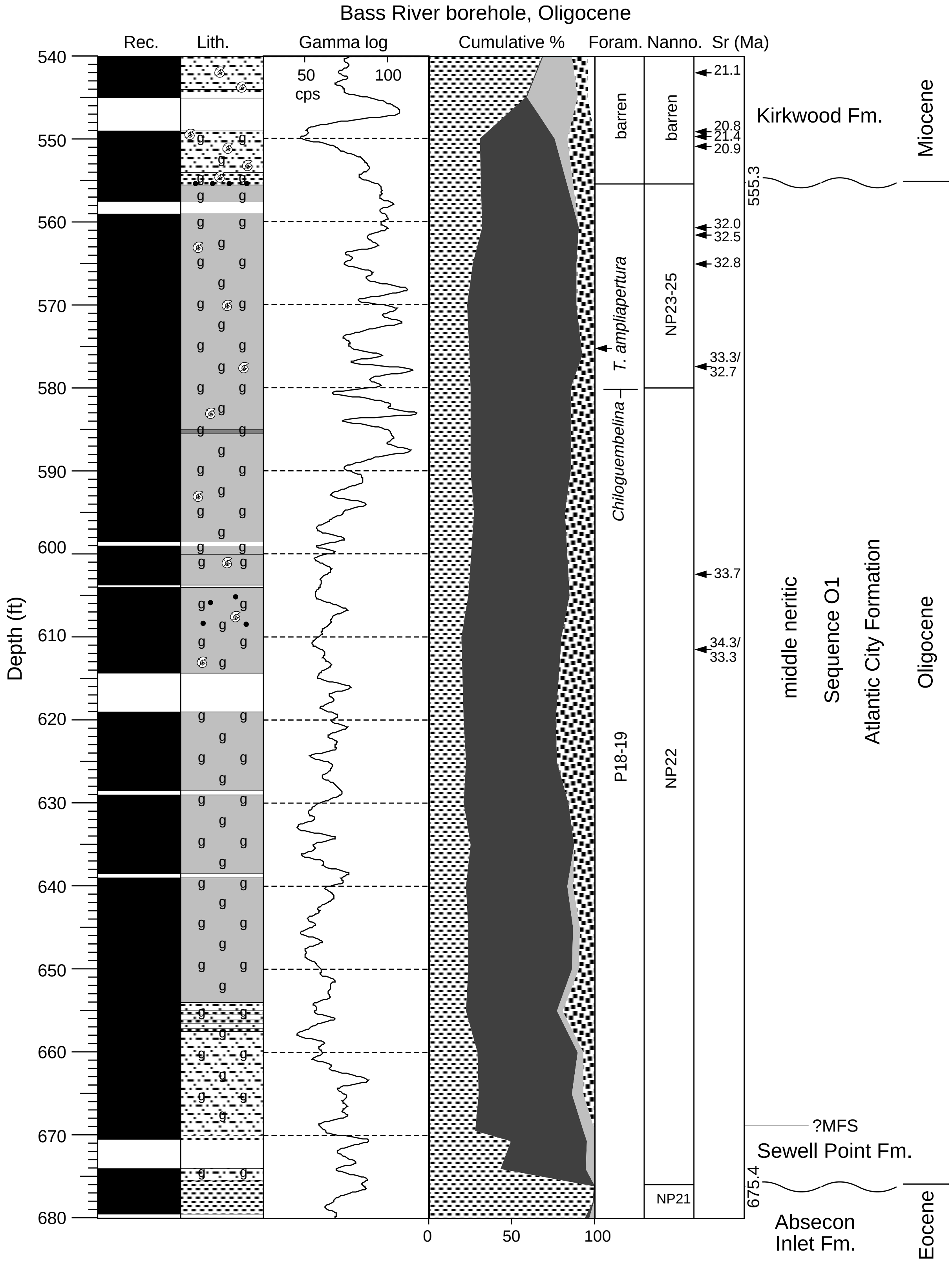

Figure 7. Atlantic City and Sewell Point Formations (Oligocene) from the Bass River borehole. O1 is a sequence defined by Pekar et al. (1997). See Figure 4 for key to symbols.

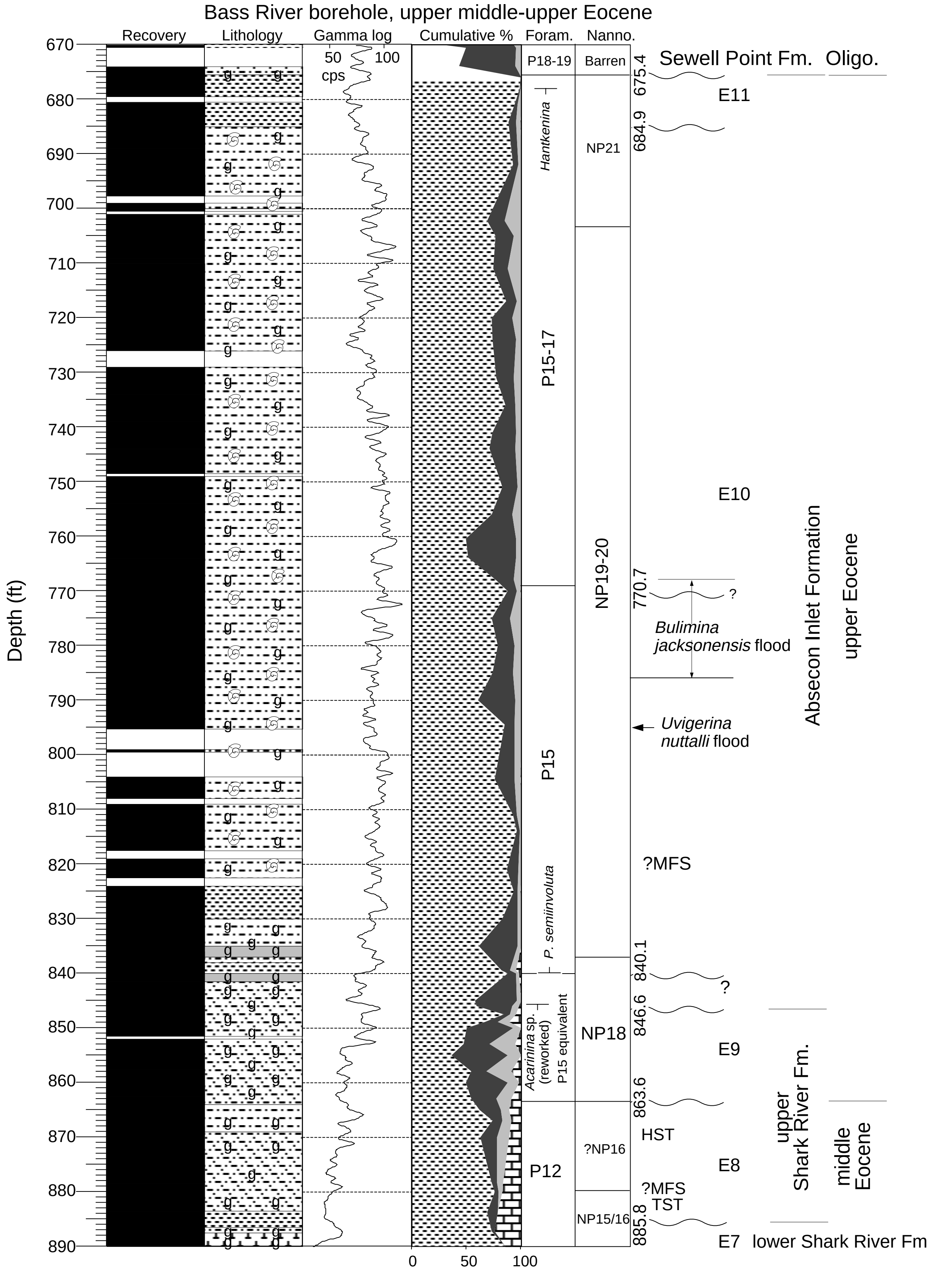

Figure 8. Absecon Inlet Formation (upper Eocene) and upper Shark River Formation (middle to upper Eocene) from the Bass River borehole. E7–E11 are sequences defined by Browning et al. (1997a) and Browning et al. (1997c). See Figure 4 for key to symbols.

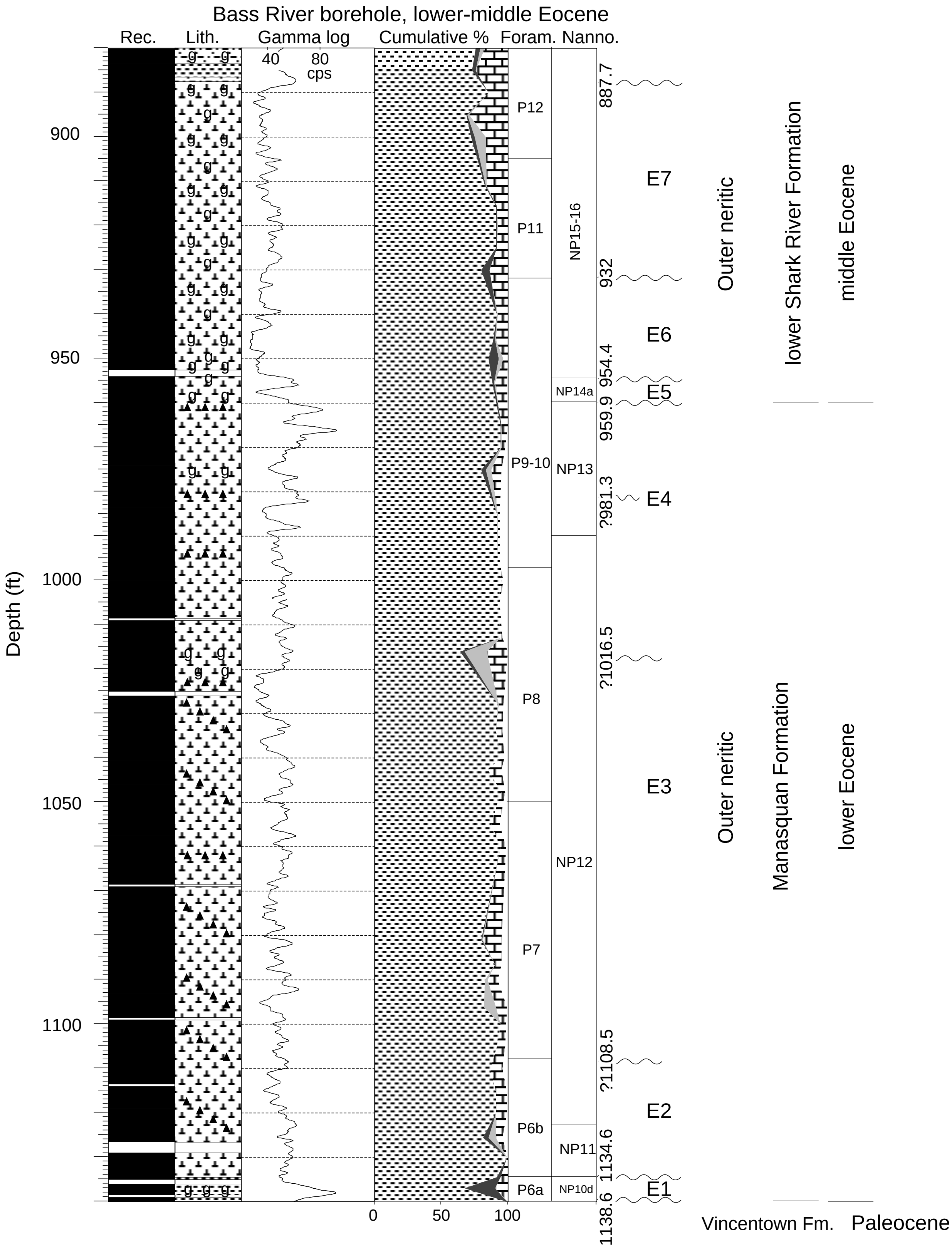

Figure 9. Lower Shark River Formation (middle Eocene) and Manasquan Formation (lower Eocene) from the Bass River borehole. E1–E7 are sequences defined by Browning et al. (1997c). See Figure 4 for key to symbols.

from E4; both are associated with sharp gamma-log peaks (Fig. 9). The lower of these two surfaces is the contact between the Shark River Formation and the Manasquan Formation. The E6 sequence grades up from glauconite sand to medial silty clays to slightly glauconitic (?reworked) clays at the top; in contrast, Sequence E5 grades from glauconite sands to clays, perhaps indicating truncation of this thin (5.5 ft [1.68 m]) sequence.

Manasquan Formation

Age: early Eocene
Interval: 959.85–1138.6 ft (292.56–347.05 m)

Bioturbated silty clays of the Manasquan Formation were first encountered at 959.85 ft (292.56 m; Fig. 9). These sediments differ from the overlying Shark River Formation in containing less glauconite, being generally darker in color, and in containing more extensive porcellanite nodules and layers. Although the Manasquan Formation is well bioturbated, there are intervals that preserve laminations and cross laminations (e.g., 1000–1001 ft [304.80–305.10 m]). The section is very fossiliferous to 1009 ft (307.54 m) and moderately to slightly fossiliferous below that.

A glauconite-rich interval at 962.7–963.8 ft (293.43–293.77 m) may be a sequence boundary; it appears to be offset from a gamma-log kick at 966 ft (294.44 m; Fig. 9). If this is a sequence boundary, it is one of three closely spaced unconformities that span the lower/middle Eocene contact at Bass River.

A contact at 981.3 ft (299.10 m) separates slightly glauconitic clays above and indurated porcellanites below (Fig. 9). This level is associated with a gamma-log kick and may be a sequence boundary, although the precise age and significance of this boundary is not known.

Within the silty clays, slightly glauconitic interbeds occur at 1015.5–1016.5 ft (304.65–309.83 m), associated with a minor gamma-log peak at 1018–1022 ft (310.29–311.51 m). A thick (~10 ft [3.05 m]) porcellanite bed underlies the glauconitic clays. The contact between these two lithologies may mark a sequence boundary, although there is no distinct surface. Initial biostratigraphy indicates this may be the E4/E3 sequence boundary of Browning et al. (1997c).

Porcellanitic interbeds occur from 1018 to 1069 ft (310.29 to 325.83 m). Porcellanites increase from 1069 to 1084 ft (325.83 to 330.40 m), with the section consisting of approximately equal proportions of porcellanitic silty clays and clayey silts. From 1084 to 1126.5 ft (330.40–343.36 m), bioturbated porcellanite alternates with thinly bedded silty clays. There are no distinct surfaces in this interval, although a faint lithologic contact at 1108.5 (337.87 m) may be the sequence boundary at the base of E3 of Browning et al. (1997c), with clayier, less porcellanitic, slightly sandy clays overlying more porcellanitic sediments below. From 1126.5 to 1134.6 ft (343.36–345.83 m), porcellanite decreases, although the cores are still fairly indurated. Clays increase and silts decrease downsection to the base of this unit at 1134.6 ft (345.83 m). A contact occurs at 1134.6 ft (345.83 m), with rip-up clasts from the unit below (glauconitic clays) contained within a zone 0.3 ft above the contact. Glauconitic clays that extend from 1134.6 to 1138.6 ft (345.83–347.05 m) are probably equivalent to Sequence E1 of Browning et al. (1997c) and may be equivalent to the Farmingdale Member of the Manasquan Formation.

Vincentown Formation

Age: late Paleocene
Interval: 1138.6–1248.9 ft (347.05–380.66 m)

A contact occurs at 1138.6 ft (347.05 m), with very glauconitic clays above overlying green clays (Fig. 10). The green clays are massive; the sand fraction consists primarily of foraminifers. The section is generally burrowed and contains intervals with pyrite and indurated dark nodules. Silt and mica appear downsection at 1178 ft (359.05 m) where we tentatively place a sequence boundary. Rare quartz sand and ?recycled glauconite is found from 1178 to 1205 ft (359.05–367.28 m; Fig. 10), indicating the upper HST. Silt increases downsection, becoming micaceous clayey silt of the lower HST below 1210 ft (368.81 m). Macrofossils were noted at 1230–1231 ft (374.9–375.21 m), just below a peak in foraminiferal abundances (Fig. 10); we interpret this as the MFS separating the HST from the TST. At 1230–1236 ft (374.90–376.73 m), the section becomes laminated with numerous burrows, with glauconite increasing to the base of the sequence at 1240.8 ft (378.20 m).

We note a possible sequence boundary at 1240.8 ft (378.20 m) where there is a subtle change from darker, more glauconitic gray clayey silt above to lighter gray, less glauconitic silty clay below (Fig. 10). The contact is irregular and sharp. This may be the boundary separating Sequence Pa3 from Pa2 (Liu et al., 1997a). Calcareous nannofossil biostratigraphy indicates a hiatus across this level, with Zone NP7 not represented.

The section from 1240.8 to 1248.9 (378.20–380.66 m) consists of glauconitic quartzose silts (Fig. 10). The contact with the underlying Hornerstown Formation is gradational and is tentatively placed at 1248.0 ft (380.39 m) at a level where glauconite sand predominates. The formational name of the silts and clays and underlying glauconitic silts and clays between 1138.6 and 1248.9 ft (347.05 and 380.66 m) is debatable. Owens et al. (1997) assigned a similar lithologic unit at Island Beach to the Vincentown Formation, whereas Olsson and Wise (1987) identified upper Paleocene silts as an unnamed unit. Liu et al. (1997a) assigned similar glauconitic clays at Island Beach to the Vincentown Formation, and we follow this assignment.

Hornerstown Formation

Age: early to earliest late Paleocene
Interval: 1248.9–1260.25 ft (380.66–384.12 m)

The section becomes increasingly glauconitic downsection, becoming glauconite sand from 1248.9 to 1258.7 ft (380.66–383.65 m), with fine quartz sand present below 1255 ft (382.52 m). We place these sands in the lower to lowermost upper Paleocene Hornerstown Formation (Fig. 11). *Gryphaea dissimilis* shells are found between 1252 and 1253 ft (381.61 and 381.91 m). We note a possible sequence boundary at 1256.5 ft (382.98 m) with glauconite sand above and clayey glauconite sand below; the sequence from 1240.8 to 1256.5 ft (378.2–382.98 m) is assigned to Zones P4a and P3a (see "Biostratigraphy" section, this chapter) and is equivalent to Liu et al.'s (1997a) Pa2 sequence. Another sequence boundary occurs at 1258.7 ft (383.65 m) with angular siderite cemented clasts or nodules spanning the contact. Glauconitic clay lies below this contact, with clayey glauconite sand lying above it, similar to the sequence boundary at 1256.5 ft (382.98 m). The overlying sequence (1256.5–1258.7 ft [382.89–383.65 m]) is assigned to Subzone P1c (see "Biostratigraphy" section, this chapter) and is equivalent to the Sequence Pa1 of Liu et al. (1997a). A thin sequence not sampled at Island Beach occurs at the base of the Paleocene at Bass River (1258.7–1260.25 ft [383.65–384.12 m]) and is assigned to Subzone P1a (see "Biostratigraphy" section, this chapter).

Cretaceous/Tertiary Boundary Section

Interval: 1260.25 ft (384.12 m)

We cored the K/T boundary at 1260.25 ft (384.12 m), with the boundary occurring within a core. Black clayey glauconite sands (1259.0–1260.25 ft [383.74–384.12 m]) overlie a laminated, indurated interval (5Y6/2, light olive gray) between 1260.25 and 1260.4 ft (384.12 and 384.17 m). This zone contains white spherules and dark grains. Large (2 cm wide and up to 6 cm long) clasts that occur above the contact zone contain reworked Cretaceous foraminifers (1259.9–1260.25 ft [384.02–384.12 m]). Heavily burrowed, brown-

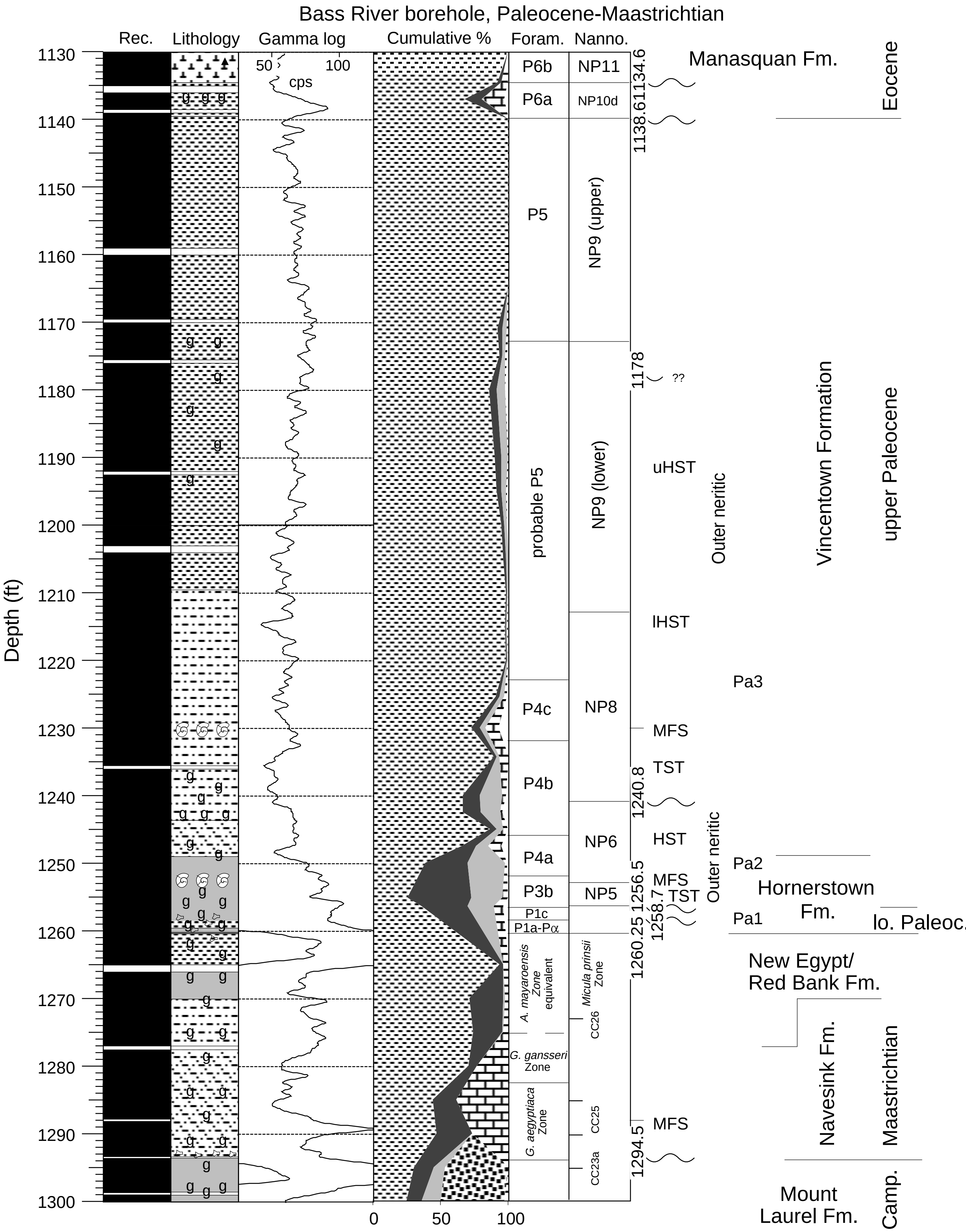

Figure 10. Vincentown Formation (upper Paleocene), Hornerstown Formation (lower to lowermost upper Paleocene), New Egypt Formation/Red Bank equivalent (Maastrichtian), and Navesink Formation (Maastrichtian) from the Bass River borehole. Pa1–Pa3 are sequences defined by Liu et al. (1997a). Camp. = Campanian. See Figure 4 for key to symbols.

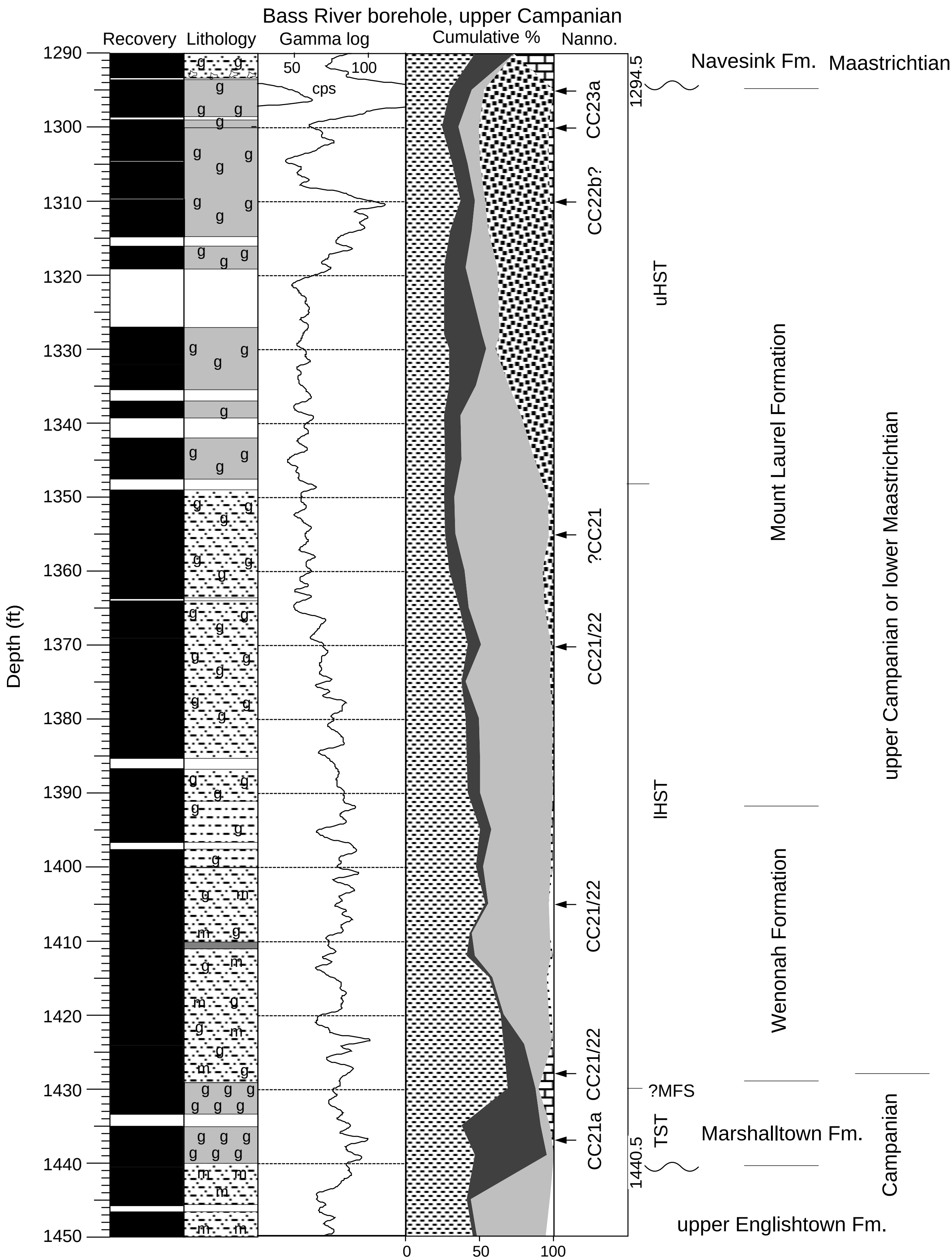

Figure 11. Mount Laurel, Wenonah, and Marshalltown Formations (upper Campanian or lower Maastrichtian) from the Bass River borehole. See Figure 4 for key to symbols.

ish gray glauconitic clay underlies the spherule-bearing layer. Details of this section are reported by Olsson et al. (1997).

New Egypt Formation/Red Bank Equivalent

Age: Maastrichtian
Interval: 1260.25–1270 ft (384.12–387.10 m)

The brownish gray shelly clays underlying the spherule layer become siltier and more glauconitic downsection to 1270 ft (387.10 m). We follow Olsson (1960) in placing these brownish gray glauconitic clays in the New Egypt Formation. The glauconitic clays are equivalent to the HST of the Navesink-Red Bank sequence of Sugarman et al. (1995). The formation was deposited in a relatively deep environment (middle neritic). This unit is uppermost Maastrichtian (calcareous nannofossil *Micula prinsii* Zone CC26; Table 3).

Navesink Formation

Age: Maastrichtian
Interval: 1270–1294.5 ft (387.10–394.56 m)

The contact of the New Egypt Formation with the glauconitic clays to clayey glauconite sands of the Navesink Formation is gradational between ~1270 and 1277 ft (387.10 and 389.23 m). Clayey, fossiliferous, very bioturbated glauconite sands at 1277.5 ft (389.38 m) mark the top of the definite Navesink Formation, which varies between glauconitic sandy clays and clayey glauconite sands. Brown clay clasts are found throughout. Glauconite carbonate clays (marls) found between 1281.5 and 1288 ft (390.60 and 392.58 m) may represent a condensed section; a gamma-log kick at the base of these marls (1288 ft [392.58 m]) is interpreted as the MFS. The Navesink Formation was deposited in a relatively deep (outer neritic) environment. The Navesink Formation is Maastrichtian (calcareous nannofossil Subzone CC25b to Zone CC26; Table 3).

Mount Laurel Formation

Age: late Campanian or early Maastrichtian
Interval: 1294.5–1391 ft (394.56–423.98 m)

A remarkable contact occurs at 1294.5 ft (394.56 m; Fig. 11). The entire interval between 1293.5 and 1294.5 ft (394.26 and 394.56 m) is a contact zone, with reworked Mount Laurel sands mixed with Navesink clayey glauconite sands. Phosphoric pellets occur above the boundary, whereas the section below the boundary is slightly indurated with siderite to 1316 ft (401.12 m). The Mount Laurel Formation is found below the contact zone; it consists of heavily burrowed, slightly micaceous, silty, glauconitic, fine to medium quartz sand containing shells, echinoid spines, and foraminifers. Above 1350 ft (411.48 m), medium to coarse quartz sand becomes increasingly common and dominates above ~1310 ft (399.29 m; Fig. 11). The section becomes more glauconitic below ~1309 ft (398.98 m), silty below ~1354 ft (412.70 m), and silty/clayey below ~1377 ft (419.71 m). Thus, the contact with the underlying micaceous silts of the Wenonah Formation is transitional. Benthic foraminiferal assemblages indicate deposition in an inner neritic environment. Calcareous nannofossils (Zones CC23 to CC19/20; Table 3) and planktonic foraminifers indicate that the Mount Laurel Formation is upper Campanian to lowermost Maastrichtian (see “Biostratigraphy” section, this volume).

Wenonah Formation

Age: late Campanian or early Maastrichtian
Interval: 1391–1429 ft (423.98–435.56 m)

Table 3. Occurrences of Cretaceous nannoplankton in the Bass River borehole.

Depth (ft)	Zone	Key species	Age	Formation
1264.8	CC26	*Micula prinsii*	Maastrichtian	Red Bank
1273	CC26	*Lithraphidites kennethii*	Maastrichtian	Navesink
1285	CC25b	*Arkhangelskiella cymbiformis*	Maastrichtian	Navesink
1290	CC25b	*Arkhangelskiella cymbiformis*	Maastrichtian	Navesink
1295	CC23a	*Broinsonia parca, Reinhardtites levis, Quadrum trifidum*	late Maastrichtian-Campanian	Mount Laurel
1300	CC23a	*Broinsonia parca, Reinhardtites levis, Quadrum trifidum*	late Maastrichtian-Campanian	Mount Laurel
1310	CC22b?	*Reinhardtites anthophorus, Reinhardtites levis*	late Maastrichtian-Campanian	Mount Laurel
1355	CC21?	*Broinsonia parca, Quadrum nitidum*	late Maastrichtian-Campanian	Mount Laurel
1370	CC21/CC22	*Broinsonia parca, Calculites obscurus*	late Maastrichtian-Campanian	Mount Laurel
1405	CC21/CC22	*Broinsonia parca, Calculites obscurus*	late Maastrichtian-Campanian	Wenonah
1427.8	CC21/CC22	*Ceratolithoides aculeus, Quadrum nitidum*	late Maastrichtian-Campanian	Wenonah
1436.8	CC21a?	*Ceratolithoides aculeus, Lucianorhabdus maleformis*	Campanian	Marshalltown
1488	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Englishtown/Woodbury
1520	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Woodbury
1560	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Woodbury
1581.6	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Woodbury
1604.9	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Woodbury
1620	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Woodbury
1639.9	CC19/CC20	*Broinsonia parca, Calculites obscurus*	Campanian	Woodbury
1659.9	CC18	*Calculites obscurus, Marthasterites furcatus*	Campanian	Merchantville
1670.7	CC17	*Calculites obscurus, Calculites ovalis*	Sant./Camp.	Merchantville
1676	CC16	*Calculites ovalis*	Santonian	Merchantville
1683.5	CC16	*Lucianorhabdus cayeuxii*	Santonian	Cheesequake
1700	CC15	*Micula decussata, Reinhardtites anthophorus*	Santonian	Cheesequake
1705	?	Barren	?	Cheesequake
1708	?	Poor	?	Cheesequake
1710.2	CC14?	*Eiffellithus eximius, Micula decussata*	Coniacian/Santonian	Magothy
1816.3	CC11??	Poor	Turonian	Bass River
1824.9	CC11?	Diverse but general	Turonian	Bass River
1841.1	CC11??	Poor	Turonian	Bass River
1861	CC11	Diverse but general	Turonian	Bass River
1889	CC11	Diverse but general	Turonian	Bass River
1910.9	CC11	Diverse but general	Turonian	Bass River
1914.3	CC11	*Axopodorhabdus albianus*?, *Eiffellithus* aff. *eximius*	Turonian	Bass River
1916.1	CC11		Turonian	Bass River
1920.9	CC11	*Axopodorhabdus albianus*?	Turonian	Bass River
1925	CC11	*Parhabdolithus asper, Ahmuellerella octoradiata*	Turonian	Bass River
1930.9	CC11	*Parhabdolithus asper, Axopodorhabdus albianus*	Turonian	Bass River
1937.9	CC10	*Lithraphidites acutus, Microstaurus chiastus*		
1943.6	CC10	*Axopodorhabdus albianus, Lithraphidites acutus*	Cenomanian	Bass River
1951.5	CC10	*Axopodorhabdus albianus, Lithraphidites acutus*		

Wenonah Formation micaceous silts were recovered at 1391 ft (423.98 m); below this level, silt and clay exceed 50% (Fig. 11). These silts are slightly glauconitic with occasional silty very fine sand intervals. The formation ranges from faintly laminated (e.g., 1404–1405 ft [427.94–428.24 m]) to pervasively bioturbated (e.g., 1410–1411 ft [429.77–430.07 m]), with excellent ichnostructures. Glauconite increases toward the base, and the contact with the underlying Marshalltown Formation is gradational. The Wenonah Formation is fossiliferous at this site, in contrast to most other localities in New Jersey where it is poorly fossiliferous or barren. It was deposited in a shelfal (probable inner neritic) environment.

Marshalltown Formation

Age: late Campanian or early Maastrichtian
Interval: 1429–1440.5 ft (435.56–439.06 m)

The micaceous, glauconitic silts of the Wenonah Formation are gradually replaced downsection by clayey, shelly, glauconite sands and glauconitic clays of the Marshalltown Formation. The Marshalltown Formation is fossiliferous at this site, with foraminifers and large oyster shells, in contrast to most other localities in the state where it is poorly fossiliferous or barren. A peak in foraminiferal abundances at 1430 ft (435.86 m) may represent the MFS of the Marshalltown-Wenonah-Mount Laurel sequence. Benthic foraminifers indicate deposition in a middle neritic environment.

The Wenonah-Mount Laurel Formations represent a coarsening-upward succession (HST) that overlies the Marshalltown transgressive section (TST). Downhole log comparisons with core lithologies (“core-log integration”) in the Mount Laurel and Wenonah Formations are excellent. The coarsening-upward pattern in these units is reflected in the gamma-ray log by decreasing values upsection. This decrease is interrupted by an interval of high radiation between 1310 and 1320 ft (399.29 and 402.34 m), which may be caused by slight induration, concentrating radioactive minerals in this interval.

The Marshalltown-Wenonah-Mount Laurel sequence had been dated as uppermost Campanian to lowermost Maastrichtian in other New Jersey boreholes using calcareous nannofossils (Subzone CC22b in the Mount Laurel; Zone CC20/21 in the Marshalltown) and Sr-isotopic stratigraphy (Sugarman et al., 1995). At Bass River, the Mount Laurel Formation is assigned to Zones CC21/22–CC23a, the Wenonah to Zones CC21/22, and the Marshalltown to Subzone CC21a (Table 3). Olsson (1991) assigned the Wenonah and Mount Laurel Formations in outcrop and updip subsurface sections to the Maastrichtian, whereas at Bass River planktonic foraminifers indicate that these units may be upper Campanian or Maastrichtian. The sequence is thinner in outcrop (80 ft [24.38 m]) and at the Clayton borehole (130 ft [39.62 m]; Sugarman et al., 1995) than at Bass River (146 ft [44.5 m]).

Englishtown Formation

Age: Campanian
Interval: 1440.5–1488 ft (439.06–453.54 m)

A sequence boundary occurs at 1440.5 ft (439.06 m; Fig. 12). Near the base of the Marshalltown Formation, an indurated clayey glauconite sand overlies a shelly clayey glauconite sand (1436.6–1439 ft [437.88–438.61 m]). This, in turn, overlies an interesting contact zone (1439–1440.5 ft [438.61–439.06 m]) that consists of slightly indurated, reworked micaceous, clayey fine sands with cemented nodules and increasing glauconite upsection. This contact zone is reminiscent of the base of the Navesink Formation observed in outcrop. Although the sequence boundary at 1440.5 ft (439.06 m) occurs between core runs, recovery was apparently complete.

The Englishtown Formation can be informally divided into upper (1440.5–1472.6 ft [439.06–448.85 m]) and lower lithologic successions (Fig. 12). The upper part of the upper Englishtown Formation consists of very micaceous, slightly glauconitic, heavily bioturbated, occasionally shelly, clayey fine sand (1440.5–1457 ft [439.06–444.09 m]) that becomes progressively clayey downsection. Sandy, clayey silts and silty clays predominate from 1459 to 1469 ft (444.70–447.75 m), becoming increasingly glauconitic downsection. A contact at 1467.4 ft (447.26 m) separates fossiliferous clays with interspersed glauconite sands above from heavily burrowed, glauconitic clays (1467.4–1469 ft [447.26–447.75 m]) below. This surface may be a MFS. Shelly glauconite sands lie at the base of the upper Englishtown Formation (1469–1472.6 ft [447.75–448.85 m]); the glauconite sands are indurated between 1471.6 and 1472.6 ft (448.54 and 448.85 m). This lithologic succession of basal glauconite sands (upper TST to lower HST deposited in middle neritic environments), medial silts and clays (lower HST), and upper sands (upper HST deposited in inner neritic environments) constitutes a typical New Jersey shallowing-upward sequence (Sugarman et al., 1995).

A dramatic sequence boundary occurs at 1472.6 ft (448.85 m; Fig. 12). A heavily indurated glauconitic shelly zone containing rip-up clasts (1471.6–1472.6 ft [448.54–448.85 m]) overlies a micaceous silty fine quartz sand. Glauconite is found piped down into burrows in the fine sand.

The lower Englishtown Formation (1472.6–1488 ft [448.85–453.54 m]) lies beneath the unconformity and consists of micaceous silty fine sand (Fig. 12); this sand comprises the upper HST of the Merchantville-Woodbury-lower Englishtown sequence (Fig. 12). Sands are cross bedded, although bioturbation may obscure cross bedding in many intervals. Pale brown clay is found in burrows, and there are occasional black clay lenses. Pyrite nodules occur in the section, and washed samples contain abundant lignite. It is difficult to assign a formational contact between the lower Englishtown and Woodbury Formation because sands become progressively less common below ~1480 ft (451.10 m). We place the boundary at 1488 ft (453.54 m) at the top of the first thick silty clay. The lower Englishtown Formation sands were deposited in inner neritic environments and comprise the upper HST of a sequence.

Woodbury Formation

Age: ?early Campanian
Interval: 1488–1654 ft (453.65–504.14 m)

Micaceous, fossiliferous silty clays of the Woodbury Formation appear at 1488 ft (453.54 m; Fig. 12). The clay is bioturbated, fossiliferous, and contains pyrite nodules. Lignite stringers are noted below 1514 ft (461.47 m). Abundant benthic foraminifers and common planktonic foraminifers are found throughout the Woodbury Formation at Bass River. Benthic foraminifers indicate deposition in neritic, probably middle neritic, environments. Silty clays are sandy down to ~1520 ft (463.30 m) and are interpreted as part of the upper HST. The section becomes finer grained below 1574 ft (479.76 m), consisting of slightly silty clay to clay. The thick clays comprise the lower HST of the Merchantville-Woodbury-lower Englishtown sequence. The Woodbury Formation at Bass River is lower Campanian (Zones CC19/CC20; Table 3).

Merchantville Formation

Age: Santonian to earliest Campanian
Interval: 1654–1683.2 ft (504.14–513.17 m)

Abundant foraminifers occur from 1654.0 to 1674.1 ft (504.14–510.27 m); we assign these glauconitic foraminiferal clays to the Merchantville Formation. Peak abundances of foraminifers at ~1660 ft (505.97 m) may mark a possible flooding surface/condensed section. From 1654 to 1684 ft (504.14–513.28 m), glauconite sand increases from <5% to over 50% (up to 70% in places), and the section changes from foraminiferal clays to interbeds of glauconitic clays and clayey glauconite sand (Fig. 12). The entire section is heavily

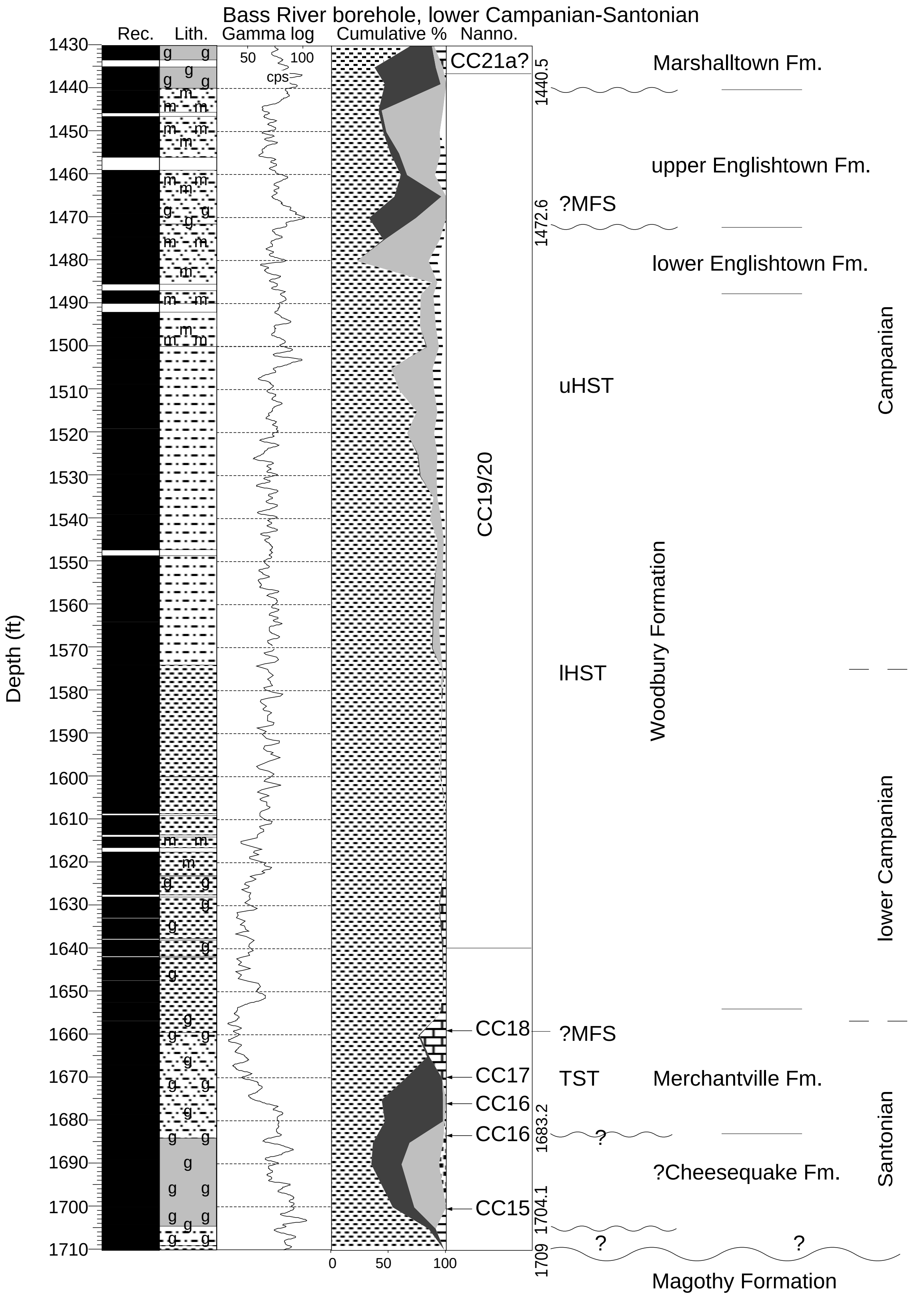

Figure 12. Englishtown (Campanian), Woodbury (?lower Campanian), Merchantville (Santonian to lowermost Campanian), and Cheesequake Formations (Santonian) from the Bass River borehole. See Figure 4 for key to symbols.

bioturbated with abundant shells. The Merchantville Formation was deposited in middle to outer neritic environments. The Merchantville Formation is Santonian to lower Campanian at Bass River according to calcareous nannofossils (Zones CC16–18; Table 3) and planktonic foraminifers (see "Biostratigraphy" section, this chapter).

Cheesequake Formation

Age: Santonian
Interval: 1683.2–1709.2 ft (513.04–520.96 m)

We place the base of the Merchantville Formation at 1683.2 ft (513.04 m) at an unconformity separating glauconite clay above from clayey glauconite-quartz sand below (1683.2–1704.15 ft; 513.04–519.42 m; Fig. 12). The approximate co-equal mixture of glauconite and quartz sand below the unconformity is interpreted as resulting from reworking of glauconite in the HST. The glauconite-quartz sands grade down to glauconite clay to 1704.15 ft (519.42 m); at this level, there is a surface with pebbly, shelly glauconite clay overlying gray clay that may be a sequence boundary. The base of the thin underlying sequence (1704.15–1709.2 ft [519.42–520.96 m]) is marked by a thin bed of glauconite sand (1709.0–1709.2 ft [520.90–520.96 m]). The formational and sequence assignments of the section between 1683.2 and 1709.2 ft (513.03 and 520.96 m) is uncertain; it may correspond to the Cheesequake Formation of Litwin et al. (1993). This lithologic unit is assigned to Zones CC15 and CC16 (Santonian) at Bass River (Fig. 12).

Magothy Formation

Age: undifferentiated early Turonian–Santonian (?Coniacian)
Interval: 1709.2–1806.4 ft (520.96–550.59 m)

A contact at 1709.2 ft (520.96 m) occurs between glauconite sands above with a slightly micaceous laminated clay (1709.2–1710.8 ft [520.96–521.45 m]) and interbedded clay and clayey, pebbly medium to coarse quartz sand (1710.8–1713.6 ft [521.45–522.31 m]) below (Fig. 13). Both the laminated clay and interbedded clays and sand contain shell fragments and were deposited in marginal marine (probably estuarine) environments. We tentatively place the top of the Magothy Formation at 1709.2 ft (520.96 m), although it is possible that the contact is at 1714 ft (522.56 m), the level of a gamma-log kick and facies change. Well-sorted, lignitic, medium to fine quartz sand (1714–1724 ft [522.56–525.48 m]) grades down to interbedded sandy silty clay and clayey very fine sand to 1727 ft (526.39 m). The sediments are generally laminated or slightly bioturbated; they are very lignitic throughout. The interbeds of sands and clays were deposited in a delta front environment and show a generally coarsening-upward pattern. Recovery was poor below this, with a white (?kaolinitic) clean clay (1733.0–1734.5 ft [528.22–528.68 m]) and a white (?kaolinitic) and red clay (1744.0–1744.8 ft [531.57–531.82 m]) with red sandstone (?Triassic) clasts. These clays are interpreted as terrestrial. We tentatively place a sequence boundary in the interval of no recovery between 1744.8 and 1749.0 ft (531.82 and 533.1 m) at a major gamma-log kick; alternatively, a sequence boundary may separate these terrestrial clays from the overlying delta front clays.

From 1749.0 to 1755.8 ft (533.10–535.17 m), a pebbly, moderately sorted sand may indicate deposition in a fluvial setting (Fig. 13). This grades downsection to lignitic silty sands and fine sands and occasional clays (1759–1776 ft [536.14–541.32 m]) deposited in a delta front environment. From 1776.0 to 1806.4 ft (541.32–550.59 m), micaceous, lignitic silty clays were deposited in a prodelta environment. The upsection transition from prodelta to delta front to fluvial sediments represents deposition in a prograding, regressive deltaic setting. The terrestrial clays (1733.0–1744.8 ft [528.22–531.82 m]) may cap this succession or represent the base of an overlying succession.

The upper part of the Magothy Formation at Bass River is assigned to pollen Zone V of Christopher (1982), which is generally correlated to the upper Turonian–Santonian, agreeing with outcrop relationships (see "Biostratigraphy" section, this chapter). The lower part of the Magothy Formation at Bass River is assigned to pollen Zone IV (upper Cenomanian to lowermost Turonian), which contradicts outcrop relationships (see discussion in "Biostratigraphy" section, this chapter).

Bass River Formation

Age: Cenomanian to Turonian
Interval: 1806.4–1956.5 ft (550.59–596.34 m)

The Bass River Formation was named by Petters (1976). Its type section is in the Transco 16 well, Bass River Township (39°38.0′N, 74°30.6′W), ~4 mi (6.4 km) west-northwest of our location (projected as ~135–180 ft [41.15–54.86 m] shallower than at this site; note that Petters [1976] reports the depth as 1450–1654 ft [441.96–504.14 m]; this appears to be too shallow). The formation was named as the more fully marine equivalent of the Raritan Formation; it is differentiated from the latter by its common shells and deeper-water environment of deposition. It is differentiated from the overlying Magothy Formation by abundant chlorite. At the Leg 174AX Bass River borehole, the Bass River Formation was encountered from 1806.4 ft to TD (1956.5 ft; 550.59–596.34 m).

A major sequence boundary between the Magothy and Bass River Formations at 1806.4 ft (550.59 m; Figs. 13, 14) separates clays above a contact zone (1806.4–1807.1 ft [550.59–550.80 m]) from a fossiliferous chloritic, micaceous fine–very fine sandy silt below 1807.1 ft (550.80 m). The contact zone consists of light brown, sideritic clay; the base of this zone contains a bed of numerous (hundreds) nested thin shells. Shells are bioturbated above the contact to 1805.75 ft (550.39 m). Indurated zones (1812.4–1813.6 and 1814.4–1814.9 ft [552.42–552.79 and 553.03–553.18 m]) of heavily cemented, fossiliferous chloritic, quartz sands appears to have sharp erosional basal contacts. These zones may be storm beds and not sequence boundaries.

In the Bass River borehole, the Bass River Formation consists of primarily fossiliferous, micaceous (chloritic), clayey silts and silty clays with occasional sandy silts (Fig. 14). The upper part of the formation (1806.4–1821 ft [550.59–555.04 m]) is slightly sandy. From 1821 to 1899 ft (555.04–578.82 m), the section is primarily clayey silts, becoming silty clay from 1899 to 1924 ft (578.82–586.44 m), and primarily clay with silty interbeds from 1924 to 1956.5 ft (586.44–596.34 m). Siderite concretions are noted in the upper part of the section (1832.2–1832.4 and 1823.5–1823.6 ft [558.45–558.52 and 555.80–555.83 m]). Several concentrations of shells are present, including a graded shell layer at 1848–1848.5 ft (569.98–563.42 m) interpreted as a storm bed, a shell bed at 1856 ft (565.71 m), a very shelly interval at 1870–1871 ft (569.98–570.28 m), an interval of large, thick mollusk shells at 1917–1918.5 ft (584.30–584.76 m), and a very shelly layer at 1937–1938 ft (590.40–590.70 m). There are two carbonate-cemented intervals at 1893.2–1893.4 ft and 1906.2–1906.4 ft (577.05–577.11 m and 581.01–581.07 m). The clays below 1924 ft (586.44 m) are typically laminated, although some intervals are massive due to moderate bioturbation.

The Bass River Formation was deposited on a marine shelf, mostly in inner to middle neritic environments, although some siltier, less shelly laminated intervals are interpreted as prodelta or delta front (1839.1–1844.8 ft [560.56–562.30 m]). It is lower Turonian (calcareous nannofossil Zone CC11; Table 3) to 1930.9 ft (588.54 m) and Cenomanian below 1937.9 ft (590.67 m; Zone CC10; Table 3).

The Bass River Formation recovered in this borehole may be divided into two shallowing-upward sequences (Fig. 14): 1806.4–1839.1 ft (550.59–591.04 m) and 1839.1 ft (560.56 m) to TD. The upper sequence consists of a lower shelly, bioturbated clayey silt depos-

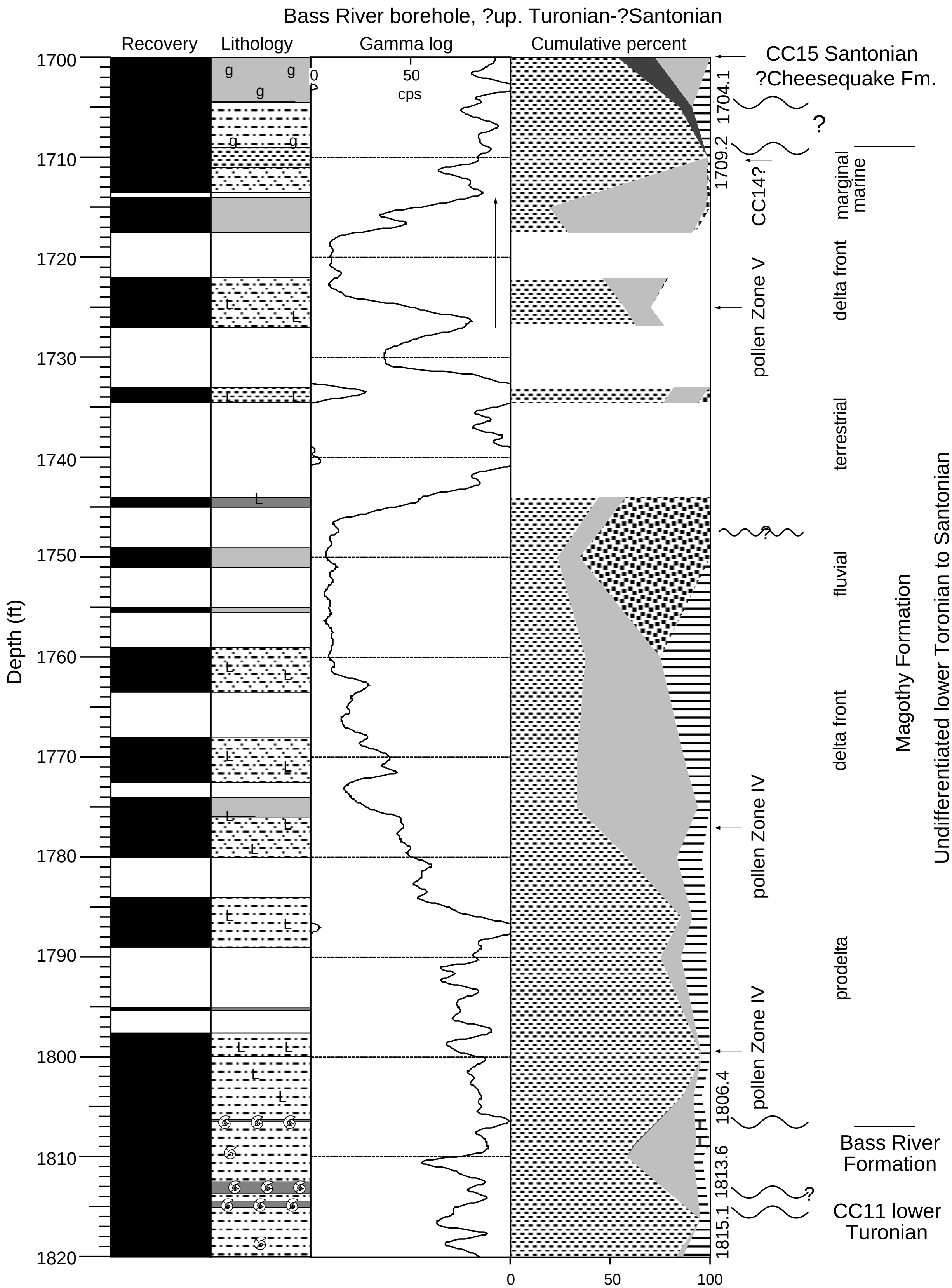

Figure 13. Magothy Formation (undifferentiated lower Turonian–Santonian [?Coniacian]) from the Bass River borehole. See Figure 4 for key to symbols.

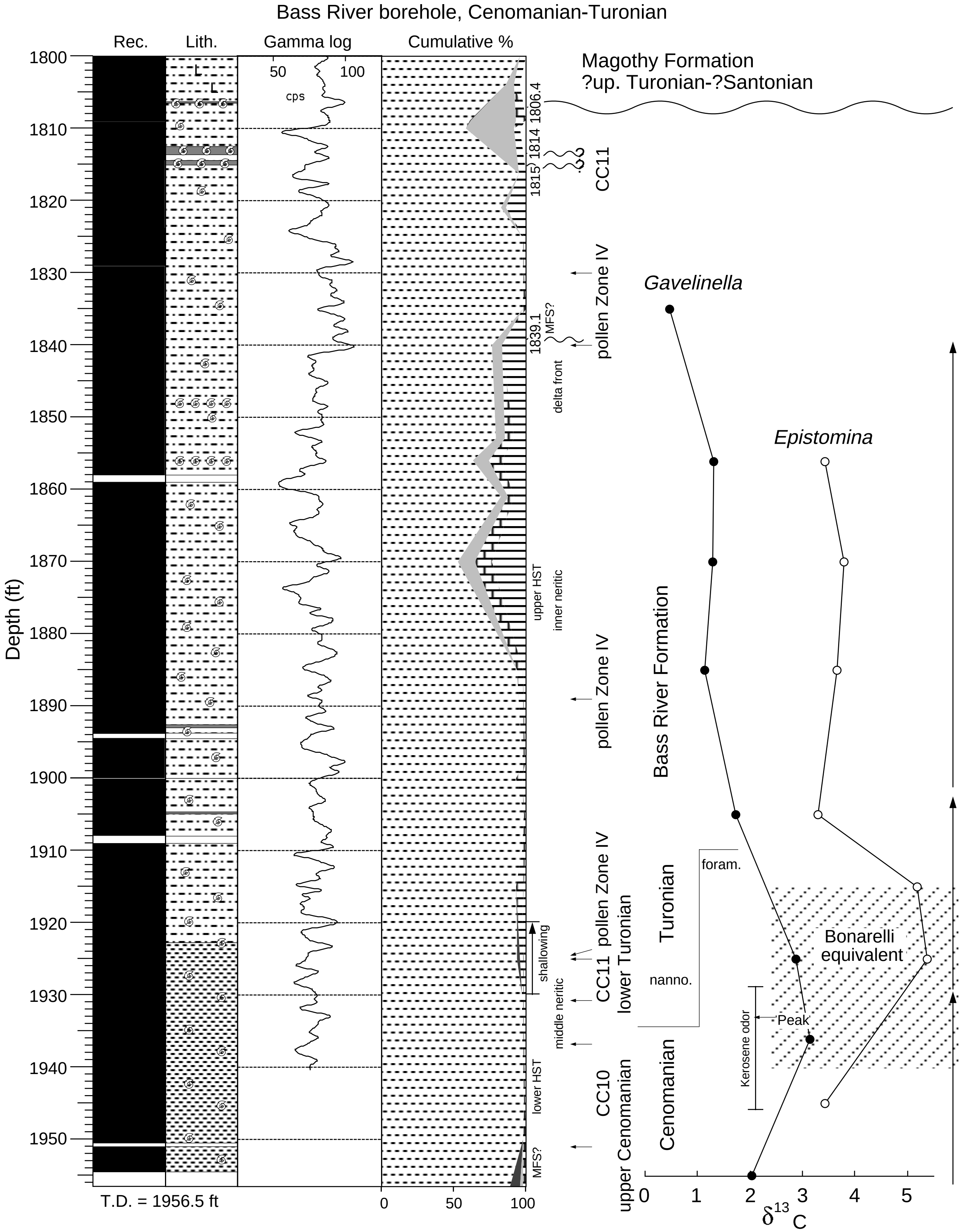

Figure 14. Bass River Formation (Cenomanian to Turonian) from the Bass River borehole. See Figure 4 for key to symbols. Carbon isotope data are reported to the Peedee belemnite standard. Arrows indicate shallowing-upward paleobathymetric trends (parasequences within the 1839.1-mbsf to TD sequence) shown by benthic foraminifers.

ited in inner neritic environments coarsening upward to a sandy silt deposited in inner neritic to prodelta environments. Shells are more abundant to 1838 ft (560.22 m), perhaps marking the MFS, and less common above. At 1817.6–1817.1 ft (554.00–553.85 m), a laminated sand bed is deposited in a prodelta setting. Shelly, sandy silty clay (1815–1817 ft [553.21–553.82 m]) continues to the top of the sequence (1806.4 ft [550.59 m]).

A sequence boundary at 1839.1 ft (560.56 m; Fig. 14) consists of a burrowed surface separating shelly, marine shelf above from delta front interbedded micaceous silts. This break occurs within calcareous nannofossil Zone CC11 (Table 3). The lower sequence (1839.1 ft [560.56 m] to TD) appears to be a relatively complete transgressive-regressive cycle. Glauconite at the base of the cored section (1955 ft [595.88 m]) may indicate a MFS near the base of a sequence. Planktonic foraminiferal studies indicate a shallowing upsection from 1931 ft (588.57 m; middle neritic with a good planktonic fauna) to 1910 ft (582.17 m) and above (inner neritic with abundant epistominids). This interval corresponds with a change from clay below to silty clay above, decreasing carbon isotopic values (see "Isotopic Stratigraphy" section, this chapter), and the Cenomanian/Turonian boundary (Fig. 14). Cores from 1929 to 1946 ft (587.96–593.14 m) had a strong petroleum odor in the field; the odor could not be traced to onsite contamination. Re-examination of this interval in the Rutgers core library revealed a strong odor only at 1933 ft (589.18 m); this corresponds to the peak carbon isotope values (see "Isotopic Stratigraphy" section, this chapter) and may reflect high sediment organic carbon. The peak in carbon isotopic values corresponds to an uppermost Cenomanian global interval of high carbon extraction (e.g., the Bonarelli bed; Scholle and Arthur, 1980; Jenkyns et al., 1994). Coarse fraction data indicate further shallowing from 1880 to 1840 ft (573.02–560.83 m), with increasing concentrations of quartz sand and mica and the presence of storm shell beds. Interbeds of clay and shelly sand from 1848 ft (563.27 m) indicate further shallowing to shallow neritic/delta front. The section from 1931 to 1839.1 ft (588.57–560.56 m) is interpreted as upper HST, with progressive shallowing upsection.

BIOSTRATIGRAPHY

Planktonic Foraminifers

Foraminiferal biostratigraphic control is poor in the Miocene, limited in the Oligocene, improves in the upper Eocene, and is generally very good in the middle Eocene to Santonian and Turonian to Cenomanian. Sections with good biostratigraphic control were generally deposited in middle to outer neritic environments (i.e., 50–200 m).

Miocene

Two Miocene samples (545 and 550 ft [166.12 and 167.64 m]) contained foraminifers. Inner neritic benthic foraminifers dominate these samples (e.g., *Bulimina gracilis*, *Bolivina paula*, *Epistominella pontoni*). Planktonic foraminifers are rare and poorly preserved. A single occurrence of *Globorotalia zealandica* places this section within the lower Miocene (Fig. 6). Other planktonic foraminifer specimens observed (e.g., *Globigerina praebulloides*) are not age diagnostic.

Oligocene

The Oligocene at Bass River borehole (555.3–675.4 ft [169.26–205.86 m]; Fig. 7) is less fossiliferous than Leg 150X boreholes (e.g., Cape May, Atlantic City). Inner to middle neritic benthic foraminifers dominate at Bass River (e.g., *Cibicides lobatulus*, *E. pontoni*, *B. paula*, *Rectobolivina* spp.), and planktonic foraminifers are characterized by fair to poor preservation, low abundance, rare marker species, low diversity, and the dominance of nondiagnostic planktonic taxa.

Oligocene at Bass River is assigned to undifferentiated Zones P18–P19 (Fig. 7). From 555.3 to 570.0 ft (169.26–173.74 m), foraminifers are rare, and planktonic foraminiferal marker species are absent. The occurrences of *Chiloguembelina cubensis* between 580.0 and 620.0 ft (176.78 and 188.98 m) and *Turborotalia ampliapertura* at 576 ft (175.56 m) and the absence of *Pseudohastigerina* spp. may indicate planktonic foraminiferal Zone P19. However, because of poor preservation and rare occurrences of planktonic specimens, the absence of *Pseudohastigerina* spp. may be due to a premature highest occurrence (HO). Assignment to undifferentiated Zones P18–P19 agrees with calcareous nannofossil data (Zone NP22; 32.3–32.8 Ma) and Sr-isotopic age estimates (32.0–33.6 Ma); the latter data imply that the section is correlative to Zone P18. Near the base (675.4–669.0 ft [205.86–203.91 m]), planktonic foraminifers are rare, consisting of small non–age diagnostic species (*Tenuitella neoclemenciae*, *T. munda*, *T. gemma*, and *T. angustiumbilicata*).

Eocene

In contrast to the Oligocene and Neogene, Eocene sediments are more fossiliferous and generally contain well-preserved marker taxa allowing for planktonic foraminiferal zonation. The top of the Eocene is marked by the HO of *Hantkenina primitiva* and *Turborotalia cerroazulensis* at 678 ft (206.65 m; Fig. 8). The interval between 678 and 770 ft (206.65 and 234.70 m) is sparsely fossiliferous and is assigned to Zones P15–P17 undifferentiated. Calcareous nannofossil Zone NP21 occurs between 676 and 702.4 ft (206.04 and 214.09 m; see "Biostratigraphy" section, this chapter), indicating that this section may be equivalent to uppermost Zones P16 and P17 (Fig. 8). *Cribrohantkenina inflata* is absent from this core and from others on the New Jersey Coastal Plain (Liu et al., 1997b; Poore and Bybell, 1988), making it difficult to determine the top of Zone P15. The presence of *Turborotalia cerroazulensis pomeroli* indicates that the section below 770 ft (234.70 m) is Zone P15 and older. The base of Zone P15 is recognized by the lowest occurrence (LO) of *Porticulasphaera semiinvoluta* at 840.2 (256.09 m).

The section between 863.6 and 840.1 ft (263.23 and 256.06 m) is assigned to the upper Eocene using calcareous nannofossils (Zone NP18); however, this section yields only middle Eocene foraminifers (abundant and well-preserved *Acarinina* spp. and *Morozovella* spp., equivalent to middle Eocene Zone P14 and older; Fig. 8). There are no foraminiferal taxa indicative of the upper Eocene in this interval. Similar discrepancies between planktonic foraminifers and calcareous nannofossils were noted in other boreholes on the New Jersey Coastal Plain (Liu et al., 1997b; Poore and Bybell, 1988). We interpret the middle Eocene planktonic foraminifer fauna as reworked (see also Liu et al., 1997b; Poore and Bybell, 1988), and, based on calcareous nannofossil evidence, we suggest that the sediments are upper Eocene (Zone P15 equivalent).

The base of Zone P13 is defined by the LO of *Globigerapsis beckmanni* (Berggren et al., 1995), which is absent from the Bass River borehole. The base of Zone P13 can be approximated by the HO of *Acarinina bullbrooki* (Berggren et al., 1995). *A. bullbrooki* is present at 870 ft (265.18 m), indicating that the sediments below are Zone P12 and older (Fig. 8). The base of Zone P12 is at 905 ft (275.84 m; Fig. 9) and is marked by the HO of *Morozovella aragonensis* at 911 ft (277.67 m) and the LO of *Morozovella lehneri* at 900 ft (274.32 m). The lowest sample containing Zone P11 is at 930 ft (283.46 m), containing *Globigerapsis kugleri* along with an abundant and diverse fauna (including *G. kugleri*, *Globigerapsis mexicana*, *M. aragonensis*, *M. spinulosa*, and *Turborotalia possagnoensis*).

Sediments between 940 and 996 ft (286.51 and 303.58 m) are assigned to Zones P9-P10 undifferentiated (Fig. 9). Zones P9 and P10 cannot be separated in the Bass River borehole because of the delayed first occurrence of the genus *Hantkenina* (*H. alabamensis*) at 911 ft (277.67 m). The first occurrence of *Planorotalites palmerae*, which defines the base of Zone P9, is at 996 ft (303.58 m). The highest occurrence of *Morozovella formosa formosa* is at 1049.9 ft (320.01 m) and marks the base of Zone P8, although this taxon is very rare. The base of Zone P7 is marked by the LO of *M. aragonensis* at 1105 ft (336.80 m). Sediments between 1110 and 1130 ft (338.33 and 344.42 m) are assigned to Subzone P6b based on the LO of *Morozovella formosa formosa* at 1130 ft (344.42 m). A sample at 1137 ft (346.56 m) is assigned to lowermost Eocene Subzone P6b based on the absence of *Morozovella velascoensis* and *M. formosa formosa* and the co-occurrence of *Pseudohastigerina micra*, *Morozovella formosa gracilis*, and *M. aequa*.

Paleocene

The top of the Paleocene occurs at 1138.6 ft (347.05 m) at the contact between the glauconitic clays of the Manasquan Formation and green clays of the Vincentown Formation (Fig. 10). Foraminifers are poorly preserved in the uppermost part of this unit (sample 1140 ft [347.48 m]). From 1145 to 1170.0 ft (349.00–356.62 m), abundant well-preserved foraminifers are present. This interval is placed in the *Morozovella velascoensis* Zone (P5) and contains *Morozovella aequa, M. gracilis, M. subbotinae, M. velascoensis*, and *Acarinina soldadoensis.* In addition, two species (*Acarinina africana* and *A. sibaiyaensis*) that are associated with the late Paleocene thermal maximum (LPTM) at Site 865 in the tropical Pacific (Kelly et al., 1996) occur throughout this interval. These species are thought to represent short-lived “excursion taxa” that evolved rapidly during the LPTM at Site 865 and then quickly disappeared. Their presence throughout a 25 ft (7.6 m) section at Bass River may indicate a longer survival time in the North Atlantic. Further study on more closely spaced samples and carbon and oxygen isotope analyses should help clarify the relationship of these species to the LPTM. Benthic foraminifers, represented by species of *Bolivina, Bulimina, Cibicides, Gyroidinoides, Pseudouvigerina, Pulsiphonina, Tappanina,* and *Uvigerina* indicate middle neritic paleodepths for this interval at Bass River.

The interval from 1170 to 1225.3 ft (356.62–373.47 m) contains sparse, poorly preserved foraminifers. Rare occurrences of *Acarinina coalingensis, Morozovella acuta, Subbotina triangularis,* and *S. velascoensis* are noted. The stratigraphic position of this interval between Subzone P4c below and Zone P5 above suggests that it lies within Zone P5. The benthic foraminiferal assemblage contains outer neritic and upper bathyal taxa, such as *Cibicidoides eocaena, Stensioina beccariformis, Pullenia eocaena,* and *Osangularia* sp. Radiolarians are present in the lowermost part of the interval.

The HO of *Globanomalina pseudomenardii* marks the top of Zone P4 at 1225.3 ft (373.47 m), and its LO at 1247.5 ft (380.24 m) marks the base of the zone (Fig. 10). Preservation of foraminifers in this zone is generally good, except at the top of the zone where radiolarians are abundant. Both planktonic and benthic foraminifers are diverse and abundant. In addition to the zonal markers, typical planktonic foraminifers include *Acarinina mckannai*, *Morozovella apanthesma, M. occlusa*, *Subbotina triangularis,* and *S. velascoensis.* Zone P4 can be further divided into Subzones P4a, P4b, and P4c of Berggren et al. (1995). The base of Subzone P4c is identified at 1230.0 ft (374.90 m) on the LO of *Acarinina soldadoensis.* Subzone P4a is identified in sample 1247.5 ft (380.24 m) by the HO of *Acarinina subsphaerica.* Middle neritic paleodepths are suggested by the benthic foraminiferal assemblage, which includes *Anomalinoides acuta, Cibicidoides alleni, Gavelinella danica, Nodosaria latejugata, Pullenia americana, Stilostomella plummerae,* and *Tappanina selmensis.*

The section from 1247.5 to 1256.3 ft (380.24–382.92 m) is placed in Subzone P3b (Fig. 10) based on the presence of *Acarinina strabocella, Igorina pusilla, Morozovella angulata, Parasubbotina variospira,* and *Subbotina triloculinoides.* Foraminifers are fewer than in the zone above and less well preserved. The benthic foraminiferal assemblage is similar to the Zone P4 assemblage, suggesting a similar paleodepth.

Foraminifers are abundant, diverse, and generally well preserved in the section from 1256.3 to 1258.8 ft (382.92–383.68 m; Fig. 10). This section is placed in Subzone P1c (*Globanomalina compressa/ Praemurica inconstans–Praemurica uncinata* interval subzone; see Berggren et al., 1995) on the occurrences of *Globanomalina compressa, Globoconusa daubjergensis, Parasubbotina pseudobulloides, Praemurica inconstans,* and *Subbotina triloculinoides.* A hiatus, representing Zone P2 and Subzone P3b, separates this section from that above. A hiatus (missing Subzone P1b) also occurs at the base of this section. A middle to outer neritic paleodepth is indicated by an abundant, diverse benthic foraminiferal assemblage that is characterized by *Bulimina quadrata, Cibicidoides alleni, Gavelinella lellingensis, Osangularia plummerae,* and *Tappanina selmensis*.

A thin section from 1258.8 to 1260.25 ft (383.68–384.12 m) occurs at the base of the Tertiary (Fig. 10). This section includes a 6-cm-thick spherule layer above the Cretaceous/Tertiary (K/T) boundary at 1260.25 ft (384.12 m) and includes Zone P0 (*Guembelitria cretacea* Zone), Zone Pα (*Parvularugoglobigerina eugubina* total range Zone), and Zone P1a (*Parvularugoglobigerina eugubina-Praemurica uncinata* interval Zone; Berggren et al., 1995). Zone P0 is defined as the interval between the extinction of Cretaceous planktonic foraminiferal taxa and the LO of *Parvularugoglobigerina eugubina*, and thus includes the spherule layer. The zone is 7 cm thick. The LO of *P. eugubina* marks the base of Subzone P1a. Zone Pα is 8 cm thick, and Subzone P1a is 26 cm thick. Characteristic taxa that occur in Zone Pα and Subzone P1a include *Eoglobigerina edita*, *E. eobulloides*, *Parasubbotina pseudobulloides*, *Praemurica taurica*, *Subbotina trivialis, Woodringina claytonensis,* and *W. hornerstownensis.* In addition to the planktonic foraminiferal data, two dinoflagellate datums are worth noting (data supplied by D. Habib, pers. comm., 1996). The LO of *Senoniasphaera inornata,* which lies within Zone P0 (Habib et al., 1996), also occurs within this zone at Bass River. The LO of *Damassadinium californicum* is associated with the base of Zone Pα and coincides with the LO of *P. eugubina* in the Gulf Coast (Habib et al., 1996) and at Bass River. The benthic foraminiferal assemblage in the basal Danian section is similar to that present in the uppermost Maastrichtian below the spherule layer (Olsson et al., 1997) and is indicative of middle neritic paleodepths. Typical species include *Alabamina midwayensis, Anomalinoides acuta, A. midwayensis, Buliminella carseyae, Osangularia plummerae, Pulsiphonina prima, Stilostomella pseudoscripta,* and *Valvulineria depressa.* Foraminifers in the basal Danian section are relatively sparse and moderately preserved.

Maastrichtian

The Navesink Formation (1270–1294.5 ft [387.10–394.56 m]) and the New Egypt Formation/Red Bank equivalent (1260.25–1270 ft [384.12–387.10 m]) contains abundant, well-preserved foraminifers (Fig. 10). Because of the absence of *Abathomphalus mayaroensis*, a planktonic species which apparently developed its adult morphology in the deeper part of the water column (it is present in the upper Maastrichtian at Deep Sea Drilling Project Site 605 on the New Jersey slope), the lower boundary of the *A. mayaroensis* Zone can only be approximated. It is tentatively placed at 1275 ft (388.62 m) above the HOs of *Globotruncana bulloides* and *Rosita fornicata* (1285 ft [391.67 m]), which occur in the middle part of the *Gansserina gansseri* Zone (Fig. 10). The HO of *Gansserina gansseri*, which occurs in the middle part of the *A. mayaroensis* Zone, is at 1269.9 ft (387.07 m). Typical species that occur in the *A. mayaroensis* Zone at Bass River include *Globotruncana aegyptiaca, Hedbergella monmouthensis, Laeviheterohelix dentata, Planoglobulina acervulinoides, Pseudoguembelina hariaensis, Racemiguembelina fructi-*

cosa, and *Rugoglobigerina scotti*. The presence of the calcareous nannofossil *Micula prinsii* from 1264.8 to 1260.25 ft (385.51–384.12 m) also indicates that this section is equivalent to the uppermost *A. mayaroensis* Zone (Table 3; D. Habib, pers. comm., 1997). In addition, the dinoflagellate *Palynodinium grallator*, an uppermost Maastrichtian species, occurs with *M. prinsii* at Bass River (D. Habib, pers. comm., 1997). The base of the *Gansserina gansseri* Zone is placed between 1285 and 1280 ft (391.67 and 390.14 m). The LO of *Globotruncana linneiana,* which occurs at the base of the *G. gansseri* Zone, is at 1285 ft (391.67 m). The lower part of the Navesink Formation (1285–1294.5 ft [391.67–394.56 m]) is placed in the *Globotruncana aegyptiaca* Zone.

The Navesink–New Egypt sequence was deposited in a gradually shallowing sea-level cycle. The Navesink Formation was deposited in an upper bathyal to outer neritic environment of ~200 m paleodepth. Benthic foraminifers typical of these paleodepths that occur in the Navesink Formation at Bass River include *Bolivina incrassata, Bolivinoides draco, B. giganteus, Chilostomella trinidadensis, Eggerella trochoides, Gavelinella spissocostata, Gyroidinoides globosa, Arenobulimina subsphaerica,* and *Pullenia cretacea.* A shallowing to about 100 m paleodepth occurs in the New Egypt Formation. Benthic species that are characteristic of this section include *Anomalinoides midwayensis, Globulina gibba, Gyroidinoides imitata, Pseudoclavulina clavata, Pullenia americana, Pulsiphonina prima, Stilostomella pseudoscripta, Tappanina selmensis, Vaginulina cretacea,* and *Valvulineria depressa.* A slight shallowing in paleodepth to ~75 m is evident 4 cm below the K/T boundary. Species that appear are ones typical of Danian assemblages. These include *Alabamina midwayensis, Angulogerina naheolensis, Anomalinoides acuta, Gavelinella neelyi,* and *Quadrimorphina allomorphinoides*. This assemblage continues into the lower Danian.

Upper Campanian or lower Maastrichtian

Foraminifers are sparse in the Mount Laurel Formation (1294.5–1391 ft [394.56–423.98 m]). Small specimens of Campanian–lower Maastrichtian planktonic foraminifers include *Globigerinelloides prairiehillensis, Globotruncana bulloides, G. linneiana,* and *Rosita fornicata*. A low diversity, inner neritic assemblage of benthic foraminifers includes *Cibicides harperi, Gavelinella compressa,* and *G. pinguis*.

Abundant, well-preserved, small-sized (<125 µm) foraminifers occur in the Wenonah Formation. The planktonic foraminiferal assemblage is more diverse than in the Mount Laurel Formation and includes *Globotruncanita stuartiformis, Laeviheterohelix glabrans,* and *Rugoglobigerina rugosa,* in addition to the above species. An inner neritic environment of deposition is indicated by a low-diversity assemblage of species of *Buliminella, Gavelinella, Praebulimina,* and *Valvulineria.*

Campanian

The Marshalltown Formation (1429–1440.5 ft [435.56–439.06 m]) contains abundant, highly diverse, well-preserved foraminifers. The *Globotruncanita calcarata* Zone, which is used in foraminiferal biostratigraphy as the uppermost zone of the Campanian, has been identified in the uppermost part of Marshalltown Formation in Delaware (Houlik et al., 1983), in outcrop samples of the Marshalltown Formation in New Jersey (Olsson, 1964), and in cuttings of the Marshalltown Formation in the Anchor Dickinson well in southeastern New Jersey (Petters, 1977). *Globotruncanita calcarata* was not identified in the Bass River samples that were examined for this report. The species has a very short stratigraphic range, so that more closely spaced samples of the upper part of the Marshalltown Formation will need to be examined to determine if this diagnostic zonal species is present at Bass River. Typical planktonic foraminifers of the Marshalltown Formation are *Archeoglobigerina cretacea, Globigerinelloides prairiehillensis, Globotruncana bulloides, G. linneiana,* and *Rosita fornicata.*

The Marshalltown benthic foraminiferal assemblage at Bass River is diagnostic of this formation in New Jersey and Delaware. Large-sized *Gavelinella dumblei* and *Globorotalites michelinianus* are typical. Other typical species of this middle to outer neritic assemblage include *Clavulina trilatera, Gavelinella nelsoni,* and *Gavelinella pinguis.*

The upper Englishtown Formation (1440.5–1472.6 ft [439.06–448.85 m]) contains a sparse, low-diversity assemblage of small-sized foraminifers. Rare specimens of the planktonic foraminifers *Globotruncana bulloides, Heterohelix striata,* and *Rosita fornicata* are noted. The formation contains an inner neritic benthic foraminiferal assemblage of species of *Epistomina, Gavelinella, Globulina, Lenticulina, Praebulimina,* and *Tritaxia.*

The lower Englishtown Formation (1472.6–1488 ft [448.85–453.54 m]) also contains a sparse, low-diversity assemblage of small-sized foraminifers. The planktonic foraminifers include rare specimens of *Archeoglobigerina cretacea, Heterohelix striata,* and *Rugoglobigerina rugosa*. The inner neritic benthic foraminiferal assemblage is less diverse than in the upper unit and consists of species of *Gaudryina* and *Gavelinella.*

The Woodbury Formation (1488–1654 ft [453.65–504.14 m]) can be divided into two sections, an upper section (1488–1575 ft [453.54–480.06 m]) with low abundances of small-sized foraminifers and ostracods and a lower section (1575–1654 ft [480.18–504.14 m]) of abundant, well-preserved, diverse, larger sized foraminifers. The upper section contains rare planktonic foraminifers such as *Archeoglobigerina blowi, A. cretacea, Globotruncana bulloides,* and *Heterohelix striata.* The low-diversity benthic foraminiferal assemblage of species of *Bulimina, Epistomina, Gavelinella, Gyroidinoides, Lenticulina,* and *Valvulineria* suggests an inner to middle neritic environment.

The lower section of the Woodbury Formation (1575–1654 ft [480.06–504.14 m]) contains a diverse, early Campanian planktonic foraminiferal assemblage, which includes *Archeoglobigerina cretacea, A. tradinghousensis, Globigerinelloides ultramicra, Globotruncana linneiana, G. manaurensis,* and *Rosita fornicata.* The benthic foraminiferal assemblage is diverse and consists of species of *Bulimina, Gavelinella, Globorotalites, Marginulina, Sigmoilina,* and *Valvulineria. Gavelinella texana* and *Globorotalites conicus* are characteristic species of this middle to outer neritic assemblage.

Santonian

The Merchantville Formation (1654–1683.2 ft [504.14–513.04 m]) contains abundant, well-preserved, large-sized foraminifers except in the basal 10 ft (3.05 m), where abundance and size drops off. The Campanian/Santonian boundary is placed at 1659.9 ft (505.94 m), where species of *Marginotruncana* first occur. Species of *Marginotruncana* that occur in the Merchantville Formation are *M. coronata, M. marginata, M. pseudolinneiana,* and *M. sinuosa.* The benthic foraminiferal assemblage is similar to that present in the lower section of the Woodbury Formation. The greater numbers of *Gaudryina, Gavelinella infrequens, G. texana, Globorotalites conicus,* and *Gyroidinoides* suggest somewhat deeper paleodepths.

The Cheesequake Formation (1683.2–1709.2 ft [513.04–520.96 m]) contains low numbers of small-sized foraminifers in the upper part of the section. Foraminifers are absent in the lower part where molluscan shell material is abundant. The absence of planktonic foraminifers and the low diversity of benthic foraminifers *(Gaudryina, Gavelinella, Globulina, and Valvulineria)* suggest a shallow inner neritic environment.

?Coniacian

No foraminifers were noted in the ?Coniacian Magothy Formation (Fig. 13). Its age is only inferred by superposition (Santonian above and lower Turonian below bounding unconformities).

Cenomanian to Turonian

In general, foraminifers are abundant and well preserved in the Bass River Formation (1806.4–1956.5 ft [550.59–596.34 m]). The environment of deposition varies from inner to middle neritic. As a consequence, planktonic foraminifers are very rare to absent in some parts and moderately abundant in other parts. It is difficult to determine the Cenomanian/Turonian (C/T) boundary because of the very rare occurrences of species of the Cenomanian planktonic foraminiferal genus *Rotalipora*. The first occurrence of *Rotalipora* downhole is at 1920 ft (585.22 m), where *R. brotzeni* is identified. Because this species does not range to the top of the *Rotalipora cushmani* Zone, the C/T boundary is probably higher. We tentatively place the C/T boundary at the top (1910 ft [582.17 m]; Fig. 14) of a shallowing-upsection trend in which *Rotalipora* is first observed. *Rotalipora cushmani* has not been observed in the Bass River borehole, although it has been identified at other New Jersey Coastal Plain sites (Petters, 1977; Sikora and Olsson, 1991). This is probably because of the more widely spaced samples used for this report. The upper part of the Bass River Formation is placed in the lower Turonian, based on the presence of *Helvetoglobotruncana praehelvetica, Praeglobotruncana gibba, P. stephani,* and *Whiteinella archeocretacea*.

Of interest in the Bass River Formation is the repetition of shallowing-upward paleobathymetric trends (parasequences?) that are observed in the distribution and abundance of three benthic foraminiferal taxa, *Reinholdella, Ceratobulimina,* and *Epistomina*. The section shallows upsection from 1806.4 to 1900 ft (550.59–579.12 m; Fig. 14), with a low-diversity assemblage dominated by *Reinholdella* overlying a slightly more diverse assemblage dominated by *Ceratobulimina*, which, in turn, overlies a more diverse assemblage dominated by *Epistomina*. The planktonic foraminiferal assemblages become more abundant and diverse downsection, reaching their greatest abundance and diversity in the *Epistomina* assemblage. The *Ceratobulimina–Epistomina* succession is repeated from 1900 to 1925 ft (579.26–586.74 m). Abbreviated trends involving mostly *Epistomina* assemblages occur from 1925 to 1945 ft (586.74–592.84 m) and from 1945 to 1955 ft (592.84–595.88 m). Each time the *Epistomina* assemblage appears, it is composed of different species, suggesting either origination of new species or somewhat different paleohabitats for each species.

Cenozoic Calcareous Nannofossils

The Neogene sediments recovered from the Bass River borehole are barren of calcareous nannofossils. In contrast, the Paleogene deposits yield abundant and diverse calcareous nannofossil assemblages except for a thin, barren lowermost Oligocene interval and for monotonous assemblages in the middle Eocene Shark River Formation (Subzone NP14a–Zone NP16; Fig. 9). Preservation varies greatly through the section, from excellent in the uppermost Paleocene part of the Vincentown Formation (upper Zone NP9) to very poor in the lower Oligocene (Zone NP22) Atlantic City Formation and the middle Eocene Shark River Formation due to strong dissolution in the former and calcite overgrowth in the latter.

Although most Paleogene calcareous nannofossil zones were identified, it is clear that large stratigraphic gaps occur in the section (see discussion in Aubry, 1995). Temporal incompleteness of the section is indicated by the thinness of zones that are limited to unconformity-bounded intervals. This is the case for Subzone NP14a, which is limited to the 5.5-ft (1.68 m) unit (Sequence E6, see "Lithostratigraphy" section, this chapter) between the two surfaces at 954.35 and 959.85 ft (290.89 and 292.56 m). In addition, Zone NP7 and Subzone NP14b are absent. Correlation between lithostratigraphic and biozonal boundaries may also indicate hiatuses. For instance, the contact between the Vincentown and Manasquan Formations coincides with the NP9/NP10 zonal boundary. Similarly, the contact between the Manasquan and Shark River Formations coincides with the NP13/NP14a zonal contact.

Two stratigraphic intervals are remarkably well developed in the Bass River borehole. Upper Eocene Zone NP19–20 is ~133.5 ft (40.69 m) thick (Fig. 8). Lower Eocene Zone NP12 is ~132.3 ft (40.33 m; Fig. 9). In addition, the upper part of Zone NP9, as indicated by the occurrence of representatives of the genus *Rhomboaster* without *Tribrachiatus,* is well represented in this borehole (Fig. 10), in contrast with nearby Island Beach borehole and with many deep-sea sections. Because calcareous nannofossil preservation is pristine in this interval, the Bass River borehole provides a unique opportunity to document calcareous nannofossil diversity changes associated with late Paleocene global events.

The zonal scheme used below is that of Martini (1971) and Martini and Müller (1976). Determination of the zones is based on the recognition of the zonal markers.

Atlantic City Formation (555.3–655.3 ft [169.26–199.74 m])

The Atlantic City Formation belongs to Zones NP23–NP25 undifferentiated (sample at 560.6 ft [170.87 m]) and Zone NP22 (between 580.0 and 640.0 ft [176.78 and 195.07 m]; Fig. 7). The base of the formation (between 645.0 and 655.0 ft [196.60 and 199.64 m]) is barren. Nannofossils are few to common and are poorly preserved at most levels because of dissolution.

Sewell Point Formation (669.0–675.4 ft [203.91–205.86 m])

One sample examined from the Sewell Point Formation at 669.4 ft (204.03 m) was barren.

Absecon Inlet Formation (675.4–846.6 ft [205.86–258.04 m])

The Absecon Inlet Formation comprises Zone NP21 (676.0–702.3 ft [206.04–214.06 m]), Zone NP19–20 (705.0–835.0 ft [214.88–254.51 m]), and Zone NP18 (839.5–845.0 ft [255.88–257.56 m]; Fig. 8). As elsewhere on the New Jersey Margin, Zone NP19–20 is remarkably thick (133.6 ft [40.72 m]). Temporal completeness is indicated by the sequential HO's of *Discoaster saipanensis* (at 705.0 ft [214.88 m]), *D. barbadiensis* (at 720.0 ft [219.46 m]) and *Reticulofenestra reticulata* (at 751.3 ft [229.00 m]). Using these datum levels and the Berggren et al. (1995) time scale, sedimentation rates for the Absecon Inlet Formation are estimated as 73 ft/m.y. (22 m/m.y.).

Shark River Formation (846.6–959.85 ft [258.04–292.56 m])

Calcareous nannofossils are poorly to very poorly preserved at most levels in the Shark River Formation. Although diversity is high, despite clear dominance by placoliths of the genus *Chiasmolithus*, neither the zonal/subzonal markers (*Nannotetrina fulgens*, *Chiasmolithus gigas*, *Blackites gladius*) nor the secondary markers (e.g., *Sphenolithus furcatolithoides*) were encountered.

Chiasmolithus oamaruensis is very rare between 850.0 and 855.0 ft (259.08 and 260.60 m). Unless its presence reflects bioturbation, the uppermost part of the Shark River Formation belongs to Zone NP18 (Fig. 8). The highest occurrence of *Chiasmolithus solitus* appears to be at 860.0 ft (262.13 m) although a few specimens of *Chiasmolithus* sp. cf. *C. solitus* were encountered at 860.0 ft (262.13 m). No biozonal subdivision is possible down to 950.0 ft (289.56 m). Most of the Shark River Formation is thus assigned to Zones NP15–NP16 undifferentiated (Figs. 8, 9). *Reticulofenestra reticulata,* which has a first appearance datum in mid-Biochron NP16 (see Berggren et al., 1995) seems to have its lowest occurrence at 880.0 ft (268.22 m). This indicates that the upper Shark Formation essentially belongs to the upper part of Zone NP16 (Fig. 8).

Sample 955.4 ft (291.21 m) contains a poorly preserved, low-diversity assemblage; *Discoaster sublodoensis* is relatively common. The co-occurrence of *D. lodoensis* and *D. kuepperi* indicates the lower part of Zone NP14 (Subzone NP14a of Aubry, 1995; Fig. 9). Subzone NP14b is thus missing and corresponds to the stratigraphic gap represented by the surface at 954.35 ft (290.89 m). A coeval gap has been identified elsewhere on the New Jersey Margin (Aubry, 1991, 1995; Browning et al., 1997c).

Manasquan Formation (959.85–1138.6 ft [292.56–347.05 m])

Calcareous nannofossils are few to abundant in the Manasquan Formation depending on preservation, which varies from very good (e.g., at 960.0, 965.0, 1060.2, 1134.5, and 1137.0 ft [292.61, 294.13, 323.15, 345.80, and 346.56 m) to very poor (e.g., at 970.0, 1019.2, and 1019.5 ft [295.66, 310.65, 310.4 m]). Accordingly, diversity varies from very high to very low. Biozonal assignment is straightforward except for a level at 965.0 ft (294.13 m), which contains forms that appear to be intermediate between *D. lodoensis* and *D. sublodoensis*, some of which are rather similar to the latter. However, this is an isolated level within an interval clearly assignable to Zone NP13 (with species as characteristic as *Discoaster cruciformis*, restricted to the upper Zone NP12–lower Zone NP13, although indicated to have a discontinuous range into Subzone NP14a by Perch-Nielsen [1985]).

The lower surface of the contact at 959.85 ft (292.56 m) lies in Zone NP13, which extends down to 985.0 ft (300.23 m; Fig. 9). Zone NP12 extends from 996.0 to 1119.9 ft (303.58–341.35 m). Based on the time scale of Berggren et al. (1995) it was deposited at an estimated rate of 59.5 ft/m.y. (18 m/m.y.). The interval between 1125.6 and 1134.5 ft (343.08 and 345.80 m) is assignable to Zone NP11. Near the base of the Manasquan Formation, sample 1137.0 ft (346.56 m) belongs to Subzone NP10d (Aubry, 1996).

Vincentown Formation (1138.6–1248.9 ft [347.05–380.66 m])

Sample 1140.0 ft (347.47 m) is almost barren, and no confident zonal assignment can be made. The interval between 1145.0 and 1210.0 ft (349.00 and 368.81 m) belongs to Zone NP9 (Fig. 10). *Rhomboaster cuspis* and *R. calcitrapa* have their lowest occurrence at 1170.0 ft (356.62 m), which marks the upper part of Zone NP9. In other upper Paleocene sections, the well-established carbon isotope excursion is closely associated with the lowest occurrence of these taxa (Aubry, unpubl. data). Calcareous nannofossil diversity is high throughout Zone NP9, although it clearly increases at 1170 ft (356.62 m), and preservation is essentially good to excellent. This expanded upper Paleocene section, deposited at an estimated rate of 80 ft/m.y. (24 m/m.y.) provides a rare opportunity to document the evolutionary changes that occurred among the calcareous nannoplankton in relation to the late Paleocene climatic and oceanographic events (Aubry et al., in press).

The interval between 1215.1 and 1240.0 ft (370.36 and 377.95 m) belongs to Zone NP8 (Fig. 10). The interval between 1242.5 and 1244 ft (378.71 and 379.17 m) is confidently assigned to Zone NP6. Zone NP7 is missing. It corresponds to a stratigraphic gap that is expressed by the irregular and sharp contact at 1240.8 ft (378.20 m; see lithology above).

It is difficult to delineate the NP5/NP6 zonal contact in the borehole. *Heliolithus cantabriae* is very common at level 1247.5 ft (380.24 m) where no typical specimens of *H. kleinpelli* were encountered. According to Romein (1979), *H. cantabriae* evolved during late Biochron NP5. On the other hand, rare *H. kleinpelli* occurs at 1250 ft (381.00 m). Additional sampling is needed to determine confidently the LO of this marker in the section.

Hornerstown Formation (1248.9–1260.25 ft [380.66–384.12 m])

Zone NP5 extends from 1255.1 to 1256.3 ft (382.55–382.92 m; Fig. 10). No samples were available for analysis below 1256.3 ft (382.92 m).

Cretaceous Calcareous Nannofossils

Twenty-nine samples were examined for Cretaceous calcareous nannofossil biostratigraphy (Table 3). The Cretaceous Coccolith (CC) zonal scheme used is that of Perch-Nielsen (1985). Key marker taxa used are provided (Table 3). Highlights include the following:

1. The uppermost Cretaceous (1264.8–1260.25 ft [385.51–384.12 m]) is assigned to the *Micula prinsii* Subzone of CC26 (Fig. 10).
2. The Navesink Formation is assigned to Subzone CC25b and Zone CC26 (Fig. 10) as it is elsewhere in the New Jersey Coastal Plain (Sugarman et al., 1995).
3. The Mount Laurel Formation at Bass River includes Zones CC23a, CC22b, CC21, and CC19/CC20 (i.e., spanning the Campanian/Maastrichtian boundary; Fig. 11). This contrasts with results from outcrop and the Clayton borehole in which this formation is restricted to Subzone CC22b (Sugarman et al., 1995) and may indicate that the thick section at Bass River is more complete than it is elsewhere.
4. The Woodbury Formation is Zone CC19/20 (lower Campanian; Fig. 12).
5. The Merchantville Formation is Zones CC16–18 (Santonian–lower Campanian; Fig. 12).
6. The Cheesequake Formation is Zone CC15–16 (Santonian; Fig. 12).
7. The Magothy Formation is poorly fossiliferous for calcareous nannoplankton, but may be ?Coniacian (i.e., it is bracketed by Santonian above and Turonian below bounding unconformities [Fig. 13]). This is supported by an assignment of a sample immediately below the top of the Magothy Formation to Zone CC14? (uppermost Coniacian to lower Santonian).
8. The Bass River Formation is Zones CC11 (lower Turonian) and CC10 (Cenomanian); the Cenomanian/Turonian boundary appears to be complete in this unit (Fig. 14).

Diatoms

The Miocene section contained two intervals of common diatoms that allow provisional biostratigraphic zonation (Table 4). An interval of diatom-bearing sediments occurs between 135 and 175 ft (41.15 and 53.34 m). From 175 to 230.8 ft (53.34–70.35 m), most samples contained few or no diatoms. Most of the section from 230.8 to 325 ft (70.35–99.06 m) contained common diatoms. The section from 135 to 217.4 ft (41–66.26.15 m) is provisionally assigned to ECDZ 2, although this interval may include ECDZ 3–4. Additional evidence for the assigned age is the HO of the silicoflagellate *Corbisema triacantha* at 135 ft (41.15 m), which has been found to occur as high as the lower middle Miocene (Bukry, 1985). The section from 224 to 325 ft (68.28–99.06 m) can be assigned to ECDZ 2 of Andrews (1988). Such forms as *Delphineis ovata*, *Rhaphoneis scalaris*, *Rhaphoneis margaritata*, *Sceptroneis caduceus*, and *S. grandis* all point to ECDZ 2.

Samples between 328.7 and 440 ft (100.19 and 206.04 m) contained few diatoms and/or diatom fragments. Although no specific age could be assigned, the sparse assemblage is Neogene, and the environment of deposition was either marine or marine/brackish water. Samples from 440 to 1950 ft (134.11–594.36 m) contained no diatoms, although many samples between 440 and 676 ft (134.11 and 206.04 m) contained pollen and opal phytoliths and, in a few cases, woody material.

Table 4. Occurrences of diatoms in the Bass River borehole.

Depth (ft)	Species/comments
20.2-20.3	Diatom fragments; Common to abundant sponge spicules
25.0-25.1	Rare diatom fragments; Rare sponge spicules
26.5-26.6	Abundant sponge spicules; *Paralia sulcata;* Diatoms in fragments; Difficult to identfy even to genus but have aspect of brackish water environment
30.0-30.1	No diatoms; Some fungal spores
37.0-37.1	No diatoms; Some fungal spores
40.0-40.1	No diatoms
43.0-40.1	*Actinocyclus tenellus; Coscinodiscus marginatus; Rhaphoneis elegans* (?); Very few diatoms
44.0-44.1	*Rhaphoneis* sp.; *Thalassionema nitzschioides;* Few diatom fragments. Neogene.
	No diatoms in samples: 50.0-50.1, 60.0-60.1,65.0-65.1, 69.9-70.0, 74.4-74.5 , 79.2-79.3, 84.2-84.3, 89.5-89.6, 94.1-94.2, 97.4.-97.5, 100.5-100.6, 103.0-130.1, 110.0-110.1, 115.0-115.1, 120.0-120.1, 125.0-125.1, and 130.0-130.1 ft
135.0-135.1	*Actinoptychus senarius; Actinocyclus tenellus; Cavitatus jouseanus; Corbisema triacantha; Delphineis ovata* (?)*; Denticulopsis norwegica; Dictyocha crux; Diploneis bombus; Melosira westii; Paralia coronata; Rhaphoneis amphiceras*
140.0-140.1	*Biddulphia semicircularis; Cavitatus jouseanus; Corbisema triacantha; Coscinodiscus obscurus; Cussia* aff. *C. paleocea; Cymatogonia amblyoceras; Delphineis* sp.*; Delphineis ovata* (?); *Dicladia capreola; Dictyocha crux; Diploneis crabro; Eunotia* sp.; *Paralia coronata; Pseudauliscus radiatus; Pyrgupyxis johnsoniana; Pyxilla* sp.; *Rhaphoneis amphiceras; Rhaphoneis scalaris; Rhizosolenia miocenica; Stephanogonia actinoptychus; Thalassionema nitzschioides*
145.0-145.1	*Actinoptychus halionyx; Cavitatus jouseanus; Cymatogonia amblyoceras; Delphineis penelliptica* (?); *Diploneis bombus; Diploneis crabro;* Few diatoms; *Melosira westii; Paralia coronata; Rhizosolenia styliformis*
150.0-150.1	*Actinocyclus tenellus; Actinoptychus senarius; Asteromphalus* cf. *A. imbricatus; Cavitatus jouseanus; Cocconeis* sp.; *Corbisema triacantha; Coscinodiscus curvatulus; Coscinodiscus marginatus; Coscinodiscus obscurus; Coscinodiscus perforatus; Coscinodiscus vetustissimus; Cussia paleacea; Delphineis ovata* (?); *Delphineis penelliptica* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Podosira stelligera; Pseudauliscus radiatus; Pyxilla* sp.
160.0-160.1	*Actinoptychus senarius; Actinocyclus tenellus; Cavitatus jouseanus; Corbisema triacantha; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Podosira stelligera; Rhaphoneis margaritata; Stephanopyxis turris*
165.0-165.1	*Cavitatus jouseanus; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Podosira stelligera; Pseudauliscus radiatus; Rhaphoneis amphiceras; Rhaphoneis scalaris*
171.7-171.8	*Actinocyclus ehrenbergii; Actinoptychus senarius; Cavitatus jouseanus; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia sulcata; Paralia coronata; Stephanopyxis turris*
	Few diatom fragments or no diatoms in samples: 175.0-175.1, 182.5-182.6, 187.0-187.1, 190.0-190.1, 195.0-195.1, 201.3-201.4 ft
210.0-210.1	Few diatom fragments; *Cavitatus jouseanus; Paralia sulcata*
215.0-215.1	Few diatom fragments; *Cavitatus jouseanus*
217.4-217.5	Few diatom fragments
224.0-224.1	Few diatoms; *Biddulphia semicircularis; Dictyocha crux; Paralia coronata; Sceptroneis* cf. *S. grandis*
230.8-231	*Actinoptychus senarius; Cavitatus jouseanus; Corbisema triacantha; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis margaritata; Sceptroneis* cf. *S. grandis; Stephanopyxis turris; Triceratium condecorum*
232.5-232.6	*Cavitatus jouseanus; Corbisema triacantha; Coscinodscus curvatulus; Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis amphiceras; Rhaphoneis margaritata; Rhizosolenia miocenica; Sceptroneis* cf. *S. grandis; Stephanopyxis turris*
236.8-237	*Actinocyclus ehrenbergii; Biddulphia tuomeyi; Coscinodiscus marginatus; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis margaritata; Sceptroneis caduceus; Sceptroneis* cf. *S. grandis; Xanthiopyxis oblonga; Xanthiopyxis ovalis*
242.8-243	*Actinoptychus senarius; Coscinodiscus marginatus; Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis margaritata; Sceptroneis caduceus; Stephanopyxis turris*
247.0-247.2	*Actinocyclus ehrenbergii; Actinoptychus senarius; Coscinodiscus marginatus; Coscinodiscus obscurus; Coscinodiscus perforatus; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Stephanopyxis turris*
252.0-252.2	*Actinoptychus senarius; Biddulphia tuomeyi; Cavitatus jouseanus; Coscinodiscus marginatus; Coscinodiscus obscurus; Coscinodiscus perforatus; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia sulcata; Paralia coronata; Podosira stelligera; Pyrgupyxis johnsoniana; Rhaphoneis margaritata; Tetracyclus rupestris*
257.0-257.2	*Actinocyclus ehrenbergii; Amphora* sp.; *Cavitatus jouseanus; Corbisema triacantha; Coscinodiscus obscurus; Coscinodiscus perforatus; Delphineis ovata* (?); *Diploneis crabro; Melosira westii; Paralia sulcata; Paralia coronata; Pyrgupyxis johnsoniana*
260.0-260.2	*Actinocyclus ehrenbergii; Actinoptychus senarius; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Hemiaulus bipons; Melosira westii; Paralia coronata; Paralia sulcata; Pyrgupyxis johnsoniana; Pyxilla turris; Rhaphoneis margaritata*
264.7-264.8	*Actinocyclus ehrenbergii; Corbisema triacantha; Coscinodiscus obscurus; Coscinodiscus perforatus; Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis margaritata; Rhaphoneis scalaris; Xanthiopyxis oblonga*
270.0-270.2	*Actinoptychus senarius; Delphineis ovata* (?); *Dictyocha crux; Dimerogramma* sp.; *Diploneis crabro; Coscinodiscus marginatus; Coscinodiscus obscurus; Coscinodiscus perforatus; Craspedodiscus coscinodiscus; Paralia coronata; Paralia sulcata; Rhaphoneis* cf. *R. scalaris*
275.0-275.1	*Actinoptychus senarius; Cavitatus jouseanus; Coscinodiscus obscurus; Coscinodiscus perforatus; Craspedodiscus coscinodiscus; Delphineis ovata* (?); *Dictyocha crux; Dimerogramma* sp.; *Diploneis crabro; Melosira westii; Paralia sulcata; Paralia coronata; Rhaphoneis margaritata; Terpsinoe americana; Triceratium condecorum*
280.0-280.1	*Actinocyclus ehrenbergii; Actinoptychus senarius; Coscinodiscus marginatus; Coscinodiscus obscurus; Coscinodiscus perforatus; Delphineis ovata* (?); *Diploneis crabro; Rhaphoneis margaritata; Sceptroneis caduceus; Triceratium condecorum*
285.0-285.1	*Actinocyclus ehrenbergii; Actinoptychus senarius; Coscinodiscus radiatus; Delphineis ovata* (?); *Melosira westii; Paralia coronata; Paralia sulcata; Xanthiopyxis oblongus*
290.0-290.1	*Actinocyclus ehrenbergii; Cavitatus jouseanus; Coscinodiscus obscurus; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia sulcata; Paralia coronata; Sceptroneis caduceus*
295.0-295.1	*Actinoptychus senarius; Anaulus birostratus; Biddulphia semicircularis; Cavitatus jouseanus; Coscinodiscus marginatus; Coscinodiscus obscurus; Coscinodiscus perforatus; Delphineis ovata* (?); *Dictyocha crux; Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis magnapunctata; Rhaphoneis margaritata; Sceptroneis caduceus*
301.0-301.1	*Actinoptychus senarius; Coscinodiscus obscurus; Coscinodiscus perforatus; Delphineis ovata* (?); *Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Sceptroneis caduceus*
304.0-304.1	*Coscinodiscus marginatus; Coscinodiscus obscurus; Delphineis ovata* (?); *Diploneis crabro; Melosira westii; Paralia coronata; Paralia sulcata; Sceptroneis caduceus*
310.0-310.1	Few diatoms; Mostly in fragments; *Melosira westii*
313.7-313.8	Diatom fragments; *Delphineis ovata* (?); *Paralia sulcata; Melosira westii; Sceptroneis caduceus*
314.7-314.8	Diatoms fragments
319.3-319.4	No diatoms
325.0-325.1	*Actinocyclus ehrenbergii; Actinoptychus senarius; Biddulphia toumeyii; Coscinodiscus radiatus; Delphineis ovata* (?); *Dictyocha crux; Melosira westii; Paralia coronata; Paralia sulcata; Rhaphoneis margaritata; Xanthiopyxis oblongus; Xanthiopyxis ovalis*
328.7-328.8	No diatoms
330.0-330.2	Diatom fragments; *Diploneis bombus*
335.0-335.2	Diatom fragments; *Coscinodiscus radiatus; Diploneis bombus; Paralia coronata*
344.4-344.6	*Delphineis* cf. *D.ovata* (a fragment); *Paralia sulcata; Rhaphoneis amphiceras*
350.2-350.4	*Diploneis bombus; Paralia sulcata; Rhaphoneis* sp.; Diatom fragments
355.0-355.2	Diatom fragments; Pollen
360.0-360.2	No diatoms

Table 4 (continued).

Depth (ft)	Species/comments
370.0-370.2	*Cocconeis* sp.; Pollen; Woody fragments
375.0-375.1	*Diploneis bombus;* Rare diatoms; Probably brackish water; Pollen
380.0-380.1	Diatom fragments
385.0-385.1	No diatoms
390.0-390.1	No diatoms
395.0-395.1	*Thalassionema nitzschioides;* Rare diatoms. Marine
401.0-401.1	*Actinocyclus* sp.; *Diploneis bombus; Stephanopyxis* sp.; Few diatoms. Marine
405.0-405.1	*Diploneis bombus; Rhaphoneis* sp.; Few diatom fragments. Marine
407.1-407.2	Diatom fragments; Woody material
412.0-412.1	Diatom fragments; Few diatoms, mostly in fragments. However, the assemblage is definitely marine and Neogene.
415.0-415.1	Diatom fragments; *Paralia sulcata; Thalassionema nitzschioides;* Few diatoms, mostly in fragments. However, the assemblage is definitely marine and Neogene.
420.0-420.1	Pollen; Diatom fragments (probably marine)
423.7-423.8	*Coscinodiscus radiatus; Diploneis bombus; Paralia coronata; Thalassionema nitzschioides;* Few diatoms, mostly in fragments. However, the assemblage is definitely marine and Neogene.
434.0-434.1	*Thalassiosira decipiens;* Diatom fragments (usually not identifiable but are marine to brackish water)
	No diatoms in samples: 440.0-440.1, 445.0-445.1, 450.0-450.1, 460.0-460.1, 465.0-465.1, 490.0-490.1, 495.0-495.1, 500.0-500.1, 505.0-505.1, 515.0-515.1, 525.0-525.1, 530.0-530.1, 535.0-535.1, 538.6-538.7, 541.0-541.1, 544.9-545, 550.0-550.1, 560.7-560.8, 565.0-565.1, 570.0-570.1, 576.0-576.1, 580.0-580.1, 595.0-595.1, 605.0-605.1, 650.0-650.1, 676.0-676.1, 702.3-702.4, 750.9-751, 811.0-811.1, 850.0-850.1, 900.0-900.1, 950.0-950.1, 1000.0-1000.1, 1047.8-1047.9, 1100.0-1100.2, 1150.0-1150.1, 1200.0-1200.1, 1255.1-1255.2, 1300.0-.1, 1350.0-1350.1, 1405.0-1405.1, 1555.0-1555.1, 1604.9-1605, 1649.9-1650, 1700.0-.1, 1733.0-1733.1, 1750.6-1750.7, 1760.0-1760.1, 1803.6-1803.7, 1853.0-1853.1, 1900.0-1900.1, 1950.0-1950.1 ft

Pollen

Fifteen samples were examined from the lower part (Woodbury and older formations) of the borehole for pollen biostratigraphic zonation. The upper six samples (between 1630 and 1710 ft [496.82 and 521.21 m]) were barren for pollen; the plant organic matter was highly degraded. The sample from 1725.1 ft (525.81 m) was assigned to pollen Zone V of Christopher (1982), which is generally correlated to the upper Turonian–Santonian (Fig. 13). This is consistent with previous studies that correlate the Magothy Formation to lower Zone V (Christopher, 1982). Two Magothy Formation samples from 1777 to 1799 ft (541.63–548.34 m) are assigned to pollen Zone IV of Christopher (1982), which is correlated to the upper Cenomanian to lowermost Turonian. If this pollen correlation is correct, it suggests that (1) the sequence from ~1747 to 1806.4 ft (532.49–550.59 m) is equivalent to the Woodbridge Clay Member of the Raritan Formation in outcrop and not equivalent to the Magothy Formation; and (2) the major mid-Turonian sequence boundary is at 1747 ft (532.49 m), not at the top of the Bass River Formation (1806.4 ft [550.9 m]). Additional pollen studies are needed to confirm these correlations. Assignment of samples below 1830 ft (557.78 m) to pollen Zone IV are consistent with correlation of the Bass River Formation with the Raritan Formation in outcrop.

ISOTOPIC STRATIGRAPHY

Strontium Isotopes

Twelve Sr-isotopic age estimates were obtained from mollusk shells (~4–6 mg) at the Bass River borehole (Table 2; Fig. 7). Sediments adhering to the shells were removed by ultrasonic cleaning for 3–5 s. Samples were dissolved in 1.5 N HCL, centrifuged, and introduced into ion-exchange columns. Standard ion-exchange techniques were used to separate the strontium (Hart and Brooks, 1974), and samples were analyzed on a VG Sector Mass Spectrometer at Rutgers University. Internal precision on the sector for the data set averaged 0.000025, and the external precision is approximately 0.000020–0.000030 (Oslick et al., 1994). NBS 987 is measured for these analysis at 0.710255 (2σ standard deviation [SD] = 0.000008, n = 22) normalized to $^{87}Sr/^{86}Sr$ of 0.71194. Ages were assigned using the Berggren et al. (1995) time scale (Table 1), the early Miocene regression of Oslick et al. (1994), and the Oligocene regressions of Reilly et al. (1996). Because of the poorly fossiliferous nature of the upper 540 ft (164.8 m) of the borehole, the first Sr-isotopic ratio was obtained from 542.1 ft (141.8 m). From 540.0 to approximately 620 ft (164.8–189.0 m), the core contained ample calcareous material for Sr-isotopic analysis.

Four Sr-isotopic age estimates from shells between 542.1 and 550.9 ft (165.2 and 167.9 m) ranged from 20.8 to 21.4 Ma and are correlated to lower Miocene Kw1a sequence (Fig. 6; Sugarman et al., 1993; Miller et al., 1997). Sr-isotopic age estimates from six intervals sampled within the Oligocene indicate that only lowermost Oligocene strata were preserved at Bass River (Fig. 7). Sr-isotopic age estimates range from 32.0 Ma at 560.0 ft (170.7 m) to 33.6 Ma at 611.0 ft (186.2 m), correlating this section to the O1 sequence by Pekar et al. (1997). This is consistent with nannofossil data assignment of 580–645 ft (176.8–196.6 m) to Zone NP22 (32.8–32.3 Ma) and 560–576 ft (170.7–175.6 m) to NP23 or younger (<32.3 Ma).

Stable Isotopes

Sixteen samples were analyzed for oxygen and carbon isotopic composition (Table 5). Aliquots were picked for mixed species of the benthic foraminiferal genera *Gavelinella* (eight samples) and *Epistomina* (eight samples). *Gavelinella* yields $\delta^{13}C$ values similar to *Cibicidoides* and $\delta^{18}O$ values that are slightly (0.3‰) lower than equilibrium (Shackleton et al., 1984). The isotopic systematics of *Epistomina* are not well known. Samples examined for benthic foraminiferal isotope analyses were washed with sodium metaphosphate (5.5 g/L) in tap water through a 63-µm sieve and air dried. Benthic foraminifers were ultrasonically cleaned for 5–10 s and roasted at 370°C in a vacuum. Stable isotope measurements (Table 5) were made using an Autocarb attached to a VG Prism II mass spectrometer at the University of Maine (Table 5). Samples were lightly crushed and reacted in phosphoric acid at 90°C. The isotopic values are reported relative to the Peedee belemnite (PDB) scale via NBS-19 and NBS-20 standards. Values for each of these standards are reported in Coplen et al. (1973). The precision (1σ) of the NBS standards analyzed along with the samples was 0.06‰ for $\delta^{18}O$ and 0.05‰ for $\delta^{13}C$. Carbon isotopic records of both *Gavelinella* and *Epistomina* show a large (>1‰) decrease across the C/T boundary (Fig. 14); this decrease is global and follows an interval of very high global $\delta^{13}C$ values (e.g., the Bonarelli bed; Scholle and Arthur, 1980; Jenkyns et al., 1994). *Epistomina* $\delta^{13}C$ values are similar to but offset from *Gavelinella*. *Epistomina* is an aragonitic taxa that yields $\delta^{13}C$ values that are significantly (~2‰) enriched relative to *Gavelinella*, even as *Hoeglundina* (another aragonitic taxon of the Family Ceratobuliminidae) yields $\delta^{13}C$ values that are significantly (~1.3‰) enriched relative to *Cibicidoides* (Shackleton et al., 1984). Therefore, we conclude that both *Gavelinella* and *Epistomina* faithfully track global $\delta^{13}C$ changes across the C/T boundary.

Table 5. Carbon and oxygen isotopic data for the Bass River Formation, Bass River borehole.

Depth (ft)	Depth (m)	Genus	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)
1835	559.31	*Gavelinella*	0.45	-2.42
1856	565.71	*Gavelinella*	1.30	-2.78
1870	569.98	*Gavelinella*	1.28	-2.48
1885	574.55	*Gavelinella*	1.12	-2.05
1905	580.64	*Gavelinella*	1.72	-2.71
1925	586.74	*Gavelinella*	2.87	-2.11
1936	590.09	*Gavelinella*	3.14	-2.01
1955	595.88	*Gavelinella*	2.02	-1.66
1856	565.71	*Epistomina*	3.42	-2.43
1870	569.98	*Epistomina*	3.79	-2.15
1885	574.55	*Epistomina*	3.64	-2.65
1905	580.64	*Epistomina*	3.28	-2.87
1915	583.69	*Epistomina*	5.18	-2.41
1925	586.74	*Epistomina*	5.37	-1.77
1945	592.84	*Epistomina*	3.42	-2.64
1955	595.88	*Epistomina*	3.75	-1.24

SUMMARY AND CONCLUSIONS

The 1956.6-ft Bass River borehole provides a continuously cored record of Cretaceous (Cenomanian) to Holocene strata that addresses problems in global sea level, regional tectonics, and local hydrogeology. Studies of the Bass River borehole will complement offshore Leg 174A drilling by allowing us to verify correlations of Oligocene to middle Miocene sequence boundaries with $\delta^{18}O$ increases and to develop a rigorous backstripped sea-level curve for this interval. In addition, onshore drilling sampled four intervals that were not sampled offshore: (1) Cretaceous–Eocene sequences needed to evaluate sea level during past warm climates; (2) sections along-strike needed to understand tectonic effects on stratigraphic records; and (3) updip facies needed to evaluate sequence stratigraphic models. Bass River provides the first continuous downdip, onshore cores needed to date Upper Cretaceous sequences in New Jersey, to determine the facies relationships within these sequences, and to compare these sequence with other proxies of global sea-level change. This is a particularly intriguing task, because sequence stratigraphic studies in New Jersey and elsewhere provide evidence for large, rapid sea-level changes during the Cretaceous to early Eocene, although this period is thought to have been ice-free, and the only known mechanism for large, rapid sea-level changes is glacioeustasy. The Campanian–Maastrichtian section is fossiliferous and should allow development of a reference section for this interval at Bass River. Recovery and stratigraphic resolution across the K/T and C/T boundaries is exceptional, whereas the uppermost Paleocene section, including the equivalent of the late Paleocene global isotopic excursion, is remarkably thick; detailed studies of these sections will provide better understanding of the global changes associated with these events. Finally, results from the Bass River borehole will provide important information on aquifer potential (particularly the thick "Atlantic City 800-ft sand," the Mount Laurel sands, and the Magothy sands) for future water resource planning in the state of New Jersey.

REFERENCES

Andrews, G.W., 1988. A revised marine diatom zonation for Miocene strata of the southeastern United States. Geol. Surv. Prof. Pap. U.S., 1481:1–29.

Aubry, M.-P., 1991. Sequence stratigraphy: eustasy or tectonic imprint? *J. Geophys. Res.,* 96:6641–6679.

————, 1995. From chronology to stratigraphy: interpreting the lower and middle Eocene stratigraphic record in the Atlantic Ocean. *In* Berggren, W.A., Kent, D.V., Aubry, M.-P., and Hardenbol, J. (Eds.), *Geochronology, Time Scales, and Global Stratigraphic Correlation: A Unified Temporal Framework for an Historical Geology.* Spec. Publ.—Soc. Econ. Palaeontol. Mineral., 54:213–274.

————, 1996. Towards an upper Paleocene–lower Eocene high resolution stratigraphy based on calcareous nannofossil stratigraphy. *Israel J. Earth Sci.,* 44:239–253.

Aubry, M.-P., Lucas, S., and Berggren, W.A., in press. *Late Paleocene–early Eocene climatic and biotic events:* New York (Columbia Univ. Press).

Austin, J., Christie-Blick, N., Malone, M., et al., 1998. *Proc. ODP, Init. Repts.,* 174A: College Station, TX, (Ocean Drilling Program).

Berggren, W.A., Kent, D.V., Swisher, C.C., III, and Aubry, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy. *In* Berggren, W.A., Kent, D.V., Aubry, M.-P., and Hardenbol, J. (Eds.), *Geochronology, Time Scales and Global Stratigraphic Correlation.* Spec. Publ.—Soc. Econ. Paleontol. Mineral., 54:129–212.

Browning, J.V., Miller, K.G., and Bybell, L.M., 1997a. Upper Eocene sequence stratigraphy and the Absecon Inlet Formation, New Jersey Coastal Plain. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 243–266.

Browning, J.V., Miller, K.G., and Olsson, R.K., 1997b. Lower to middle Eocene benthic foraminiferal biofacies and lithostratigraphic units and their relationship to sequences, New Jersey Coastal Plain. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station TX (Ocean Drilling Program), 207–228.

Browning, J.V., Miller, K.G., Van Fossen, M., Liu, C., Pak, D.K., Aubry, M.-P., and Bybell, L.M., 1997c. Early to middle Eocene sequences of the New Jersey Coastal Plain and their significance for global climate change. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 229–242.

Bukry, D., 1985. Tropical Pacific silicoflagellate zonation and paleotemperature trends of the late Cenozoic. *In* Mayer, L., Theyer, F., Thomas, E., et al., *Init. Repts. DSDP,* 85: Washington (U.S. Govt. Printing Office), 477–497.

Christopher, R.A., 1982. The occurrence of the *Complexiopollis-Atlantopolis* Zone (palynomorphs) in the Eagle Ford Group (Upper Cretaceous) of Texas. *J. Paleontol.,* 56:525–541.

Coplen, T.B., 1973. A double focusing double collecting mass spectrometer for light stable isotope ratio analysis. *Int. J. Mass Spectrom.,* 11.

Habib, D., Olsson, R.K., Liu, C., and Moskovitz, S., 1996. High-resolution biostratigraphy of sea-level low, biotic extinction, and chaotic sedimentation at the Cretaceous/Tertiary boundary in Alabama, north of the Chicxulub Crater. *In* Ryder, G., Fastovsky, D., and Gartner, S. (Eds.), *The Cretaceous/Tertiary event and other catastrophes in Earth history.* Spec. Pap.—Geol. Soc. Am., 307:243–252.

Hart, S.R., and Brooks, C., 1974. Clinopyroxene-matrix partitioning of K, Rb, Cs, and Ba. *Geochim. Cosmochim. Acta,* 38:1799–1806.

Houlik, C.W., Jr., Olsson, R.K., and Aurisano, R.W., 1983. Upper Cretaceous (Campanian–Maestrichtian) marine strata in the subsurface of northern Delaware. *Southeast. Geol.,* 24:57–65.

Kelly, D.C., Bralower, T.J., Zachos, J.C., Premoli Silva, I., and Thomas, E., 1996. Rapid diversification of planktonic foraminifera in the tropical Pacific (ODP Site 865) during the late Paleocene thermal maximum. *Geology,* 24:423–426.

Jenkyns, H.C., Gale, A.S., and Corfield, R.M., 1994. Carbon- and oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its palaeoclimatic significance. *Geol. Mag.,* 131:1–34.

Litwin, R.J., Sohl, N.F., Owens, J.P., and Sugarman, P.J., 1993. Palynological analysis of a newly recognized upper Cretaceous marine unit at Cheesequake, New Jersey. *Palynology,* 17:123–135.

Liu, C., Browning, J.V., Miller, K.G., and Olsson, R.K., 1997a. Paleocene benthic foraminiferal biofacies and sequence stratigraphy, Island Beach borehole, New Jersey. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 267–275.

————, 1997b. Upper Cretaceous to Miocene planktonic foraminiferal biostratigraphy: results of Leg 150X, the New Jersey Coastal Plain Drilling Project. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 111–127.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed.), *Proc. 2nd Int. Conf. Planktonic Microfossils Roma:* Rome (Ed. Tecnosci.), 2:739–785.

Martini, E., and Müller, C., 1976. Current Tertiary and Quaternary calcareous nannoplankton stratigraphy and correlations. *Newsl. Stratigr.,* 16:99–112.

Miller, K.G., Browning, J.V., Liu, C., Sugarman, P., Kent, D.V., Van Fossen, M., Queen, D., Goss, M., Gwynn, D., Mullikin, L., Feigenson, M.D., Aubry, M.-P., and Burckle, L.D., 1994a. Atlantic City site report. *In* Miller, K.G., et al., *Proc. ODP, Init. Repts.,* 150X: College Station, TX (Ocean Drilling Program), 35–55.

Miller, K.G., Kent, D.V., Brower, A.N., Bybell, L.M., Feigenson, M.D., Olsson, R.K., and Poore, R.Z., 1990. Eocene–Oligocene sea-level changes on the New Jersey coastal plain linked to the deep-sea record. *Geol. Soc. Am. Bull.,* 102:331–339.

Miller, K.G., et al., 1996. *Proc. ODP, Init. Repts.,* 150X (Suppl.): College Station, TX (Ocean Drilling Program).

Miller, K.G., and Mountain, G.S., 1994. Global sea-level change and the New Jersey margin. *In* Mountain, G.S., Miller, K.G., Blum, P., et al., *Proc. ODP, Init. Repts.,* 150: College Station, TX (Ocean Drilling Program), 11–20.

Miller, K.G., Rufolo, S., Sugarman, P.J., Pekar, S.F., Browning, J.V., and Gwynn, D.W., 1997. Early to middle Miocene sequences, systems tracts, and benthic foraminiferal biofacies, New Jersey coastal plain. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 169–185.

Miller, K.G., and Sugarman, P.J., 1995. Correlating Miocene sequences in onshore New Jersey boreholes (ODP Leg 150X) with global $\delta^{18}O$ and Maryland outcrops. *Geology,* 23:747–750.

Miller, K.G., Sugarman, P., Van Fossen, M., Liu, C., Browning, J.V., Queen, D., Aubry, M.-P., Burckle, L.D., Goss, M., and Bukry, D., 1994b. Island Beach site report. *In* Miller, K.G., et al., *Proc. ODP, Init. Repts.,* 150X: College Station, TX (Ocean Drilling Program), 5–33.

Miller, K.G., Wright, J.D., and Fairbanks, R.G., 1991. Unlocking the Ice House: Oligocene–Miocene oxygen isotopes, eustasy, and margin erosion. *J. Geophys. Res.,* 96:6829–6848.

Mountain, G.S., Miller, K.G., Blum, P., et al., 1994. *Proc. ODP, Init. Repts.,* 150: College Station, TX (Ocean Drilling Program).

NJGS Information Circular 1, 1990. Generalized stratigraphic table for New Jersey. *New Jersey Geol. Surv.*

Olsson, R.K., 1960. Foraminifera of latest Cretaceous and earliest Tertiary age in the New Jersey coastal plain. *J. Paleontol.,* 34:1–58.

————, 1964. Late Cretaceous planktonic foraminifera from New Jersey and Delaware. *Micropaleontology,* 10:157–188.

————, 1991. Cretaceous to Eocene sea-level fluctuations on the New Jersey margin. *Sediment. Geol.,* 70:195–208.

Olsson, R.K., Miller, K.G., Browning, J.V., Habib, D., and Sugarman, P.J., 1997. Ejecta layer at the Cretaceous/Tertiary boundary, Bass River, New Jersey (Ocean Drilling Program Leg 174AX). Geology, 25:759–762.

Olsson, R.K., and Wise, S.W., 1987. Upper Paleocene to middle Eocene depositional sequences and hiatuses in the New Jersey Atlantic Margin. *In Ross, C., and Haman, D. (Eds.), Timing and Depositional History of Eustatic Sequences: Constraints on Seismic Sratigraphy.* Spec. Publ. Cushman Found. *Foraminiferal Res.,* 24:99–112.

Oslick, J.S., Miller, K.G., Feigenson, M.D., and Wright, J.D., 1994. Oligocene–Miocene strontium isotopes: correlation to a glacioeustatic record. *Paleoceanography,* 9:427–443.

Owens, J.P., Miller, K.G., and Sugarman, P.J., 1997. Lithostratigraphy and paleoenvironments of the Island Beach borehole, New Jersey Coastal Plain Drilling Project. *In* Miller, K.G., and Snyder, S.W., (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 15–24.

Owens, J.P., and Sohl, N.F., 1969. Shelf and deltaic paleoenvironments in the Cretaceous–Tertiary formations of the New Jersey Coastal Plain. In Subitzky, S. (Ed.), *Geology of Selected Areas in New Jersey and Eastern Pennsylvania and Guidebook of Excursions:* New Brunswick, NJ (Rutgers Univ. Press), 235–278.

Owens, J.P., Sugarman, P.J., Sohl, N.F., Parker, R., Houghton, H.H., Volkert, R.V., Drake, A.A., and Orndorff, R.C., 1995. Geologic map of New Jersey: Central Sheet. *Open-File Rep.—U.S. Geol. Surv.,* 95–253.

Pekar, S.F., Miller, K.G., and Browning, J.V., 1997. New Jersey Coastal Plain Oligocene sequences. *In* Miller, K.G., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 187–206.

Perch-Nielsen, K., 1985. Cenozoic calcareous nannofossils. *In* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy:* Cambridge (Cambridge Univ. Press), 427–554.

Petters, S.W., 1976. Upper Cretaceous subsurface stratigraphy of Atlantic coastal plain of New Jersey. *AAPG Bull.,* 60:87–107.

————, 1977. Upper Cretaceous planktonic foraminifera from the subsurface of the Atlantic coastal plain of New Jersey. *J. Foraminiferal Res.,* 7:165–187.

Poore, R.Z., and Bybell, L.M., 1988. Eocene to Miocene biostratigraphy of New Jersey core ACGS#4: implications for regional stratigraphy. *U.S. Geol. Surv.,* 1829:1–22

Reilly, T.J., Miller, K.G., and Feigenson, M.D., 1996. Sr-isotopic changes during the late Eocene to Oligocene: a revised record from Site 522, eastern South Atlantic. *Geol. Soc. Am. Abstr. Prog.,* A-426.

Romein, A.J.T., 1979. Lineages in early Paleogene calcareous nannoplankton. *Utrecht Micropaleontol. Bull.,* 22:1–231.

Scholle, P.A., and Arthur, M.A., 1980. Carbon isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool. *AAPG Bull.,* 64:67–87.

Shackleton, N.J., Hall, M.A., and Boersma, A., 1984. Oxygen and carbon isotope data from Leg 74 foraminifers. *In* Moore, T.C., Jr., Rabinowitz, P.D., et al., *Init. Repts. DSDP,* 74: Washington (U.S. Govt. Printing Office), 599–612.

Sikora, P.J., and Olsson, R.K., 1991. A paleoslope model of late Albian to early Turonian foraminifera of the western Atlantic margin and North Atlantic basin. *Mar. Micropaleontol.,* 18:25–72.

Sugarman, P.J., Miller, K.G., Bukry, D., and Feigenson, M.D., 1995. Uppermost Campanian–Maestrichtian strontium isotopic, biostratigraphic, and sequence stratigraphic framework of the New Jersey Coastal Plain. *Geol. Soc. Am. Bull.,* 107:19–37.

Sugarman, P.J., Miller, K.G., Owens, J.P., and Feigenson, M.D., 1993. Strontium isotope and sequence stratigraphy of the Miocene Kirkwood Formation, Southern New Jersey. *Geol. Soc. Am. Bull.,* 105:423–436.

Zapecza, O.S., 1989. Hydrogeologic framework of the New Jersey coastal plain. *Geol. Surv. Prof. Pap. U.S.,* 1404-B.

Ms 174AXIR-101