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6. Sea Girt Site[1]

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

Operations: Cobbs, Miller, Sugarman
Lithostratigraphy: Browning, Harris, Katz, Kulpecz, McLaughlin, Miller, Misintseva, Monteverde, Patrick, Pekar, Sugarman, Uptegrove
Biostratigraphy:
- Spores, pollen and dinocysts: Brenner
- Planktonic foraminifers: Olsson, Browning
- Benthic foraminifers: Browning, Harris, Misintseva, Olsson
- Calcareous nannofossils: Aubry (Cenozoic), de Romero (Mesozoic)

Logging: McLaughlin
Sr isotopic Stratigraphy: Browning, Feigenson, Monteverde

SEA GIRT SITE SUMMARY

Sea Girt was the tenth site drilled as part of the Coastal Plain Drilling Project (CPDP) and the seventh site drilled as part of Leg 174AX. Drilling at the National Guard Training Base, Sea Girt, New Jersey (40°07′12.698″N, 74°01′58.25″W; elevation = 9.8 ft [3.05 m]; Point Pleasant quadrangle, Monmouth County) targeted Upper Cretaceous sequences and aquifers with a 1500 ft (457.20 m) corehole drilled 24 September to 11 November 2003. At Sea Girt, we recovered 1215.76 ft (370.56 m); mean recovery was 77.9% for the 1600 ft (487.68 m) cored.

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Gamma ray logs were collected from the inside of the rods, and a full suite of multitool logs were obtained from the HQ hole (depth = 1070 ft; 326.14 m), but hole instability prevented further logging. A team of scientists from the New Jersey Geological Survey (NJGS), Rutgers University, the Delaware Geological Survey (DGS), and the U.S. Geological Survey (USGS) collaborated in drilling and stratigraphic studies of this corehole that was funded by the National Science Foundation (NSF; Earth Science Division, Continental Dynamics Program). Onsite and postdrilling studies of lithology, sequence stratigraphy, biostratigraphy, and Sr isotopic stratigraphy comprise the data sets on which this site report is based.

A thin paleosol, uniform massive medium sand, and medium sand with heavy mineral laminations (3.4–23.15 ft; 0.4–7.06 m) are provisionally assigned to the ?Holocene/Pleistocene Cape May Formation. These sediments were deposited in a nearshore setting in upper shoreface to foreshore environments.

The Miocene Kirkwood Formation consists of four sequences in the Sea Girt corehole. The uppermost Kirkwood Formation (23.15–45.5 ft; 7.06–13.87 m) consists of micaceous clays with silt laminations and uniform, tight, dark olive-green clays deposited in lagoonal or lower estuarine environments. These clays comprise a confining unit and probably correlate with one of the Kw2 sequences of Sugarman et al. (1993). The highstand systems tract (HST) of the Kirkwood 1b? sequence (45.5–106.4 ft; 13.87–37.46 m) consists of (1) medium to fine sands (45.5–63.6 ft; 13.87–19.39 m) deposited in lagoonal–estuarine or proximal upper shoreface environments, (2) interlaminated sand and sandy silt (63.6–76.7 ft; 19.39–23.38 m) interpreted to represent bay fill/estuarine environments, (3) heavily burrowed silty fine sand (80–91.6 ft; 24.38–27.92 m) representing shelf deposits influenced by a delta, and (4) delta front sands (91.6–106.4 ft; 27.92–32.43 m). The sequence from 45.5 to 106.4 ft (13.87 to 32.43 m) probably correlates to the Kw1b sequence. The underlying sequence (106.4–122.9 ft; 32.43–37.46 m) consists of interbedded fine–medium sand, clayey silt, and coarse sand deposited in delta front and prodelta environments and is probably correlative with the Kw1a sequence.

A sequence from 122.9 to 136.3 ft (37.46 to 41.54 m) may correlate to the Kw0 sequence of Miller et al. (1997). Coarser beds from 122.9 to 130.6 ft (37.46 to 39.81 m) comprise the upper HST sand, and finer beds from 130.6 to 134.4 ft (40.97 to 40.93 m) comprise the lower HST. The section from 134.4 to 136.6 ft (40.97to 41.64 m) may comprise the transgressive systems tract (TST). Alternatively, there may be a sequence boundary at 134.4 ft (40.97 m) and the sands below could be the HST of an underlying sequence.

The top of the upper Shark River Formation and the top of middle Eocene Sequence E8 is placed at the first downhole appearance of glauconite sand and a sharp gamma ray peak (~140 ft; 42.67 m). The HST consists of upper sands, deposited in lower shoreface environments and finer grained clays and silts deposited in inner–middle neritic environments (140–220 ft; 42.67–67.06 m). Glauconite increases downsection below 220 ft (67.06 m) to a maximum flooding surface (MFS) at 228 ft (69.49 m), a TST (228–236.2 ft; 69.49–71.96 m), and a burrowed sequence boundary at 236.1 ft (71.96 m).

Hard, occasionally porcellanitic, foraminiferal-rich, slightly glauconitic clay of the lower Shark River Formation is found from 236.1 to 255.5 ft (71.96 to 77.88 m). The section grades to a glauconitic sand below 261 ft (79.55 m). A surface at 265.8 ft (81.02 m) with indurated clay clasts associated with a major biostratigraphic break (Subzones NP15b at 261 ft [79.55 m] and NP14a at 266 ft [81.08 m]) is a sequence boundary separating Sequence E7 above from Sequence E5 of Browning et al. (1997) below. Clayey glauconite sand below the contact continues to a major irregular erosional contact at 271.75 ft (82.83 m) representing a sequence boundary separating Subzone NP14a and Sequence E5 of Browning et al. (1997) from the slightly glauconitic clay of Zone NP12 and Sequence E3 below. Sequence E4 is not represented at Sea Girt. Systems tracts are difficult to differentiate in the relatively deep paleodepths represented in middle Eocene Shark River Sequences E7 and E5 and lower Eocene Manasquan Sequences E3, E2, and E1.

Uniform clay assigned to the lower Eocene Manasquan Formation appears below the sequence boundary at 271.75 ft (82.83 m). The upper sequence (E3; 271.75–318 ft; 82.83–96.93 m) of the Manasquan Formation consists of (1) an upper, slightly sandy HST; (2) a heavily burrowed MFS at 288 ft (87.78 m); and (3) increasing quartz content in the TST. A tentative sequence boundary separating Sequence E3 from E2 is picked at 318 ft (96.93 m) based on a biostratigraphic break between nannofossil Zone NP12 above and NP11 below.

Quartz and glauconite sand increase below the 318 ft sequence boundary to a heavily burrowed irregular contact at 348.6 ft (106.25 m) that could be a sequence boundary or MFS. Below 348.6 ft (106.25 m), glauconite increases from trace at top to 80% above a contact at 358.8 ft (109.36 m). Nannofossil biostratigraphy suggests that the section above 358.8 ft (109.36 m) is equivalent to Sequence E2, and the contact at 358.8 ft (109.36 m) is a sequence boundary separating Sequence E2 above from E1 below. Sequence E1 consists of a glauconite sand that continues to a sequence boundary at 365.2 ft (111.31 m).

Below a burrowed contact (365.2 ft; 111.53 m) is a unique lithologic unit associated with the Paleocene/Eocene Thermal Maximum (PETM) (Zachos et al., 2001; Cramer et al., 1999). This green, brown, and reddish brown clay (365.2–384.7 ft; 111.31–117.26 m), though previously termed the “Vincentown equivalent” (Miller, et al., 1998), is lithologically distinct from the Vincentown Formation at outcrop and probably should be assigned unique member status.

The upper Paleocene Pa3 sequence first recognized at Island Beach, New Jersey (Liu et al., 1997) is uniform, micaceous, sandy, glauconitic clayey silt at Sea Girt (384.7–461.3 ft; 117.26–140.60 m). Glauconite increases below 452 ft (137.77 m) to clayey glauconite sand at 456 ft (138.99 m). An irregular contact at 461.3 ft (140.60 m) is interpreted as the lower sequence boundary. The base of the Vincentown Formation is placed at 465 ft (141.73 m), below which glauconite content consistently remains >50%. As at other sites, the formational boundary is offset from the sequence boundary.

The upper Hornerstown Formation consists of heavily bioturbated glauconitic sand deposited in lower shoreface to middle neritic environments. There are four sequence boundaries associated with the Hornerstown Formation: (1) below a brachiopod-rich shell hash at 469.8 ft (143.20 m) separating Sequence Pa2 of Liu et al. (1997) from Pa1b below, (2) at a hard zone at 482.4 ft (147.04 m), (3) in a coring gap (495.2–500.0 ft; 150.94–152.40 m) associated with a large gamma ray log kick and a biostratigraphic gap (Zone NP3/Subzone NP4a above and NP2 below) separating Sequence Pa1b of Liu et al. (1997) from Pa1a below, and (4) at the base of the Hornerstown Formation at 509.8 ft (155.39 m).

The Maastrichtian Navesink Formation consists of two different lithofacies that may represent two sequences. The upper Navesink Formation (509.65–535.8 ft; 155.34–163.31 m) consists of a black, clayey, massively burrowed glauconite sand interpreted as an inner neritic environment interfingering with lower shoreface environments. A lithologic contact at 535.8 ft (163.31 m) separates the sandier zone above from intensely burrowed silty glauconite sand with more common interbedded light gray clay. This may be a sequence boundary separating the Navesink I/II contact postulated by Miller et al. (2004). The lower Navesink lithofacies consists of interbedded glauconite silty sand and carbonate clay facies more typical of the Navesink Formation. This facies was deposited in middle–outer neritic environments. The contact zone (565.1–566.2 ft; 172.24–172.58 m) between the Navesink and Mount Laurel Formations is interpreted as a lowstand systems tract (LST). It consists of the glauconite clays above mixed together with the quartz sands below and includes shell and phosphate pellets deposited in nearshore to starved middle shelf environments.

The upper Campanian (Zones CC21–CC22) Mount Laurel Formation is the upper HST of a sequence that includes the Wenonah (lower HST) and Marshalltown (TST) Formations. The Mount Laurel Formation (565.1–621 ft; 172.24–189.28 m) at Sea Girt consists of lower shoreface medium- to coarse-grained quartz sand that fines downsection to a silty, bioturbated fine sand. The contact with the sandy silts of the underlying middle–upper Campanian (Zones CC20–CC21) Wenonah Formation is gradational. Micaceous lignitic silt with very fine sand laminations between 621 and 675.7 ft (189.28 and 205.95 m) is placed in the Wenonah Formation. The Wenonah Formation at Sea Girt is coarser grained and has more physical structures than at either Ancora or Bass River, suggesting a shallower paleoenvironment (lower shoreface with a prodelta influence). An increase in glauconite content to >30% at 675.7 ft (205.97 m) marks the contact with the middle–upper Campanian (Zone CC20) Marshalltown Formation. The Marshalltown Formation consists of very glauconitic, slightly quartzose, massive to heavily burrowed silt and glauconite sand (675.7–687.2 ft; 205.95–209.46 m). The MFS of the sequence is placed at 676 ft (206.04 m), where clay is at a maximum, quartz sand is absent, and there are rare shells. The Marshalltown Formation was deposited in middle–outer neritic environments. The contact of the Marshalltown and Englishtown Formations is interpreted as a transgressive surface (687.2 ft; 209.46 m). The upper part of the Englishtown Formation (687.2–691.25; 209.46–210.68 m) is a LST consisting of a brown clay bed and very micaceous, silty medium–fine quartz sand containing phosphate pellets. An irregular surface at 691.25 ft (210.68 m) separates the quartz sands above from delta front sands below.

One of the major scientific achievements of drilling at Sea Girt is the recovery of a very thick upper sequence from the middle Campanian (Zones CC19–CC20) Englishtown Formation (691.25–837.6 ft; 210.68–255.30 m). There are three major lithofacies in the upper Englishtown sequence. On top, the sequence (691.25–757 ft; 210.68–230.73 m) consists of fine- to medium-grained micaceous sands with thin beds and laminae of silt, clay, and lignite deposited in delta front environments. The second lithofacies consists of slightly micaceous interbedded and interlaminated silt and clay with occasional very fine sand laminae, interpreted as prodelta deposits. A glauconitic clay between 780.05 and 784.8 ft (237.76 and 239.21) is a condensed section or flooding surface. We place the MFS at 829 ft (252.68 m) at a maximum in glauconite and the top of a zone with concretions and brown clay. The third lithofacies consists of glauconitic silty quartz sand with shells (below 829 ft;

252.68 m) that was deposited in lower shoreface environments and is interpreted as the TST. A thick indurated zone at 839.1 ft (255.76 m) marks a sequence boundary.

The upper Santonian–lower Campanian (Zones CC16–CC19) lower Englishtown–Woodbury–Merchantville sequence begins below the sandstone (839.15 ft; 255.77 m). The top of the lower Englishtown Formation consists of heavily burrowed, silty, fine–medium sand deposited in lower shoreface and delta front paleoenvironments and heavily bioturbated, micaceous, fossiliferous silt deposited in an offshore environment influenced by a delta. The lower Campanian (Zone CC18) Woodbury Formation (891–943.5 ft; 271.58–287.43 m) is a micaceous silty clay to clay. The top of the formation is moderately to heavily burrowed and represents offshore environments. The bottom of the formation is a laminated prodelta deposit. The upper Santonian–lower Campanian (Zones CC16–CC18) Merchantville Formation (943.5–1056 ft; 287.58–321.87 m) is a very clayey glauconite sand deposited in inner to middle neritic environments. A burrowed contact at 962.15 ft (293.26 m) and a major facies shift at 1000.9 ft (305.07 m) are interpreted as sequence boundaries within the Merchantville Formation. The lower Campanian (Zones CC18–CC19) sequence from 837.7 to 962.15 ft (255.33 to 293.26 m; lower Englishtown–Woodbury–upper Merchantville) is probably equivalent to the Merchantville III sequence of Miller et al. (2004). The uppermost Santonian (Zone CC17) sequence from 962.15 to 1000.9 ft (293.26 to 305.07 m) is probably equivalent the Merchantville II sequence of Miller et al. (2004). The upper Santonian (Zone CC16) sequence from 1000.9 to 1056 ft (305.07 to 321.87 m) correlates with the Merchantville I sequence of Miller et al. (2004).

Poor recovery from 1056 to 1070 ft (321.87 to 326.14 m) precludes definitive identification of the Santonian Cheesequake Formation and sequence.

Several sequences are recognized in the upper Turonian–lower Santonian Magothy Formation (1063–1286.5/1289 ft; 324.00–392.13/392.89 m) and most can be tentatively correlated to the members at outcrop.

1. The upper sequence (1072–1110.65 ft; 326.75–338.53 m) contains an upper unit of cross-bedded to burrowed fine sand and interbedded organic-rich sands deposited in deltaic, lower delta plain to upper delta front environments. A lower unit consists of thicker bedded, cleaner, heavily burrowed medium sands representing a proximal upper shoreface deposit and faintly laminated, organic-rich, slightly silty clay interpreted as a bay/lagoon deposit. This sequence is named Magothy IVB, is probably lower Santonian, and may be equivalent to the Cliffwood Beds in outcrop (Kulpecz, 2005).
2. The second Magothy sequence (1110.65–1148.05 ft; 338.53–349.93 m) generally consists of cross-bedded sand with intermittent mud beds deposited in a delta front to lower delta plain environment. Subenvironments represented in this section include marsh, tidal channel, and tidal channel/bay. This sequence was named Magothy IVA, is probably upper Coniacian–lower Santonian, and may be equivalent to the Morgan Beds in outcrop (Kulpecz, 2005).
3. A thick medial sequence (1148.05–1213.2 ft; 349.05–369.78 m) consists of tan clays with thin sand beds and laminae at top representing soils deposited in a delta plain setting. A fining-upward succession of interbedded and interlaminated cross-bedded mi-

caceous fine sand and clay beds probably represents a migrating levee complex. Interlaminated gray and reddish brown clay, organic-rich clay beds, and micaceous sand were deposited in lower delta plain overbank swamps. At the bottom, organic-rich clays with interlaminated sands represent lower delta plain overbank deposits including cut-off channels and oxbow lakes. This sequence is assigned to pollen Zone V and thus correlates to the Magothy III sequence of Miller et al. (2004) and may be equivalent to the Amboy Stoneware Clay in outcrop.

4. A sequence from 1213.2 to 1262.8 ft (369.78–384.90 m) consists of an upper structureless granuliferous medium to very coarse sand with several 1–3 ft fining-upward packages and a lower yellow, white, and red mottled clay containing sphaerosiderite, representing paleosols deposited in an upper delta plain environment. The sandy channel sediments were deposited in a nearshore setting (fluvial delta, subaqueous bay mouth delta front, or tidal channel). This sequence is assigned to pollen Zone V and thus correlates to the Magothy II sequence of Miller et al. (2004) and may be equivalent to the Old Bridge Sand and South Amboy Fire Clay in outcrop.
5. A sequence from 1262.8 to 1289 ft (384.90 to 392.89 m) contains bioturbated and cross-bedded poorly sorted sands and organic-rich clays and is interpreted as an estuarine deposit. This sequence may correlate to the Magothy I sequence of Miller et al. (2004) and the Sayreville Sand in outcrop.

The Cenomanian–lower Turonian (Subzone CC10a through Zone CC1) Bass River Formation at Sea Girt is represented by at least three sequences. An uppermost Cenomanian–Turonian (Subzone CC10b through Zone CC11) sequence from 1289.0 to 1418.95 ft (392.89 to 432.50 m) consists of nearshore and delta front sands and silts on top and fines downsection to laminated silty clays deposited in proximal to distal prodelta environments. Very dark gray to black clays from 1370.15 to 1379.5 ft (417.62 to 420.79 m) may correlate to global ocean anoxic Event 2 (OAE2). This sequence correlates to the Bass River III sequence of Miller et al. (2004).

The sequence from 1418.95 to 1457.7 ft (432.50 to 444.31 m) consists of silt and sand deposited below wave base on a shelf overlying prodelta clays and silts. The upper part of this sequence contains calcareous nannofossils assigned to middle Cenomanian Subzone CC10a and it could correlate to either the Bass River II (Subzones CC10a–CC10b) or Bass River I (Zone CC9 through Subzone CC10a) sequence at Ancora (Miller et al., 2004). Based on superposition, we favor correlation to the Bass River II sequence.

A sequence from 1457.7 to 1494.95 ft (444.31 to 455.66 m) consists of prodelta clays on top, clayey very fine sand deposited in a delta front in the middle, and prodelta silts at the base. The sediments from 1480.15 to 1494.95 ft (451.15 to 455.66 m) contain distinct bands of light and dark colors, suggesting an environment alternating between organic-poor and organic-rich deposits. These organic-rich bands may represent changes controlled by Milankovitch cyclicity. The organic-rich sediments clearly predate OAE2. We tentatively correlate this sequence with the Bass River I sequence of Miller et al. (2004), though this is largely based on superposition because diagnostic fossils are absent from this sequence at Sea Girt.

The sequence from 1494.95 to 1520.2 ft (455.66 to 463.36 m) has a distinct blocky gamma ray log signature typical of the Potomac Formation. However, the upsection change from prodelta silts to delta front sands is typical of Upper Cretaceous marginal marine to marine sequences, and is not typical of the Potomac Formation. We tentatively term the sequence from 1494.95 to 1520.2 ft (455.66 to 463.36 m) the "Bass River 0.5" sequence and correlate it with the upper Potomac sequence at Ancora.

The top of the sequence deposited between 1520.2 and 1563 (463.36 and 476.40 m) consists of micaceous, lignitic, fine sands deposited in lower delta plain environments that may be the downdip equivalent to the Farrington Sand of the Raritan Formation. We tentatively term the sequence the "Bass River 0" sequence, though it could correlate to a Potomac sequence. The bottom of the sequence is a micaceous clay with subordinate interbedded very fine sand deposited in lower delta plain environments with oxbow and interfluvial marsh subenvironments. These sediments are notable for containing common leaf fossils.

The ?Albian–lower Cenomanian Potomac Formation (total depth [TD] = 1563–1600 ft; 476.40–487.68 m) contains mottled red and white clay and silt with sphaerosiderite and root casts representing paleosols that accumulated as overbank/interfluvial deposits. These probably correlate with Potomac Unit 3. Thus, the Sea Girt corehole penetrated the marine Bass River Formation, the marginal marine Bass River Formation–uppermost Potomac Formation undifferentiated, and the terrestrial Potomac Formation.

One of the major scientific achievements of drilling at Sea Girt is the recovery of very thick Upper Cretaceous sequences that were poorly or moderately represented in previous coastal plain coreholes. In particular, we targeted and recovered sequences from the middle Campanian upper Englishtown Formation, the lower Campanian Merchantville Formation (cryptic sequences Merchantville I and II), the upper Turonian–Coniacian Magothy Formation, and the Cenomanian–Turonian Bass River Formation.

BACKGROUND AND OBJECTIVES

This chapter is the site report for Sea Girt corehole, the tenth continuously cored and logged onshore site drilled as part of the CPDP. The CPDP began with drilling at Island Beach (March–April 1993), Atlantic City (June–August 1993), and Cape May (March–April 1994) as part of Ocean Drilling Program (ODP) Leg 150X (Miller et al., 1994a,1994b, 1996a; Miller, Newell, and Snyder, 1997). These three sites targeted Oligocene–Miocene sequences and tried to unravel icehouse sea level changes tied to continental slope drilling by the *JOIDES Resolution* on Leg 150 (Miller and Mountain, 1994; Miller et al., 1996b, 1998).

Leg 174AX continued onshore drilling at the following locations:

- Bass River, New Jersey (October–November 1996) (Miller et al., 1998), targeting Upper Cretaceous to Paleocene strata poorly sampled during Leg 150X.
- Ancora, New Jersey (July–August 1998) (**Miller et al.,** this volume), an updipping, less deeply buried Cretaceous–Paleocene section complimentary to the Bass River Formation.

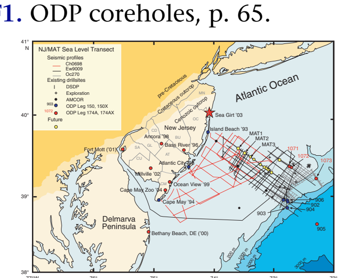
- Ocean View, New Jersey (September–October 1999) (**Miller et al.,** this volume), focusing on upper Miocene–middle Eocene sequences.
- Bethany Beach, Delaware (May–June 2000) (**Miller et al.,** this volume), concentrating on the thick Miocene sequences in the depocenter of the Salisbury Embayment.
- Fort Mott, New Jersey (October 2001) (**Sugarman et al.,** this volume), targeting the largely nonmarine Potomac Group.
- Millville, New Jersey (May–June 2002) (**Sugarman et al.,** this volume), drilled to further our understanding of Upper Cretaceous "greenhouse" sequences.

These sites provided a chronology of sequences over the past 100 m.y. (e.g., Miller et al., 2005). The Joint Oceanographic Institutions for Deep Earth Sampling Planning Committee and Science Committee designated drilling at these sites as ODP Leg 174AX. In total, these previous coreholes recovered 6082 ft (1854 m) from 6991.5 ft (2131.01 m) drilled (recovery = 87%).

Despite logistic and scientific success in onshore coring to date, there is a significant gap in our understanding of Upper Cretaceous greenhouse sequences. Both Ancora and Bass River are excellent Upper Cretaceous sections, as summarized in Miller et al. (2004), but they each have important limitations. Drilling updip at Ancora recovered unaltered Upper Cretaceous strata (531 ft; 161.85 m) that were dated using integrated Sr isotopic stratigraphy and biostratigraphy, with resolution as good as ±0.5 m.y. (Miller et al., 2004). However, because of its updip location, the section at Ancora was thin and poorly fossiliferous in a few critical sections (e.g., the Cenomanian/Turonian boundary, middle Campanian Englishtown sequence). Drilling at Bass River provided thicker Upper Cretaceous sequences (700 ft; 213.36 m). Although the ages of sequences agree well between Bass River and Ancora (Miller et al., 2004), Sr isotopic values at Bass River below 1500 ft (450 m) were affected by diagenesis, resulting in greater age uncertainty than at Ancora. One or more additional sections are needed to verify the regional significance and global ages of these greenhouse sequences and attendant sea level changes. The "Goldilocks" location (neither too far updip nor too far downdip) is midway between Bass River and Ancora.

We have targeted two sites between Ancora and Bass River that should provide ideal settings for sampling Upper Cretaceous sequences. The first, along strike to the south at Millville, New Jersey, was chosen primarily to sample important aquifers and the NJGS paid for all drilling costs for this hydrostratigraphic test corehole in summer 2002 (**Sugarman, et al.,** this volume). Because Upper Cretaceous sections thin along strike toward Millville, only 439.6 ft (133.99 m) of Cretaceous strata were recovered. Nevertheless, this site is very useful in evaluating Upper Cretaceous facies variations and provides a key location for mapping Cretaceous hydrogeologic units (**Sugarman et al.,** this volume, 2006) and sequences (Kulpecz, 2005). Regional trends show that the Upper Cretaceous thickens toward the north of the Ancora-Bass River dip transect (Perry et al., 1975; Olsson et al., 1988) (Fig. **F1**). Stratigraphic sections from poorly sampled wells at Toms River, Sandy Hook, and Fire Island show that a location between Toms River and Sandy Hook will provide the thickest Upper Cretaceous marine section. Though the Upper Cretaceous thickens further toward Fire Island, there are no Cenomanian–Turonian strata there and the section is very sandy (hence poorly fossiliferous and nonmarine in parts). Thus, the NSF

F1. ODP coreholes, p. 65.



funded drilling of a 1600 ft (187.68 m) corehole at Sea Girt, New Jersey, along strike of Millville. This site will be tied into the nearshore seismic grid collected in May 2003 by G.S. Mountain, N. Christie-Blick, S. Pekar, and C. McHugh in May 2002 that includes Chirp sonar (1 m resolution) and high-resolution (5 m vertical) multichannel seismic data (Fig. F1), allowing us to evaluate Upper Cretaceous sequences with a resolution not previously possible.

OPERATIONS

Drilling at the National Guard Training Base, Sea Girt, New Jersey (40°07′12.698″N, 74°01′58.25″W; elevation = 9.8 ft [3.05 m]; Point Pleasant quadrangle, Monmouth County) began in September 2003. Drilling operations were superintended by Gene Cobbs, chief driller, USGS Eastern Earth Surface Processes Team (EESPT; Don Queen, Drilling Coordinator). Glenn Berwick and Jeff Grey III were the assistant drillers. On 21 September, the EESPT drillers arrived onsite and began rigging up and connecting electrical and water hookups. On 23 September, James Browning moved equipment onsite and set up a field laboratory in a trailer. A digital zoom camera (6.5–19.5 mm lens; 4 megapixel resolution), computer, and photography stand were set up to photograph 2-ft (0.61-m) core segments. Camera default settings (including flash) were used following procedures established at Ocean View, New Jersey (Miller et al., 2001).

All cores were measured in feet and tenths of feet, all depths are given in feet and meters below land surface, and all operations are described in feet and meters. We continued 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 24 September 2003 using a Christensen 94-mm (HQ) system. For unconsolidated sands, an extended (“snout”) shoe was used to contact the sample 1.5–2.5 in ahead of the bit; core diameter is 2.4 in with a rock shoe and 2.1 in with the snout shoe. Approximately 1.0 ft (0.30 m) of large-diameter (10 in) surface casing was set. The large diameter was designed to catch cuttings from reaming a 5-in hole for casing targeted at 220 ft (67.06 m).

Core recovery was poor at the beginning of the day on 24 September. In the afternoon, the drillers pulled the drill string out of the ground and cleaned the bit, improving recovery. Overall we recovered 58.5 ft (17.83 m) from 90 ft (27.43 m) drilled (recovery = 65.7%).

On the first core run (90–100 ft; 27.43–30.48 m) on 25 September, the cable clamp broke and drilling was suspended for a short time while a replacement was obtained. Drilling resumed and there was 7.4 ft (2.26 m) of recovery from 100 to 110 ft (30.48 to 33.53 m). On the next run from 110 to 120 ft (33.53 to 36.58 m), only 1.7 ft (0.52 m) was recovered. The interval recovered was a loose, coarse to very coarse sand. This sand kept caving in, requiring the drillers to spend time flushing the hole. In the afternoon, we penetrated a firm sandy clay which cored quickly. Overall we recovered 51.55 ft (15.71 m) from 80 ft drilled (24.38 m; recovery = 64.4%).

Coring went well on 26 September. We recovered 100% on all runs from 170 to 210 ft (51.82 to 64.01 m). Drilling was stopped to log the hole prior to setting casing to prevent caving of surficial and Kirkwood sands. The rods were pulled, and the DGS attempted open-hole logging. The hole was successfully logged using the DGS Century Corporation gamma-electric multitool and winch to 185 ft (56.39 m), beyond which the tool could not pass because of an obstruction. The multitool obtained a gamma ray log and suite of electric logs including spontaneous potential (SP), short normal resistivity (16N), long normal resistivity (64N), point resistivity, and lateral resistivity.

The hole was reamed with a 7⅞ in tricone bit to 143 ft (43.59 m) on 27 September. The alternator on the drill truck blew and we used the alternator on the pick-up truck to power the deck motor. The casing would not go below 113 ft (34.44 m) in the lower Kirkwood sand, ending a tough day onsite. Operations were delayed by rain on the morning of 28 September. The drillers rereamed the hole to 143 ft (43.59 m) and successfully inserted 5-in (12.7 cm) polyvinyl chloride (PVC) casing to 143 ft (43.59 m). We reran the rods to 200 ft (60.96 m) and conditioned the hole to resume coring operations on the next day.

Coring resumed at 210 ft (64.01 m) on 29 September. We ran 5 ft (1.52 m) on the first core (210–215 ft; 64.01–65.53 m), recovering 2.4 ft (0.73 m) of solid core and 0.3 ft (9 cm) of caved pebbles and charcoal/lignite that was pushed into the core during casing. Smooth coring through glauconitic clay on Runs 28 (215–220 ft; 65.53–67.06 m) and 29 (220–230 ft; 67.06–70.10 m) allowed excellent recovery. Run 30 (230–240 ft; 70.10–73.15 m) had 3 ft (0.91 m) of slurry at the top that was discarded. This run became blocked 6.5 ft (1.98 m) into the run by hard yellow clay, though we recovered the lithologic contact that was penetrated. Runs 31 (240–250 ft; 73.15–76.20 m), 32 (250–260 ft; 76.20–79.25 m), 33 (260–270 ft; 79.25–82.30 m), 34 (270–280 ft; 82.3–85.34 m), and 35 (280–290 ft; 85.34–88.39 m) had good recovery using the modified rock shoe in these semi-indurated clays and increasingly porcellanitic rock beds. There was only 20% recovery, however, in the last run of the day from 290 to 300 ft (88.39 to 91.44 m). The day ended at 300 ft (91.44 m) with 72.05 ft (21.96 m) recovered from 90 ft drilled (27.43 m; recovery = 72.1%).

On 30 September, the first core (300–310 ft; 91.44–94.49 m) recovered 7.7 ft (2.35 m) out of a 10 ft run (3.05 m). There was a porcellanite at the base of the run. There was 7.8 ft (2.38 m) of recovery in the next 10-ft (3.05 m) run to 320 ft (97.54 m), and 7.6 ft (2.32 m) of recovery from 320 to 330 ft (97.54 to 100.58 m). There was 96% recovery from 330 to 340 ft (100.58 to 103.63 m). From 340 to 350 ft (103.63 to 106.58 m), there was 75% recovery. Recovery was perfect from 350 to 360 ft (106.58 to 109.73 m), whereas from 360 to 370 ft (109.73 to 112.78 m) 6.65 ft (2.03 m) was recovered, and 7.15 ft (2.18 m) was recovered from 370 to 380 ft (112.78 to 115.82 m). From 380 to 390 ft (115.82 to 118.87 m) there was 70% recovery. By the end of the day, we recovered 80.8 ft (24.63 m) from 100 ft drilled (30.48 m; recovery = 80.8%).

On 1 October 2003, drilling was delayed to replace the alternator on the rig and we planned our approach to the Cretaceous/Tertiary (K/T) boundary. The K/T boundary at the Department of Geothermal Energy (DGE) test well 2-78 gamma ray log (~300 ft [91.44 m] east) is associated with a gamma ray log kick at 493 ft (150.27 m). The contacts in the DGE well appear to be offset from the contacts in the Sea Girt core by ~2–4 ft (0.61–1.22 m) based on rough comparison of our DGS gamma ray log with the DGE gamma ray log and core depths of the base of the Shark River glauconites and base of the Manasquan Formation glauconites in our cores vs. DGE log depths. We thus targeted the K/T boundary on 2 October. To free up the drillers for mid-November seismic refraction studies of the Chesapeake Bay Impact Structure, we planned for extended operations beginning on 25 October. We discussed 24 hr/day coring or a modified 16 hr/day coring operation (0600–2200 hr), turning the rods from 2200 to 0600 hr to avoid problems with local neighbors.

The first cores on 1 October (Runs 47–48; 400–420 ft; 121.92–128.02 m) obtained full recovery in Vincentown Formation silts. Run 49 (420–430 ft; 128.02–131.06 m) recovered 7.3 ft (2.23 m) in silty clay, whereas Runs 50 (430–440 ft; 131.06–134.11 m) and 51 (440–450 ft; 134.11–137.16 m) had full recovery. The day ended at 450 ft (137.16 m) with 47.9 ft (14.60 m) recovered from 50 ft drilled (15.24 m; recovery = 95.8%).

On 2 October, we recovered 7.2 ft (2.19 m) on Run 52 (450–460 ft; 137.16–140.21 m). Drilling stopped while a section of the cable was replaced and then resumed with Runs 53 (460–465 ft [140.21–141.73 m]; 4.35 ft [1.33 m] recovery), 54 (465–470 ft [141.73–143.26 m]; 5 ft [1.52 m] recovery), and 55 (470–475 ft [143.26–144.78 m], 4.3 ft [1.31 m] recovery). We ran 10 ft (3.05 m) from 475 to 485 ft (144.78 to 147.83 m) with perfect recovery and then shifted to a 5-ft (1.52- m) run (485–490 ft [147.83–149.35 m], 3.5 ft [1.07 m] recovery) and then a 10-ft (3.05 m) run (490–500 ft; 149.35–152.40 m) in an attempt to get the K/T boundary within a single core run. We only obtained 5.2 ft (1.58 m) of recovery on this run, but did not penetrate the Cretaceous (Danian Zone P1 at 495.2 ft [150.94 m]) and decided to drill one additional 5-ft (1.52 m) run (Run 59; 500–505 ft; 152.40–153.92 m). The day ended at 505 ft (153.92 m) with 44.15 ft (13.46 m) recovered from 55 ft drilled (16.76 m; recovery = 80%).

On 3 October, the first core recovered 100% from 505 to 510 ft (153.92 to 155.45 m). The core slipped out of the shoe but was fortunately retrieved by the driller. The K/P boundary was recovered at 509.65 ft (155.34 m). On the next run from 510 to 520 ft (155.45 to 158.70 m), 9.9 ft (3.02 m) was recovered. There was a vertical fracture in the core. From 520 to 530 ft (158.50 to 161.545 m), 10.1 ft (3.08 m) was recovered, and 7.6 ft (2.32 m) was recovered from 530 to 540 ft (161.54 to 164.59 m). In the run from 540 to 550 ft (164.54 to 167.59 m), 10.3 ft (3.14 m) was recovered. Recovery in the clayey Navesink Formation was excellent, but recovery fell off in the Mount Laurel Formation sands. The day ended at 575 ft (175.26 m) with 63.9 ft (19.48 m) recovered from 70 ft drilled (21.34 m; recovery = 91.3%).

On 4 October, Don Queen, driller, and Casey McKinney, driller's assistant, from the Central Regional Branch (Denver), Geologic Division, of the Earth Services Processes (ESP) team, took over coring duties. We recovered 2.9 ft (0.88 m) on the first 5-ft (1.52-m) run of the day. On the next run, from 580 to 590 ft (176.78 to 179.83 m), 10.2 ft (3.11 m) was recovered. Recovery was again over 100%, with 10.35 ft (3.15 m) recovered between 590 and 600 ft (179.83 and 182.88 m). The next run was stopped at 5 ft (1.52 m; 600–605 ft [182.88–184.40 m]) because of stiff drilling, and 2.35 ft (0.72 m) was recovered. Drilling was very slow for the final run of the day; we recovered 5.4 ft (1.65 m) from 605 to 610 ft (184.40 to 185.93 m). The day ended at 610 ft (185.93 m) with 31.2 ft (9.51 m) recovered from 35 ft drilled (10.67 m; recovery = 89.1%).

The first core on 5 October was delayed to pump out sands that had caved into the hole overnight. The first core from 610 to 620 ft (185.93 to 188.98 m) recovered 4.8 ft (1.46 m). The drillers believe that the soft sand slipped out of the core barrel while it was being pulled to the surface; the DGE gamma ray log confirms this is a sandy interval. The drillers decided to flush the hole and clean the mud pump before drilling another core. Recovery improved on Run 74 (620–630 ft [188.98–192.02 m]; 9.25 ft [2.82 m]) but was poor on the last two runs of the day. The drillers decided to flush the hole and clean the mud pump in preparation for the next day. The day ended at 650 ft (198.12 m) with 19.85 ft (6.05 m) recovered from 40 ft drilled (12.19 m; recovery = 49.6%).

Recovery problems continued on Run 77 (650–660 ft; 198.12–201.17 m) on 6 October, with 2 ft (0.61 m) of slurry and 3.3 ft (1.01 m) of core recovered. Don Queen reported that variable pressures occurred while recovering silts, suggesting we blew away the sandier silts. The next run was cut short at 7 ft (2.13 m) because of a change in lithology; the core recovered 2 ft (0.61 m) of slurry that was discarded and 6.9 ft (2.10 m) of solid core, including a shift from silts to glauconite sands at 6.5 ft (1.98 m). Run 79 (667–672 ft; 203.30–204.83) had 2 ft (0.61 m) of drilling slurry and 4.45 ft (1.36 m) of solid core with a thick rind. The rind was removed with a knife, exposing well-preserved silts with sand laminae. The slurry contained balls of glauconite sand that must have come from the base of the last run. We concluded that the slurry came from the bottom of the previous run that resulted from lowering the rods. Run 80 (672–677.5 ft; 204.83–206.50 m) was stopped at 5.5 ft (1.68 m) at a slight change to glauconite sand that blocked the shoe. We stopped drilling at a sudden pressure drop 4.5 ft (1.37 m) into Run 81 (677.5–682 ft; 206.50–207.87 m) and recovered 4.15 ft (1.26 m) of core. Run 82 (682–690 ft; 207.87–210.31 m) had 9.2 ft (2.80 m) of recovery. The day ended with 33 ft (10.06 m) recovered from 40 ft drilled (12.19 m; recovery = 83.5%). Final depth for the day was 690 ft (210.31 m), according to the driller's records, although 691.2 ft (210.68 m) was the depth of the deepest core.

On 7 October, the rods were stuck in the hole for two hours and the first core was not recovered until 1245 hr. From Runs 83 (690–700 ft; 210.31–213.36 m) and 84 (700–710 ft; 213.36–216.41 m), 10 and 8.9 ft (3.05 and 2.71 m) were recovered, respectively. The day ended at 710 ft (216.41 m) with 18.9 ft (5.76 m) recovered from 20 ft drilled (6.10 m; recovery = 95%).

The rods were stuck for 15 min on 8 October, delaying drilling. We did have circulation, suggesting that this problem was not due to swelling Manasquan Formation clays as experienced in the corehole at Millville. Rather, it appears that the rods were becoming stuck because of positive sidewall pressure in the Mount Laurel aquifer. We pulled up 40 ft (12.19 m) overnight to bring the bottom of the drilling string above the Englishtown aquifer. Continued circulation of bentonite freed up the rods. We hoped that a sufficient mudcake would develop in the Mount Laurel aquifer to curtail sidewall suction. Run 85 penetrated 3 ft (0.91 m; 0710–713 ft [216.41–217.32 m]) and hit a hard zone, recovering 1–2 ft (0.30–0.61 m) of slurry and 1.86 ft (0.57 m) of core. Runs 86 (713–720 ft; 217.32–219.46 m), 87 (720–730 ft; 219.46–222.60 m), and 88 (730–740 ft; 222.60–225.55 m) had recoveries of 96%, 90%, and 94%, respectively. These sands compress easily and we probably attained nearly full recovery. Rocks in the hole chewed up the shoe. The last run of the day (Run 89; 740–750 ft [225.55–228.60 m]) had 5.9 ft (1.80 m) of recovery and was complicated by several indurated and clay zones. The day ended at 750 ft (228.60 m) with 32.86 ft (10.02 m) recovered from 40 ft drilled (12.19 m; recovery = 82%).

On 9 October, drilling began with 0.6 ft (18 cm) recovered between 750 and 760 ft (228.6 and 231.65 m). The drillers tried to go back and recover the remaining core, but it was lost. Recovery improved for the rest of the day coring silt and clay. At the end of the day, the drillers pulled off 60 ft (18.29 m) of the drill rods and flushed the hole with 200 gallons of fresh mud. The day ended at 800 ft (243.84 m) with 29.6 ft (9.02 m) recovered from 50 ft drilled (15.24 m; recovery = 59.2%).

On the morning of 10 October, clays at the bottom of the hole had swelled overnight and the drillers had difficulty getting the rods back to the bottom of the hole. As a result, the first core was delayed until 1200 hr. The day ended at 830 ft (252.98 m) with 27.5 ft (8.38 m) recovered from 30 ft drilled (9.14 m; recovery = 91.7%).

A hydraulic line blew out at the end of 10 October and was replaced in the morning of 11 October. As we prepared to lower the inner core barrel, we found that the overshot would not engage the quad latch. We replaced the spring in the overshot. The hole was in good shape in the morning, with none of the grabbing that had occurred the previous mornings. The first core (Run 99; 830–840 ft [252.98–256.03 m]), brought up at 1230 hr, recovered 9.3 ft (2.83 m) of spectacular sediment. Run 100 (840–850 ft; 256.03–259.08 m) recovered 1.5 ft (0.46 m), and we switched to the extended shoe to help capture the sands. The last run of the day (Run 101; 850–860 ft [259.08–262.13 m]) recovered 4 ft (1.22 m). At the end of the day, the drillers took 60 ft (18.29 m) of pipe off the drill string. The day ended with a total of 14.8 ft (4.51 m) recovered from 30 ft drilled (9.14 m; recovery = 49%).

On 12 October, Don Queen and Casey McKinney left the site and Gene Cobbs resumed drilling. Heavy rains at the site delayed drilling and the first core was up at 1100 hr. The first core (860–861 ft; 262.13–262.43 m) ran only 1 ft (0.30 m) because slop collected in the inner core barrel when the drillers replaced the 60 ft (18.29 m) of drill string removed the night before. Coring proceeded without incident the rest of the day. The day ended at 910 ft (277.37 m) with 40.2 ft (12.25 m) recovered from 50 ft drilled (15.24 m; recovery = 80.3%).

The rods were pulled up to 870 ft (265.18 m) overnight, but were stuck on the morning of 13 October. We had circulation, but sidewall suction, probably from the Englishtown aquifer, prevented the rods from turning. The rods were freed at 1139 hr by working them up and down. Runs 108–110 (910–920, 920–930, and 930–940 ft [277.37–280.42, 277.37–283.46, and 283.46–286.51 m], respectively), recovered 9.5, 10.35, and 10 ft (2.90, 3.15, and 3.05 m), respectively. The cores consisted of silty clay that became more clayey and glauconitic in the bottom 10 ft (3.05 m). The day ended at 940 ft (286.51 m), yielding 29.85 ft (9.10 m) recovered from 30 ft drilled (9.14 m; recovery = 99.5%). At the end of the day the drillers pulled 100 ft (30.48 m) of rod off the drill string.

On 14 October, the drill string was again stuck in the hole. The drillers freed the rods at ~1130 hr and pulled the rods out of the hole to ream the areas that were pinching. The drillers reported that there were two zones that pulled on the rods during withdrawal: between 560 and 580 ft (170.69 and 176.78 m) and between 460 and 480 ft (140.21 and 146.30 m). Gene Cobbs reported that Don Queen had problems with the zone at 580 ft (176.78 m) when drilling at 620 ft (188.98 m). This zone corresponds to the Mount Laurel Formation.

After pulling all of the rods, the drillers found that the drill bit was worn out. Instead of reaming using the tricone bit, they decided to ream the hole using a 4½-in (11.43 cm) coring bit to save time. This new bit is ¼ in (6.4 mm) wider than the bit they had been using. The drill string entered the hole with no problems until 460 ft (140.21 m), and the hole was reamed from that level down. On 15 October, despite having to work in howling winds, the drillers advanced drill string back to 800 ft (243.84 m).

The remainder of the drill string was put in the hole on the morning of 16 October. The first run (111; 940–950 [286.51–289.56 m]) came up at 1245 hr. Run 113 (960–960.6 ft; 292.61–292.79 m) was cut short because the drillers hit hard sediment that would not penetrate the shoe. All other cores came up without incident. The day ended at 970 ft (295.66 m) with 16.7 ft (5.09 m) recovered from 30 ft drilled (9.14 m; recovery = 55.7%).

On 17 October, rods were stuck for a short time in the morning. Run 115 (970–975 ft; 295.66–297.18 m) fell out of the shoe during retrieval. Run 116 (975–980 ft; 297.18–298.70 m) recovered 5.9 ft (1.8 m). We attribute all of this core to Run 116 and readjusted the depths of the runs. The interval from 970 to 974 ft (295.66 to 296.88 m) is assigned to Run 115 and has 0% recovery. The interval from 974 to 980 ft (296.88 to 298.70 m) is assigned to Run 116 and has 98% recovery. Run 117 (980–990 ft; 298.70–301.75 m) recovered 10.2 ft (3.11 m) of core. An indurated zone allowed only 3.2 ft (0.98 m) of recovery on Run 118 (990–993 ft; 301.75–302.67 m). From 993 to 1000 ft (302.67 to 304.80 m), 5.1 ft (1.55 m) was recovered. The scientific team left the site before the last core of the day came up and it was washed by the drillers to be described the next day. The day ended at 1010 ft (307.85 m) with 35.6 ft (10.85 m) recovered from 40 ft drilled (12.19 m; recovery = 89.0%).

The rods were not stuck on the morning of 18 October, allowing an early start. The first run was up at 0930 hr but the core had slipped out and the inner barrel was empty. The drillers made two attempts to run back into the hole to recover the core and managed to retrieve 5.7 ft (1.74 m). Run 123 (1030–1033 ft; 313.94–314.86 m) was stopped short of a full 10 ft (3.05 m) because the formation became too hard for the shoe to penetrate. The core slipped out of the barrel from Run 125 (1037.5–1047.5 ft; 316.23–319.28 m) and only 0.4 ft (0.12 m) of core was recovered on the second try. The final run of the day (Run 126; 1047.5–1050 ft [319.28–320.04 m]) recovered 1.7 ft (0.52 m). This core is assumed to have come from 1047.5–1050 ft (319.28–320.04 m) but could have come from anywhere in the interval from 1037.5 to 1050 ft (316.23 to 320.04 m). The drill crew mixed a batch of EZ Mud and pumped it into the hole at the end of the day. The day ended at 1050 ft (320.04 m) with 34 ft (10.36 m) recovered from 50 ft drilled (15.24 m; recovery = 68%).

The rods were stuck again on the morning of 19 October. The drillers freed the rods and pumped bentonite through the system. The first coring run (127; 1050–1060 ft [320.04–323.09 m]) recovered a short (0.4 ft; 12 cm) lithified interval that appeared to have blocked the bottom of the inner barrel, preventing recovery of much core. The inner barrel was again lowered to the bottom and a small piece (0.2 ft; 6 cm) of lithified core was recovered. The lithified core was scratched in several orientations, suggesting that it had been drilled over more than once or rolled while being redrilled. The drillers changed to an inner core barrel with a rock shoe in the hope of recovering core from the bottom of the outer barrel on a third try at mid-day but no core was recovered. Total recovery for Run 127 was 0.6 ft (18 cm). During Run 128, the drillers reported that drilling behavior suggested a softer lithology and that the mud rapidly thinned during the run, suggesting significant volumes of water were flowing into the hole. Upon retrieval of the inner core barrel, 0.5 ft (15 cm m) of core was recovered. Total recovery for the day was 1.1 ft of 20 ft (6.10 m) drilled (recovery = 0.5%). The drillers conditioned the hole for geophysical logging at the end of the afternoon by adding additional bentonite mud and the entire HQ drill string was pulled. Once the drill string was removed, the open hole was successfully logged by Pete McLaughlin using the DGS Century Geophysical Corporation gamma-electric multitool and the Rutgers/DGS Century winch to 1063 ft (324.00 m), just short of the 1070 ft (326.14 m) TD. The multitool obtained a suite of logs in both the downhole and uphole directions including gamma radiation, spontaneous potential (SP), short normal resistivity (16N), long normal resistivity (64N), point resistance, and lateral resistivity. Logging was completed at 2130 hr and operations ended for the day. Log quality was excellent as evaluated by registry of major inflections against the cores.

Drilling in the HQ hole was successful, with 817.11 ft (249.06 m) recovered from 1070 ft drilled (326.14 m; mean recovery = 76%; median recovery = 87%). Recovery was excellent in the Paleogene Shark River, Manasquan, Vincentown, and Hornerstown Formations (314.1 ft [95.74 m] recovered between 140 and 500 ft [42.67 and 152.4 m]; recovery = 85%), with virtually all sequence boundaries recovered within cores. Recovery was excellent in the Maastrichtian Navesink-Red Bank Formations and surprisingly good in the Mount Laurel Formation sands. Recovery problems in parts of the Englishtown and Merchantville Formations appear to be in relatively uniform portions of the section, with most, if not all, sequence boundaries recovered. Coring problems limit our understanding of the thin Cheesequake sequence.

On 20 October, NQ rods were lowered but had trouble advancing because of excessive pressure in the hole. The rods reached the bottom of hole at 1070 ft and coring resumed on 21 October using a Christensen CNWL (NQ) system, 3.162-in (8.03 cm) hole diameter, and 1.875-in (1⅞-in [4.76 cm]) core diameter with the rock shoe and 1.67-in (4.24 cm) core diameter with extended shoes. Part of the lost core from Run 128 (1060–1070 ft; 323.09–326.14 m) was recovered with the NQ rod. This core is a loose gravel and might be the Magothy Formation. The rods were stuck again on the afternoon of 21 October, preventing additional core recovery and forcing the rods to be pulled. The rods were again stuck on the mornings of 22 October and 23 October. The drill rods were freed in the afternoon of 23 October and we managed to obtain one core (1070–1074 ft; 326.14–327.36 m). The drillers believe the Mount Laurel aquifer has a positive head and is pushing water into the hole. This water is flowing into the Englishtown aquifer that, because of pumping, has a negative head. This water flow is pushing the pipe against the side of the hole into the Wenonah silts and clays, where the rods are sticking. The drillers removed 500 ft (152.40 m) of pipe from the hole overnight to help prevent sticking. It was decided that we would need to operate 24 hr/day to prevent stuck rods.

On 24 October, rods were firmly stuck and could not be freed. The drillers decided that the torque needed to free the NQ rods would probably snap them off; therefore, they ran HQ rods around the NQ. By 880 ft (268.22 m), the HQ rods had freed the NQ rods that were still hung to 1073.5 ft (327.20 m), but then the HQ rods became stuck. While working the HQ rods, the rotary transmission blew. On 26 October, 1073.5 ft (327.20 m) of NQ rods could still be rotated with a pipe wrench and the drillers had circulation, but the HQ rods were still stuck at 880 ft (268.22 m). The rotary transmission was removed and was taken to a local transmission shop in Manasquan. We hoped to complete repairs and resume coring by later that week.

Repairs to the transmission were completed on 1 November. The NQ rods were still free and rotating and there was full circulation through both sets of rods. We decided to use the HQ rods as a temporary casing and begin coring to TD.

Coring resumed on 2 November 2003 at 1074 ft (327.36 m). The drillers were able to make four core runs before darkness halted operations. The day ended at 1110 ft (338.33 m) with 22.5 ft (6.86 m) recovered from 36 ft (10.97 m) drilled (recovery = 62.5%). The drillers put nylon fibers into the hole in an attempt to free the HQ rods. Some of the fibers stuck to the outside of the cores.

On 3 November, 30 ft (9.14 m) of core was run (1110–1140 ft; 338.33–347.47 m). In the first 10-ft (3.05 m) run, only 0.65 ft (20 cm) was recovered. During the next 20 ft (6.10 m) of coring, 20.4 ft (6.22 m) was recovered for a total recovery of 70% for the day.

On 4 November, Run 137 (1140–1150 ft; 347.47–350.52 m) recovered 9.75 ft (2.97 m), Run 138 (1150–1160 ft; 350.52–353.57 m) recovered 9.25 ft (2.82 m), Run 139 (1160–1170; 353.57–356.62 m) recovered 8.7 ft (2.65 m), and Run 140 (1170–1180 ft; 356.62–359.66 m) recovered 10.0 ft (3.05 m), yielding 94% recovery (37.7 ft [11.49 m] from 40 ft [12.19 m] drilled) during daylight operations. The drillers planned to go to 24-hr operations on 3 November, but had difficulty finding sufficient lighting. Lights were delivered on 4 November and 24-hr operations commenced with two two-person shifts working from midnight to noon and noon to midnight. The science team decided not to work overnight because insufficient light and freezing temperatures made it difficult to adequately describe and prepare the cores. Cores brought up overnight were washed by the drillers, labeled, and set aside for the science team the next morning. Overnight drilling was successful. The drillers recovered 31.45 ft (9.59 m) from 60 ft (18.29 m) drilled (recovery = 52.4%) in fine to very coarse sands of the Magothy Formation. Despite working through cold and rainy conditions, the drillers recovered a core every 3 hr. Core 145 (1220–1230 ft; 371.86–374.90 m) had to be pumped out of the inner barrel. When the core came loose from the barrel, it shot out and the loose sand was spread on the ground. All the drillers could recover was 0.45 ft (14 cm) from a longer core. Shortly after the last core came up (0800 hr, 5 November) the alternator stopped functioning. In addition, the case holding the ball bearings (the race) inside the quad latch broke and needed replacement. Rather than waiting for the race to be delivered Gene Cobbs III drove to Reston, Virginia, returning to the site with a new race at 0100 hr on 6 November. Second shift (Big Gene and Glenn) started conditioning the hole as soon as the piece arrived. Coring resumed ~0300 hr. Drilling continued throughout the day in a steady drizzle. Sand at the bottom of Run 148 (1250–1260 ft; 381.00–384.05 m) was lost because the sands were too soft to push the clays up inside the core barrel. Recovery was variable during early night drilling in interbedded sands and clays, with 10, 3.0, and 6.5 ft (3.05, 0.91, and 1.98 m) recovered on Runs 149 (1260–1270 ft; 384.05–387.10 m), 150 (1270–1280 ft; 387.10–390.14 m), and 151 (1280–1289 ft; 390.14–392.89 m), respectively. Run 151 was stopped by a hard layer. The day ended with 33.3 ft (10.15 m) recovered from 49 ft drilled (14.94 m; recovery = 68%).

On 7 November, Run 152 (1289–1300 ft; 392.89–396.24 m) was inadvertently run 11 ft (3.35 m) across a shift change and only recovered 5.85 ft (1.78 m), though we were fortunate to capture the contact with the Bass River Formation. An indurated layer at 1295 ft (394.72 m) probably blocked the barrel. The next run (153; 1300–1310 ft [369.24–399.29 m]) was made with a rock shoe because of indurated sediments on the last run; mud pressures dropped and recovery was only moderate (4.85 ft; 1.48 m). There were caved, indurated chips at the top of Run 153. Run 154 (1310–1320 ft; 399.29–402.34 m) recovered 10.7 ft (3.26 m); the top of this core also contained indurated, caved, angular chips. We believe that this run includes ~0.7–1.0 ft (21–30 mm) from the last run. We experienced problems with fogging of the camera lens but fixed it with the hair dryer. Runs 155 (1320–1330 ft; 402.34–405.38 m), 156 (1330–1340 ft; 405.38–408.43 m), 157 (1340–1350 ft; 408.43–411.48 m), and 158 (1350–1360 ft; 411.48–414.53 m) recovered 8.1, 9.65, 9.6, and 10.6 ft (2.47, 2.94, 2.93, and 3.23 m), respectively.

Drilling crews changed at 0320 hr with the arrival of Don Queen, driller, and Jim Ruman, helper. On the morning of 8 November, the scientific staff had 60 ft (18.29 m) of core (1360–1420 ft; 414.53–432.82 m) waiting to be described on site. The drillers reported no problems drilling in the night. Overnight temperatures were quite cold, although it stayed above freezing. No problems were encountered during the day. The scientific staff left the site having processed 90 ft (27.43 m) of core (recovery = 97.1%). Smooth coring continued into the early part of the night. For the 24-hr period of 8 November, recovery was 87.45 ft (26.65 m) from 90 ft drilled (27.43 m; recovery = 97%; 1370–1460 ft [417.58–445.01 m]).

Conditions deteriorated through the night, with temperatures dropping to 22°F and severe wind chills of ~11°F. The drillers tried to keep operations going, running water to keep the lines unfrozen, and managed to pull three cores between 0000 and 0900 hr on Runs 169 (1460–1470 ft; 445.01–448.06 m), 170 (1470–1480 ft; 448.06–451.10 m), and 171 (1480–1490 ft; 451.10–454.15 m). Recovery on Runs 168–170 (7.9, 5.1, and 6.2 ft; 2.41, 1.55, and 1.89 m, respectively) was hampered by variable lithologies, including indurated zones which blocked the core barrel at 1457.9 and 1476.2 ft (444.37 and 449.95 m); Run 171 had nearly full recovery. The cores drilled overnight were frozen solid by the time the science party arrived at 0600 hr but were partially thawed in the field trailer before description. Run 172 (1490–1500 ft; 454.15–457.20 m) drilled with variable pressures but returned an excellent core with 9.8 ft of recovery including a transition from organic-rich to organic-poor sediments and a sequence boundary at the top of a sand bed. A hard layer at 1507.5 ft (459.49 m) blocked Run 173 (1500–1510 ft; 457.20–460.25 m), recovering 7.5 ft (2.29 m).

Temperatures fell well below freezing over night. Any hose that did not have water running through it froze. In addition, the mud line and the mud pump pressure gauge froze, which meant that the drillers could not tell when the barrel blocked off during drilling. A total of 30 ft (9.14 m) of core was drilled in the night. We ended up with 40.1 ft (12.22 m) recovered from 60 ft (18.29 m) drilled on 9 November (recovery = 67% recovery) from 1460 to 1520 ft (445.01 to 463.30 m).

On 10 November, recovery overnight was poor (45% on Runs 175–177), reflecting freezing of the gauges and variations from clays to sands within runs. The drillers could not wash the drilling mud off of the cores that came up in the night but were able to circulate mud and drill. In the morning, the first core was up at 0745 hr. The drillers had to wait until the mud line thawed before they could remove the core from the inner core barrel. When the scientific staff arrived on site, the cores brought up overnight were frozen and had to be thawed before being processed. The National Guard Base asked the drillers to finish operations so that water could be turned off for the winter. Temperatures ameliorated during the day. Recovery was 6.4 ft (1.95 m) on Run 178 (1550–1560 ft; 472.44–475.49 m). Run 179 blocked off at ~8.5 ft (2.59 m; 1560–1568.5 ft [475.49–478.08 m]), penetrating the top of the Potomac Formation, which was the target of the hole. We were delighted to have achieved this because it was always unclear if it would be possible to penetrate the Potomac Formation here (log predictions varied from 1505 to 1540 ft [458.72 to 469.39 m]). We advised the drillers to advance at least another 20 ft (6.10 m) for logging. The evening shift drilled to 1590 ft by midnight, with excellent recovery. For 10 November, we recovered 45.65 ft (13.91 m) of core from 70 ft drilled (21.34 m; recovery = 65.2%). The night shift drilled and recovered the final core at 0439 hr on 11 November, reaching TD of 1600 ft (487.68 m).

Logging was conducted through the drill rods on 11 November with the Rutgers/DGS Century Geophysical Drawworks and the DGS Century Slimline Gamma Tool to ensure a gamma ray log of the complete hole in case the hole was lost before open-hole logging. A quick downhole run (60–70 ft/min; 18.29–21.34 m/min) was completed to 1598.6 ft (487.68 m). The log below 1590 ft (484.63 m), obtained when the tool passed through the drill bit into the open hole, has relatively elevated gamma ray values. On the slow run (30 ft/min; 9.14 m/min) in the uphole direction, the tool hung on the bottom of the bit, The tool was lowered, raised again, and successfully passed through the bit and core barrel, but the electrical connection to the tool was lost at 1441 ft (439.22 m). The tool was raised to the top of the hole, another rapid downhole run (60–70 ft/min; 18.29–21.34 m/min) was made to just above the top of the core barrel at 1593.7 ft (485.76 m), and then an uneventful slow (30 ft/min; 9.14 m/min) uphole run from 1593.7 ft (485.76 m) was made to the surface. The multitool would not pass below the HQ depths, so operations in the hole were ended. After removing the rods, the hole was plugged and abandoned.

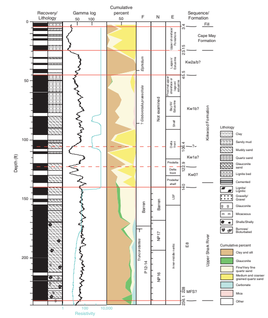
At Sea Girt, we recovered 1215.76 ft (370.56 m) from TD of 1600 ft (487.68 m) drilled and achieved a recovery of 77.9% (median recovery = 86%). Lithologies were described onsite and subsequently at the Rutgers core facility. These descriptions form the basis for the preliminary lithologic descriptions. Cores were cut into 2-ft (0.61 m) sections, labeled at the top and bottom of each section, placed into split PVC pipe (3-in diameter), wrapped in plastic sheeting, and stored in 2-ft (0.61 m) NQ wax boxes. A total of 168 core boxes were moved to permanent storage at the Rutgers University core library for further study. Cores were sampled at ~5-ft (1.52 m) intervals for planktonic foraminiferal, calcareous nannofossil, palynology, dinocyst, and diatom biostratigraphy and coarse-fraction lithologic studies at the Rutgers core library.

LITHOSTRATIGRAPHY

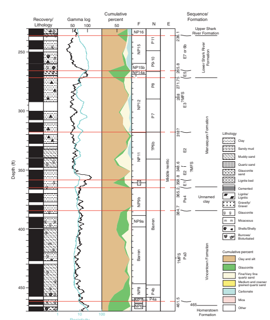
The onsite scientific team provided preliminary descriptions of sedimentary textures, structures, colors, fossil content, identification of lithostratigraphic units (NJGS Information Circular 1, 1990), and lithologic contacts (Table T1; Figs. F2, F3, F4, F5, F6, F7, F8). Subsequent studies integrated preliminary descriptions with additional descriptions, biostratigraphy, biofacies studies, isotopic stratigraphy, and the gamma ray log (Table T1; Figs. F2, F3, F4, F5, F6, F7, F8). Unconformities were identified on the basis of physical stratigraphy, including ir-

T1. Core descriptions, p. 83.

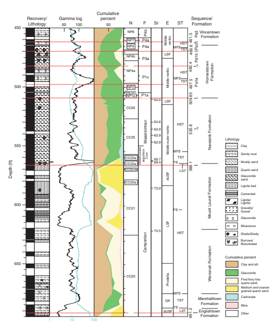
F2. Stratigraphic section, Cape May Formation, p. 66.



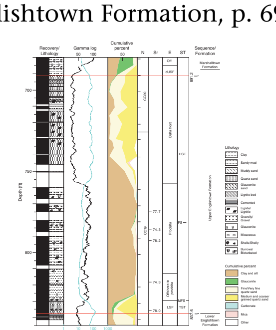
F3. Stratigraphic section, lower Shark River Formation, p. 67.



F4. Stratigraphic section, Hornerstown Formation, p. 68.



F5. Stratigraphic section, upper Englishtown Formation, p. 69.



regular contacts, reworking, bioturbation, major facies changes, gamma ray peaks, and paraconformities inferred from biostratigraphic breaks. For the marine sections, benthic foraminiferal biofacies (e.g., Fig. F9) and lithofacies were used to infer paleoenvironments. For the nonmarine and nearshore sections (primarily the upper Miocene and younger section and Magothy and Potomac Formations), lithofacies interpretations provide the primary means of recognizing unconformities and interpreting paleoenvironments. Examples of the various lithofacies are given in Figures F10, F11, F12, F13, F14, F15, and F16; full photographs of all cores are given in the visual core descriptions (see the "Appendix").

Cumulative percent plots of the sediments in the cores were computed from samples washed for paleontological analysis (Table T2; Figs. F2, F3, F4, F5, F6, F7, F8). Each sample was dried and weighed before washing and the dry weight was used to compute the percentage of sand. This differs from the method used in previous New Jersey coastal plain cores (Bass River, Island Beach, Atlantic City, and Cape May) in which the samples were not dried before washing.

Fill

Age: recent
Interval: 1.3–3.4 ft (0.40–1.04 m)

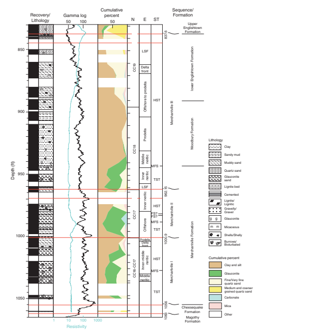
Pebbly gray sand with asphalt (1.3 ft; 0.40 m) occurs from 1.3 to 3.4 ft (0.40 to 1.04 m) and represents modern fill.

?Cape May Formation

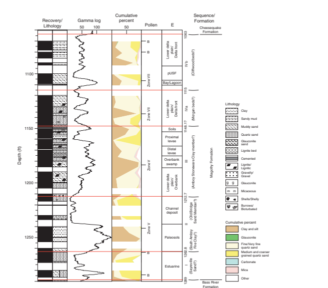
Age: ?Holocene–?Pleistocene
Interval: 3.4–23.15 ft (1.04–7.06 m)

The upper strata at Sea Girt are poorly dated (?Holocene–?Pleistocene) and have uncertain formational assignments, though the facies interpretations are clear (Fig. F2). A dark, organic-rich fine–medium sand from 3.4 to 3.9 ft (1.04 to 1.19 m) is interpreted as a paleosol. A sharp color change from dark brown to light brown silty fine–medium sands at 3.9 ft (1.19 m) probably represents a change within the soil horizon from O to A. Light brown paleosols continue to 6.6 ft (2.01 m). The soils probably formed in the current back dune environment. Below 6.6 ft (2.01 m), there is a change to better sorted, yellow-brown medium sands. Uniform, massive, medium sands continue to a thin (<0.1 ft; <3 cm) gravel layer at 14.6 ft (4.45 m). Bedding appears below this gravel layer with heavy mineral laminations and a "beachy" aspect. Another thin gravel layer (20.0–20.2 ft; 6.10–6.16 m) appears below a coring gap (15.5–20.0 ft; 4.72–6.10 m); this gravel may be caved. From 20.2 to 20.6 ft (6.16 to 6.28 m), slightly silty, medium- to coarse-grained quartz sands with ~1% opaque heavy minerals (ohms) coarsens downsection below 20.6–22.0 ft (6.28–6.71 m) to a medium–coarse sand with scattered pebbles and granules. From 22.0 to 22.1 ft (6.71 to 6.74 m) is a thin gravel. From 22.1 to 23.1 ft (6.74 to 7.04 m) is a gravely medium–coarse sand with heavy mineral laminations at 22.35 ft (6.81 m) and a heavily iron-stained section from 22.7 to 22.9 ft (6.92 to 6.98 m). From 22.9 to 23.15 ft (6.98 to 7.06 m) is a very coarse sand with abundant granules and pebbles (to 14 mm). The section fines upward from 22.1 to 23.15 ft (6.74 to 7.06 m). There is a sharp, irregular contact at 23.15 ft (7.06 m). The sediments

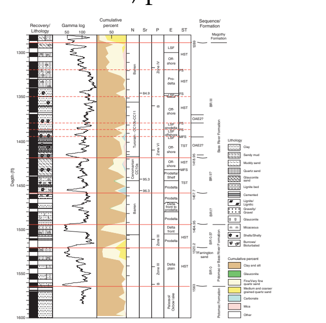
F6. Stratigraphic section, lower Englishtown Formation, p. 70.



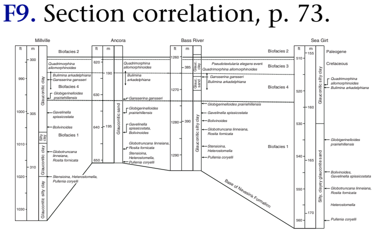
F7. Stratigraphic section, Magothy Formation, p. 71.



F8. Stratigraphic section, Bass River Formation, p. 72.



F9. Section correlation, p. 73.



from 6.6 to 23.15 ft (2.01 to 7.06 m) were deposited in a nearshore setting in upper shoreface to foreshore environments. The formational assignment of the ?Holocene–?Pleistocene sands and paleosols is unclear, though the paleosols are probably Holocene. In New Jersey, these surficial sediments are generally assigned to the Cape May 1 Formation (Newell et al., 2000).

Kirkwood Formation

Age: early Miocene
Interval: 23.15–140 ft (7.06–42.67 m)

A sharp surface at 23.15 ft (7.06 m) (Fig. F2) separates gravelly yellow-brown sands of the ?Cape May Formation from well sorted, micaceous, whitish gray fine sand (23.15–23.7 ft; 7.06–7.22 m). The white sands have sparse heavy mineral laminations and appear to be shoreface deposits. Fine sands with organic-rich and mica-rich laminae appear below this (23.7–24.2 ft; 7.22–7.38 m). It is unclear if these sands are in situ Kirkwood Formation, cryptically reworked Kirkwood lithology, or part of the Cape May Formation.

Below a coring gap (24.2–30 ft; 7.38–9.14 m), micaceous organic-rich clays with thin sandy silt laminations (30–31 ft; 9.14–9.45 m) appear in the cores. This section below 30 ft (9.14 m) is clearly assignable to the Kirkwood Formation and was deposited in lagoonal or lower estuarine environments (Fig. F2).

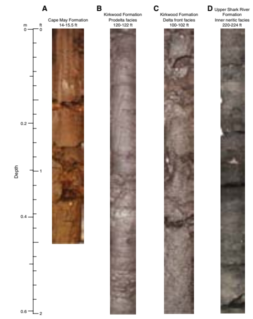
Uniform, tight, dark olive-green clays (35–42.3 ft; 10.67–12.89 m) appear below 31–35 ft (9.45–10.67 m). The clays have rare sand wisps at the top and traces of mica. The environment of deposition is not clear based on lithofacies interpretations. The presence of *Elphidium* sp. and the absence of other foraminiferal taxa at 36 ft (10.97 m) suggests a lagoonal/bay environment. The paucity of laminations, mica, shells, and lignite all argue against a prodelta environment. These clays compose a confining unit that may correlate with one of the Kw2 sequences of Sugarman et al. (1993) (Fig. F2).

A thin coarsening-upward section occurs from 42.0 to 45.5 ft (12.80 to 13.87 m). A very silty, very fine sand bed (42.0–42.5 ft; 12.80–12.95 m) overlies a very fine sandy, clayey silt (42.5–43.1 ft; 12.95–13.14 m), a coring gap (43.1–45.0 ft; 13.14–13.72 m), and a silty clay (45.0–45.5 ft; 13.72–13.87 m). This thin succession is probably also lagoonal–estuarine and thus genetically associated with the clays above (Fig. F2).

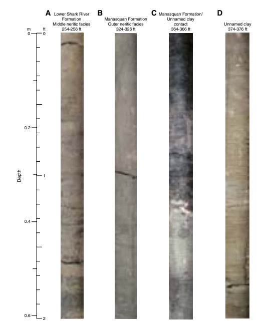
We tentatively interpret a sharp lithofacies shift from clays above to sands below at 45.5 ft (13.87 m) as a sequence boundary (Fig. F2). Sands are burrowed up to 0.3 ft (9 cm) above the sequence boundary. There is a gamma ray log minimum at 47–45 ft (14.33–13.72 m) and a gamma ray log increase at 45–38 ft (13.72–11.58 m), consistent with this interpretation.

Sands from 45.5 to 51.5 ft (13.87 to 15.70 m) are silty and very fine, laminated, have common ohm (5%–10%), and rare shells (44.5 ft; 13.56 m). A medium sand (51.5–51.7 ft; 15.70–15.76 m) overlies a dark, slightly silty micaceous clay bed (51.7–52.4 ft; 15.76–15.97 m). Structureless, slightly micaceous fine sands with common ohms return from 52.4 to 57.9 ft (15.97 to 17.65 m). A thin gravel at 57.9–58.1 ft (17.65–17.71 m) has large (as much as 2 cm) quartz pebbles, returning to fine sand from 58.1 to 63.6 ft (17.71 to 19.39 m), though the sands below are more organic rich and micaceous than above. The environment of the sands from 45.1 to 57.9 ft (13.75 to 17.65 m) could be either proxi-

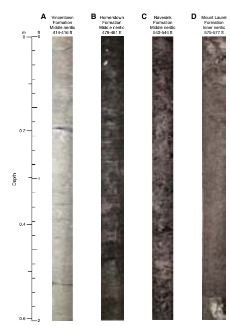
F10. Representative lithologies, Cape May Formation, p. 74.



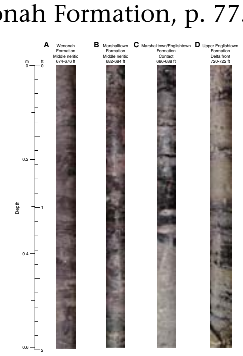
F11. Representative lithologies, lower Shark River Formation, p. 75.



F12. Representative lithologies, Vincetown Formation, p. 76.



F13. Representative lithologies, Wenonah Formation, p. 77.



mal upper shoreface or lagoonal–estuarine, though the association with rapid facies changes at ~51 and 58 ft (15.54 and 17.68 m) and the organic-rich sands below suggest the latter. The sands compose the HST of a sequence that probably correlates with the Kw1b sequence of Sugarman et al. (1993). A sample at 86.0 ft (26.21 m) contains planktonic foraminifers indicative of shelfal deposition, including *Globorotalia ?praescitula,* which suggests an age probably younger than 18.8 Ma (i.e., this sequence is equivalent to Kw1c or younger), although this cannot be said for certain. Considering regional correlations, including the presence of two distinct sand units at 100 and 110 ft (30.48 and 33.53 m) that are probably equivalent of the Atlantic City 800-foot sand (Kw1a and Kw1b), we favor correlation of this unit to the Kw1b sequence (~19–20 Ma) (Fig. F2).

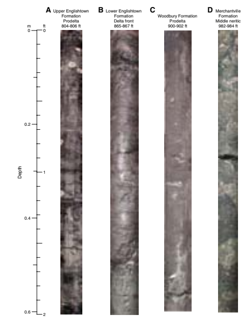
Beginning at 63.6 ft (19.39 m), the lithology becomes interbedded and interlaminated sand and sandy silt interpreted to represent bay fill/estuarine deposition (Fig. F2). The sands are micaceous and peaty. Lenticular beds at 76.3–76.7 ft (23.26–23.38 m) suggest tidal effects, consistent with the shallowest part of the bay fill. Below an unrecovered interval (76.7–80 ft; 23.38–24.38 m), micaceous silty fine sands (80–91.6 ft; 24.38–27.92 m) are heavily burrowed and appear to represent shelf deposits influenced by a delta. The environmental shift from shelf below to bay above does not appear to be associated with a sequence boundary, though there is a minor gamma ray log kick in the unrecovered interval between the bay fill above and shelf sands below. Instead, the shift appears to reflect a transition from maximum water depths at 80–90.2 ft (24.38–27.49 m) to HST bay fill above.

Another major facies change occurs at ~91 ft (27.74 m) (Fig. F2). From 91 to 96.5 ft (27.74 to 29.41 m), the lithology is interbedded fine sand and peaty clayey silt, with some minor coarse sand beds (e.g., 95.7–96 ft [29.17–29.26 m]). These sands are interpreted as delta front and are part of the TST. A coarse delta front sand (100–102.5 ft; 30.48–31.24 m) occurs below an unrecovered zone (96.5–100 ft; 29.41–30.48 m). Below this, from 102.5 to 106.4 ft (31.24 to 32.43 m), is an interbedded/interlaminated clayey silt and very fine–medium sand deposited in a delta front environment. A coarse–very coarse sand bed occurs from 106.4 to 106.9 ft (32.43 to 32.58 m). There is a possible sequence boundary at 106.4 ft (32.43 m); this could be facies shift, though a major log shift at 105 ft (32.00 m) indicates that it is a sequence boundary separating Kw1b from Kw1a (Fig. F2).

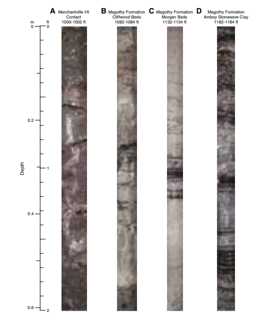
There is a return to interbedded silts and sands at the bottom of the run at 107.4 ft (32.74 m). From 110 to 111.2 ft (33.53 to 33.89 m), the interval is dominantly a massive coarse to very coarse sand deposited in a delta front; the sand might be thicker, but was not recovered to 120 ft. Gamma ray logs suggest a thick sand from ~105 to 112 ft (32.00 to 34.14 m) and a confining bed from 116 to 122.9 ft (37.46 m). From 120 to 122.9 ft (36.58 to 37.46 m), a micaceous, woody interbedded clay with silt and sand is present. This fine-grained unit comprises the base of a sequence; the sands from ~106.4 to 116 ft (32.43 to 35.36 m) may constitute a parasequence or the HST of a thin sequence.

A probable sequence boundary occurs at 122.9 ft (37.46 m) (Fig. F2), separating a prodelta silty clay above from a delta front medium–coarse sand (122.9–123.2 ft; 37.46–37.55 m) below. A silty, organic-rich, slightly micaceous delta front sand continues below (123.2–124.9 ft; 37.55–38.07 m). A thin layer of interbedded clay and sand returns in 124.9–125.4 ft (38.07–38.22 m), with a thin coarse-sand bed from 125.4 to 125.9 ft (38.22 to 38.37 m). The interval below this was lost, suggest-

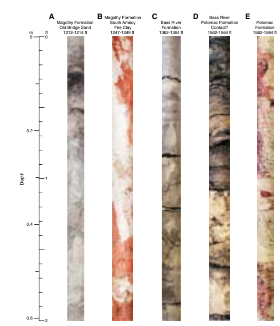
F14. Representative lithologies, upper Englishtown Formation, p. 78.



F15. Representative lithologies, Merchantville Formation, p. 79.



F16. Representative lithologies, Magothy Formation, p. 80.



T2. Cumulative percent plot data, p. 86.

ing the sand may be thicker. A thin coarse-sand bed from 130 to 130.6 ft (39.62 to 39.81 m) was present at the top of the next run. From 130.6 to 134.3 ft (39.81 to 40.93 m), brownish gray organic-rich interbedded silts and clays with thin sand laminae are present; these appear to be prodelta deposits. The coarser beds from 122.9 to 130.6 ft (37.46 to 39.81 m) comprise the upper HST sands, whereas the finer beds from 130.6 to 134.3 ft (39.81 to 40.93 m) comprise the lower HST of a sequence. From 134.4 to 136.3 ft (40.97 to 41.54 m), there are muddy sands, sandy muds, and a thin clayey silt at the base that appear to be shelfal. The unit from 134.4 to 136.6 ft (40.97 to 41.64 m) may comprise a TST; alternatively, there may be a sequence boundary at 134.4 ft (40.97 m) and the sands below could be the HST of an underlying sequence. The contact at 134.4 ft (40.97 m) is irregular, consistent with it being a sequence boundary. This sequence (122.9–134.3/136.3 ft; 37.46–40.93/41.54 m) may correlate to the Kw0 sequence of Miller et al. (1997).

Shark River Formation

Age: early, late, and middle Eocene
Interval: 140–271.75 ft (42.67–82.83 m)

The top of the Shark River Formation is placed in a coring gap (136.3–140.0 ft; 41.54–42.67 m) at the first downhole appearance of glauconite sand and a sharp gamma ray peak (~139 ft; 42.37 m) (Fig. F2). The top part of the Shark River Formation (140–155 ft; 42.67–47.24 m) is glauconitic (~5%), slightly micaceous, bioturbated clayey sand with fine, white sand–filled burrows. Clay increases downcore from muddy sand to a sandy clayey silt (155–167.5 ft; 47.24–51.05 m). A very slightly sandy clay (167.5–173 ft; 51.05–52.73 m) overlies a slightly sandy, slightly glauconitic clayey silt (173–200 ft; 52.73–60.96 m); there is no evidence that this facies shift from clay to silt represents a sequence boundary. There are no calcareous fossils from 140 to 169 ft (42.67 to 51.51 m); shells appear at 169 ft (51.51 m), where mica begins to decrease downsection. The slightly shelly clayey silt (173–200 ft; 52.73–60.96 m) overlies a laminated shelly/foraminiferal-rich, occasionally pyritic clay (200–220 ft; 60.96–67.06 m). The sands were deposited in lower shoreface environments. The presence of common gypsum crystals and sulfides on the core surface indicates shell dissolution. The finer clays and silts were deposited in an inner–middle neritic environment.

Glauconite increases from ~5% above 215 ft (65.53 m) to >20% below 220 ft (67.06 m). Very glauconitic sandy clay (220–228.1 ft; 67.06–69.52 m) overlies a heavily burrowed, glauconitic shelly clay (228.1–231.6 ft; 69.52–70.59 m); the contact between these two units (228.1 ft; 69.52 m) may be the MFS (i.e., there is little evidence that it is a sequence boundary and has no biostratigraphic break). Glauconite increases again downsection from 231.6 to 234.2 ft (70.59 to 71.38 m), becoming a clayey glauconite sand from 234.2 to 236.1 ft (71.38 to 71.96 m). A sharp lithologic change occurs at 236.1 ft (71.96 m) to a hard, slightly glauconitic ash-colored clay below (236.1–255.5 ft; 71.96–77.88 m); this contact is heavily burrowed and is a sequence boundary that marks the top of the lower Shark River Formation (Figs. F2, F3). It is associated with a biostratigraphic break from Zone NP16 above to NP15 below (Fig. F3; see "Calcareous Nannofossils," p. 52). Scattered shells are found throughout the interval from 169 to 236.1 ft (51.51 to 71.96 m). The glauconitic clays from 220 to 236.1 ft (67.06 to 71.96 m) were deposited in inner–middle neritic environments. The sequence from 140 to 236.1 ft (42.67 to 71.96 m) correlates with Sequence E8 of Browning et al. (1997) and is assigned to the upper Shark River Formation. The sandy bed at the top (140–167.5 ft; 42.67–51.05 m) may correlate with the Toms River Member.

The hard, foraminiferal-rich, slightly glauconitic, very slightly sandy, laminated clay continues below a coring gap (2236.50–240 ft; 72.09–73.15) to 255.5 ft (77.88 m). Glauconite increases from <5% to ~10% below 255.5 ft (77.88 m) and is mostly concentrated in burrows. The cores are indurated from 250 to 260 ft (76.20 to 79.25 m), with intervals of porcellanitic clay. Glauconite increases below 261 ft (79.55 m); by 263 ft (80.16 m), the section is a glauconitic sand with numerous large clay burrows. A surface at 265.8 ft (81.02 m) with small (as much as 10 mm) indurated clay clasts separates the clayey, heavily burrowed glauconite sand above from a more massive glauconite sand with sparse burrows below. A major biostratigraphic break occurs between 261 ft (79.55 m; Subzone NP15b) and 266 ft (81.08 m; Subzone NP14a). Therefore, we interpret the surface at 265.8 ft (81.02 m) as a sequence boundary separating Sequence E7 above from Sequence E5 of Browning et al. (1997) below (Fig. F3); Sequence E6 does not appear to be represented at Sea Girt.

Glauconite sand below the contact at 265.8 ft (81.02 m) grades downward to a clayey glauconite sand at 268 ft (81.69 m). A large (355 mm) brown clay clast occurs at 269.2–269.3 ft (82.05–82.08 m). Clayey glauconite sand continues downward to a major irregular erosional contact at 271.75 ft (82.83 m). This contact is a sequence boundary separating Subzone NP14a and Sequence E5 of Browning et al. (1997) from a slightly glauconitic clay, Zone NP12, and Sequence E3, below (Fig. F3). Sequence E4 does not appear to be represented at Sea Girt.

Manasquan Formation

Age: early Eocene
Interval: 271.75–365.2 ft (82.83–111.31 m)

Uniform slightly glauconitic clay (ash-colored "marls") assigned to the Manasquan Formation appear below the sequence boundary at 271.75 ft (82.83 m) (Fig. F3). The Manasquan Formation at Sea Girt is predominantly a slightly calcareous to calcareous silty clay to clay (marl) with varying abundances of quartz (1%–40%) and glauconite (0%–12%, except for two distinct beds) sands with porcellanitic intervals (279.4, 285.2–285.6, 288.3–283.5, 290.7, 291.55–292, 305–305.8, 307.3, 307.5–307.7, 323, and 325.5–326 ft; 85.16, 86.93–87.05, 87.87–86.41, 88.61, 88.86–89.00, 92.96–93.21, 93.67, 93.73–93.79, 98.45, and 99.21–99.36 m).

There is burrowing of common glauconite below the sequence boundary at 271.75 ft (82.83 m) to ~275 ft (83.82 m), with glauconite from the base of the Shark River Formation burrowed into the ash marl of the Manasquan Formation. Large shells occur at the sequence boundary to 1 ft (0.30 m) below.

The upper part of the Manasquan Formation to 285 ft (86.87 m) is slightly sandy (20% quartz), with low amounts of carbonate, particularly in the sand-sized fraction (Fig. F3). There are some silty and scattered very fine sand laminae and interbeds. We interpret this as the upper part of the HST.

There is a heavily burrowed zone at 288 ft (87.78 m) associated with a peak in clay content (288–290.5 ft; 87.78–88.54 m). Quartz sand content increases below a coring gap (300–311 ft [91.44–94.79 m]; ~20%–35%), suggesting deepening up to this level. The surface at 288 ft (87.78 m) is thus interpreted as a flooding surface, possibly a MFS (Fig. F3).

Quartz sand decreases below 311 ft (94.79 m) to 318 ft (96.93 m), where there is a coring gap overlying a tight clay (320–324 ft; 97.54–98.76 m). We tentatively place a sequence boundary in the coring gap, which is also a break from nannofossil Zone NP12 above 316 ft (96.32 m) and Zone NP11 below 321 ft (97.84 m), separating Sequence E3 above from E2 below (Fig. F3).

Quartz sand increases downsection from 324 ft (98.76 m) to a tight clay (330–333 ft; 100.58–101.50 m). Quartz sand and glauconite increase again downsection below 333 ft (101.50 m). From 340 to 346.8 ft (103.63 to 105.70 m), the beds are greenish gray (1%–4% glauconite sand) and laminated, with clay and silt toward the top and silt and very fine sand (as much as 41%) toward the bottom of this interval, with sand concentrated in small bacilliform burrows. A heavily burrowed irregular contact (3–5 cm relief) at 348.6 ft (106.25 m) separates sandy clayey silt above from tight clay below (348.6–357.6 ft; 106.25–109.00 m). We initially placed a sequence boundary at 348.6 ft (106.25 m). This contact occurs within Sequence E2 based on the assignment of the section to 356 ft (108.51 m) to Zone NP11. Alternatively, this burrowed surface may be a MFS of Sequence E2.

Glauconite appears in burrows at 357.6 ft (109.00 m) and increases to 80% at 358.8 ft (109.36 m). A contact at 358.8 ft (109.36 m) separates glauconitic clay above from clayey glauconite sand below, with burrows ~0.3 ft (9 cm) from the contact. Nannofossil biostratigraphy suggests that the section above 356 ft (108.51 m) correlates to Sequence E2. This further suggests that the contact at 358.8 ft (109.36 m) is a sequence boundary separating Sequence E2 above from E1 below (Fig. F3). Further study is needed to evaluate the significance of surfaces at 348.6 ft (106.25 m) and 358.8 ft (109.36 m) and the correlation of the section from 348.6 to 365.2 5 ft (106.25 to 111.31 m).

The glauconite sand continues to an irregular contact at 365.2 ft (111.31 m) that is a clear sequence boundary (Fig. F3). At the boundary is a layer of phosphate and a small amount of fine quartz sand. The glauconite sand was burrowed ~0.7 ft (21 cm) in distinct burrows; there was also a rip-up clast of the clay from below. This sequence boundary separates Sequence E1 above from an unnamed clay and sequence below.

Unnamed Clay

Age: earliest Eocene
Interval: 365.2–384.7 ft (111.31–117.26 m)

A clay appears below a spectacular sequence boundary at 365.2 ft (111.31 m) (Fig. F11). Below the burrowed contact zone (365.2–365.9 ft; 111.31–111.53 m), the section consists of a dark greenish gray clay to 366.65 ft (111.75 m), turning into a brown to progressively reddish brown clay 370–377.15 ft (112.78–114.96 m). Greenish clay returns from 380–384.7 ft (115.82–117.26 m), where there is a burrowed surface. At the contact are pyrite nodules and possible phosphate pellets; 0.1 ft (3 cm) above is a rip-up clast. Burrows extend ~1 ft (0.30 m) below the contact. The lithology changes from clay above the surface to a glauconitic

(10%–20%) sandy silty clay to 384.7 ft (117.26 m). Glauconite concentration is higher in burrows toward the base of this interval. The silty clay is more similar to the downdip Vincentown Formation of Owens et al. (1997) than the clay above, which is a unique lithologic unit associated with the PETM (Cramer et al., 1999). We assign this PETM clay above 384.7 ft (117.26 m) as an "unnamed clay," though we have previously termed them "Vincentown equivalent" (see **Miller et al.,** this volume) (Fig. **F3**). It comprises a distinct sequence here at Sea Girt that we term Pa4 (i.e., immediately above Sequence Pa3 of Liu et al. [1997]). The clays to clayey silts below the 384.7 ft (117.26 m) sequence boundary are assigned to the Vincentown Formation sensu Owens et al. (1997) and **Miller et al.** (this volume).

Vincentown Formation

Age: late Paleocene
Interval: 384.7–465 ft (117.26–141.73 m)

Uniform, slightly micaceous, slightly sandy, clayey silts occur from 384.7 to 420 ft (117.26 to 128.02 m). The silts appear to be finely laminated (1–2 cm scale, though the laminations are broken by bioturbation). Glauconite is common to abundant from 384.7 to 401 ft (117.26 to 122.22 m); total sand-sized fraction is ~40% in this interval. This sandier section from 384.7 to 401 ft (117.26 to 122.22 m) is the upper part of the HST. The section fines downward from a slightly sandy, slightly glauconitic micaceous clayey silt (401–420 ft; 122.22–128.02 m) to a massive to finely (1–2 mm scale) laminated, slightly micaceous, slightly glauconitic silty clay with only a trace of quartz sand from 420 to 430 ft (128.02 to 131.06 m). Two large brown nodules (421.8 and 426.9 ft; 128.56 and 130.12 m) may represent replaced shell material (equivalent of the *G. dissimilis* bed?) that may mark the MFS (Fig. **F3**).

Silty clays to clayey silts continue from 430 to 452 ft (131.06 to 137.77 m). Glauconite increases from generally <5% from 411 to 443 ft (125.27 to 135.03 m) to >10% at 445 ft (135.64 m). Small, thin shells appear at 452 ft (137.77 m) and persist to 461.5 ft (140.67 m). A carbonate concretion occurs at 454.7 ft (138.59 m). Slightly micaceous glauconitic clay continues from 452 ft (137.77 m), with glauconite increasing downsection, to a clayey glauconite sand at 456 ft (138.99 m). Large *Thalassinoides* burrows appear downsection at 460 ft (140.21 m). From 456 to 461.5 ft (138.99 to 140.67 m), the lithology is a silty, slightly clayey glauconite sand. There is an irregular contact between 461.3 and 461.5 ft (140.60 and 140.67 m). We interpret this as a sequence boundary at 461.5 ft (140.67 m), separating a glauconite sand above from a glauconitic sandy clay below (Fig. **F3**). This is probably the base of Sequence Pa3 of Liu et al. (1997). Glauconitic sandy clay (461.5–465 ft; 140.67–141.73 m) at the top of the underlying sequence becomes more glauconitic from 463.5 to 465 ft (141.27 to 141.73 m; Zone P3) and changes to >50% glauconite at 465 ft (141.73 m), where we place the top of the Hornerstown Formation.

The base of the Vincentown Formation has been defined in various ways. Based on Owens et al. (1988), the base of the Vincentown Formation would be placed at the contact of the glauconite sand with the glauconitic clay at the base of the sequence (461.5 ft; 140.67 m). It could be placed at the first place downsection where glauconite exceeds 50% (455 ft; 138.68 m) or where glauconite consistently remains >50%

(465 ft; 141.73 m). We use the latter as the definition of the base (Figs. **F3, F4**).

Hornerstown Formation

Age: early to earliest late Paleocene
Interval: 465–499.6 ft (141.73–152.28 m)

The sequence (461.5–469.8 ft; 140.67–143.20 m) that spans the Vincentown/Hornerstown Formational boundary is heavily bioturbated with numerous clay-lined burrows concentrated from 463 to 466.2 ft (141.12 to 142.10 m). Glauconite sand continues to comprise >50% to 469.8 ft (143.20 m). Scattered brachiopod shells (*Oleneothyris* and other taxa) appear at 467 ft (142.34 m), becoming more common downcore to a brachiopod-rich shell hash from 469 to 469.8 ft (142.95 to 143.20 m). We tentatively place a MFS at ~467 ft (142.34 m) at a gamma ray log peak (Fig. **F4**). We place a sequence boundary at 469.8 ft (134.20 m) separating the glauconitic shell hash above from silty, clayey, very quartzose glauconitic sand below. The sequence boundary is associated with a gamma ray log increase (Fig. **F4**). This sequence boundary separates Sequence Pa2 of Liu et al. (1997) from Sequence Pa1 below, as supported by nannofossil assignment of 466 ft (142.04 m) to Zone NP6 and 471 ft (143.56 m) to Zone NP4. Sandy upper HST facies are absent, with a clayey HST and glauconitic TST, both deposited in a middle neritic environment.

The interval from 469.8 to 474.3 ft (143.20 to 144.57 m) is composed of silty, very glauconitic, very fine to fine quartz sand (Fig. **F4**) with some glauconitic clay interbeds. There are thin shell hashes (?oysters) from 472.8 to 473.0 and 473.6 to 473.7 ft (144.11 to 144.57 and 144.35 to 144.38 m). Large oyster shells occur at 476.3 and 476.6–476.7 ft (145.18 and 145.27–145.30 m). These sands may have been deposited within a storm wave base and represent lower shoreface environments. Glauconite increases from 475.0 to 476.6 ft (144.78 to 145.27 m) to >50%; this glauconite-quartz sand (476.6–478.1 ft; 145.27–145.27 m) was deposited in offshore (middle neritic, based on benthic foraminifers) environments. A possible MFS occurs at a gamma ray log peak at ~475 ft (144.78 m). There is a lithologic change at 478.1 ft (145.27 m), with silty glauconite-quartz sand overlying a slightly micaceous glauconitic sandy silt (478.1–480.0 ft; 145.78–146.30 m) also deposited in middle neritic environments (on the basis of benthic foraminifers; see **"Benthic Foraminifers,"** p. 50). Glauconite increases downsection from 480 to 481 ft (146.30 to 146.61 m), where glauconite sand returns and continues to 482.4 ft (147.04 m) and a possible sequence boundary (hard zone, pyrite nodule, and lithofacies shift). Foraminiferal biostratigraphic data indicate a break from Subzone P3a to P1c below, though nannofossil data indicate that this boundary occurs within Subzone NP4a. The sequence from 469.8 to 482.4 ft (143.20 to 147.04 m) correlates with Sequence Pa1 partim of Liu et al. (1997) and is designated Sequence Pa1b here.

Micaceous interbedded glauconitic silty clay and clayey silts with sand burrows continue from 482.4 to 495.2 ft (147.04 to 150.94 m), becoming slightly clayier below 493 ft (150.27 m). This level may be a MFS (Fig. **F4**). These silts and clays may represent prodelta environments, probably deposited in outer inner to middle neritic paleodepths (sparse benthic assemblage with *Gavelinella, Cibicidoides, Bulimina,* and no plankton). There is a coring gap from 495.2 to 500.0 ft (150.94 to

152.40 m) associated with a large gamma ray log kick and a biostratigraphic gap from Zone NP2 below to Subzone NP4a above. This is clearly a major hiatus and unconformity (497.5 ft [151.64 m] on Fig. **F4**). A sample from 494.7 ft (150.78 m) has high glauconite (>50%) because of burrowing from below. The sequence from 482.4 to 497.5 ft (147.04 to 151.64 m) correlates with Sequence Pa1 partim of Liu et al. (1997) and is designated Sequence Pa1a here.

The base of the Hornerstown Formation at Sea Girt from 500.0 to 509.65 ft (152.40 to 155.34 m) is a heavily bioturbated, dark black, clayey silty glauconite sand with sporadic thin clay laminae and traces of mica. The section becomes clayier toward the base. The environment of deposition of this thin sequence was probably middle neritic. The base of this sequence (Subzone P1a) appears to be older than Sequence Pa1 (Subzone P1c, partim) of Liu et al. (1997) and we named it Sequence Pa1a (Subzone NP1a through Zone NP2 and Subzone P1a).

Navesink Formation

Age: late Maastrichtian
Interval: 509.65–565.1 ft (155.34–172.21 m)

The interval from 500 to 519 ft (152.40 to 158.19 m) is a black, silty glauconite sand, with glauconite varying from ~50% to 75% (Fig. **F4**). It is difficult to differentiate the Hornerstown Formation (glauconite sand) from the Navesink Formation (clayey glauconite sand) at Sea Girt because the Red Bank Formation that is present at outcrop is not represented because of a facies change. We place the base of the Hornerstown Formation at the base of a friable sand (509.65 ft; 155.34 m) overlying a thin (509.65–510.0 ft; 155.34–155.45 m) glauconitic clay. The sand has lithic fragments of apparently Cretaceous chalk with glauconite grains; this may be the equivalent to the clay clast unit overlying the K/T boundary at Bass River (Olsson et al., 1997). The clay is overlain by Tertiary strata of Subzone P1a (509 ft [155.14 m]; *Eoglobigerina eobulloides* and reworked Cretaceous species); samples at 509.5 and 510 ft (155.3 and 155.45 m) appear to be Upper Cretaceous based on the absence of Tertiary planktonic foraminiferal species and the presence of Cretaceous taxa. Thick shell fragments appear at 510.1 ft (155.48 m), suggesting assignment to the Navesink Formation.

The upper part of the Navesink Formation (509.65–514.75 ft; 155.34–156.90 m) consists of a black, clayey, silty, slightly micaceous, massively burrowed glauconite sand. It weathers to very dark greenish gray and contains sandier intervals that are generally lighter green and richer in sulfur and gypsum (509.5–509.65, 511.1–511.15, 511.5–511.6, 512.2–512.3, 512.6–512.7, 512.8–512.9, and 513–513.55 ft; 155.30–155.34, 155.78–155.80, 155.91–155.94, 156.12–156.15, 156.24–156.27, 156.30–156.30, and 156.36–156.53 m), clayier intervals (509.65–510; 155.34–155.45 m), and intervals where these two lithologies appear to be burrowed together. The depositional environment of this section is interpreted as offshore interfingering with lower shoreface.

The section below 514.75 ft (156.90 m) is a clayey, silty, glauconite sand. Shells occur from 517.1 to 519.9 ft (157.61 to 158.47 m) and at 519.3 ft (158.28 m) and increase downsection below 529 ft (161.24 m) to a peak at 555 ft (169.16 m). Pyritized, slightly, sandier burrows with lighter green glauconite occur at 517.5–517.7, 518.6, 519.5, 531.1, and 531.4 ft (157.73–157.79, 158.07, 158.34, 161.88, and161.97 m). Clay increases downsection from 522 to 524 ft (159.11 to 159.72 m) with more visible burrows. The section contains light gray clay (more carbonate) bioturbated with glauconite sand from 522 to 524, 529.2 to 530, and 531.6 to 533.0 ft (159.11 to 159.72, 161.3 to 161.54, and 162.03 to 162.46 m). The section from 532.8.0 to 535.8 ft (162.40 to 163.31 m) is similar to above but has slightly higher glauconite and is darker (black vs. dark gray) and more friable when dried. A contact at 532.8 ft (162.40 m) is distinct but does not appear to be a sequence boundary. There is another lithologic contact at the base of this sandier interval at 535.8 ft (163.31 m), separating the sandier zone from intensely burrowed silty glauconite sand with more common interbedded light gray clay; this may represent a sequence boundary (Fig. **F4**). The sandier bed is associated with a gamma ray increase at its base and a minimum at its top. If there is a sequence boundary between 532.8 ft (162.40 m) and 535.8 ft (163.31 m), it would be equivalent to the Navesink I/II contact postulated by Miller et al. (2004).

This interbedded glauconite silty sand and carbonate clay facies is typical of the deepest water Navesink marls and were deposited in deeper shelf environments (middle–outer neritic). There is little mica in this interval. An interval with higher glauconite sand (550–551.1 ft; 167.64–167.98 m) is associated with a gamma ray increase. This is not noted in the cumulative percentage on Figure **F4** because it is between samples. Quartz sand disappears below 550 ft (167.64 m). Carbonate increases downsection from 535.8 ft (163.31 m) to a maximum at 555 ft (169.16 m), which may represent the MFS (middle–outer neritic; ~60–100 m paleowater depth) and a regressive section above. The carbonate-rich glauconite silty sand becomes slightly clayier from 564 to 565.1 ft (171.91 to 172.24 m), where there is a contact zone from 565.1 to 566.2 ft (172.24 to 172.58 m) in which the glauconite clays of the Navesink Formation are mixed together with the quartz sands of the Mount Laurel Formation.

Mount Laurel Formation

Age: late Campanian
Interval: 565.1–621 ft (172.24–189.28 m)

The contact with the Navesink and Mount Laurel Formations (Fig. **F4**) is a zone between 565.1 and 566.12 ft (172.24 and 172.55 m) that includes large oyster shells and phosphate layers at 565.15 and 566.15 ft (172.26 and 172.56 m). The zone compares well with that reported from the Route 34 Matawan, New Jersey, outcrops (Miller et al., 2004) and consists of

1. An interval of large oyster shells that appear to be partially replaced/diagenetically altered associated with the upper phosphate bed and deposited on a very starved shelf, probably in ~35–50 m paleodepths;
2. Clayey sands with large, fresh-looking oyster shells (565.25–565.6 ft; 172.29–172.39 m) that appear to represent in situ middle shelf environments (?30 m paleodepths);
3. A heterolithic interval (565.6–566.15 ft; 172.39–172.56 m) containing a variety of clasts, clays, and sands (quartz and glauconite sand). Clasts include sideritic partially cemented Mount Laurel lithology and calcarenitic clasts of carbonate-cemented Mount Laurel sand. We interpret this reworked zone as the up-

per part of the regressive LST deposited in nearshore environments; and

4. The lower phosphate bed (565.15–565.2 ft; 172.26–172.27 m) occurs at the base; this again must have been deposited in starved middle shelf environments and is interpreted as the lower part of the LST.

Below the contact, the Mount Laurel Formation consists of medium- to coarse-grained muddy quartz sand (565.2–585.2 ft; 172.27–178.37 m) that fines downsection. The sand is slightly glauconitic, has traces of large mica flakes, contains carbonate (probably largely as foraminifers), and is heavily bioturbated, yielding a mottled texture. From 575 to 577.9 ft (175.26 to 176.14 m), the formation is finer grained, primarily medium sand. Clay-lined burrows appear in the medium sands at 581.2 ft (177.15 m). The sands are indurated from 583.1 to 583.9 ft (177.73 to 176.97 m). This section was deposited in distal upper shoreface environments. From 583.2 to 590 ft (177.76 to 179.83 m), the sand becomes finer and large mica flakes appear, as well as silt interbeds. Scattered shells occur at 585–587 ft (178.31–178.92 m) with numerous clay-filled burrows. This interval was deposited in lower shoreface environments and is transitional to the Wenonah Formation.

Silty, fine, micaceous bioturbated sands and interbedded clayey silts (590–600 ft; 179.83–182.88 m) could be placed in either the Wenonah or Mount Laurel Formation; we follow the convention of Miller, Sugarman, Browning, et al. (1998) in placing the top of the Wenonah Formation at a level where sand is <50% (Fig. **F4**). From 600 to 602.35 ft (182.88 to 183.60 m), the lithology is an interbedded clayey, silty, very fine sand with slightly glauconitic, micaceous, woody medium quartz sand. These finer grained units were deposited in lower shoreface environments. There is a slightly irregular contact at 605.1 ft (184.43 m), associated with a gamma ray log increase; it lacks obvious rip-up clasts, heavy bioturbation, and other characteristics of a sequence boundary. Therefore, we interpret this as a flooding surface.

The lithology is sandier from 605.1 to 610 ft (184.43 to 185.93 m). It is mostly slightly glauconitic fine sand with interbeds of darker clay. The sand is coarser from 610 to 614.8 ft (185.93 to 187.39 m), consisting of medium quartz sand interbedded with sand containing clayey silt laminae. The entire section from 605 to 614.8 ft (184.40 to 187.39 m) is interpreted as a lower shoreface.

These shoreface sediments may continue below a coring gap (614.8–620 ft; 187.39–188.98 m) to 621 ft (189.21 m). Below a contact at 621 ft (189.21 m), the lithology changes to interbedded micaceous, lignitic, clayey silt with very fine sand. We place the Wenonah contact at this level. The contact is gradational, with clay beds at 613.65–613.7 ft (187.04–187.06 m) and 620.7–620.8 ft (189.19–189.22 m).

Wenonah Formation

Age: late Campanian
Interval: 621–675.7 ft (189.28–205.95 m)

Micaceous, lignitic, sandy clayey silt with very fine sand laminations from 621 to 675.7 ft (189.28 to 205.95 m) is placed in the Wenonah Formation (Fig. **F4**). The Wenonah Formation at Sea Girt is coarser grained and has more sedimentary structures than at Ancora or Bass River, suggesting a shallower paleoenvironment (lower shoreface with a prodelta influence). Recovery in the Wenonah Formation was moderate (60%).

Micaceous, lignitic, clayey fine sand to silt with traces of glauconite from 621 to 650 ft (189.21 to 198.12 m) (Fig. **F4**) is dominated by physical structures including thin sand cross laminae (e.g., 625.3–625.4 ft [190.59–190.62 m]). The section is burrowed to heavily burrowed in places, with sand carried into burrows. Clay increases downsection in this interval. The section was deposited in lower shoreface environments, though shells are rare. Common mica and lignite indicate the proximity of a deltaic influence that dominates below 650 ft (198.12 m).

Micaceous clayey silts with scattered sand laminae and scattered pyrite nodules (650–671 ft; 198.12–204.52 m) are more laminated than above. The dominance of laminae over bioturbation with common lignite and mica suggest that these sediments were deposited in prodelta environments (Fig. **F4**). Scattered small shell fragments (660–671 ft; 201.17–204.52 m) and glauconite-rich sandy zones occur (665.5–671 ft; 202.84–204.52 m), suggesting offshore deposition influenced by a delta. Glauconite increases in micaceous silts (671–675.7 ft; 204.52–205.97 m), where there is a change to a very glauconitic (>30%) silt. We place the top of the Marshalltown Formation at this level.

Marshalltown Formation

Age: late Campanian
Interval: 675.7–687.2 ft (205.97–209.46 m)

The Marshalltown Formation (Fig. **F4**) consists of very glauconitic (~38%–53%), slightly quartzose, structureless to heavily burrowed silt and subordinate glauconite sand (675.7–687.2 ft; 205.95–209.46 m). Large, clay-lined brown burrows, rare thin scattered shell fragments, and pyrite nodules occur throughout the Marshalltown Formation. Several very large (as much as 0.5 ft [15 cm]) tan burrows occur at 677.5–679.5 ft (206.50–207.11 m). We tentatively place the MFS at 676 ft (206.04 m) near the top of a glauconite-rich interval where clay is at a maximum, quartz sand is absent, and there are rare carbonate shells. The Marshalltown Formation was deposited in environments deeper than inner neritic (i.e., middle–outer neritic) and represents the TST of the Marshalltown-Wenonah-Mount Laurel sequence. The Marshalltown Formation is less glauconitic and clayier at Sea Girt than in outcrop or at Ancora (~60% glauconite) and Bass River (~50% glauconite). The Marshalltown Formation is readily differentiable from the Wenonah Formation at Sea Girt by its high abundances of glauconite, smaller mica flakes, less sand, and green vs. brown color and its deeper water paleoenvironment.

Englishtown Formation

Age: middle–late Campanian
Interval: 687.2–891 ft (209.46–271.58m)

Upper Englishtown

Age: middle–late Campanian
Interval: 687.2–837.6 ft (209.46–255.30 m)

A contact at 687.2 ft (209.46 m) is very irregular with 0.1 ft (3 cm) of relief and separates micaceous, bioturbated, clayey, silty, fine-grained glauconite sand above from a thin (0.5 ft; 15 cm) brown clay below. This contact separates the Marshalltown Formation from the upper Englishtown Formation (Fig. **F5**). Glauconite is burrowed down to 687.25 ft (209.47 m). The section from 687.25 to 691.8 ft (209.47 to 210.86 m) consists of very micaceous, silty medium–fine quartz sand with numerous brown clay burrows that give the core a mottled aspect. Phosphate pellets occur at 690.4 and 691.2 ft (210.43 and 210.68 m), immediately above an irregular contact. The interval from 691.1 to 691.2 ft (210.65 to 210.68 m) contains clay (mud chip) rip-up clasts. A surface at 691.2–691.25 ft (210.68–210.68 m) is irregular and separates clayey, clast-rich sands above from classic delta front lignitic medium sands below. We interpret the succession as follows:

1. Delta front sands of the upper Englishtown Formation are separated by a sequence boundary at 691.2 ft (210.68 m) from sands above that are also assigned to the Englishtown Formation.
2. The sequence boundary is overlain by phosphate pellets and rip-up clasts.
3. The unit from 687.1 to 691.2 ft (209.43 to 210.68 m) is an LST sand. These sands are cannibalized from the Englishtown Formation and were redeposited in distal upper shoreface environments.
4. The surface at 687.1 ft (209.43 m) is the transgressive surface.

The Englishtown Formation, and particularly the upper Englishtown sequence, is greatly expanded at Sea Girt, where it is 149.9 ft (45.69 m) vs. 35 ft (10.67 m) at Ancora and 31.5 ft (9.60 m) at Bass River. Below the LST lag unit, the top of the Englishtown Formation (691.2–701.5 ft; 210.68–213.82 m) consists of fine- to medium-grained, micaceous sands with thin beds and laminae of sandy clayey silt and lignite. The sections are burrowed with obvious circular (10 mm diameter) clay-lined burrows. Occasional pyrite nodules are present. Some of the thin interbeds are dark silts; others are lighter brown clays. The lignite layers are ~0.1–0.2 ft (3–6 cm) thick. Below a nodule-rich layer (701.5 ft; 213.82 m), the section becomes finer grained to 710 ft (216.41 m); the lithology is similar to above, although the dark organic clay-silt beds predominate and sands are <20 cm thick. This appears to be a delta front deposit (Fig. **F5**).

Interbedded fine–medium sands and subsidiary sandy, silty clays (710–731 ft; 216.41–222.81 m) contain laminae to thin beds of lignite. There is a pebbly sand bed at 710.9–711 ft (216.68–216.71 m). Lignite occurs in laminae, cross laminae (e.g., 725–726 ft [220.98–221.28 m]), and in disseminated form; it increases in abundance in thicker beds downsection in this interval. The sands are occasionally iron-stained and there are nodule zones (e.g., 714.6–714.7 ft [217.81–217.84 m]). There are no clear channel structures (e.g., cut and fill or fining-upward successions) and no thick organic-rich beds; therefore, we interpret the depositional environment as delta front (Coleman, 1975; Owens and Gohn, 1985). The presence of nannofossils (see **"Calcareous Nannofossils,"** p. 52) indicates that these delta front facies were submarine.

There is a layer of angular clasts at 730.9–731 ft (222.78–222.81 m), with other clasts disseminated to ~746 ft (227.38 m). The clasts include a large (5 cm) piece of petrified wood; some appear to be purple clasts that are probably fragments of large concretions.

A minor facies change occurs below the angular clast layer, with the section from 731 to 750 ft (222.71 to 228.60 m) consisting of organic-rich (finely disseminated organic material) sands with abundant clay and lignite laminae. There also appear to be diagenetic concretions, burrows, and large mica flakes. Lignite increases below 736 ft (224.33 m). The interval from 740.5 to 745.1 ft (225.70 to 227.11 m) is predominantly sand with disseminated organic matter and may represent an interdistributary bar. Organic-rich sands return from 745.1 to 745.9 ft (227.11 to 227.35 m). These sands were deposited in a delta front environment (Fig. **F5**).

There is a coring gap from 745.9 to 760 ft (227.35 to 231.65 m), except for 0.6 ft (18 cm; placed arbitrarily at 750–750.6 ft [228.60–228.78 m]) of fragmented ironstone concretions and lignite. Thus, the contact between the upper sand facies and lower clay facies of the upper Englishtown sequence was lost in the interval, though logs suggest it should be placed at ~757 ft (230.73 m) (Fig. **F5**).

A silty clay upper Englishtown facies is found in the core beginning at ~760 ft (231.65 m; there is 0.1–0.2 ft [3–6 cm] of caved material at 760 ft [231.65 m]), where it consists of slightly micaceous interbedded and interlaminated silts and silty clays with occasional very fine sand laminae and sand-filled burrows. Thin shells appear at 764.9 ft (233.14 m), along with an increase in bioturbation. The laminated clays and silts are interpreted as prodelta deposits (Fig. **F5**).

There is a contact at 780.05 ft (237.76 m) separating laminated silty clay with wispy sand laminae from a slightly glauconitic clay. The glauconite is fine to very fine and concentrated in burrows. From 781.05 to 782.3 ft (238.06 to 238.45 m) there are numerous brown carbonate concretions (as long as 2.5 cm in longest dimension) that are replaced shell material. From 782.3 to 782.8 ft (238.45 to 238.60 m) is a bioturbated clay with few concretions, fine mica, and some silt. There is an irregular surface at 782.8 ft (238.60 m) with glauconite clay below that continues to 783.4 ft (238.78 m). A shell hash (including aragonitic shells) occurs at 783.3–783.5 ft (238.75–238.81 m). Another surface at 783.4 ft (238.78 m) is a very heavily bioturbated micaceous clay with scattered shells. A large concretion occurs at 783.6 ft (238.84 m) with additional concretions from 784.5 to 784.8 ft (239.12 to 239.21 m). Below this, there are few concretions. This interesting and complex interval (780.05–784.8 ft; 237.76–239.21 m) is probably a condensed section/flooding surface. The depth of the flooding surface probably should be placed at 782.8 ft (238.60 m), where there is a peak in glauconite and gamma ray log values (Fig. **F5**).

Below the glauconitic zone, the sediments return to micaceous interbedded and interlaminated silt and clay grading to clay below ~803.5 ft (244.91 m). The sediments are bioturbated with silts burrowed into clays; laminations are generally disrupted. Scattered shells occur throughout. There is an indurated shelly clay with carbonate cement at 787.0–787.1 ft (239.88–239.91 m). The clay from 803 to 828 ft (244.75 to 2552.37 m) is relatively uniform with scattered silt laminae, silt burrows, sulfur-rich burrows (812.2 ft; 247.56 m), and pyrite concretions (e.g., 813.0–813.1 ft [247.80–247.83 m]). If exposed in outcrop, this section would be identified as the Woodbury Formation. The clayey silts and clays comprise an excellent confining unit on top of the lower Englishtown Formation sands and were deposited in a distal prodelta environment, though the siltier sediments above ~803–810 ft (244.75–246.89 m) may have been deposited in more proximal prodelta environments (Fig. **F5**).

Abundant glauconite occurs in burrows from 824 to 825.7 ft (251.16 to 251.67 m), but there is less glauconite from 825.7 to 828.3 ft (251.67 to 252.47 m). The section becomes slightly siltier at 827–828.6 ft (252.07–252.56 m), with interlaminations of silty clay and clay deposited in distal prodelta environments.

The section from 828.6 to 829.7 ft (252.56 to 252.89 m) consists of micaceous silty clay with glauconite that was deposited in neritic environments with little deltaic influence. We place the MFS at 829 ft (252.68 m) (Fig. F5) at a maximum in glauconite and the top of a zone with concretions and brown clay.

The section from 829.7 to 832.2 ft (252.89 to 253.65 m) consists of glauconitic (~10%–15%) silty clay with burrows and laminae of slightly glauconitic (~5%) brown clay and indurated concretions. Silty, burrowed, glauconite quartz sand occurs from 832.2 to 834.8 ft (253.65 to 254.45 m). Common shells appear at 829.5 ft (252.83 m), and the section becomes very shelly with brown, indurated burrows and brown carbonate (?siderite) concretions from 834.8 to 836.5 ft (254.45 to 254.97 m). This zone has the appearance of a heterolithic interval, but the clasts are concretions, mostly after shell material. This interval also was deposited in lower shoreface environments. A glauconitic, silty quartz sand with shells (836.5–837.5 ft; 254.97–255.27 m) was deposited in lower shoreface environments. We interpret the facies from 829.7 to 837.5 ft (252.89 to 255.27 m) as part of the TST deposited in lower shoreface environments with reworked glauconite.

A thick indurated zone (837.6–839.1 ft; 255.30–255.76 m) marks a sequence boundary (Fig. F5). The top of the indurated zone has a few shells and glauconite; below ~838.1 ft (255.45 m), the section is a clean sandstone that overlies unlithified micaceous, slightly glauconitic quartz sands (839.1–841.5 ft; 255.76–256.46 m). We interpret the shells and glauconite at the top of the indurated zone as burrows and place the sequence boundary at the top of the sandstone (837.6 ft; 255.30 m); the interval from 837.5 to 837.7 ft (255.27 to 255.33 m) has quartz sand mixed from below and either is a mixing zone above the sequence boundary or the sequence boundary may be slightly higher (837.5 ft; 255.27 m). This sequence boundary separates the TST glauconite quartz sands of the upper Englishtown sequence from the upper HST aquifer sands of the lower Englishtown Formation that is part of the Merchantville–Woodbury–lower Englishtown sequence of Miller et al. (2004).

The expanded upper Englishtown sequence (150.4 ft; 45.84 m) was a major target of drilling at Sea Girt. Owens et al. (1998) first observed that the subsurface upper Englishtown sequence had a classic boxcar log pattern in northern Ocean and southern Monmouth counties, where the sequence is best developed. The logs show low values in the upper HST sands and a sharp change to high values in the lower HST silty clays and TST glauconite sands/glauconitic clays. Owens had planned to name this the Manchester sequence (J.P. Owens, pers. comm., 1992), though the name was never approved. Our studies at Sea Girt should provide better age control on this middle Campanian sequence and possibly allow recognition of additional sequences or parasequences within it. Our studies should also provide valuable information on aquifer potential for the upper Englishtown sands in this region.

Lower Englishtown

Age: middle Campanian
Interval: 837.6–891 ft (255.30–271.58 m)

Below the base of the sandstone (839.15 ft; 255.77 m) and a minor coring gap (839.15–840 ft; 255.77–256.03 m), the top of the lower Englishtown Formation consists of a heavily burrowed, silty, fine–medium slightly micaceous sand (Fig. F6). The sand contains finely disseminated lignite (840–841.8 ft; 256.03–256.58 m) that is lighter colored and more mottled than the section below, reflecting heavy bioturbation from the sequence boundary. Below this to 862 ft (262.74 m), is a very micaceous, heavily burrowed, silty, fine sand that is slightly fossiliferous. It represents deposition in a lower shoreface setting. There is a sharp facies change across an irregular surface at 861.9 ft (262.71 m) to interbedded and interlaminated, bioturbated, very micaceous (including chlorite), very fine silty sand and sandy silt with rare clay laminae and beds, common lignite laminations (e.g., 862–862.3 ft [262.74–262.83 m]), and scattered shells that continue 869.5 ft (265.02 m). These are interpreted as delta front deposits. The section fines below 869.5 ft (265.02 m) to homogenized, heavily bioturbated, sandy, slightly clayey, micaceous, slightly shelly silt. These silts were deposited in offshore environments slightly influenced by a delta (i.e., some laminated intervals might be prodelta to distal prodelta). The cores become increasingly finer grained downsection from 869.5 to 900 ft (265.02 to 274.32 m), becoming a shelly silty clay at ~891 ft (271.58 m), which is where the top of the Woodbury Formation is placed. The boundary between the lower Englishtown and the Woodbury Formations is gradational and was placed at a change from clayey silts to shelly silty clays; sand disappears between washed samples at 891 and 896 ft (271.58 and 273.10 m) and gamma ray log values increase at 890 ft (271.27 m), consistent with the placement of the formational boundary at ~891 ft (271.58 m). The lower Englishtown Formation comprises the upper HST of the sequence.

Woodbury Formation

Age: early–middle Campanian
Interval: 891–943.5 ft (271.58–287.43 m)

The Woodbury Formation is a micaceous silty clay to clay (Fig. F6). It contains scattered shells, pyrite, and gypsum on the core surface. The top of the formation is moderately to heavily burrowed and represents offshore environments. At ~904.5 ft (275.69 m), the clay changes from predominantly bioturbated to laminated and the section is predominantly laminated to 940 ft (286.51 m). Laminations are faint and many are broken by bioturbation. This laminated interval is probably a prodelta deposit. The section becomes more clay rich at 931 ft (283.77 m). Traces of glauconite appear at 916 ft (179.20 m) in the washed samples and reaches 1%–2% at 931 ft (283.77 m). Between 930 and 940 ft (283.46 and 286.51 m), the lithology becomes a clay with some silt that is less micaceous and has fine glauconite in burrows. Glauconite continues to increase to 943.7 ft (287.64 m), where the amount of glauconite exceeds 50%. The section from ~931 to 943.5 ft (283.77 to 287.58 m) was deposited in neritic environments (probably middle neritic). The Woodbury Formation at Sea Girt is thinner (52.5 ft; 16.00 m), less laminated, and lighter colored than at Bass River (160 ft; 48.77 m) and Ancora (100 ft; 30.48 m).

Merchantville Formation

Age: early Campanian to Santonian
Interval: from 943.5 to ~1056 ft (287.58 to 321.87 m)

The contact between the Merchantville and the Woodbury Formations is gradational and is placed at 943.5 ft (287.58 m), the depth where glauconite sand concentration is >50% (Fig. F6). We place a MFS at 943–944 ft (287.43–287.73 m) in a very clayey, gray (carbonate rich?), glauconite sand at a peak in glauconite, a minimum in quartz sand, and a peak in gamma ray values. The section from the MFS to 947.1 ft (288.68 m) is very heavily bioturbated ("churned") clayey, slightly quartzose glauconite sand. Below a coring gap (947.1–950 ft; 288.68–289.56 m), very fine quartz sand is more common to 955 ft (291.08 m) in clayey micaceous quartzose glauconite sands, with occasional sulfide-filled burrows. Mica is common throughout the upper Merchantville Formation at Sea Girt, but appears to peak at 950–952 ft (289.56–290.17 m). The section from 943.5 to 945 ft (287.58 to 288.04 m) was deposited in neritic (probably middle neritic) environments, and the section from 950 to 955.1 ft (289.56 to 291.11 m) was probably inner neritic based on common quartz sand. There is a coring gap from 955.1 to 960 ft (291.11 to 292.61 m).

From 960.0 to 964.4 ft (292.61 to 293.95 m) is a slightly micaceous glauconite sand with bicolored (green and brown) grains. From 960.4 to 960.9 ft (292.73 to 292.88 m) is an indurated glauconite sand with bicolored grains. From 960.9 to 962.1 ft (292.88 to 293.25 m) is a clayey, finely micaceous, slightly shelly, quartzose glauconite sand with bicolored glauconite. We interpret the section with bicolored glauconite (960–962.15 ft; 292.61–293.26 m) as lower shoreface with reworked glauconite (Fig. F6).

There is a burrowed contact at 962.15 ft (293.26 m) with an abrupt change in lithology from limonitic glauconite sand above to burrowed, micaceous, slightly shelly, sandy silt with sulfide burrows and virtually no glauconite below. This silt continues downward to a coring gap (964.5–974 ft; 293.98–2996.88 m) and was deposited in lower shoreface environments. The burrowed contact is irregular and has large (as much as 1 cm in diameter) vertical and horizontal burrows. We tentatively place a sequence boundary at the 962.15 ft (293.26 m) contact with glauconite burrowed to as much as 5 cm into the brown clay below, though the boundary lacks obvious rip-up clasts and gamma ray expression. Alternatively, it is possible that the sequence boundary occurs in a coring gap (964.5–974.0 ft; 293.98–296.88 m) associated with a large gamma ray kick. However, the sandy silt from 962.15 to 964.5 ft (293.26 to 293.98 m) is unusual in that it lacks glauconite and is best interpreted as the HST of the underlying sequence. There is a biostratigraphic break between Zones CC18 (961 ft [292.91 m] and above) and CC17 (964.4 ft [293.95 m]) (see "Calcareous Nannofossils," p. 52), consistent with a major sequence boundary at 962.15 ft (293.26 m).

The sequence from 837.7 to 962.15 ft (255.33 to 293.26 m) includes the lower Englishtown, Woodbury, and upper Merchantville Formations and is equivalent to the Merchantville III sequence of Miller et al. (2004). This sequence is restricted to Zones CC18 and CC19 at Sea Girt (see "Calcareous Nannofossils," p. 52), as it is at Ancora and Bass River

(Miller et al., 2004). A gamma ray log increase at ~970 ft (295.66 m) occurs in an interval of no recovery (964.4–974 ft; 293.95–296.88 m). It is possible that an unconformity could be associated with this kick (with implications to the age of the overlying sequence), though the micaceous clayey silts above and below the coring gap are similar and we favor placing a sequence boundary at 962.15 ft (293.26 m), as discussed above.

Below the coring gap, the interval from 974 to 979.9 ft (296.88 to 198.47 m) is similar to 962.15–964.5 ft (293.26–293.98 m), consisting of a micaceous, burrowed clayey silt with some dispersed shell fragments and a few intervals of pyrite nodules. At the top of this section (974–976 ft; 296.88–297.48 m), glauconite sand is found only in the silt fraction. Glauconite increases in size and abundance, mica decreases, and the section becomes less clayey downsection from 976 to 979.9 ft (297.48 to 298.67 m). The section from 962.15 to 979.9 ft (293.26 to 298.67 m) was deposited in an offshore, "dirty" inner neritic environment, perhaps influenced by a prodelta (Fig. **F6**).

A facies change occurs at 979.9 ft (298.67 m) from silty clay above to muddy glauconite sand that is intensely burrowed with cemented burrows. The cemented burrows are brown and have the false appearance of rip-up clasts. The glauconite is mostly dark green, with subordinate rusty brown glauconite grains. Burrows consist of rusty brown silty clay to clayey silt that has more carbonate than the surrounding section. From 982.5 to 983.2 ft (299.47 to 299.68 m) is a more homogenized rusty and green glauconite sand. Two burrowed surfaces at 982.5 and 983.2 ft (299.47 and 299.68 m) could be flooding surfaces (Fig. **F6**). The section becomes less burrowed and muddier from 983.2 to 988.4 ft (299.68 to 301.26 m), with burrows becoming smaller downsection. Another surface is present at a distinct horizon at 988.4 ft (301.26 m), separating very fine glauconite sand above from medium weathered glauconite sand below. We interpret the section from 979.9 to 988.4 ft (298.67 to 301.26 m) as a zone of maximum flooding associated with gamma ray log values, and tentatively place the MFS at 988.4 ft (301.26 m) at a gamma ray log peak (Fig. **F6**). The section from 979.9 to 988.4 ft (298.67 to 301.26 m) appears to shallow upward based on larger burrows upsection.

From 988.4 to 991 ft (301.26 to 302.06 m) is a coarser, medium-grained, bicolored, muddy glauconite sand. There is an indurated zone from 991 to 991.6 ft (302.06 to 302.24 m); this indurated zone is browner, coarser grained, and contains more bicolored glauconite and is interpreted as the shallowest paleodepths in this section. Spotty induration of a muddy, bicolored glauconite sand continues to 993.2 ft (302.73 m), with brown glauconite decreasing downsection. This interval is associated with low gamma ray and high resistivity values on the downhole logs (Fig. **F6**). Clayey, quartzose, heavily burrowed (with burrows to 10–15 mm), micaceous, fine, predominantly green glauconite sand occurs from 993.2 to 996.4 ft (302.73 to 303.70 m). The interval from 996.4 to 1000.9 ft (303.70 to 305.07 m) contains interbedded glauconitic sand and brown muddy glauconitic sand. We interpret the section from 988.4 to 1000.9 ft (301.26 to 305.07 m) as the TST (Fig. **F6**), though the section does not appear to uniformly deepen upsection. Rather, it appears to deepen upsection from 996 to 1000.9 ft (303.58 to 305.07 m), stay deep from 996 to 993.2 ft (303.58 to 302.73 m), shallows from 993.2 to 991.6 ft (302.73 to 302.24 m), and deepens upsection above this. Benthic foraminiferal biofacies data are needed to evaluate these paleodepths trends. One possibility to consider is that the section from 991.6 to 1000.9 ft (302.24 to 305.07 m) is actually a regressive LST. There is a major sequence and facies shift at 1000.9 ft (305.07 m), where clayey glauconite sand overlies micaceous burrowed clay (to 1001.7 ft [305.32 m]) and laminated clay across a burrowed contact. This sequence boundary is associated with a major gamma ray kick. The sequence from 962.15 to 1000.9 ft (293.26 to 305.07 m) is probably equivalent the Merchantville II sequence of Miller et al. (2004). At Sea Girt, this sequence is restricted to Zone CC17 (see "Calcareous Nannofossils," p. 52); at Ancora and Bass River, the top of the Merchantville II sequence includes Zone CC18 (Miller et al., 2004).

From 1000.9 to 1004.0 ft (305.07 to 306.02 m) is slightly clayey, micaceous, dark, faintly laminated (with laminations slightly broken to broken by bioturbated), gray silt with scattered shells and distinct pyritized burrows. It probably represents a prodelta environment (Fig. F6). The micaceous silt becomes glauconitic and more intensely burrowed from 1004 to 1008 ft (306.02 to 307.24 m); the silt is slightly clayey and has glauconite concentrated in burrows, lignite, plant fragments, and laminae and thin beds of quartz sand (1005.7–1005.8, 1006.9, 1006.35–1006.45, 1007.9–1008.0 ft; 306.54–306.57, 306.90, 306.74–306.77, 307.21–307.24 m). Some burrows have been indurated. The environment of deposition was distal delta front to prodelta (Fig. F6).

From 1008 to 1015.7 ft (307.24 to 309.59 m), the section becomes finer grained downsection from a micaceous, glauconitic, sandy, clayey silt to a micaceous, glauconitic, quartzose sandy silty clay. Small pyritic, mottled burrows occur. The environment of deposition was probably inner–middle neritic with a prodelta influence (Fig. F6). There is a coring gap from 1015.7 to 1020 ft (309.59 to 310.90 m).

From 1020 to 1030 ft (310.90 to 313.94 m), the section transitions downward from burrowed, slightly clayey, very silty, slightly glauconitic quartz sand to a more heavily burrowed, siltier quartzose glauconite sand (Fig. F6). There are scattered sandy pyritic burrows and an increase in larger clay lined burrows downsection from 1025 to 1030 ft (312.42 to 313.94 m). Scattered shells occur throughout, with nested shell beds at 1020.35 and 1022.8 ft (311.00 and 311.75 m). The environment of deposition was inner to middle neritic.

The clayey, silty, quartzose glauconite sand becomes darker green with larger burrows from 1030 to 1037.5 ft (313.94 to 316.23 m). There is an indurated zone consisting of a carbonate-cemented glauconite sandstone from 1035.8 to 1036 ft (315.71 to 315.77 m). The environment of deposition of the section from 1030 to 1036 ft (313.94 to 315.77 m) was middle neritic. Recovery was poor between 1037.5 and 1060 ft (316.23 and 323.09 m), but segments recovered are similar muddy glauconite sand as above, with some of the material well lithified. The lithology showed a notable change in the short length of core (1060–1060.5 ft; 323.09–323.24 m) recovered between 1060 and 1070 ft (323.09 and 326.15 m). The recovered section is a soft, homogenous, dark, micaceous, slightly glauconitic, slightly clayey silt, with more mica and less glauconite sand than the interval above. In addition, the glauconite sand is very fine. We place a major sequence boundary at 1056 ft (321.87 m) based on a large, sharp kick in the gamma ray log across this facies shift in the cores (Fig. F6). The sequence from 1000.9 to 1056 ft (305.07 to 321.87 m) correlates with the Merchantville I sequence of Miller et al. (2004); it is assigned to Zones CC16–CC17 at Sea Girt (see "Calcareous Nannofossils," p. 52), CC17 and ?CC16–CC17 at Ancora, and CC16 at Bass River.

We may not have recovered the MFS of this sequence, with candidate levels at gamma ray peaks at 1027, 1037, 1043, 1047, and 1053 ft (313.03, 316.08, 317.91, 319.13, and 320.95 m) (Fig. F6). Possible flooding surfaces occur at facies changes at 1004, 1014, 1029.9 and 1037 ft (306.02, 309.07, 313.91, and 316.08 m). The possible flooding surface at 1029.9 ft (313.91 m) and gamma ray kick at 1027 ft (313.03 m) separate more micaceous below from less micaceous sediments below and is the best placement of the MFS considering recovery.

Cheesequake Formation

Age: Santonian
Interval: from ~1056 to ~1063 ft (~321.87 to ~324.00 m); predicted from log

Very little of the Cheesequake Formation was recovered. Between 1060 and 1060.5 ft (323.09 and 323.24 m), very micaceous silt with scattered small shells and minor glauconite is assigned to the Cheesequake Formation (Fig. F6). Neither the upper nor lower bounding surfaces were recovered. We place the base of the Cheesequake Formation and sequence at 1063 ft (324.00 m) at the base of an interval of high gamma ray log values; alternatively, it may be possible to place the contact at 1064.5 ft (324.46 m) at the base of transitional log values.

Magothy Formation

Age: undifferentiated Turonian–Santonian (?Coniacian)
Interval: ~1063–1286.5/1289 ft (~324.00–392.13/392.89 m)

Poorly sorted gravels were recovered somewhere in the interval from 1060 to 1070 ft (323.09 to 326.14 m) and may be cavings; clays from 1070 to 1072 ft (326.14 to 326.75 m) are probably a drilling artifact. The first definitive Magothy Formation was encountered at 1072 ft (326.75 m), where it consists of cross-bedded to burrowed, slightly micaceous to micaceous fine sand and interbedded organic-rich micaceous sands. The formational contact is placed at a gamma ray log increase at 1063 ft (324.00 m) (Figs. F6, F7). This facies continues to 1093 ft (333.15 m). Sand beds are typically 0.3–0.6 ft (9–18 cm) thick with scattered thin clay and lignite laminae; mud beds are as thick as 0.6 ft (18 cm). Sands vary from very clean fine sands with some medium sands to slightly muddier fine sands. Iron staining occurs and siltier beds have a red hue (e.g., 1075.7–1078 ft [327.87–328.57 m]). More lignitic beds are also more micaceous. Cross-bed sets are generally <0.3 ft (9 cm) thick. The environment of deposition is deltaic (lower delta plain to upper delta front). Heavy burrowing indicates marginal marine to marine conditions (e.g., the thin beds argue against barrier/tidal delta/lagoonal environment). Iron staining appears to indicate some subaerial exposure, although it could be post depositional. Common mica and abundant lignite indicate a fluvial influence. Differentiation of lower delta plain with marine influence vs. delta front submarine is a classic problem in facies interpretation.

Below a coring gap (1093–1100 ft; 333.15–335.28 m), the section consists of thicker bedded, cleaner, heavily burrowed, granuliferous medium well-sorted sands with lignitic interbeds (1100–1105.9 ft; 335.28–337.08). The sands are "beachy" and are interpreted as a proximal upper shoreface deposit (Fig. F7). These sands are underlain by a faintly laminated, organic-rich, slightly micaceous, slightly silty clay with thin sand laminae (1105.9–1110.65 ft; 337.08–338.53). There is an iron-cemented sand concretion at 1108.5 ft (337.87 m). The clays are interpreted as a bay/lagoon deposit (Fig. F7).

There is a coring gap from 1110.65 to 1120.0 ft (338.53 to 341.38 m) and the interval from 1120.0 to 1120.15 ft (341.38 to 341.42 m) appears to be drilling slurry. There is an indurated pyritic zone from 1120.15 to 1120.2 ft (341.42 to 341.44 m) with an irregular surface at 1120.2 ft (341.44 m). We tentatively place a sequence boundary in the coring gap (1115 ft [339.85 m] on Fig. F7) in association with a large gamma ray decrease (Fig. F7) and a shift in facies from lagoon/bay above to delta front below. We may have captured the sequence boundary at 1120.2 ft (341.44 m), though this may actually be a diagenetic surface. The sequence from ~1063 to ~1115 ft (324.00 to 339.85 m) has been named the Magothy IVB sequence (Kulpecz, 2005) and may correlate to the Cliffwood Beds in outcrop (Sugarman et al., 2005).

The section from 1120.2 to 1148 ft (341.44 to 349.91 m) is a generally cross-bedded sand with intermittent mud beds that was deposited in a delta front to lower delta plain environment (Fig. F7). From 1120.2 to 1125.1 ft (341.44 to 342.93 m) is a micaceous, trough cross-bedded, fine sand with some medium sand, common lignite laminae, and thin clay drapes that appear to be flaser beds. The subenvironment of this delta front deposit is not clear but may be tidal channel. A slightly sandy mud with thin lignite laminae and fragments occurs from 1125.1 to 1125.65 ft (342.93 to 343.10 m); it has a mottled texture from either rooting or burrowing. A yellow sulfur film occurs on the surface of the core. We interpret these clays as possibly a marsh subenvironment. From 1125.65 to 1130.1 ft (343.10 to 344.45 m) is a trough cross-bedded, micaceous, silty, fine–very fine sand with abundant mud laminae/drapes, minor organic material, and lignite. We interpret the subenvironment as possibly tidal channel. From 1130.1 to 1130.45 ft (344.45 to 344.56 m) is another sandy mud with an irregular texture reflecting burrowing or rooting. There is a fining-upward sand interval from 1130.45 to 1135.7 ft (344.56 to 346.16 m), fining from medium to fine micaceous, lignitic, trough cross-bedded sand with discontinuous mud drapes. Mica decreases upsection. Lignitic zones occur at 1130.5, 1133.1, 1134.5, and 1135.4 ft (344.58, 345.37, 345.80, and 346.07 m). The subenvironment is probably tidal channel. Another organic-rich silty clay interval from 1135.7 to 1139.3 ft (346.16 to 347.26 m) has interlaminated micaceous fine sands with sands mixed into the clay by burrowing or rooting. The burrows/roots appear almost chaotic, with various scales from large (1 cm) to very small (1 mm; ?worms). The organic-rich clay appears to be a marsh deposit. Sand increases downward and occurs in thin cross beds in the clay from 1139.3 to 1140.5 ft (347.26 to 347.62 m). Very lignitic, micaceous, medium–fine sands that occur from 1140.5 to 1148.05 ft (347.62 to 349.93 m) generally fine and becomes less micaceous upsection. Lignitic beds (e.g., 1146.6–1146.8 and 1147.6–1148.05 ft [349.48–349.54 and 349.79–349.93 m]), lignite laminae, and clay beds and laminae occur. A lighter tan clay at 1146.4–1146.5 ft (349.42–349.45 m) is transitional to clay below. The interval from 1147.95 to 1148.05 ft (349.90 to 349.93 m) is a lignite bed of possibly in situ bedded lignite (?marsh). The subenvironment of the sands is tidal channel/bay.

A possible sequence boundary occurs at 1148.05 ft (349.93 m) (Fig. F7), where a bedded muddy sandy lignite overlies a fine-grained sand with irregular pyrite cement and iron staining (1148.05–1148.25 ft;

349.93–349.99 m). The sequence from 1110.65 to 1148.05 ft (338.53 to 349.93 m) has been named the Magothy IVA sequence (Kulpecz, 2005) and may correlate to the Morgan Beds of the Magothy Formation in outcrop.

The section from 1148.05 to 1153.7 ft (349.93 to 351.65 m) consists of tan clays with thin sand beds and laminae. These clays show minor evidence of rooting and sporadic sphaerosiderite microconcretions. The sands are micaceous and fine–very fine grained. These clays are soils that were deposited in a delta plain setting (interfluve overbank?) (Fig. F7).

From 1153.7 to 1162.1 ft (351.65 to 354.21 m) the section consists of interbedded sand (0.1–1.0 ft; 3–30 cm) and clay (<0.1–0.3 ft; 3–9 cm) beds. The sands are cross-bedded, micaceous, and generally fine-grained, with some medium and very fine zones. Lignite fragments and layers are common in the sands. The clays are laminated, silty, and sandy in places. There are a few reddish zones, including hard hematite concretions at 1157.45 and 1159.3 ft (352.79 and 353.35 m). The section from 1162.1 to 1166.7 ft (354.21 to 355.61 m) is similar to above but has approximately coequal amounts of sand and clay and very fine laminations. It consists of fine–very fine micaceous sands with organic debris and dark gray, light gray, and reddish laminated clays. The dark gray clays are rich in organic material. The environment of deposition from 1153.7 to 1166.7 ft (351.65 to 355.61 m) was lower delta plain and may be a levee or crevasse splay deposit. Based on changes upsection from finer material below, it is probably a proximal levee (Fig. F7).

The interval from 1166.7 to 1175.0 ft (355.61 to 358.14 m) consists of interlaminated, dark gray, organic-rich, slightly silty clay; subordinate reddish tinged clay; and thin (1–3 mm) fine sands. The section becomes increasingly lignitic and sandier downsection. There are small spherical pyrite concretions and pyrite is scattered throughout. This is interpreted as a distal levee deposit (Fig. F7).

From 1175.0 to 1175.7 ft (358.14 to 358.35 m) is a bedded sandy lignite with pyrite concretions interpreted as a near-levee swamp (Fig. F7). In general, the section from 1153.7 to 1175.7 ft (351.65 to 358.35 m) coarsens upward and probably represents a migrating levee complex.

The section from 1175.7 to 1186 ft (358.35 to 361.49 m) is a fine-grained, organic-rich unit similar to above, but with less sand. The section from 1175.7 to 1180 ft (358.35 to 359.66 m) consists of gray and common reddish brown clay laminae, common interlaminated organic-rich laminae and beds, and micaceous sand laminae. There are numerous 1- to 2-mm spherical pyrite-cemented sand concretions. The section from 1180 to 1186 ft (359.66 to 361.49 m) is similar to above, but is less sandy and less organic rich. It consists of interbedded gray-brown clays, very dark brown clays, and a few lighter brown clays with common organic-rich laminae, rare sand laminae, and a few red rip-up clasts (common pyrite-cemented sand concretions 1–2 cm in diameter). The reddish brown laminae appear to be incipient soils that have undergone minor pedogenesis, though they could be reworking of red clays found below 1242 ft (378.56 m). We interpret this interval as lower delta plain overbank swamps (Fig. F7).

There is a coring gap from 1186 to 1190 ft (361.49 to 362.71 m) (Fig. F7). The section generally fines upward from 1190 to 1212.7 ft (362.71 to 369.63 m), passing downsection from organic-rich clays with interlaminated sands to sands with organic-rich interlaminated clays. From 1190 to 1193.5 ft (362.71 to 363.78 m) the section consists of interlaminated lighter gray, darker gray, and light brownish red clays, with common thin, micaceous, very fine sand and organic-rich laminae and beds that range in thickness from <0.5 mm to 5 cm. Pyrite cement is present in intervals. The section from 1193.5 to 1212.7 ft (363.78 to 369.63 m) consists of fine micaceous sands with zones that contain abundant clay and lignite laminae and red clay rip-up clasts. Clay laminae are black, very organic-rich/peat intervals include wood fragments.

The environment of deposition of the section from 1190 to 1212.7 ft (362.71 to 369.63 m) could be delta plain or delta front (i.e., Owens and Sohl [1969] used siderite concretions to differentiate these environments). The lack of clear bioturbation, thin laminations, common rip-up clasts, common organic matter indicative of swamps, and the lack of coarsening-upward sections argues against a subaqueous delta front interpretation. We interpret these deposits as lower delta plain overbank deposits including cut-off channels and oxbow lakes (Fig. **F7**).

There is a contact at 1213.2 ft (369.78 m) with micaceous, organic-rich fine sand above and poorly sorted, slightly silty, granuliferous medium–coarse sands below. There may a contact zone from 1212.7 to 1213.2 ft (369.63 to 369.78 m), with an iron-stained interval with granules at 1212.7 ft (369.63 m) and a micaceous fine sand from 1212.8 to 1213.2 ft (369.88 to 369.78 m) that may be burrowed down from above. We interpret the contact at 1213.2/1212.7 ft (369.78/369.63 m) as a probable sequence boundary associated with a gamma ray log increase (Fig. **F7**). The organic-rich section from 1148.05 to 1212.7 ft (349.05 to 369.63 m) is a sequence that is assigned to pollen Zone V (see **"Pollen,"** p. 56). It thus correlates to the Magothy III sequence of Miller et al. (2004) and may be equivalent to the Amboy Stoneware Clay in outcrop.

From 1213.3 to 1233.5 ft (369.81 to 375.97 m) is a structureless, granuliferous medium–very coarse sand with a few 1- to 15-mm-thick organic-rich laminae. There are several fining-upward packages ~1–3 ft (30–90 cm) thick, as seen on the gamma ray log. This is clearly a channel deposit, though it could be fluvial delta, subaqueous bay mouth delta front, or tidal channel. Based on the facies succession (with paleosols below), we favor a fluvial channel interpretation. There is a coring gap at the base of this sand unit (1233.5–1240 ft; 375.97–377.95 m). This unit may be equivalent to the Old Bridge Sand of the Magothy Formation (Fig. **F7**).

Below a pyrite-cemented sand concretion (1240.0–1240.1 ft; 377.95–377.98 m) is a light–medium gray, slightly silty clay with thin, silty, very fine sand and a few organic-rich laminae (1240.1–1242.05 ft; 377.98–378.58). This gray clay contrasts with paleosols found below 1242.05 ft (378.58 m), and its environmental and sequence stratigraphic significance is not clear. We believe that this clay probably represents an interfluvial upper delta plain deposit and is best placed with the paleosols below and contrasts with the channel sands above.

Across this abrupt contact at 1242.05 ft (378.58 m), there is a shift from clay with sand laminae above to yellow, white, and red mottled clay containing sphaerosiderite below. Reddish mottles within the orange-yellow-white clay appear to follow root traces. The sphaerosiderites are weathered with hematite rinds. These clays represent paleosols (Fig. **F7**) deposited in an upper delta plain environment; pollen suggests that it is equivalent to the South Amboy Fire Clay of the Magothy Formation in outcrop (see **"Pollen,"** p. 56). The mottled clay becomes banded with red and white clay at 1252 ft (381.61 m) and continues to 1253.7 ft (382.13 m), where there is an abrupt contact with very fine silty sand below.

From 1253.7 to 1262.8 ft (382.13 to 384.90 m) is light–medium gray, very fine silty sand that changes to a sandy silty clay with a trace of mica. These appear to be incipient or deeper horizon paleosols deposited in an upper delta plain environment. At 1262.8 ft (384.90 m) is an irregular contact associated with a facies shift from paleosols above to estuarine sands below and a major gamma ray kick (Fig. **F7**). This contact is interpreted as a sequence boundary (Fig. **F7**). The sequence from 1212.7 to 1262.8 ft (369.63 to 384.90 m) is assigned to pollen Zone V and thus correlates to the Magothy II sequence of Miller et al. (2004), possibly equivalent to the Old Bridge Sand and South Amboy Fire Clay in outcrop (Fig. **F7**).

The interval from 1262.8 to 1268.2 ft (384.90 to 386.55 m) consists of interbeds (as thick as 0.4 ft [12 cm]) of very fine–medium sand with thin clay and organic-rich cross-laminae and clay with sand and organic-rich laminae. From 1268.2 to 1272.0 ft (386.55 to 387.71 m) is a fining-upward package going from gravelly coarse sand with wood fragments and weathered pyrite concretions to silty medium sand. The interval from 1272 to 1272.5 ft (187.71 to 387.86 m) is a heterolithic mixture of sand, clay, and granules. From 1272.5 to 1273 ft (387.86 to 388.01 m) is silty fine–very fine sand with muddy sand and organic-rich laminae. There is a coring gap from 1273 to 1280.0 ft (388.01 to 390.14 m). From 1280.0 to 1282.8 ft (390.14 to 391.00 m) is a fining-upward, poorly sorted, muddy sand that fines from granules to coarse–medium sand. From 1282.2 to 1285.3 ft (390.81 to 391.76 m) is an interval of laminated sandy to silty clay and muddy very fine sand with cross laminations. From 1285.3 to 1286 ft (391.76 to 391.97 m) is a very muddy, granuliferous coarse to very fine sand. From 1286 to 1286.5 ft (391.97 to 392.13 m) is poorly sorted muddy medium sand with granules that may be caved from above. These sands and clays from 1262.8 to 1286.5 ft (384.90 to 392.13 m) are bioturbated and cross-bedded with coarse material and have contrasts in grain size from granules to clay, all of which suggest an estuarine environment (Fig. **F7**).

Below a coring gap (1286.5–1289 ft; 392.13–392.89 m), a kaolinized, white, slightly sandy micaceous silt (1289–1290.7 ft; 392.89–393.41 m) marks the top of the Bass River Formation. The kaolinized silts are weathered Bass River lithology because they appear to be distinct from the Magothy sands and clays. The contact is a significant disconformity associated with a gamma ray log kick (Figs. **F7, F8**). The sequence from 1262.8 to 1289 ft (384.90 to 392.89 m) may correlate to the Magothy I sequence of Miller et al. (2004) and the Sayreville Sand in outcrop.

Bass River Formation

Age: Cenomanian–early Turonian
Interval: 1286.5/1289–1494.95 ft (392.15/392.89–455.66 m)

Kaolinized, very sandy micaceous silt and clayey silt characterize the top of the Bass River Formation (1289–1290.4 ft; 392.89–393.31 m) (Fig. **F8**). Laminae and beds range from >1 to >4 cm thick. These silts contain ~3% mica (including large grains of chlorite characteristic of this formation) and ~3% dark grains that appear to be lignite. A zone of concretions occurs at 1290.4 ft (393.31 m) at the contact of whitish kaolinitic silts and unweathered medium to dark gray sandy silts.

From 1290.4 to 1300 ft (393.31 to 396.24 m) the Bass River Formation consists of thinly bedded to laminated to bioturbated, micaceous, very sandy silt to silty sand, clayey silt, and silty clays. The upper part of this section (1290.4–1294 ft; 393.31–394.41 m) is finer grained and the lower part (1294–1295 ft; 394.41–394.72 m) is sandier, more heavily bioturbated, and contains abundant mica and plant fragments. A cemented concretion (weathered to hematite) is associated with a gamma ray log kick at 1294.7 ft (394.62 m); it is possible that this is a sequence boundary with a thin sequence above. The environment of deposition is distal lower shoreface to offshore (~10–20 m paleodepths) (Fig. F8), but with a strong deltaic influence.

Below a coring gap (1295–1300 ft; 394.72–396.24 m), the section deepens downsection from delta front sands and silts (1300–1302.9 ft; 396.24–397.12 m) to proximal prodelta silty clay (1302.9–1303.5 ft; 397.12–397.31 m), to a shelf sand influenced by a delta (1303.5–1319.7 ft; 397.31–402.24 m) (Fig. F8). The delta front sands are silty, micaceous, and contain scattered plant debris. The prodelta silty clays are laminated and micaceous. The shelf sands are very fine, micaceous, very bioturbated, silty, and very fine grained and grade downsection to silty sand below 1315 ft (400.81 m). The shelf sands have finely disseminated organic matter and scattered pyrite and were deposited below wave base ("offshore") on a delta-influenced shelf.

There is probably a flooding surface at 1319.7 ft (402.24 m). Below this, micaceous, lignitic, laminated clayey silt to silty clay (1319.7–1323.0 ft; 402.24–403.25 m) represents a shallower, more deltaic influenced unit (prodelta). There are thin fining-upward successions (1319.7–1321 and 1321.0–1323.0 ft; 402.24–402.64 and 402.64–403.25 m).

Bioturbated to laminated slightly micaceous silty clay to clay with thin wispy sand laminae dominates from 1323 to 1346 ft (403.25 to 410.26 m) (Fig. F8). The section contains laminations with either lignite or pale brown sideritic clay that may be altered shells. Pyrite is also present. This unit probably was deposited in a prodelta environment or a shelf influenced by a delta.

An indurated very shelly sandstone occurs from 1346.3 to 1347.2 ft (410.35 to 410.63 m) consisting of a shell hash (1346.3–1436.4 ft; 410.35–437.81 m) associated with a gamma ray log low (Fig. F8). Shells and shell fragments persist in a shelly clayey silt to 1349.1 ft (411.21 m), including a hash at 1348.1–1348.2 ft (410.90–410.93 m). The environment of deposition may be lower shoreface, with a flooding surface at 1346.3 ft (410.35 m) equivalent to flooding Surface 4 of Sugarman et al. (1999) (Fig. F8).

Organic-rich and less organic-rich intervals characterize the Bass River Formation from 1349.1 to 1416 ft (411.21 to 431.60 m). A very dark gray laminated clay bed (1349.1–1349.5 ft; 411.21–411.33 m) is the uppermost of organic-rich beds that are primarily found below 1370 ft (417.58 m). A light brown-gray, laminated to thick bedded, slightly finely micaceous silty clay with scattered lignite (1349.5–1367.75 ft; 411.33–416.89 m) appears less organic rich. A siderite concretion with pyrite occurs at 1360 ft (414.53 m). A very light gray micaceous silt bed (1360.6–1361.0 ft; 414.71–414.83 m) punctuates the tight clays. The unit from 1349.1 to 1367.75 ft (411.21 to 416.89 m) was deposited in an offshore inner neritic environment (Fig. F8) with a deltaic influence.

There is a coring gap from 1367.75 to 1370.0 ft (416.89 to 417.58 m), with a large siderite concretion from 1370.0 to 1370.15 ft (417.58 to 417.62 m). From 1370.15 to 1379.5 ft (417.62 to 420.79 m), the cores are very dark gray to black and laminated, faintly micaceous silty clays. They are assigned to lower Turonian Subzone CC10b through Zone CC11 (see "Calcareous Nannofossils," p. 52), suggesting correlation to

OAE2 (Fig. F8), though another organic-rich bed at 1395.5–1416.0 ft (425.35–431.06 m) could also be correlated to OAE2. There are several more siderite concretions in this interval. From 1372.4 to 1372.5 ft (418.31 to 418.34 m) is another bioturbated silt bed. Shells appear at ~1372 ft (~418.19 m), with scattered thin bivalve shells and shell fragments to 1379.5 ft (420.47 m). A very shelly silty clay with thick mollusk shells (vs. thinner shells above) occurs from 1379.5 to 1381.2 ft (420.47 to 420.99 m). The shell bed may represent lower shoreface environments, and the top of the shell bed (1379.5 ft; 420.47 m) may be a flooding surface equivalent to flooding Surface 3 of Sugarman et al. (1999). The base of the shell bed at 1381.2 ft (420.99 m) is an irregular surface that may be the base of a submarine channel.

From 1381.2 to 1386.9 ft (420.99 to 422.73 m) is a dark gray laminated to bioturbated clayey silt (Fig. F8) with interspersed wispy sands, shells, and shell fragments. The coarser material is more bioturbated (proximal prodelta) and the finer beds are more laminated (distal prodelta).

There is an indurated zone from 1386.9 to 1388.5 ft (422.73 to 423.21 m) consisting of a very shelly, slightly micaceous, very fine sandy siltstone with carbonate cement. Again, the shell bed may represent lower shoreface environments and the top of the shell bed (1386.5 ft; 422.61 m) may be a flooding surface (Fig. F8) equivalent to flooding Surface 2 of Sugarman et al. (1999).

From 1388.5 to 1394.6 ft (423.21 to 425.07 m) is a very dark gray, shelly, slightly clayey silt with scattered fine sand. There is a very fine sand from 1391.2 to 1391.3 ft (424.04 to 424.07 m). There are occasional cross laminations. There are 0.1-ft (3 cm) regular color cycles from 1394 to 1394.6 ft (424.89 to 425.07 m), with shell laminae and light gray clays that darken upward to very dark clays. The cycles appear to continue to 1388 ft (423.06 m), though the cycles are thicker and less distinct. Another indurated shelly (with thick shells) very fine sandstone with carbonate cement (1394.6–1395.5 ft; 425.07–425.35 m) may have a flooding surface at its top (Fig. F8) equivalent to flooding Surface 1 of Sugarman et al. (1999). We tentatively identify this as the MFS (Fig. F8) of the sequence from 1289 to 1418.95 ft (392.89 to 432.50 m).

Black to very dark gray to light gray color-banded, laminated, interbedded, clayey silt and silt (1395.5–1416.0 ft; 425.35–431.06 m) probably represents the highest organic matter associated with OAE2 (Fig. F8), though OAE2 could be at 1370.15–1379.5 ft (417.62–420.79 m), as noted above. Shells are rare except in distinct laminae. There are 0.1- to 1.3-ft-scale (3–40 cm) interbeds of light gray silts, medium gray silty clays, and dark gray-black clays. Very fine sands occur as silty, wispy laminae in the coarser beds. Bioturbation ranges from bioturbated in the coarser beds to laminated in clays.

There is a large indurated zone from 1416.0 to 1418.95 ft (431.60 to 432.50 m) consisting of a shelly, very slightly micaceous, glauconitic (as much as 10%?), burrowed, silty, very fine quartz sandstone. There is an irregular surface at 1418.95 ft (432.50 m) separating the sandstone from slightly micaceous sandy silt below. We place a major sequence boundary at the base of this indurated zone associated with a very large gamma ray log shift (Fig. F8). The sequence from 1289 to 1418.95 ft (392.89 to 432.50 m) spans the Cenomanian/Turonian boundary, is assigned to Subzone CC10b through Zone CC11 (see "Calcareous Nannofossils," p. 52), and correlates with the Bass River III sequence of Miller et al. (2004). In general, the section fines upward from the sequence boundary at 1418.95 ft (432.50 m) to ~1381 ft (420.93 m), with more wispy sands at the base and more clays above 1381 ft (420.93 m).

A coarsening-upward succession occurs between 1418.95 and 1430.5 ft (432.50 and 436.02 m). The section consists of (1) a micaceous, heavily burrowed, slightly lignitic, shelly, sandy, slightly clayey silt (1418.95–1421 ft; 432.50–433.12 m); (2) a very similar unit that is a slightly finer grained clayey silt (1421–1430 ft; 433.12–435.86 m); and (3) an organic-rich clay (1430–1430.5 ft; 433.86–436.02 m). These facies represent deposition on a storm-dominated shelf below mean wave base (inner neritic to middle neritic). A laminated shelly silt (1430.5–1431.4 ft; 436.02–436.29 m) overlies a calcarenite that consists of a calcareous, cemented, very shelly siltstone. There is distinct contact at 1432.1 ft (436.50 m), with interbedded to laminated clayey silts, sandy silts, and clays below (1432.1–1442 ft; 436.50–439.52 m). We favor interpreting the 1432.1 ft (436.50 m) contact as the MFS (Fig. F8) of a sequence that continues to 1457.7 ft (444.31 m). Alternatively, the contact could represent a sequence boundary with a MFS associated with the organic-rich clays (1430–1430.5 ft; 435.86–436.02 m). The interbedded clays and silts appear to represent prodelta environments, though mica is rare.

Prodelta laminated clays and silts interfinger with shelfal bioturbated shelly sandy silts from 1442 to 1445.5 ft (439.52 to 440.59 m). At 1445.5 ft (440.59 m) is a burrowed surface with glauconite in the burrows that separates shelf facies above from a prodelta sandy silt with wispy sand burrows below; therefore, the surface at 1445.5 ft (440.59 m) potentially could represent a MFS (Fig. F8). Micaceous silt with wispy sand laminae and disseminated lignite occurs from 1445.5 to 1456 ft (440.59 to 443.79 m). The silts vary from laminated to burrowed and generally lack shell material. We interpret these sediments as primarily prodelta environments with varying shelfal influence. Slight variations from gray to black may reflect varying amounts of organic material. The micaceous silts become very shelly with nested shells and shell fragments from 1456 to 1457.7 ft (443.79 to 444.31 m); the base of the section becomes clayier and sandier. The shelly zones represent reworking on a storm-dominated shelf. A contact at 1457.7 ft (444.31 m) occurs just above an interval of no recovery (1457.9–1460 ft; 444.37–445.01 m). Carbonate nodules, hematite staining, and a mixture of sand and gray clay clasts ripped up from below mark the contact that has been disturbed by drilling. This contact is interpreted as a sequence boundary (Fig. F8). The sequence from 1418.95 to 1457.7 ft (432.50 to 444.31 m) is assigned to middle Cenomanian Subzone CC10a and unzoned (see **"Calcareous Nannofossils,"** p. 52). It could correlate with either the Bass River II (Subzones CC10a–CC10b) or Bass River I (Zone CC9 through Subzone CC10a) sequence at Ancora (Miller et al., 2004). Based on superposition, we favor correlation to the Bass River II sequence.

The section below the sequence boundary changes to clay, starting with slightly silty clay from 1460 to 1465.1 ft (445.11 to 446.56 m), with finely dispersed lignite and thin silt laminae. Rare scattered shell fragments occur from 1462 to 1465 ft (445.62 to 446.53 m). Two indurated beds or concretions occur at 1463.4–1463.55 ft (446.04–446.09 m) and 1464.9–1465.1 ft (446.50–446.56 m). The environment of deposition of the section from 1460 to 1470 ft was probably prodelta (Fig. F8).

Slightly micaceous, slightly silty clay occurs from 1470 to 1471 ft (448.06 to 448.35 m) below a coring gap (1465.1–1470 ft; 446.56–448.06 m). The section becomes sandier clay from 1471 to 1476.9 ft

(448.36 to 450.16 m), with some variation in amount of bioturbation and preservation of laminae. Rare glauconite occurs at 1476 ft (449.88 m). A thin zone of very fine sand was recovered from 1476.9 to 1477.15 ft (450.16 to 450.24 m) above a 2.85 ft (87 cm) coring gap. The gamma ray log (Fig. F8) suggests the sand is ~3 ft (91 cm) thick. A similar sand occurs from 1480 to 1480.15 ft (451.10 to 451.15 m). This section, from 1470 to 1480.15 ft (448.06 to 451.15 m), was deposited in delta front (sandier, more bioturbated) to prodelta (finer grained, more laminated) environments.

At 1480.15 ft (451.15 m), a silt-dominated section begins that is characterized by a banded appearance and dark colors suggestive of high organic content. An interval of very organic rich sediments (1482.4–1484.4 ft; 451.84–452.45 m) reaches a peak in organic content at 1482.6–1483.2 ft (451.90–452.08 m). Organic-rich sediments (1484.4–1491.6 ft; 452.45–454.64 m) have a transition to organic-poor sediments (1491.6–1494.95 ft; 454.64–455.66 m) overlying a probable sequence boundary at 1494.95 ft (455.66 m). The environment of these organic-rich beds is prodelta. Distinct banding of darker and lighter layers in organic-rich sediment may contain a Milankovitch cyclicity. This succession of organic-rich sediments at Sea Girt lies in an undated sequence (1457.7–1494.95 ft; 444.31–455.66); the overlying sequence is dated at middle Cenomanian Subzone CC10a (Fig. F8). Thus, the sequence from 1457.7 to 1494.95 ft (444.31–455.66 m) clearly predates global OAE2 (the Bonarelli bed, spanning Subzone CC10b through Zone CC11). Based on superposition and assignment of the overlying sequence to Subzone CC10b, we correlate the sequence from 1457.7 to 1494.95 ft (444.31 to 455.66 m) to the Bass River I sequence of Miller et al. (2004).

The Bass River Formation at Sea Girt generally lacks the common chlorite typical of the formation to the south at Bass River and Ancora (Miller et al., 2004, and references therein). The micas are dominated by muscovite, with rare chlorite. Nevertheless, the marine clayey silts, silty clays, and occasional sands from 1290.7 to 1494.95 ft (393.41 to 455.66 m) are clearly assigned to the Bass River Formation (Fig. F8). Assignment of the section below to either the Bass River Formation or the Potomac Formation is uncertain.

Bass River or Potomac Formation

Age: ?lower Cenomanian
Interval: 1494.95–1563 ft (455.66–476.40 m)

A sequence boundary at 1494.95 ft (455.66 m) consists of a shift from fine-grained sediments to "sugar" sands below (Fig. F8). Very slightly silty fine–very fine sands with abundant mica and occasional lignite cross-laminae continue downward from the sequence boundary to 1505.45 ft (458.86 m), where there is a cemented zone/concretion. The sands represent delta front environments. Below this, a clayey, slightly micaceous bioturbated silt (1505.65–1507.5 ft; 458.92–459.49 m) and very slightly micaceous clay continue to 1520.2 ft (463.36 m), though recovery is poor. The silts represent prodelta environments. A probable sequence boundary was recovered at 1520.2 ft (463.36 m), separating clay with sand burrows above from sands below. The sequence from 1494.95 to 1520.2 ft (455.66 to 463.36 m) has a distinct blocky gamma ray log signature (Fig. F8) more typical of the Potomac Formation. However, the upsection change from lower HST prodelta silts to upper HST delta front sands is typical of Upper Cretaceous marginal marine to marine sequences and is not typical of the Potomac Formation. We tentatively term the sequence from 1494.95 to 1520.2 ft (455.66 to 463.36 m) the Bass River 0.5/Potomac IIIc sequence and correlate it with the upper Potomac sequence at Ancora that was assigned to the pollen Zone III/IV transition (Miller, Sugarman, Browning, et al., 1998). This section at Sea Girt is assigned to pollen Zone III (see **"Pollen,"** p. 56), which suggests correlation to the Potomac Formation.

Fine, micaceous, lignitic, cross-bedded to bioturbated sands (1520.2–1534.2 ft; 463.36–467.62 m) occur below the 1520.2 ft (463.36 m) sequence boundary (Fig. **F8**). The sands contain lignite laminae, scattered clay drapes, and large micas and are thickly (1.5 ft; 46 cm) to thinly (0.1 ft; 3 cm) bedded. The section from 1522 to 1525 ft (463.91 to 464.82 m) is heavily bioturbated. The sands could be interpreted as representing nearshore/delta front or lower delta plain environments. We favor the latter based on the upsection change from lower delta plain clays and sands below. The sands are bracketed by pollen Zone III (see **"Pollen,"** p. 56) and comprise the upper HST of the 1520.2–1563.0 ft (463.36–476.40 m) sequence (Fig. **F8**).

Micaceous to very micaceous clays with subordinate interbedded very fine sands occur from 1534.5 to 1556.4 ft (467.72 to 474.39 m). This unit contains common leaf fossils (1543.5–1543.8 ft; 470.46–470.55 m), is bioturbated (e.g., 1550–1551 ft; 472.44–472.74 m) to very finely laminated (1551–1552 ft; 472.74–473.05 m), and contains common plant debris (1554–1556 ft; 473.66–474.27 m). There is an uncored interval between 1556.4 and 1560 ft (474.39 and 475.49 m). Below this, a lignitic to very lignitic silty clay (1560–1563.0 ft; 475.49–476.40 m) appears to be an oxbow lake deposit. The sandy clays were probably deposited in lower delta plain environments, with oxbow and interfluvial marsh subenvironments. They comprise the lower HST of the 1520.2–1563.0 ft (463.36–476.40 m) sequence.

There is a contact at 1563.0 ft (476.40 m), with very lignitic clay above and lignitic fine sand below; the sands contain sphaerosiderite from 1564.0 to 1564.3 ft (476.71 to 476.80 m). We place the top of the definite Potomac Formation at the top of the sphaerosiderite-bearing sands (Fig. **F8**). The correlation of the sequence from 1520.2 to 1563.0 ft (463.36 to 476.40 m) is unclear, though it may correlate with the section below 1145/1158.2 ft (349.00/353.02 m) at Ancora (pollen Zone III/IV transition; Miller et al., 2004). We tentatively name this sequence the Bass River 0/Potomac IIIb sequence.

Potomac Formation

Age: Albian
Interval: 1563–1600 ft TD (476.40–487.68 m)

Fine sugar sand (1563.0–1564.9 ft; 476.40–476.98 m) with sphaerosiderite beginning at 1564 ft (476.71 m) overlies a white, kaolinitic hard clay (1564.9–1565.4 ft; 476.98–477.13 m). The white clay shows red mottles below 1568.5 ft (478.08 m) typical of the nonmarine Potomac Formation (Fig. **F8**). Silty clay with sphaerosiderite (1571.9–1578.7 ft; 479.12–481.19 m) overlies mottled red and white clayey silt to silty clay (1578.7–1596.0 ft; 481.19–486.46 m) with sphaerosiderite and obvious root casts. A silty fine sand (1596.0–1596.5 ft; 486.46–486.51 m) overlies a dark gray, silty clay with thin lignite stringers at the base of the hole (1596.5–1598.1 ft; 486.51–487.10 m); these sediments appear to be lacustrine/oxbow lake (Fig. F8). The transition from more organic rich to less organic rich clays to sand represents a drying out of the lake.

The mottled clays are typical of the overbank/interfluvial deposits of the Potomac Formation and correlate with Potomac Unit 3 (as indicated by pollen Zone III). Thus, drilling the Sea Girt corehole reached one prime objective in penetrating the marine Bass River Formation and the marginal marine uppermost Potomac Formation to the terrestrial Potomac Formation.

BIOSTRATIGRAPHY

Planktonic Foraminifers

Cenozoic

Miocene planktonic foraminifers are rare and only one sample yielded age information. The presence of *Globorotalia praescitula* (first appearance = 18.8 Ma), *Sphaeroidinella disjuncta* (Zones N6–N11; ~18.8–12.5 Ma), and *Globorotalia zealandica* (approximately Zones N6–N8; ~18.8–15.2 Ma) at 86.0 ft (26.21 m) (Fig. F2) suggests an age less than ~18.8 Ma.

Eocene planktonic foraminifers are rare and are not generally well preserved (Table T3). Because of the nearshore location of the Sea Girt corehole, marker species are rare and zonation has relied upon secondary markers.

T3. Eocene planktonic foraminifers, p. 91.

A single specimen assigned to the genus *Truncorotaloides* is found in the Shark River Formation at 176 ft (53.64 m) indicating the sediments below are not younger than Biochron P14 (Fig. F2). *Orbulinoides beckmanni* is rarely found in New Jersey, thus Zones P12–P14 cannot be subdivided. The highest occurrence of *Morozovella aragonensis* (the marker for the base of Zone P12) at 276 ft (84.12 m) is believed to be premature based on comparisons with nannofossil biostratigraphy (Figs. F2, F10). The first occurrence of *Turborotalia pomeroli* at 235 ft (71.63 m) indicates that the sediments above the sequence boundary at 236.1 ft (71.96 m) should be assigned to Zone P12 or younger (Berggren et al., 1995). *Globigerinatheka subconglobata* is first found at 251 ft (76.50 m) and is used to approximate the Zone P11/P10 boundary. If the basal Zone P11 assignment is correct, then the sequence from 236.1 to 265.8 ft (71.96 to 81.02 m) straddles the Zone P10/P11 boundary. Most New Jersey cores contain an expanded sequence that straddles the Zone P11/P12 boundary (Sequence E7). Calcareous nannofossils cannot resolve whether these sediments should be assigned to Subzone NP15b or NP15c. If the sediments can be assigned to calcareous nannofossil Subzone NP15b, then this sequence should be assigned to Sequence E6a previously known only from the Ancora corehole and Sequence E7 is missing.

Zones P9 and P10 cannot be distinguished in the cores because of the absence of *Hantkenina*. The base of Zone P9 is approximated at 266 ft (81.08 m) by the first occurrence of *Acarinina bullbrooki* (Fig. F3). The base of Zone P8 is approximated at 290.4 ft (88.51 m) by the first occurrence of *Subbotina inaequispira* (Fig. F3). The first occurrence of *M. aragonensis,* at 316 ft (96.32 m), defines the base of Zone P7 (Fig. F3). The section between 316 and 341 ft (96.32 and 103.94 m) is difficult to zone because of the absence of *Morozovella formosa* in the core. The presence of *Morozovella gracilis* and *Morozovella subbotinae* in this interval is typical of a Subzone P6b fauna. The assignment to calcareous nannoplankton Zone NP11 also suggests that these sediments correlate to Subzone P6b. Lowermost Eocene sediments from 346 to 361 ft (105.46 to 110.03 m) are barren of foraminifers.

Paleocene planktonic foraminifers are rare and generally poorly preserved, making a detailed zonation impossible. A sample at 366 ft (111.56 m) contains *Acarinina primitiva,* but members of the Paleocene/Eocene boundary excursion fauna are absent. Samples from 376 to 446 ft (114.60 to 135.94 m) are barren of foraminifers. A sample at 451 ft (137.46 m) contains a few benthic foraminifers and a single specimen of *Subbotina triangularis*. Samples at 456 and 461 ft (138.99 and 140.51 m) contain *Globanomalina pseudomenardii,* indicating assignment to Zone P4 (Fig. F3). The sample at 461 ft (140.51 m) contains *Acarinina subsphaerica* indicating assignment to Subzone P4a (Fig. F3). The absence of *A. subsphaerica* from the sample at 456 ft (138.99 m) may indicate assignment to Subzone P4b. A sample at 457.2 ft is assigned to Subzone P3b through Zone P4, with *Acarinina mckannai*, *A. subsphaerica*, *S. triangularis*, *Igorina pusilla*, *Morozovella acuta*, *Morozovella aequa*, and *Subbotina velascoensis*. A sample at 476 ft (145.08 m) contains *Morozovella angulata* without *Igorina albeari,* perhaps indicating assignment to Subzone P3a, although the sample contains few planktonics. This assignment is consistent with calcareous nannofossil Subzone NP4b. Samples at 491 and 494 ft (149.66 and 150.57 m) contain *Globanomalina compressa* and *Globoconusa daubjergensis*, whose highest occurrence is in Subzone P1c (Olsson et al., 1999) and indicates assignment to Subzone P1c. A sample from 495.2 ft contains a Danian assemblage including *G. daubjergensis* and *Praemurica pseudoinconstans* (Zone P1, probably Subzone P1a) as did a sample from 504.4 ft.

Cretaceous/Paleogene Boundary

Samples from 505.0 to 512.0 ft (153.96 to 156.09 m) were examined for planktonic foraminifers to identify the Cretaceous/Paleogene (K/Pg) boundary (Table T4). Planktonic foraminifers in this interval were relatively sparse, probably because of a shallow inner shelf paleodepth. The K/Pg boundary is placed between samples at 509.0 and 509.5 ft (155.18 and 155.34 m). The Danian interval from 509.0 ft (155.14 m) is placed in Subzone P1a based on the presence of *Eoglobigerina edita, Eoglobigerina eobulloides, P. pseudoinconstans, Praemurica taurica, G. daubjergensis, Woodringina claytonensis,* and *Woodringina hornerstownensis*. The zonal marker for Subzone Pα, *Parvularugoglobigerina eugubina,* was not identified. This may be because of the scarcity of planktonic foraminifers in the Danian interval. In other ODP New Jersey coastal plain coreholes, the species is rare, so its absence at Sea Girt is not surprising and is probably because of the shallow paleodepth. Likewise, without this species, Zone P0 cannot be identified.

Cretaceous samples from 509.5 to 512.0 ft (155.34 to 156.09 m) contain rare specimens of *Globotruncana, Rugoglobigerina,* and *Racemiguembelina,* along with *Guembelitria cretacea,* which also occurs in the Danian interval. Other than indicating a Maastrichtian age, zonal markers are absent because of a shallow paleodepth. The presence of *Pseudoguembelina hariaensis* just below this interval, however, indicates uppermost Maastrichtian for this interval.

T4. Maastrichtian and Danian planktonic foraminifers, p. 93.

Maastrichtian

The Maastrichtian occurs from samples 509.5 to 560.0 ft (155.34 to 170.73 m), which are placed largely in the Navesink Formation except for the top 1 ft (0.3 m), which is placed in the Hornerstown Formation (Table T4). The base of the Navesink Formation is placed at 566.1 ft (172.59 m). The highest occurrences (HOs) of *Globotruncana linneiana* at 550 ft (167.64 m) and *Rosita fornicata* identify the top of the lower Maastrichtian *Globotruncana aegyptiaca* Zone. The upper Maastrichtian marker species *Gansserina gansseri* was not identified at Sea Girt, probably because of shallow paleodepth. The entire Maastrichtian section occurs within the Navesink sequence, which extends into the basal Danian with a shallowing upward HST across the K/Pg boundary (Olsson et al., 2002).

Campanian

From 570.4 to 835.0 ft (179.90 to 254.57 m), 28 samples were examined in the Mount Laurel, Wenonah, Marshalltown, and upper Englishtown Formations for planktonic foraminifers (Tables T5). Samples were taken every 5 ft (1.5 m) in the transgressive Marshalltown Formation and usually every 10 ft (3.0 m) in the regressive highstand formations, where recovery of foraminifers was expected to be sparse or none.

T5. Campanian planktonic foraminifers, p. 94.

Planktonic foraminifers were few and very rare in the Mount Laurel, Wenonah, and Marshalltown Formations. Except for one sample, the upper Englishtown Formation was barren of planktonic foraminifers (Table T5). None of the recovered species were zonal markers.

Turonian–Cenomanian

The Bass River Formation (1290.7–1495.0 ft; 393.51–455.79 m) was sampled from 1346.0 to 1477.0 ft (410.36 to 450.30 m), where foraminifers were first noted; the upper section is barren. Planktonic foraminifers (Table T6) were abundant in only one sample (1396.0 ft; 425.61 m). The most common species identified in the formation were *Guembelitria cenomana* and *Whiteinella archeocretacea*. Foraminifers were sparse or absent in most samples and diversity was very low, reflecting the shallow inner shelf paleoenvironment. The interval from 1456.0 to 1500.0 (443.90 to 457.32 m) was barren, as was sample 1431.0 ft (436.28 m). The Cenomanian/Turonian boundary, based on planktonic foraminifers, could not be identified because *Rotalipora* did not occur, again reflecting the shallow paleodepth.

T6. Cenomanian–Turonian planktonic foraminifers, p. 95.

Benthic Foraminifers

Cenozoic

Benthic foraminifers from the Eocene are generally abundant (Table T7), well preserved, and record environments ranging from middle to outer neritic paleodepths. The exceptions are from 140 to 171 ft (42.67 to 52.12 m), which is barren, and from 346 to 365 ft (111.25 to 105.46 m), which contains very few, poorly preserved specimens. Upper middle Eocene Sequence E8 (140–236.1 ft; 42.67–71.96 m) contains an assemblage including *Cibicidina*, *Globobulimina*, *Guttulina*, *Gyroidinoides*, *Lenticulina*, and *Pararotalia*. The sample at the base of the sequence (235 ft; 71.63 m) is dominated by *Cibicidoides* aff. *subspiratus* and was deposited at paleodepths of ~100 m (Biofacies C of Browning et al., 1997).

T7. Eocene benthic foraminifers, p. 96.

The remainder of the sequence is dominated by species of *Cibicidina*, *Globobulimina*, and *Pararotalia,* indicating paleodepths of ~50 m (Biofacies A of Browning et al., 1997).

Sequence E7 (235–265 ft; 71.63–80.77 m) is dominated by species of *Alabamina*, *Cibicidoides*, *Guttulina*, *Gyroidinoides*, *Lenticulina*, and *Stilostomella*. Samples at the base of the sequence (251–261 ft; 76.70–79.55 m) are dominated by *C. subspiratus,* indicating paleodepths of ~135 m (Biofacies G of Browning et al., 1997). Samples at the top of the sequence (241–246 ft; 73.46–74.98 m) are dominated by *Alabamina* and *Hanzawaia,* indicating paleodepths of ~75 m (Biofacies B of Browning et al., 1997). One sample was examined from Sequence E5 (265–271 ft; 80.77–82.60 m). It contains *C. subspiratus*, *Eponides*, and *Lenticulina*, indicating paleodepths of ~135 m (Biofacies G of Browning et al., 1997).

Sequences in the Manasquan Formation contain the deepest paleowater depths recovered in the Eocene. Sequence E3 (271–318 ft; 82.60–96.93 m) contains four different biofacies that record deepening in the TST and slow shallowing in the HST. The sample at 316 ft (96.32 m) is dominated by *Cibicidoides* aff. *pseudoungerianus,* indicating paleodepths of ~100 m (Biofacies C of Browning et al., 1997). Samples from 290 to 311 ft (88.39 to 94.79 m) are dominated by *C.* aff. *subspiratus* indicating paleodepths of ~155 m (Biofacies E of Browning et al., 1997). A sample at 286 ft (87.17 m) is dominated by *Siphonina claibornensis,* indicating paleodepths of ~125 m (Biofacies D of Browning et al., 1997). Samples at the top of the sequence (271–281 ft; 82.60–85.65 m) are dominated by *C.* aff. *pseudoungerianus,* indicating shallowing to ~100 m. (Biofacies C of Browning et al., 1997). Sequence E2 (318–359 ft; 96.93–109.42 m) contains *Gavelinella capitata* and *Cibicidoides eocaenus* in samples from 326 to 341 ft (99.36 to 103.94 m), indicating paleodepths of ~185 m (Biofacies F of Browning et al., 1997). The sample at 321 ft (97.84 m), the top of the sequence, is dominated by *C.* aff. *subspiratus,* indicating paleodepths of ~155 m (Biofacies E of Browning et al., 1997).

Paleocene sequences generally contain few fossiliferous samples. Three samples (366, 371, and 376 ft; 111.56, 113.08, and 114.60 m) from the upper Paleocene–lowermost Eocene unnamed clay contain a fauna dominated by *Pulsiphonina prima,* indicating middle neritic paleodepths. Samples in the Vincentown Formation between 386 and 446 ft (117.65 and 135.94 m) are barren. A sample at 456 ft (138.99 m), near the base of Sequence Pa3, contains a fauna that includes *Tappanina selmensis,* indicating an outer neritic paleoenvironment. A sample (466 ft; 142.04 m) from Sequence Pa2 is dominated by *P. prima* but also contains *T. selmensis,* indicating middle to outer neritic paleodepths. Sequences Pa1a and Pa1b at the base of the Hornerstown Formation contain a general midway benthic foraminiferal fauna, indicating middle neritic paleodepths.

Maastrichtian

Benthic foraminiferal Biofacies 1–4 were first established in the Navesink sequence at the Bass River corehole. They are a useful means of correlation and establishing whether the Maastrichtian section is complete. These biofacies can be recognized in the Sea Girt corehole, allowing correlation with the other New Jersey coreholes. The occurrence of benthic foraminiferal species is shown in Table **T8.** Biofacies 2, which consistently occurs in all New Jersey coreholes at the top of the Maastrichtian and extends into the basal Danian, is characterized by the occurrence of *Alabamina midwayensis* and *Anomalinoides acuta*. This

T8. Maastrichtian benthic foraminifers, p. 98.

indicates that the topmost part of the Maastrichtian is present at the Sea Girt corehole despite the absence of planktonic foraminiferal markers. The downhole appearance of several biofacies species and planktonic zonal species is a useful correlation tool among New Jersey coreholes. Correlation of the Sea Girt corehole with other coreholes is shown in Figure F9.

Campanian

Benthic foraminifers were common in the Mount Laurel, Wenonah, and Marshalltown Formations. They ranged from numerous in some samples to few in other samples (Table T9). The upper Englishtown Formation varied from intervals that were barren to intervals with a scattering of foraminifers, reflecting the inner shelf to shoreface paleoenvironment. The most common species is *Lenticulina pseudosecans,* which was also present in samples of the Marshalltown Formation. Foraminifers were most abundant in the basal part of the Marshalltown Formation (676.0–681.0 ft; 206.10–207.62 m), reflecting the initiation of a transgressive cycle. The rest of the assemblages in the Mount Laurel Formation indicate a shallowing HST deposited in inner shelf paleodepths. Foraminifers were most abundant in the top sample of the Mount Laurel Formation, probably representing bioturbation and mixing with the overlying transgressive Navesink Formation.

T9. Campanian benthic foraminifers, p. 100.

Cenomanian–Turonian

Benthic foraminifers (Table T10) range from numerous to very rare in the Cenomanian–Turonian Bass River Formation. The lower interval from sample 1460.0 ft (445.12 m) was barren. Species of *Epistomina* were most useful in establishing correlation with the Bass River corehole and in placing the Cenomanian/Turonian boundary. The samples in the Turonian interval contain *Epistomina chapmani* and *Epistomina stelligera*, placing this interval in the lowermost Turonian below the interval with *Epistomina sliteri* and *Epistomina lenticularia* in the Bass River corehole. The Cenomanian/Turonian boundary is placed between samples 1415.0 ft (431.40 m) and 1421.0 ft (433.23 m) on the first occurrence of *Epistomina suturalis*. The diagnostic Cenomanian species *G. cenomana* was identified in sample 1445.0 ft (440.55 m), where it is common. The benthic foraminiferal assemblage of the Bass River Formation indicates a shallow inner shelf paleodepth of ~30 m or less.

T10. Cenomanian–Turonian benthic foraminifers, p. 101.

Calcareous Nannofossils

Cenozoic

A total of 75 samples, taken at regular intervals of ~5 ft (1.52 m) between 141 and 508.5 ft (42.98 and 154.99 m), were analyzed for calcareous nannofossil biozonal interpretation. Examination with a Zeiss standard microscope at magnifications of ×600 and ×1200 was conducted on smear slides prepared directly from small amounts of sediment. A species inventory was attempted for every assemblage, but no quantitative record was established. Instead, attention was given to recovering markers species and determining their lowest occurrences (LOs) and/or HOs (Table T11). The biozonal framework used is that of Martini (1971) and Martini and Müller (1986).

T11. Cenozoic nannoplankton, p. 102.

In general, calcareous nannofossil abundance varies from common to rare throughout the section (Table T11). However, two intervals were barren: from 141 to 166 ft (42.98 to 50.60 m) and 401 to 446 ft (122.22 to 135.94 m). In addition, the lowermost 3.5 ft (1.07 m) of the section yielded extremely rare calcareous nannofossils. Diversity is low at most levels, but remarkably high in the lower middle Eocene (266 and 271 ft; 81.08 and 82.60 m; Subzone NP14a). Assemblages are generally rich in representatives of the genera *Helicosphaera*, *Pontosphaera,* and *Rhabdosphaera*, possibly reflecting coastal proximity. In contrast, they are generally poor in discoasters, except in the lower middle and upper lower Eocene (266–316 ft; 81.08–96.32 m; Subzone NP14a and Zone NP12). Notable are the absence of *Discoaster mohleri* (marker base of Zone NP7) and the scarcity of *Sphenolithus furcatolithoides* (a common marker of the Zones NP15–NP16 interval), *Chiasmolithus grandis* (whose HO marks the top of Zone NP17), *Discoaster barbadiensis*, *Discoaster saipanensis,* and *Ericsonia formosa*, Eocene taxa generally common at middle latitudes.

The 367-ft-thick (111.86 m) section examined is Paleogene, spanning the middle Eocene (Bartonian; Zone NP17) to lowermost Paleocene (lower Danian; Zone NP1). It is highly discontinuous, however, with most zonal boundaries occurring at unconformable contacts.

The youngest datable level (171 ft; 52.12 m) belongs to Zone NP17, as indicated by the scarce occurrence of *C. grandis* and *Sphenolithus celsus* and the absence of *Chiasmolithus oamaruensis*, the LO of which defines the base of Zone NP18. This co-occurrence was observed in the Barton beds of England (Aubry, 1983, 1985). Zone NP17 extends to 186 ft (56.69 m) and is characterized by the presence of *Chiasmolithus expansus, Corannulus germanicus, Cruciplacolithus delus, Helicosphaera wilcoxonii, Reticulofenestra reticulata, Reticulofenestra umbilicus,* and *Neococcolithes minutus*.

Samples at 191 and 196 ft (58.22 and 59.74 m) have yielded essentially uncharacteristic assemblages. A few placoliths of *Chiasmolithus solitus* were recovered at 196 ft (59.79 m). On this basis, 196 ft (59.79 m) is assigned to Zone NP16 and 191 ft (58.22 m) to Zone NP17.

The interval from 201 to 235 ft (61.26 to 71.35 m) belongs to Zone NP16. The assemblages include, among others, *C. solitus* (common except at 201 ft [61.26 m]), *C. grandis, C. germanicus, Daktylethra punctulata, Discoaster barbadiensis* (rare), *Discoaster tanii nodifer* (rare), *Helicosphaera seminulum, Pontosphaera wechesensis*, and occasionally *S. furcatolithoides* (206 ft; 62.79 m). The lowest occurrence of *R. reticulata* at 226 ft (68.88 m) marks the upper part of the zone.

There is a sharp difference in the composition of the assemblages at 235 ft and 241.5 ft (71.63 and 73.61 m). *R. umbilicus* is common and large at 235 ft (71.63 m) and absent at 241.5 ft (73.61 m). Both *Nannotetrina* sp. (overgrown) and *Chiasmolithus gigas* occur at this latter level, characterizing Subzone NP15b. *Blackites gladius*, the HO of which marks the top of Zone NP15, was not encountered, nor was *Discoaster bifax,* a species often used as a substitute marker for the base of Zone NP16. However, the frequency and size of *R. umbilicus* at 235 ft (71.63 m) is indicative of Zone NP16. *C. gigas* and overgrown specimens of *Nannotetrina* (remarkably abundant at 261 ft [79.55 m]) occur consistently between 241.5 and 261 ft (73.61 and 79.55 m), an interval thus assigned to Subzone NP15b.

Samples from 266 and 271 ft (81.08 and 82.60 m) are well characterized by abundant, well preserved, and diverse assemblages. These include *C. solitus, C. expansus, C. grandis, D. barbadiensis, Discoaster bou-*

langeri, Discoaster distinctus, Discoaster mirus, Discoaster nonaradiatus, Discoaster septemradiatus, Discoaster wemmelensis, Helicosphaera lophota, Helicosphaera seminulum, Lophodolithus mochlophorus, Lophodolithus nascens, and *Trochastrites hohnensis*. The occurrence of *Discoaster sublodoensis,* with common *Discoaster lodoensis* and rare (at 271 ft) *Discoaster kuepperi,* characterizes lower middle Eocene Subzone NP14a. *Tribrachiatus orthostylus* and *D. lodoensis* co-occur in the 276–316 ft (84.12–96.32 m) interval that is therefore assigned to Zone NP12.

There is an abrupt change in assemblage composition between the sample at 316 ft (96.32 m), where discoasters, among which *D. lodoensis* are common, and the sample at 321 ft (97.84 m), where discoasters are rare and there was no *D. lodoensis*. The absence of *D. lodoensis* at 321 ft (97.84 m) is not taken to reflect the scarcity of discoasters, because similar assemblages occur from this level to 356 ft (108.51 m). In this interval, *T. orthostylus* is common, associated with *Discoaster binodosus* and *D. kuepperi*, a trilogy characteristic of Zone NP11. The occurrences of *Discoaster pacificus* (scarce), *Discoaster multiradiatus,* and *Ellipsolithus macellus* support this zonal assignment.

The interval from 366 to 386 ft (111.56 to 117.65 m) yields rare to very rare calcareous nannofossils and is tentatively assigned to Zone NP9, based on the occurrence of *Discoaster perpolitus*, a species very closely related to *D. multiradiatus* (Romein, 1979). We note the absence of *Fasciculithus* spp. in this interval and the occurrence of *Discoaster anartios* at 376 ft (114.60 m), the occurrence of which marks the base of Subzone NP9b and with a range that is restricted to the stratigraphic extent of the carbon isotope excursion (Kahn and Aubry, 2004).

The HO of *Fasciculithus tympaniformis* lies at 391.5 ft (119.33 m). The interval between this level and 396 ft (120.70 m), in which *D. perpolitus* and *F. tympaniformis* co-occur, belongs to Subzone NP9a. *Heliolithus riedeli* is common at 451 and 460 ft (137.46 and 140.21 m), both assigned to Zone NP8. In the absence of *H. riedeli* and the presence of *Heliolithus kleinpelli* and *Discoaster helianthus*, 461 ft (140.51 m) is tentatively assigned to Zone NP7. *Discoaster mohleri* was not encountered at Sea Girt. *H. kleinpelli* is abundant at 466 ft (142.04 m), which belongs to Zone NP6. Samples at 471 and 476 ft (143.56 and 145.08 m) yield *E. macellus, Fasciculithus billi, Fasciculithus janii,* and *Sphenolithus primus*. In the absence of *F. tympaniformis,* they are assigned to Subzone NP4b. The LO of *E. macellus* lies at 494.7 ft (150.78 m), marking the base of Zone NP4. Consequently, the interval between this level and 481 ft (146.61 m) is assigned to Subzone NP4a. *Cruciplacolithus tenuis* is rare at 501 ft (152.70 m), whose assemblages include *Cyclagelopshaera alta, Cyclagelopshaera margereli, Placozygus sigmoides,* and Cretaceous species. Samples from 505 and 507 ft (153.92 and 154.53 m) are essentially barren. *Markalius inversus* and *Cyclagelosphaera* occur at 508 ft (154.84 m), without *Cruciplacolithus primus*. This level, with extremely rare coccoliths, probably belongs in the lower Danian Subzone NP1a.

Based on calcareous nannofossil stratigraphy alone, several unconformities are inferred in the sedimentary succession recovered from the Sea Girt corehole. The youngest unconformity is between 235 and 241.5 ft (71.63 and 73.61 m; lower Zone NP16 and Subzone NP15b). As mentioned above, the contrast in the composition of the assemblages at these levels is indicative of a stratigraphic gap, which encompasses all of Subzone NP15c. The next two unconformities occur between 261 and 266 ft (79.55 and 81.08 m; Subzones NP15a and NP14a) and between 271 and 276 ft (82.60 and 84.12 m; Subzones NP14a and Zone NP12) and belong to the set of unconformities associated with the lower/middle Eocene boundary on the western margin of the North Atlantic (Aubry, 1995).

The sharp change in assemblage composition between 316 and 321 ft (96.32 and 97.84 m), in particular the abrupt decrease in *D. lodoensis* from common at 316 ft (96.32 m) to absent at 321 ft (97.84 m), and preservation is suggestive of a stratigraphic gap between Zones NP12 and NP11.

The interval between 361 and 446 ft (110.03 and 135.94 m) is difficult to interpret. In contrast, two unconformities are easily inferred between 466 and 471 ft (142.04 and 143.56 m; Zone NP6 and Subzone NP4b) and between 494.7 and 501.0 ft (150.78 and 152.70 m; Zone NP2). It is likely that the Zone NP8/NP7/NP6 boundaries also represent unconformable contacts.

Cretaceous

We obtained 100 samples from the Sea Girt corehole for Cretaceous nannofossil studies, which compose an average ~10 ft (3 m) sampling interval for the 1090.5 ft (332.38 m) of Cretaceous section (from 509.5 ft to TD [155.30 m to TD]). No samples were obtained for nannofossil study, however, from the nonmarine Magothy or Potomac Formations and a closer spaced sampling was done for the Navesink and Merchantville Formations. Smear slides were prepared at Pennsylvania State University in the laboratory of T. Bralower using standard techniques and examined by L. deRomero under the light microscope at ×1250 magnification.

The nannofossil zonation and CC terminology of Sissingh (1977) were used to divide the section. Several of the Sissingh (1977) zones have been modified by Perch-Nielsen (1985), based largely on reclassification of the names of original species and genera. Perch-Nielsen (1985) also defined several zonal subunits, and these are also applied here. Zones defined by Bralower (1988) have been applied to the Cenomanian/Turonian boundary interval. All zones are correlated to stages according to the scheme of Gradstein et al. (1995).

Santonian–Maastrichtian calcareous nannofossils are generally abundant and common, allowing biostratigraphic zonation. Samples from 510 to 525 ft (155.45 to 160.02 m) contained *Nephrolithus frequens* and were assigned to upper Maastrichtian Zone CC26. Samples between 530 and 555 ft (161.54 and 169.16 m) were assigned to middle Maastrichtian Zone CC25. The sample at 560 ft (170.69 m) contained *Reinhardtites levis* and *Quadrum trifidum* and is assigned to Subzone CC23a. The highest occurrence of *Broinsonia parca* at 565 ft (172.21 m) indicates the top of Subzone CC23a. The absence of Zone CC24 could indicate an unconformity between 555 and 560 ft (169.165 and 170.69 m); however, both of the Zone CC23 samples (upper Campanian) are from the basal Maastrichtian Navesink Formation and probably reflect reworking from the underlying Mount Laurel Formation. The sample at 570.4 ft (173.86 m) is assigned to Subzone CC22b/c, based on the highest occurrence of *Reinhardtites anthophorus*. The sample at 581 ft (177.09 m) is assigned to upper Campanian Subzone CC22a based on the HO of *Quadrum grillii* and the LO of *Q. trifidum*. Samples between 591 and 621.3 ft (180.14 and 189.37 m) are assigned to middle Campanian Zone CC21. The LO of *Ceratolithoides aculeus* at 721 ft (219.76 m) indicates that samples from 631 to 721 ft (192.33 to 219.76 m) are assigned to middle Campanian Zone CC20, based on the presence of *C. aculeus*. Samples from 730.3 to 891 ft (222.60 to 271.58 m) are assigned to lower Campanian Zone CC19 based on the HO of *Marthasterites furcatus* at 901.0 ft (274.62 M). Samples from 901 to 961 ft (274.62 to 292.91 m) are assigned to Zone CC18, from the HO of *M. furcatus* to the LO of *Aspidolithus parca*. Samples from 964.4 to 1060 ft (293.95 to 323.09 m) were initially assigned to upper Santonian Zone CC17 based on the absence of *Eprolithus florilus*. Because of the rare occurrences of holococcoliths in the interval from 1030 to 1065 ft (313.94 to 324.61 m) at Sea Girt, zonal assignment is less certain. Based on reevaluation and comparison with Bass River, samples from 1001.0 to 1050.6 ft (305.10 to 322.05 m) are assigned to Zones CC16–CC17 based on the presence of *Lucianorhabdus cayeuxi* and the absence of *Lithastrinus moratus,* which is present in Zone CC15 in Bass River. The presence of *Ahmuellerella regularis* throughout the interval indicates a probable assignment to upper Zone CC16 or higher. Samples from 1060 and ~1291 ft (323.09 and 393.50 m) were not examined for calcareous nannofossils.

Nannofossil biostratigraphy places constraints on the Cenomanian–Turonian Bass River Formation. Samples from the upper Bass River Formation are barren (1290.7–1356.0 ft; 393.41–413.31 m). The section from 1356 to 1417.5 ft (413.31 to 432.05 m) is assigned to uppermost Cenomanian–lower Turonian Subzone CC10b to Zone CC11 based on the presence of *Gartnerago segmentatum* and *Isocrystallithus compactus* and the absence of *Lucianorhabdus maleformis* and *Eiffellithus eximius*. The Cenomanian/Turonian boundary is tentatively placed at 1417.5 ft (432.05 m), between samples at 1415 and 1420 ft (431.25 and 432.82 m), based on the HO of *Microstaurus chiastius* and *Lithraphidites acutus*. Sample 1420.0 ft (432.82 m), however, is the only one in which *M. chiastius* and *L. acutus* were found and also has the best preservation. Thus, the Cenomanian could extend above 1417.5 ft (432.05 m). The section from 1417.5 to 1446.5 ft (432.05 to 440.89 m) is assigned to upper Cenomanian Subzone CC10a based on the HO of *M. chiastius* and *L. acutus*. Samples from 1446.5 to 1506.2 ft (440.89 to 459.09 m) are barren.

Pollen

A total of 19 samples were analyzed from the Sea Girt corehole for palynomorphs, pollen, and spores (Table T12) ranging in age from Neogene to lower Cenomanian. Specimens in samples analyzed above 1106.7 ft (337.32 m) were generally poorly preserved and were not useful for biostratigraphic zonation. Samples below 1106.7 ft (337.32 m; Santonian and older) had better preservation and generally contained biostratigraphically useful pollen. Samples are assigned ages using the zonations of Brenner (1967) and Doyle and Robbins (1977).

T12. Pollen and dinocysts, p. 103.

Four samples were analyzed from the Cape May and Kirkwood Formations (30, 64.5, 103, and 120 ft; 9.14, 19.66, 31.39, and 36.58 m). Preservation in these samples was generally poor. The samples contained Miocene–Holocene pollen.

We analyzed 15 samples to help determine the age relationships of the Magothy, Bass River, and Potomac Formations. Samples at 1070.6 and 1080.5 ft (326.32 and 329.34 m) contained only fusain and did not contain palynomorphs. Samples at 1106.7 and 1136.3 ft (337.32 and 346.34 m) are assigned to Zone VII based on the presence of *Heidelbergipollis* sp. A and *Trudopollis* sp. B. Samples from 1183.2 and 1241.2 ft (360.34 and 378.32 m) contain *Poropollenites* sp., *Complexipollis* sp. E, and *Complexipollis* sp. B and are assigned to Zone V (equivalent to the South Amboy Fire Clay in outcrop). Samples at 1263.6 and 1284.5 ft (385.15 and 391.52 m) were barren. Samples from 1317.0 to 1410.7 ft

(401.42 to 429.98 m) are assigned to pollen Zone IV. The sample at 1317.0 ft (401.42 m) contains *Atlantopollis* sp., typical of the Woodbridge Clay Member of the Raritan Formation (the updip equivalent of the Bass River Formation). The sample at 1410.7 ft (429.98 m), although possibly brackish water, contains *Complexipollis* sp. P, an index form for the Raritan Formation in outcrop. The boundary between Zones IV and III is uncertain because the sample at 1511 ft (460.55 m) is almost barren. The sample at 1541.3 ft (469.79 m) contains a well-preserved flora assigned to Zone III, based on the occurrence of *Tricolpites vulgaris* and *Tricoporites subtlus*. The lowest sample, examined at 1560.3 ft (475.58 m), contains no diagnostic pollen.

STRONTIUM ISOTOPE CHRONOSTRATIGRAPHY

Sr isotopic age estimates were obtained from mollusk shells (Table T13). Approximately 4–6 mg of shells was cleaned in an ultrasonic bath and HCl and dissolved in 1.5-N HCl. Sr was separated using standard ion-exchange techniques (Hart and Brooks, 1974). The samples were analyzed on an Isoprobe T Multicollector thermal ionization mass spectrometer (TIM). Internal precision on the mass spectrometer for the data set averaged 0.000012, and the external precision is approximately ±0.000020 (Oslick et al., 1994). Internal precision on the Isoprobe for the data set averaged 0.000007, and the external precision is approximately ±0.000010, based on replicate analyses of standards. National Bureau of Standards (NBS) 987 was measured for these analysis at 0.710255 (2σ standard deviation 0.000008, $N = 22$) normalized to ^{86}Sr/^{88}Sr of 0.1194 for the mass spectrometer and 0.710241 for the TIM.

T13. Sr isotopic data, p. 104.

Insufficient carbonate was recovered from the Miocene section to allow Sr isotopic analyses. Correlations in these sections are based on superposition and sparse planktonic foraminifers. The Oligocene was not identified in the Sea Girt corehole.

Cretaceous ages were assigned using linear regressions developed for upper Coniacian through Maastrichtian sections by Miller et al. (2004). Using a similar late Campanian–Maastrichtian regression, Sugarman et al. (1995) conservatively estimated age errors of ±1.9 m.y. at the 95% confidence interval for one Sr isotopic analysis; age errors for the coeval and older sections are purportedly one order of magnitude better according to Howarth and McArthur (1997). We estimate that the maximum Sr isotopic age resolution for this interval is from ±0.5 to ±1.0 m.y. (i.e., the external precision of 0.000010 divided by the slopes of the regressions of ~0.000020/m.y.).

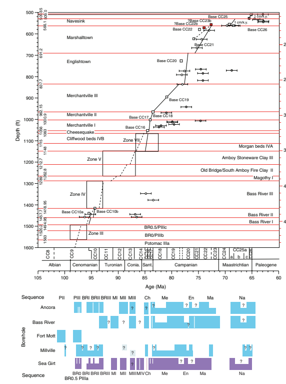
Most of the Sr analyses from shells below 691.2 ft (210.68 ft; i.e., below the Marshalltown sequence) yielded ages much younger than those predicted from calcareous nannofossil biostratigraphy. The discrepancy grew more pronounced deeper in the borehole. We conclude that the original Sr ratios in the carbonate have been altered and the Sr ages are not reliable below 691.2 ft (210.68 ft).

Sr isotopic ages were obtained from 10 samples in the Navesink Formation (Table T13). These samples yielded ages in two clusters. Seven samples (520.5–547.2 ft; 155.60–166.79 m) yield ages ranging from 62.8 to 65.0 Ma. These samples are Upper Cretaceous based on nannofossils, foraminifers, and regional correlations, which is within the error of the Sr isotopic ages. Three samples (562.7–563.6 ft; 171.51–171.79 m) yield ages ranging from 68.3 to 69.7 Ma. This is in agreement with calcareous nannofossil biostratigraphy and may indicate that there are two sequences in the Navesink Formation.

Six Sr isotopic ages (some from duplicate depths; 585.8–666 ft; 178.55–203.00 m) were obtained from the Marshalltown sequence (Table T13). The analyses yielded ages ranging from 72.5 to 75.2 Ma. These yield an overall age for the sequence of 72.7–75.8 Ma and a sedimentation rate of ~12 m/m.y.

Eight samples from the upper Englishtown sequence (691.2–837.7 ft; 210.68–255.33 m) yielded seven Sr isotopic dates (including a duplicate sample). Four samples yielded ages much younger (74.6–68.7 Ma) than predicted by calcareous nannofossil biostratigraphy and were affected by diagenesis. They are plotted in gray on Figure F17. The four analyses that agree with calcareous nannofossil biostratigraphy yield ages ranging from 78.2 to 77.7 Ma. These yield an overall age for the sequence of 77.7–72.0 Ma and a remarkably high sedimentation rate of ~63.8 m/m.y. The upper Englishtown sequence might be slightly older at Sea Girt than it is in other coreholes, though age control at other sites is poor to moderate (±2 m.y.). The upper Englishtown sequence was much thinner in other coreholes and the age determined here is believed to be slightly more reliable.

F17. Cretaceous age-depth plot, p. 81.



A total of 18 samples from the Sea Girt corehole below 837.7 ft (255.33 m) yielded ages for the sequences much younger (~2–10 m.y.) than predicted by calcareous nannofossil biostratigraphy and were much younger than the ages determined for those sequences in previously drilled coreholes. These analyses are plotted in gray on Figure F17 and ages for those sequences are determined using calcareous nannofossil biostratigraphy.

SUMMARY AND FUTURE WORK

The Sea Girt corehole recovered expanded sections of the upper Englishtown, Merchantville, Magothy, and Bass River sequences, allowing for

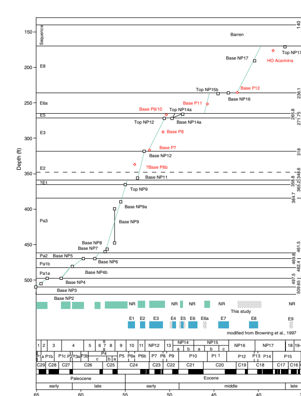
1. Better resolution and dating of Upper Cretaceous sequences, which provides a test of the age and regional significance of sequences cored at Bass River and Ancora;
2. Evaluation of facies models;
3. Ties to nearby outcrop sections, particularly the Magothy Formation and its members; and
4. Evaluation of hydrostratigraphic units.

Resolution of Upper Cretaceous Sequences

Drilling at Sea Girt confirmed the regional significance of the following:

1. The Navesink II (late Maastrichtian to earliest Danian) and Navesink I (early Maastrichtian) sequences;
2. The upper Englishtown Formation and sequence. Though the sequence remains only moderately well dated (worse than 1 m.y. uncertainty) (Fig. F18), drilling confirms that it is a distinct lithostratigraphic and sequence stratigraphic unit deserving its own name;

F18. Cenozoic age-depth plot, p. 82.



3. Two uppermost Santonian sequences within the Merchantville Formation;
4. Two new sequences in the Magothy Formation (Sequences IVA and IVB; Kulpecz, 2005) that were hinted at in outcrop studies but only confirmed by continuous coring;
5. The Magothy I, II, and III as distinct and differentiable sequences (Sea Girt is the first corehole to sample all three); and
6. Division of the Bass River Formation into at least three sequences and possibly five (though the BR0 and BR0.5 sequences might best be called the Potomac IIIb and IIIc sequences). Our previous synthesis of Bass River and Ancora identified 11 to 14 Upper Cretaceous sequences. With Sea Girt, we affirm 14 of these sequences and suggest that there are, in fact, at least 18 sequences.

Improved Facies Models and Correlation with Outcrops

Though facies models for Upper Cretaceous coastal plain sequences have been well described (Owens and Gohn, 1985; Sugarman et al., 1995; Miller et al., 2004), drilling at Sea Girt, because of its critical position in Monmouth County, allows ties of numerous gamma ray logs from various uncored wells into the thickest Upper Cretaceous section cored thus far. This "Rosetta Stone" has allowed the mapping of Upper Cretaceous sequences and the identification of their sediment sources. The Sea Girt corehole has clearly identified the complex facies of the Magothy Formation and allows detailed evaluation of the represented environments (Sugarman et al., 2005). This allows fairly precise pattern matching of the Magothy sequences identified at Sea Girt with members of the Magothy Formation that crop out in nearby portions of Middlesex County, specifically the Magothy IVB (probable equivalent of the Cliffwood Beds), IVA (probable equivalent of the Morgan Beds), III (probable equivalent of the Amboy Stoneware Clay), MII (probable equivalent of the Old Bridge Sand and South Amboy Fire Clay), and MI (probable equivalent of the Sayreville Sand) sequences. Though such pattern matching is risky, the fit between the corehole and the outcrop lithologies is compelling.

Evaluation of Hydrostratigraphic Units

Numerous potential aquifers were penetrated at Sea Girt. Though relatively thin in this updip location, the Kirkwood Formation contains two medium–coarse confined sand beds at ~100 and 110 ft (30.48 and 33.53 m) that may be the updip equivalent of the Atlantic City 800-ft sand aquifer of Zapecza (1989). The upper Shark River Formation fine sands (~136–170 ft; 41.45–51.82 m) appear to be an aquifer in hydrodynamic continuity with these coarser sands. The Mount Laurel Formation (566–670 ft; 172.52–204.22 m) appears to be a good aquifer, but it is the upper Englishtown sands (691–755 ft; 210.62–230.12 m) that comprise the richest of the aquifers. The combined effects of these two aquifers on the corehole almost resulted in the loss of the hole. Several of the sands in the Magothy Formation have potential for groundwater, but the Old Bridge Sand (1212.7–1225 ft; 369.63–373.38 m) appears to be coarsest and have greatest potential. Potential aquifers within the Bass River and Potomac Formations are generally finer grained and thinner, though the possible equivalent to the Farrington Sand (1565–

1580 ft; 477.01–481.58 m) is moderately coarse grained and sufficiently thick to be screened.

Future Work

The Sea Girt corehole provided material needed to address the primary purposes of the coastal plain drilling project: evaluate and date sequences, obtain a paleowater depth record, and thus provide data needed to extract a global sea level record through backstripping. Work is ongoing to provide the age, paleodepth, and porosity data needed to backstrip this site and compare it with published backstripped records from Ancora, Bass River (Van Sickel et al., 2004), and ongoing backstripping studies of Millville. Miller et al. (2005) provided a synthesis that includes a global sea level estimate of the past 100 m.y. that was derived from backstripping onshore coreholes. The Cretaceous portion of this synthesis was based only on records from Bass River and Ancora; we now have the material from Millville and Sea Girt to test the Upper Cretaceous portion of the synthesis.

The Sea Girt borehole will also provide an opportunity to tie Upper Cretaceous sequence into nearshore seismic profiles. Previous seismic correlations of onshore boreholes have been largely limited to Miocene correlations from Island Beach, Atlantic City, and Cape May to the Cape Hatteras 0698 multichannel seismic (MCS) data set (Monteverde et al., 2000). While this has provided insight into the seismic expression of prograding Miocene sequences, it has not provided information on Upper Cretaceous–Paleogene sequences. The thick Upper Cretaceous section at Sea Girt, with its excellent sequence stratigraphic expression, can be tied to a grid collected in May 2003 by G.S. Mountain, N. Christie-Blick, and S. Pekar and C. McHugh in May 2002 that includes Chirp sonar (1-m resolution) and high-resolution (5 m vertical) MCS data (Fig. **F1**), allowing us to evaluate Upper Cretaceous sequences with a resolution not previously possible.

The Sea Girt corehole will provide material for understanding some of the more profound events in Earth history. Though the K/Pg boundary was discontinuous at Sea Girt, the PETM, late Maastrichtian, and Cenomanian–Turonian OAE2 sections are thick and bear further investigation.

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Figure F1. Existing Ocean Drilling Program (ODP), Deep Sea Drilling Project (DSDP), and Atlantic Margin Coring Project (AMCOR) coreholes analyzed as a part of the New Jersey/Mid-Atlantic (MAT) sea level transect. Also shown are multichannel seismic data (MCS) from *Ewing* (Ew9009), *Oceanus* (Oc270), and *Cape Hatteras* (CH0698) cruises. Star = Sea Girt corehole, MN = Monmouth County, OC = Ocean County, BU = Burlington County, CD = Camden County, GL = Gloucester County, AT = Atlantic County, SA = Salem County, CU = Cumberland County, CM = Cape May County.

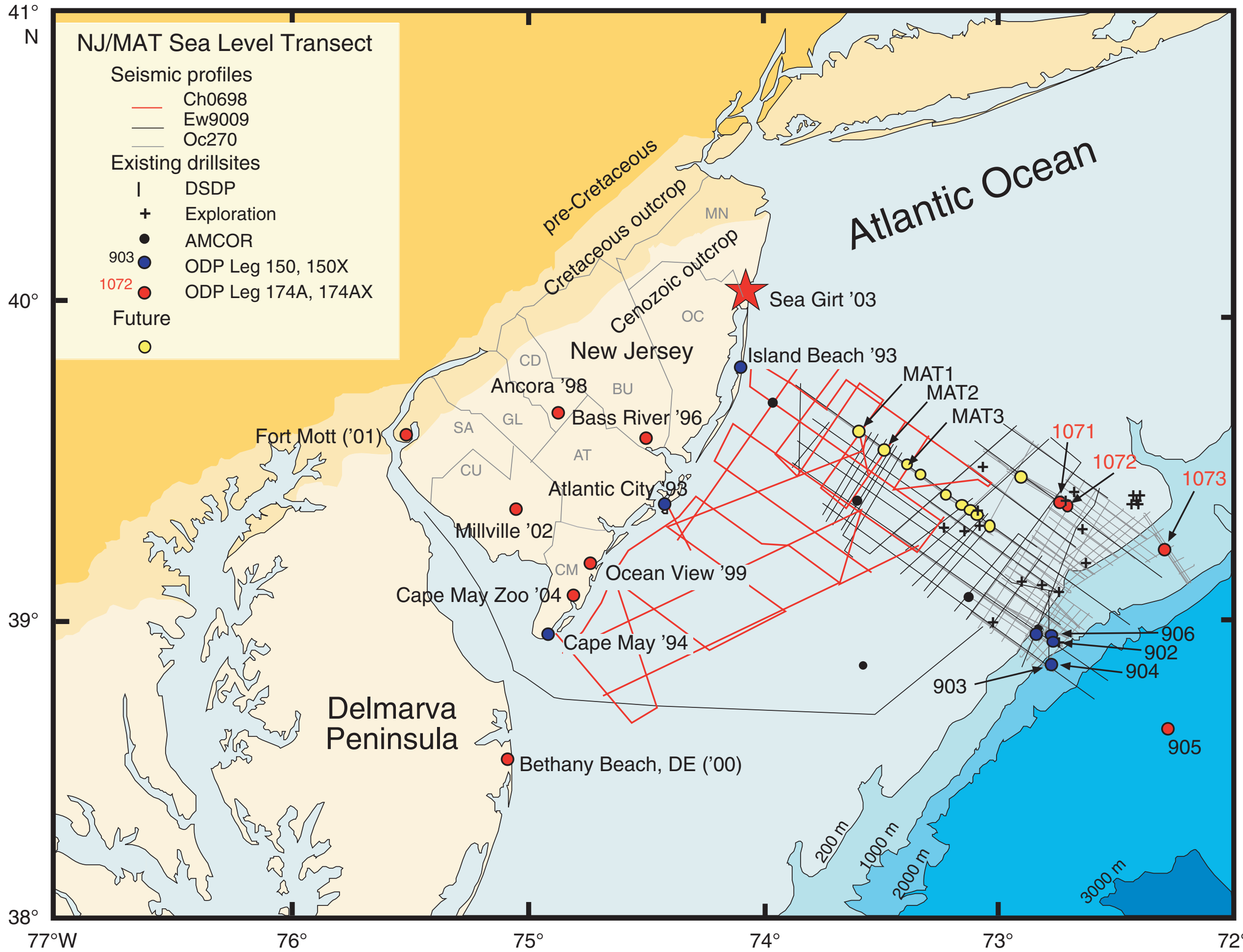

Figure F2. Stratigraphic section summarizing core recovery, lithology, gamma ray log signature, age, and environments for Cape May (Quaternary), Kirkwood (Miocene), and upper Shark River (middle Eocene) Formations in the Fort Mott corehole. F = formaminifer zone, N = nannofossil zone, E = environment. LSF = lower shorefront, MFS = maximum flooding surface.

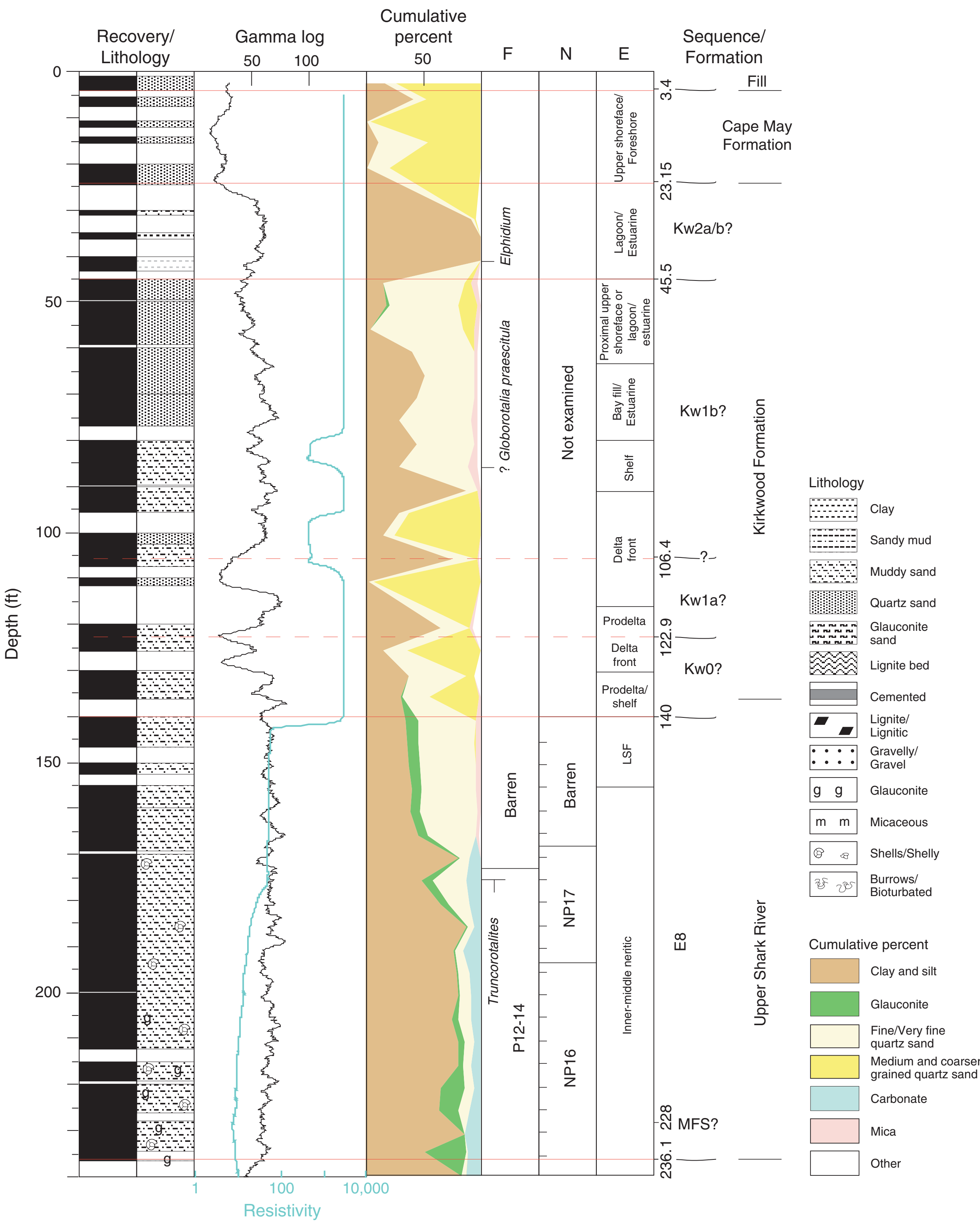

Figure F3. Summary stratigraphic section for lower Shark River (middle Eocene), Manasquan (lower Eocene), the unnamed clay (lowermost Eocene and uppermost Paleocene), and Vincentown (Paleocene) Formations in the Sea Girt corehole. F = formaminifer zone, N = nannofossil zone, E = environment. MFS = maximum flooding surface.

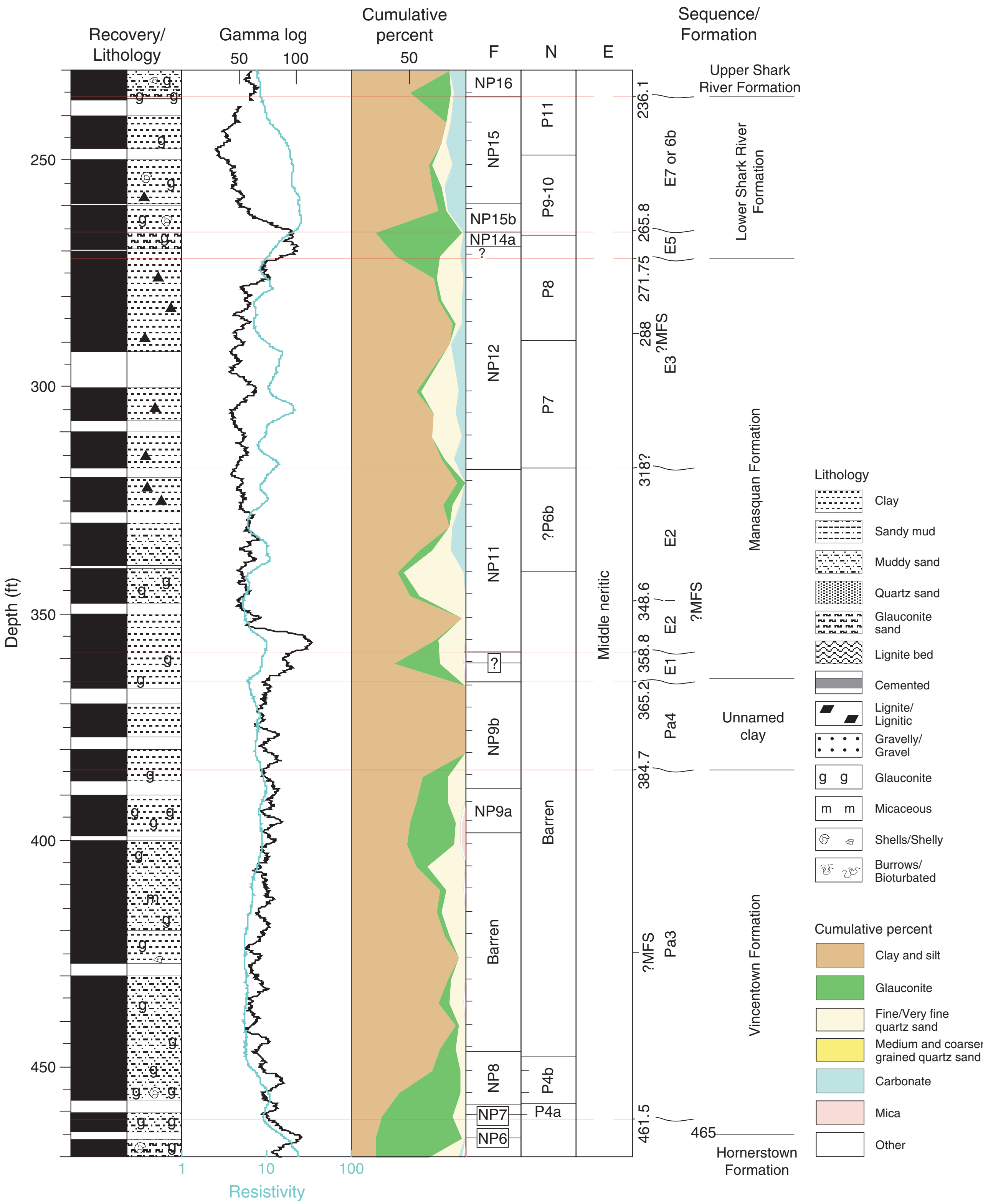

Figure F4. Summary stratigraphic section for Hornerstown (Paleocene), Navesink (Maastrichtian), Mount Laurel (Campanian), Wenonah (Campanian), and Marshalltown (Campanian) Formations in the Sea Girt corehole. N = nannofossil zone, F = formaminifer zone, Sr = strontium age estimates, E = environment, ST = systems tract. LSF = lower shoreface, dUSF = distal upper shoreface, Off. = offshore. HST = highstand systems tract, TST = transgressive systems tract, MFS = maximum flooding surface, TS = transgressive surface, FS = flooding surface.

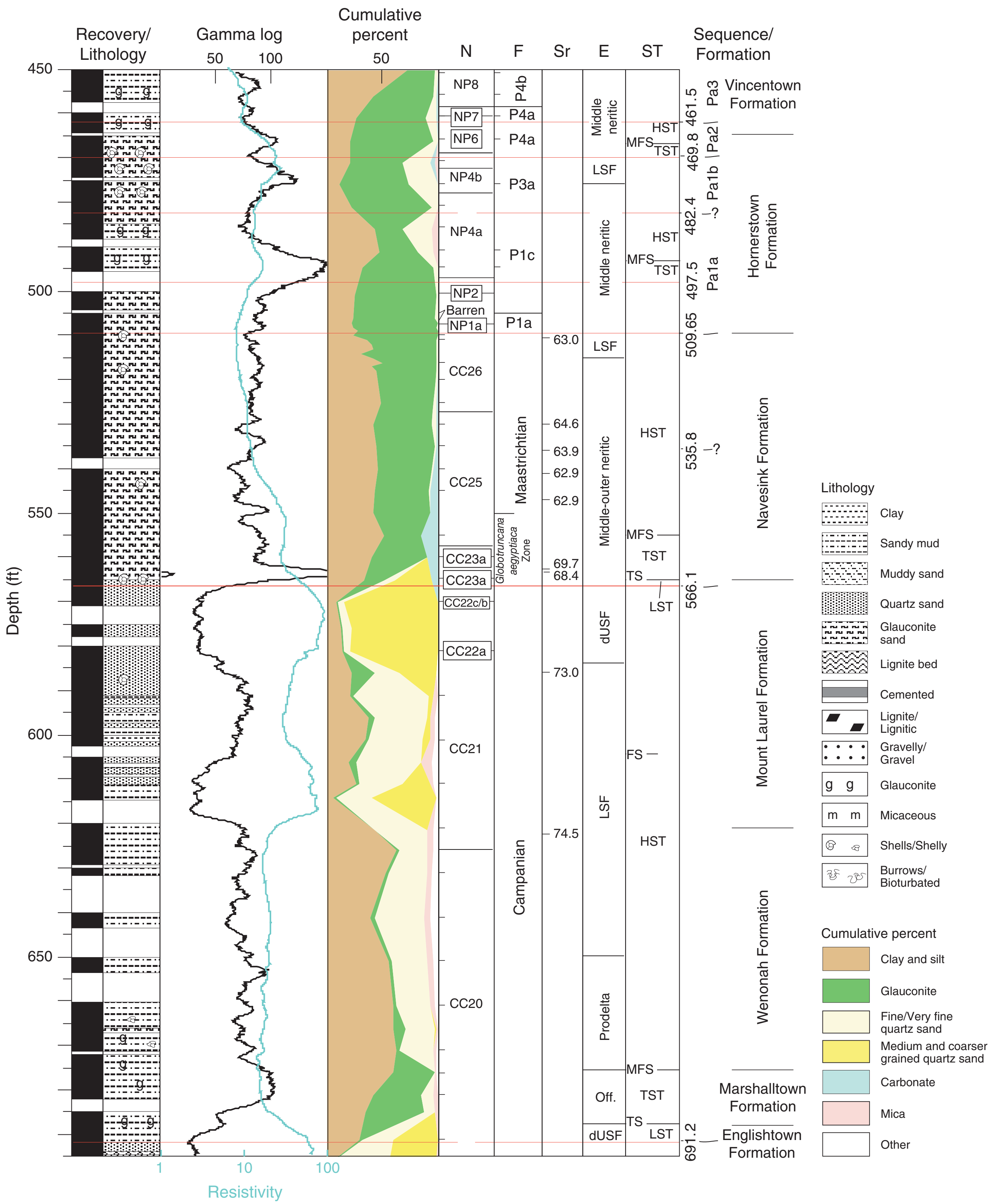

Figure F5. Summary stratigraphic section for upper Englishtown Formation (Campanian) in the Sea Girt corehole. N = nannofossil zone, Sr = strontium age estimate, E = environment, ST = system tract. Off. = offshore, dUSF = distal upper shoreface, LSF = lower shoreface. HST = highstand systems tract, FS = flooding surface, MFS = maximum flooding surface, TST = transgressive systems tract.

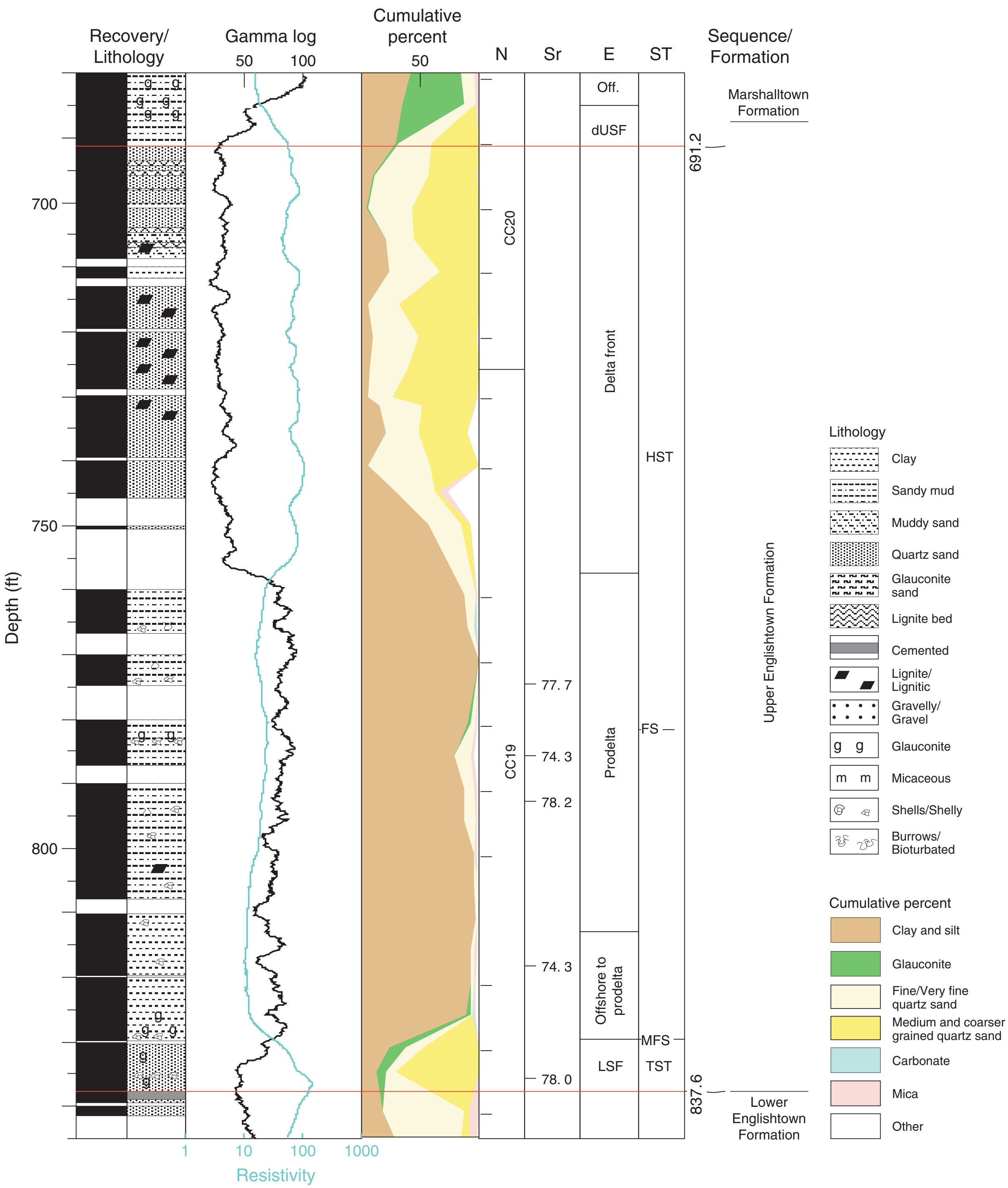

Figure F6. Summary stratigraphic section for lower Englishtown (Campanian), Woodbury (Campanian), Merchantville (Campanian–Santonian), and Cheesequake (Santonian) Formations in the Sea Girt corehole. N = nannofossil zone, E = environment, ST = systems tract. LSF = lower shoreface, HST = highstand systems tract, MFS = maximum flooding surface, TST = transgressive systems tract, FS = flooding surface.

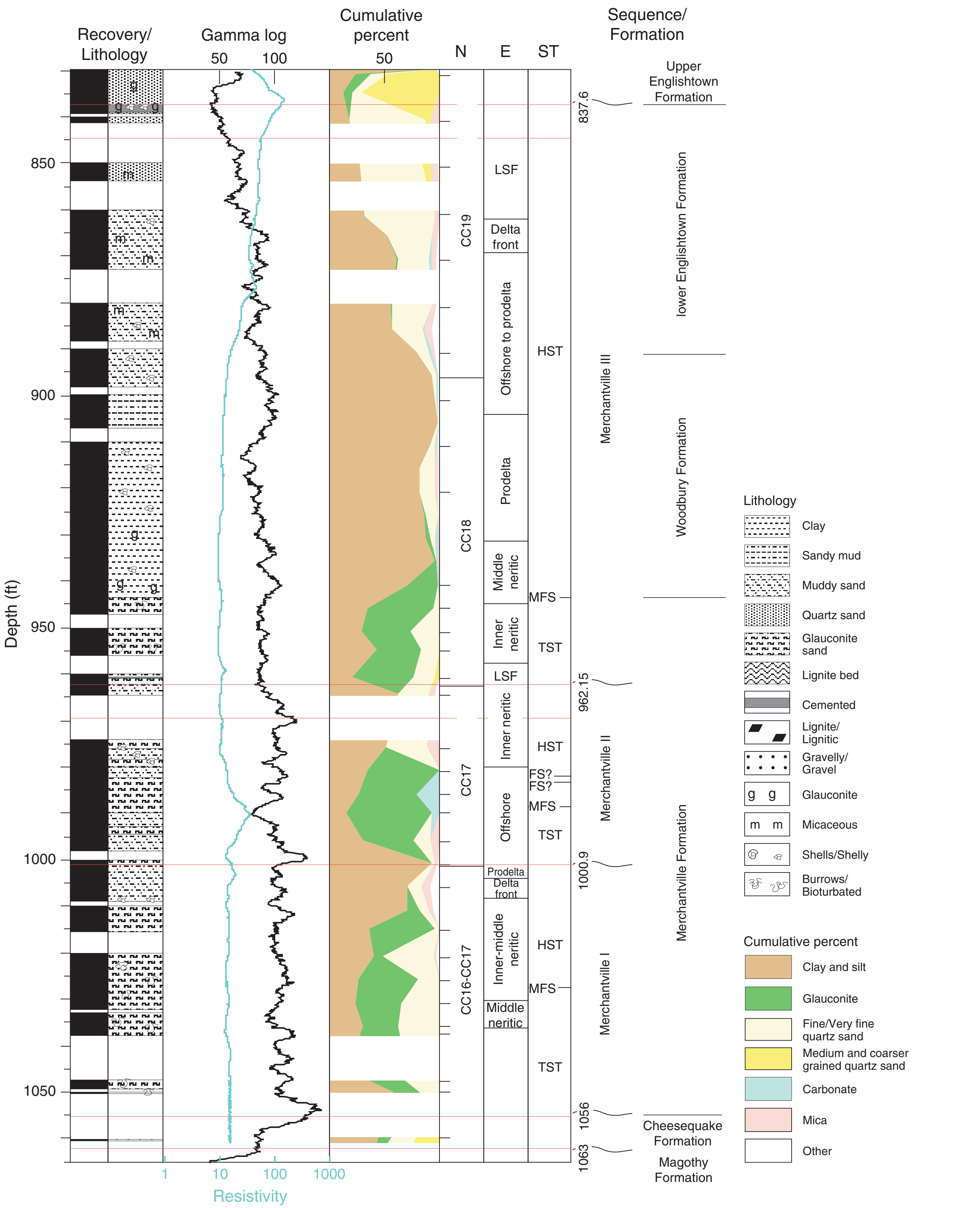

Figure F7. Summary stratigraphic section for Magothy Formation (undifferentiated early Turonian–Santonian [?Coniacian]) in the Sea Girt corehole. E = environment. B = barren, pUSF = proximal upper shoreface.

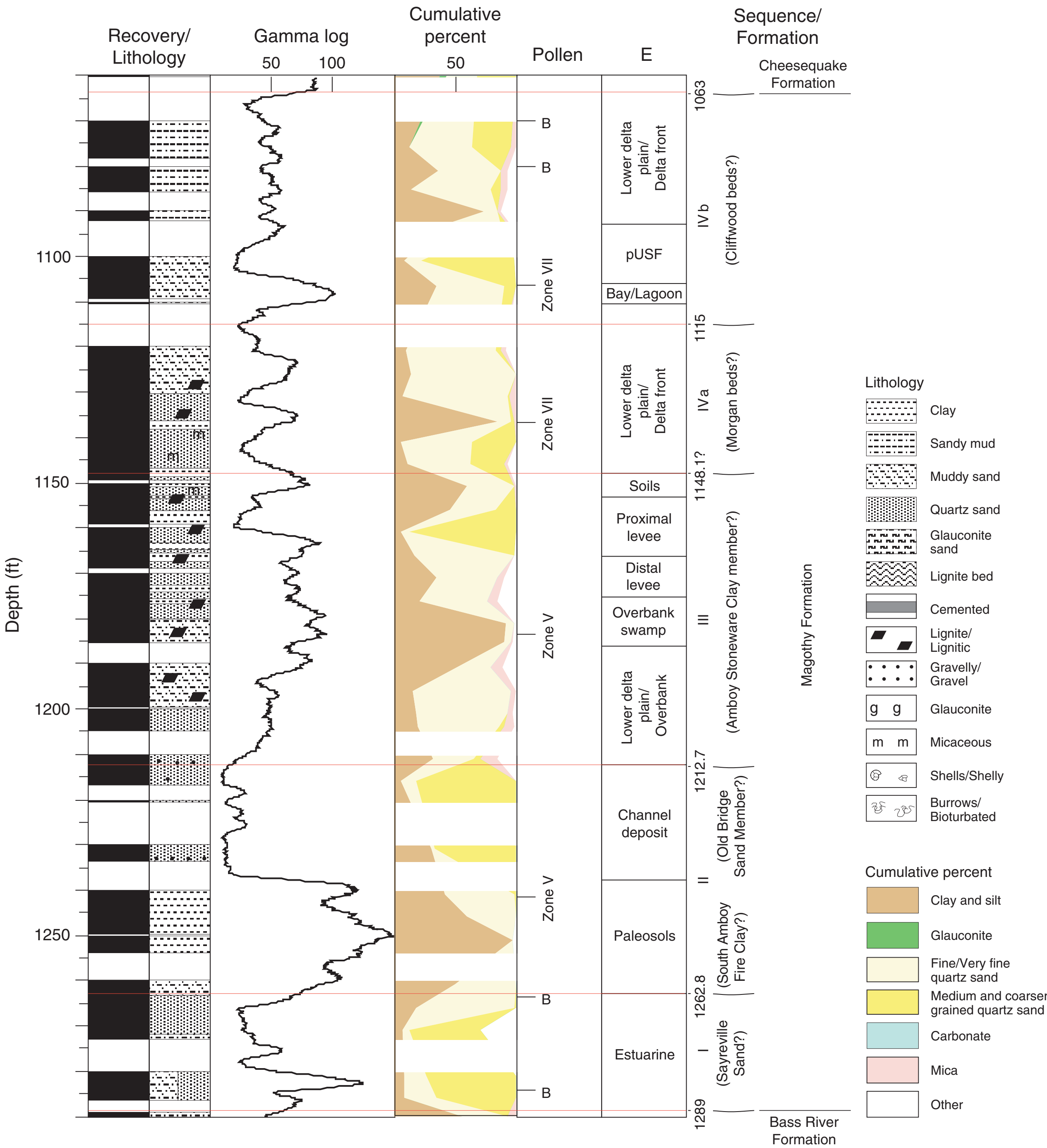

Figure F8. Summary stratigraphic section for Bass River (Cenomanian–Turonian) and Potomac (?Cenomanian–Albian) Formations in the Sea Girt corehole. N = nannofossil zone, Sr = strontium age estimate, P = pollen zone, E = environment, ST = systems tract. B = barren, LSF = lower shoreface, HST = highstand systems tract, FS = flooding surface, MFS = maximum flooding surface, TST = transgressive systems tract, OAE = ocean anoxic event.

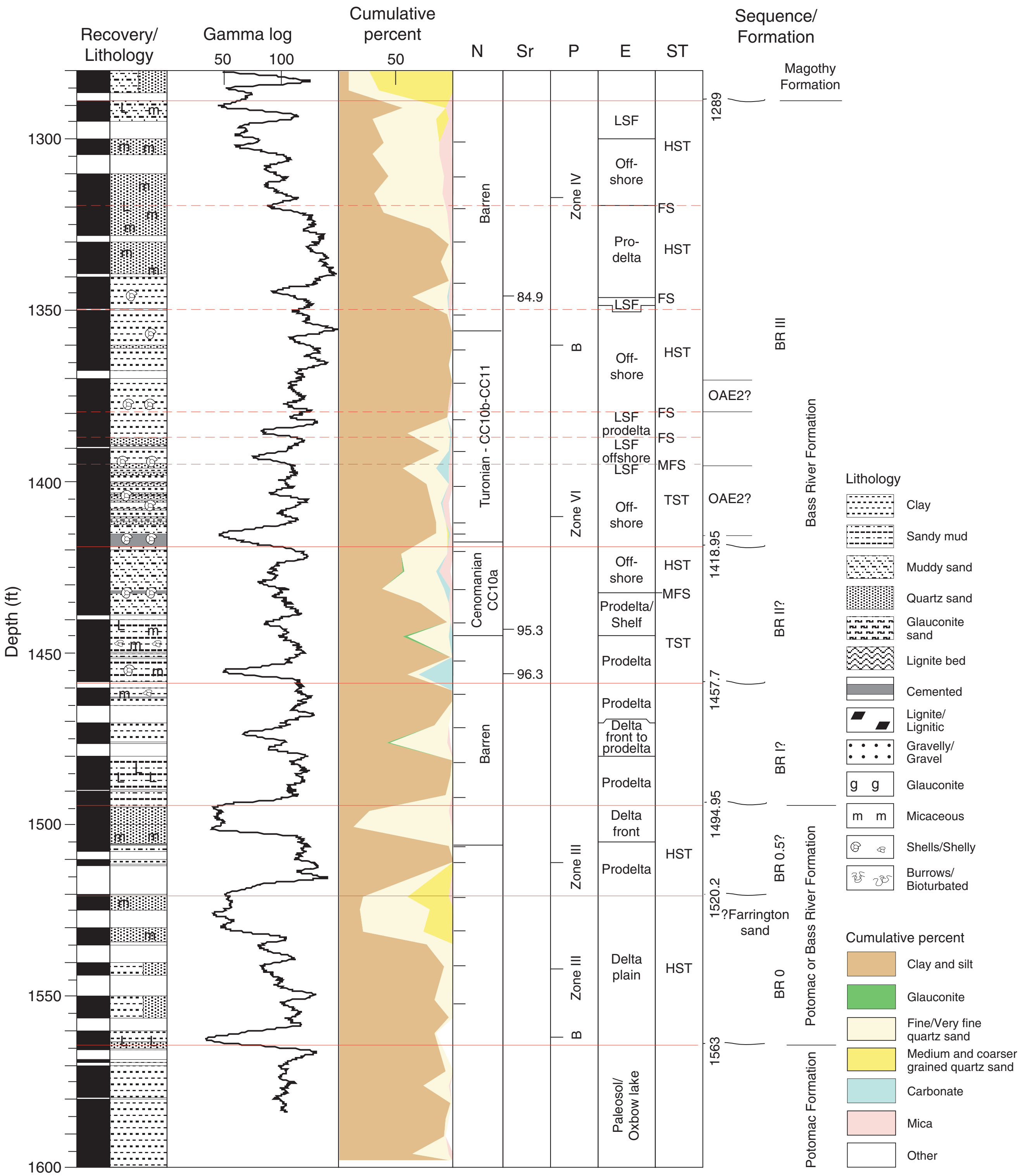

Figure F9. Correlation of Maastrichtian sections from Millville, Ancora, Bass River, and Sea Girt boreholes. Biofacies refers to benthic foraminiferal biofacies defined in Olsson et al. (1997).

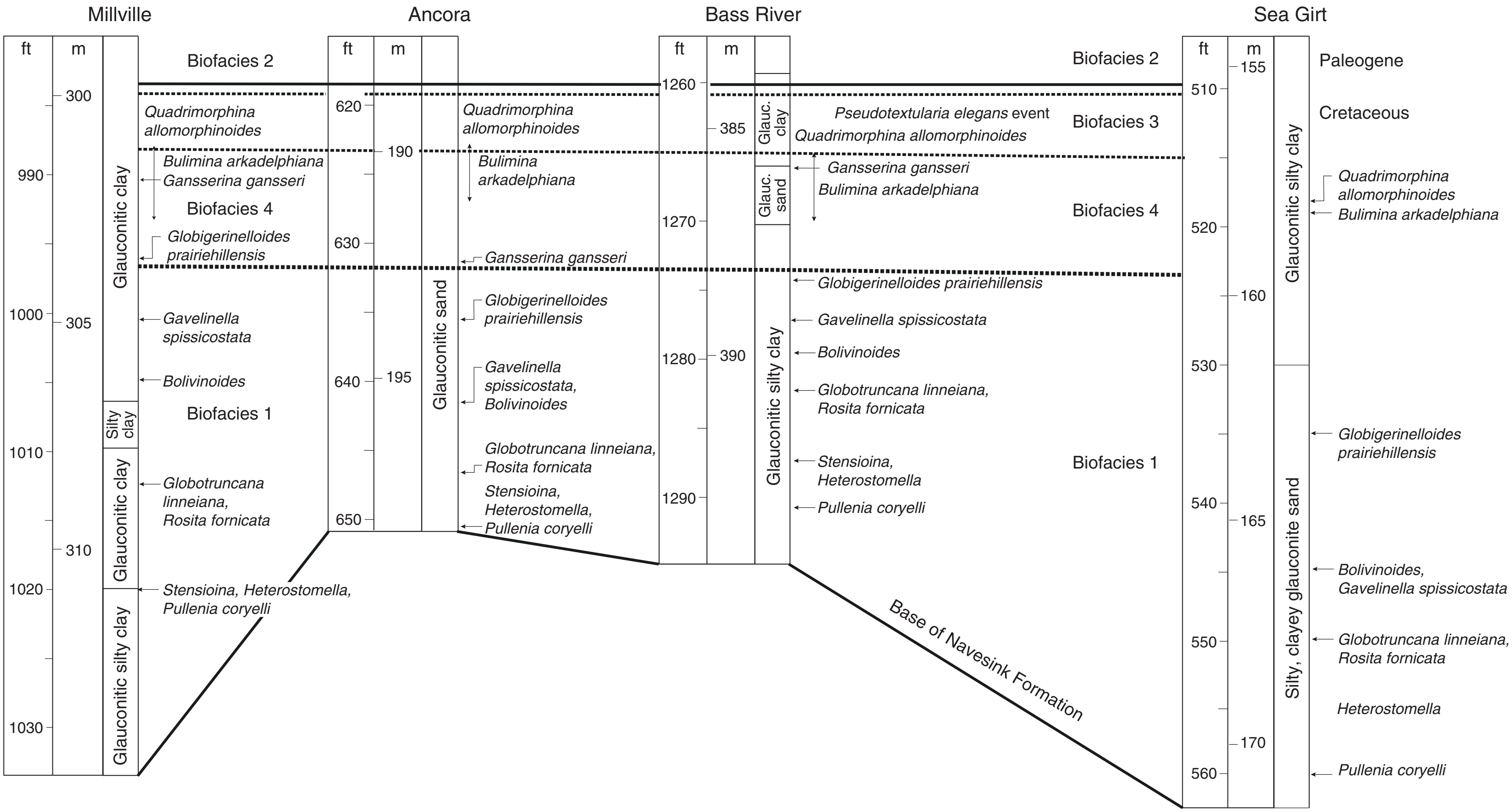

Figure F10. **A.** Medium sand from the Cape May Formation (14–15.5 ft; 4.27–4.72 m). **B.** Silty clay representing a prodelta environment from the Kirkwood Formation (120–122 ft; 36.58–37.19 m). **C.** Sand representing a delta front environment from the Kirkwood Formation (100–102 ft; 30.48–31.09 m). **D.** Inner neritic sand from the upper Shark River Formation (220–224 ft; 67.06–68.8 m).

Figure F11. **A.** Middle neritic slightly glauconitic clay from the lower Shark River Formation (254–256 ft; 77.42–78.03 m). **B.** Outer neritic clay from the Manasquan Formation (324–326 ft; 98.76–99.36 m). **C.** Burrowed contact between the Manasquan Formation (glauconitic clay) above and the unnamed clay below (364–366 ft; 110.95–111.56 m). **D.** Middle–outer neritic clay from the unnamed clay (374–376 ft; 14.00–114.60 m).

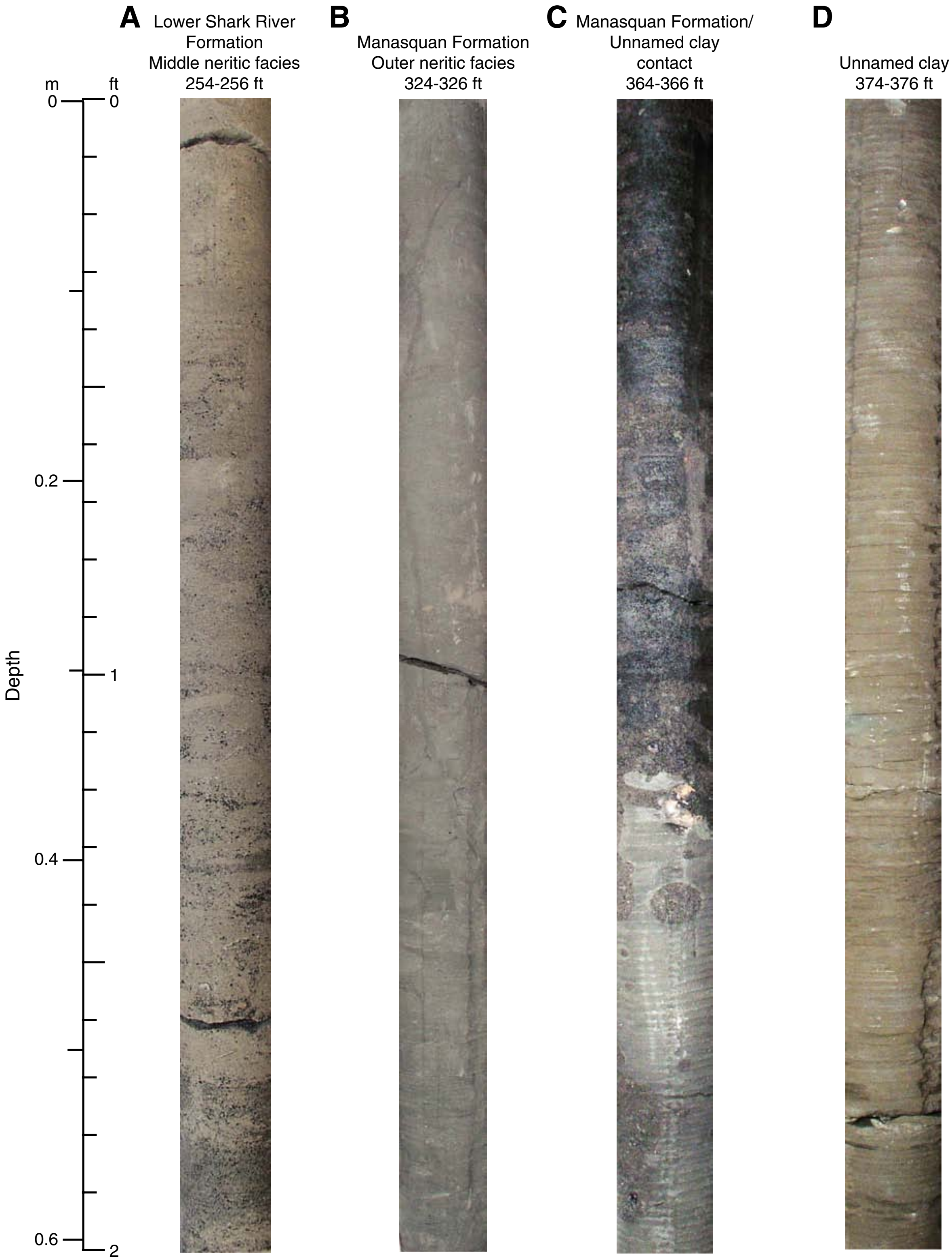

Figure F12. A. Middle neritic silty clay from the Vincentown Formation (414–416 ft; 126.19–126.80 m). **B.** Middle neritic clayey glauconite sand from the Hornerstown Formation (479–481 ft; 146.00–146.61 m). **C.** Middle neritic glauconite clays from the Navesink Formation (542–544 ft; 165.2–165.81 m). **D.** Inner neritic sand from the Mount Laurel Formation (575–577 ft; 175.26–175.87 m).

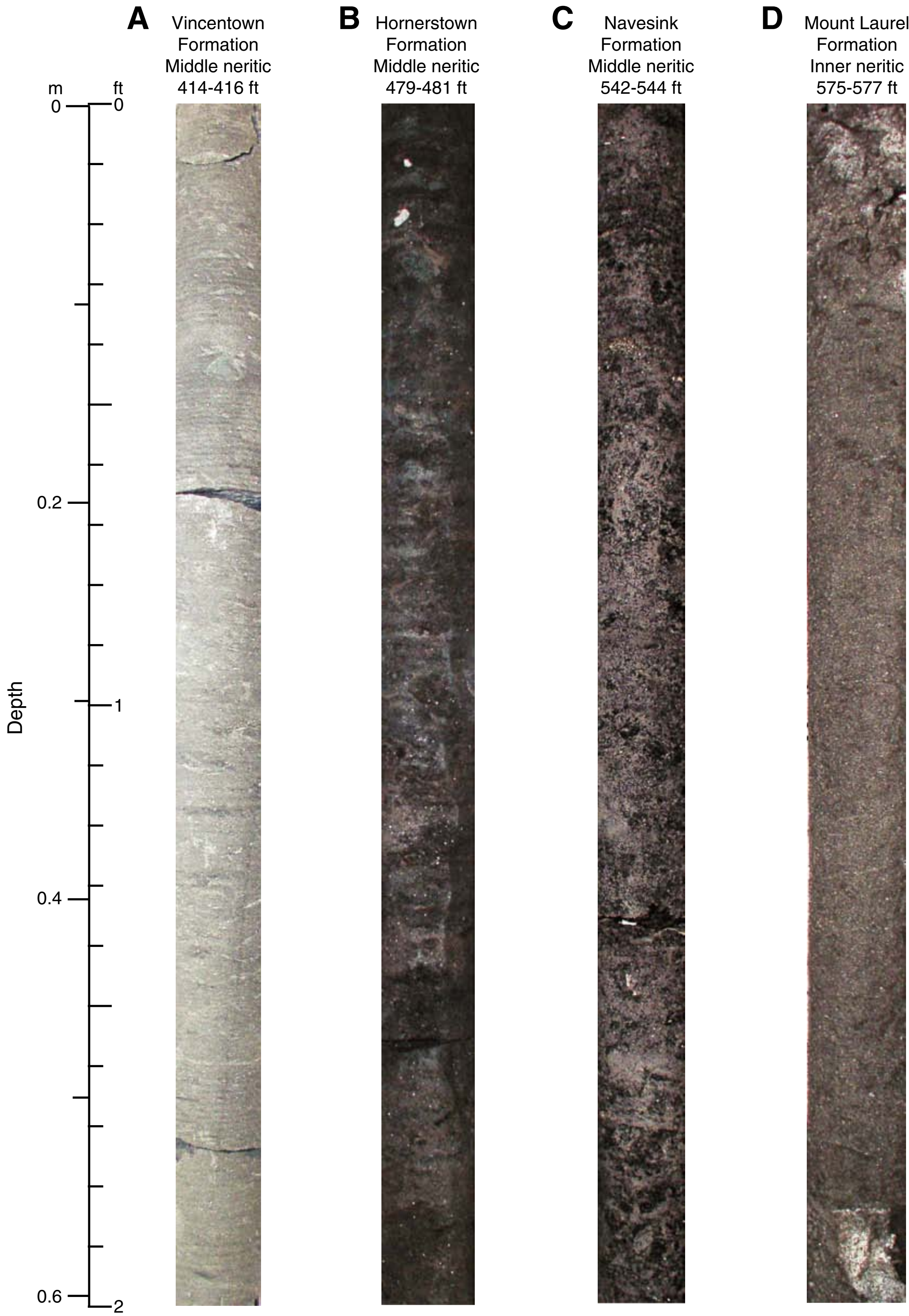

Figure F13. **A.** Middle neritic silt from the Wenonah Formation (674–676 ft; 205.44–206.04 m). **B.** Middle neritic glauconite sand from the Marshalltown Formation (682–684 ft; 207.87–208.48 m). **C.** Contact between the Marshalltown Formation (glauconite sand) above and Englishtown Formation (quartz sand) below (686–688 ft; 209.09–209.70 m). **D.** Delta front sand in the upper Englishtown Formation (720–722 ft; 219.46–220.07 m).

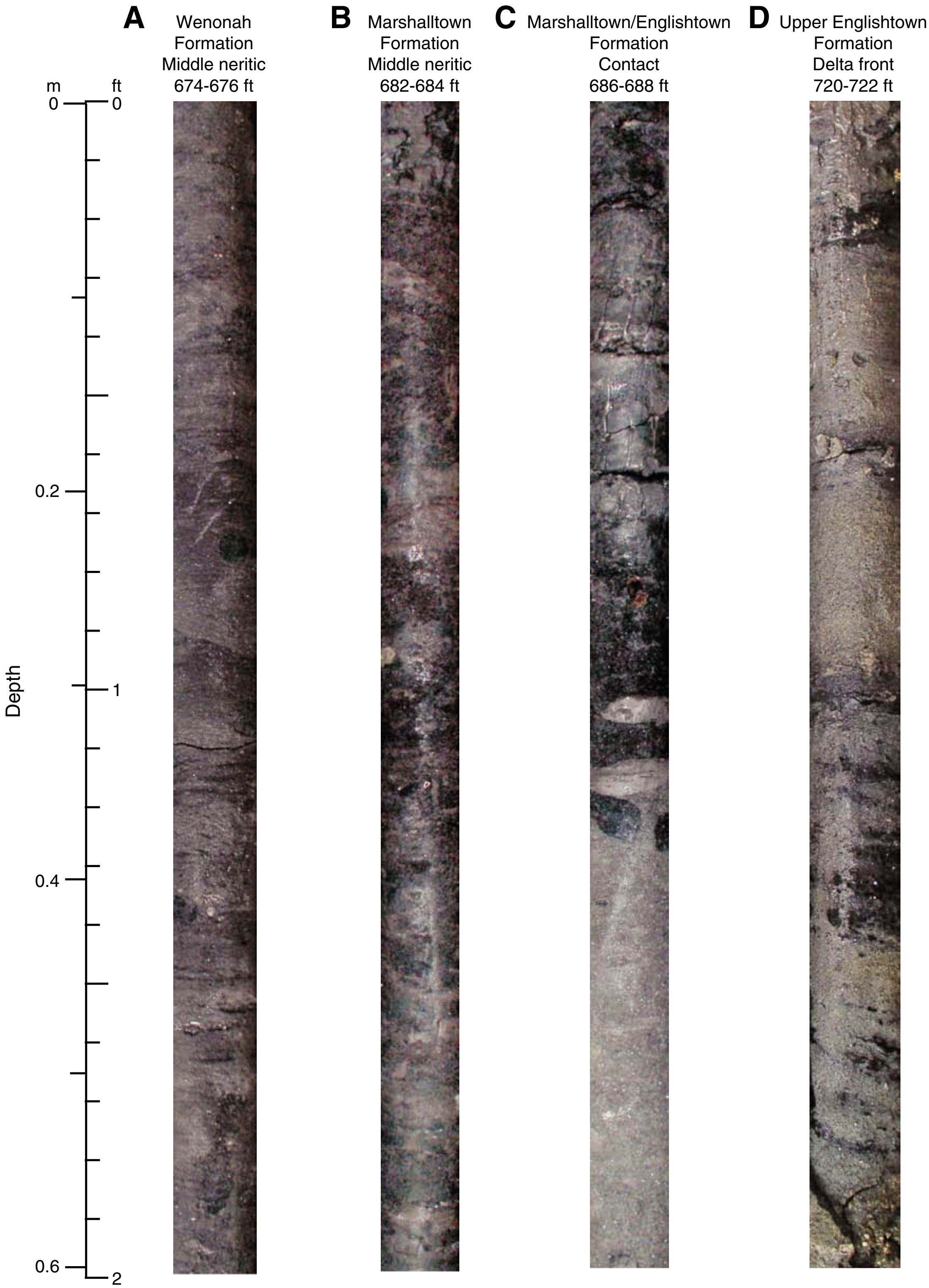

Figure F14. **A.** Prodelta clay from the upper Englishtown Formation (804–806 ft; 245.06–245.67 m). **B.** Delta front sand from the lower Englishtown Formation (865–867 ft; 263.65–264.26 m). **C.** Prodelta laminated clay from the Woodbury Formation (900–902 ft; 274.32–274.93 m). **D.** Middle neritic glauconite sand from the Merchantville Formation (982–984 ft; 299.31–299.92 m).

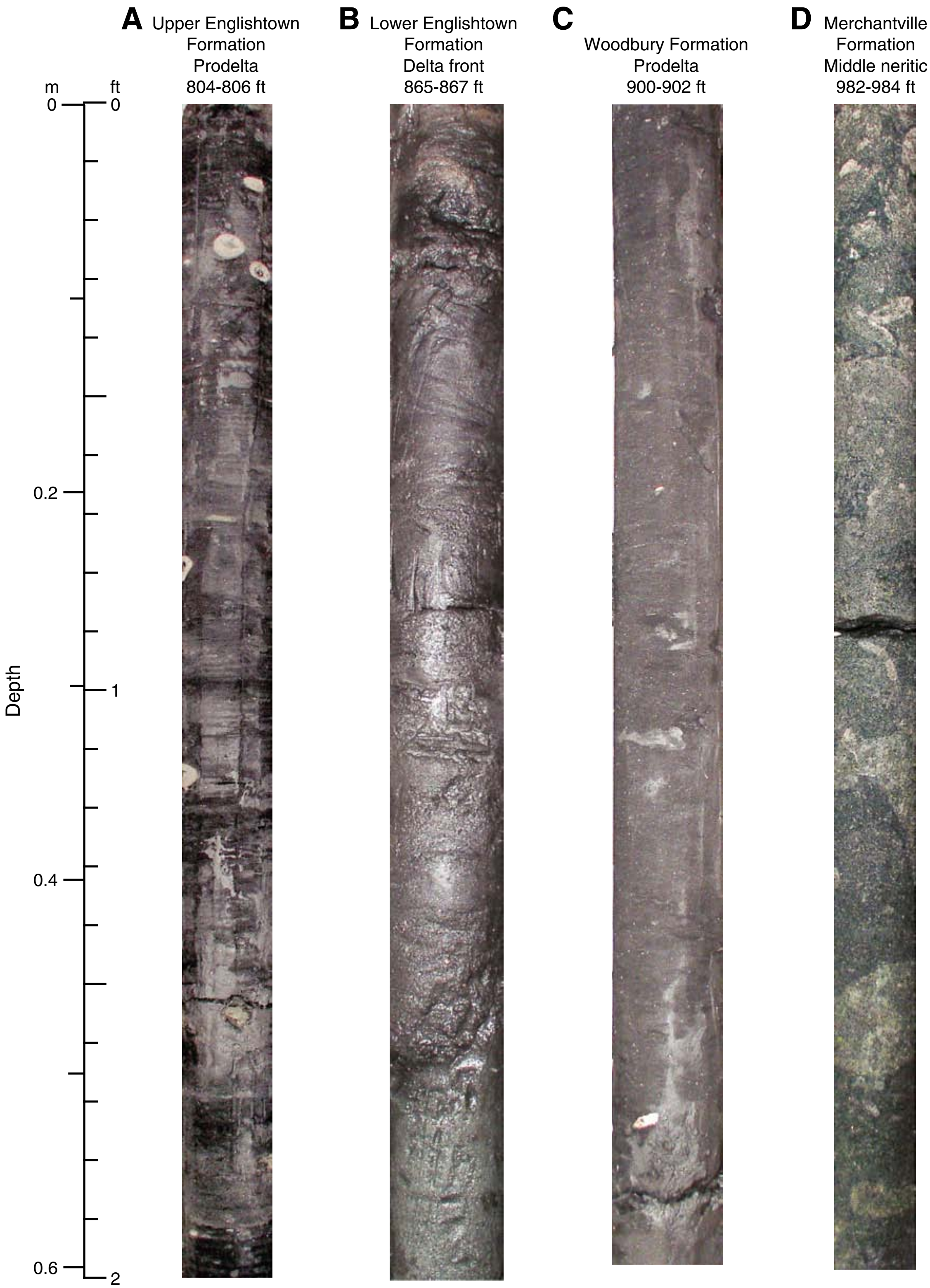

Figure F15. **A.** Contact between the Merchantville II sequence above and the Merchantville I sequence below (1000–1002 ft; 304.80–305.41 m). **B.** Sequence IVb (Cliffwood Beds) of the Magothy Formation (1082–1084 ft; 329.79–330.40 m). **C.** Sequence IVa (Morgan Beds) of the Magothy Formation (1132–1134 ft; 345.03–345.64 m). **D.** Sequence III (Amboy Stoneware Clay) of the Magothy Formation (1182–1184 ft; 360.27–360.88 m).

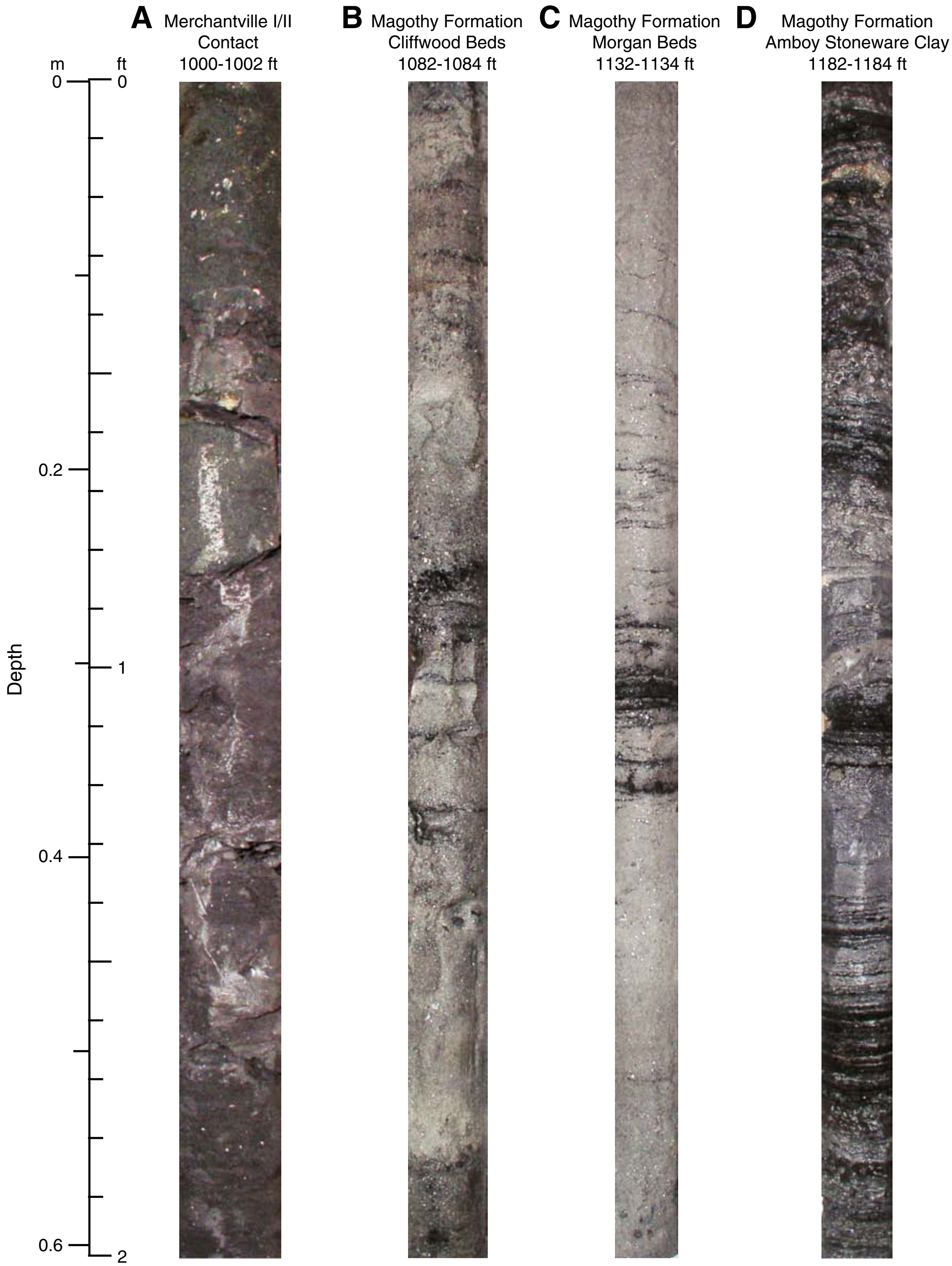

Figure F16. A. Upper part of Sequence II (Old Bridge Sand) of the Magothy Formation (1212–1214 ft; 369.42–370.03 m). **B.** Lower part of Sequence II (South Amboy Fire Clay) of the Magothy Formation (1247–1249 ft; 380.09–380.70 m). **C.** Middle–outer neritic clay from the Bass River Formation (1362–1364 ft; 415.14–415.75 m). **D.** Contact between the Bass River(?) Formation above and the Potomac Formation below (1562–1564 ft; 476.10–476.71 m). **E.** Paleosol from the Potomac Formation (1582–1584 ft; 482.19–482.80 m).

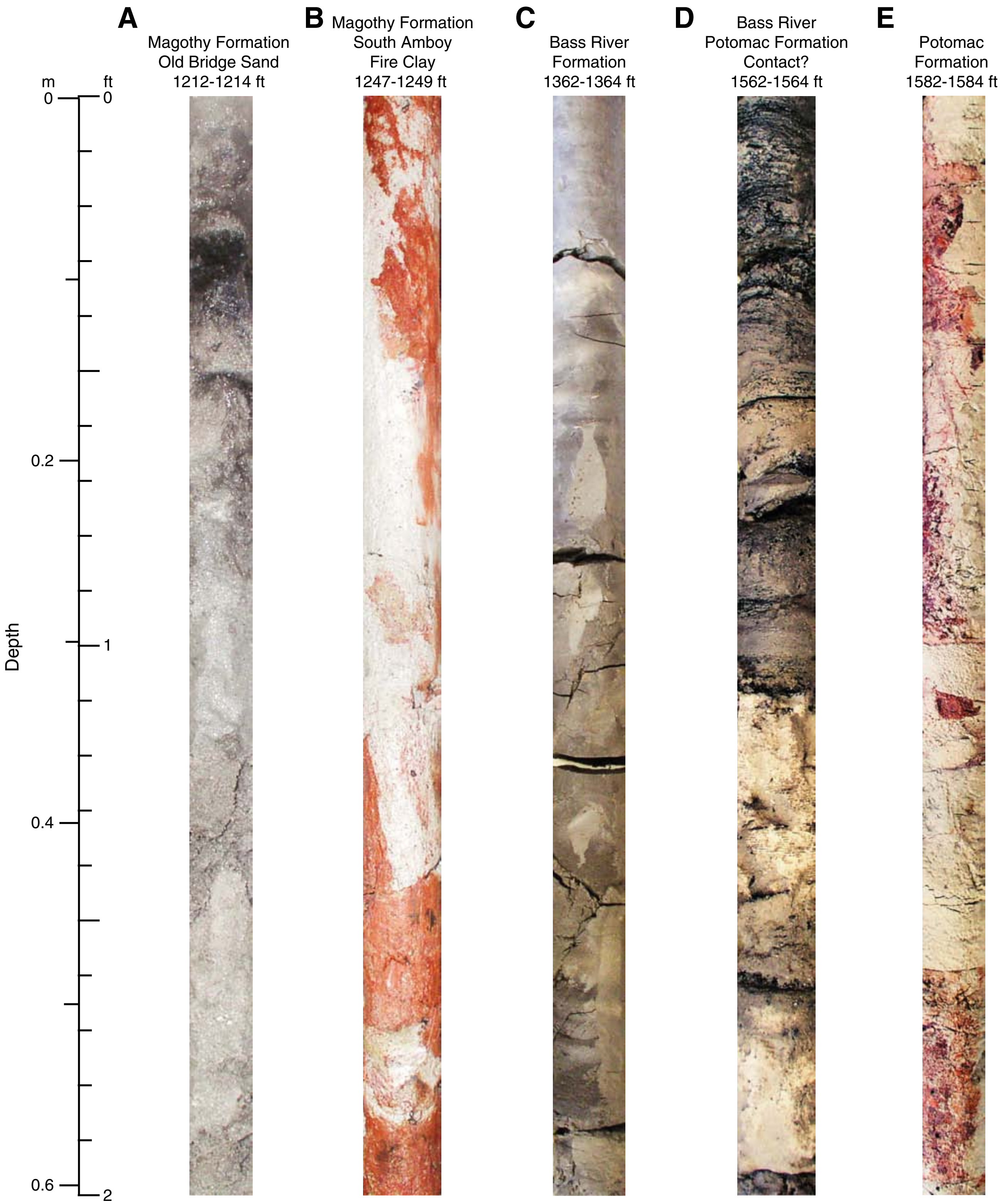

Figure F17. Cretaceous age-depth plot for the Sea Girt corehole. Error bars for Sr isotopic age estimates are two standard deviations for one analysis (Oslick et al., 1994). Points plotted in gray are interpreted as diagenetically altered, stratigraphically reworked, or alternate age interpretations (see text). Black boxes represent pollen zones. Red horizontal lines indicate sequence boundaries. Blue boxes at bottom compare the ages of Cretaceous sequences in the Ancora, Bass River, Fort Mott, Millville, and Sea Girt coreholes. Cross-hatched areas indicate uncertain ages. Sequence nomenclature of Miller et al. (2004). Biostratigraphic-timescale correlations of Bralower et al. (1995) and Erba et al. (1999) are tied to the Gradstein et al. (1995) timescale.

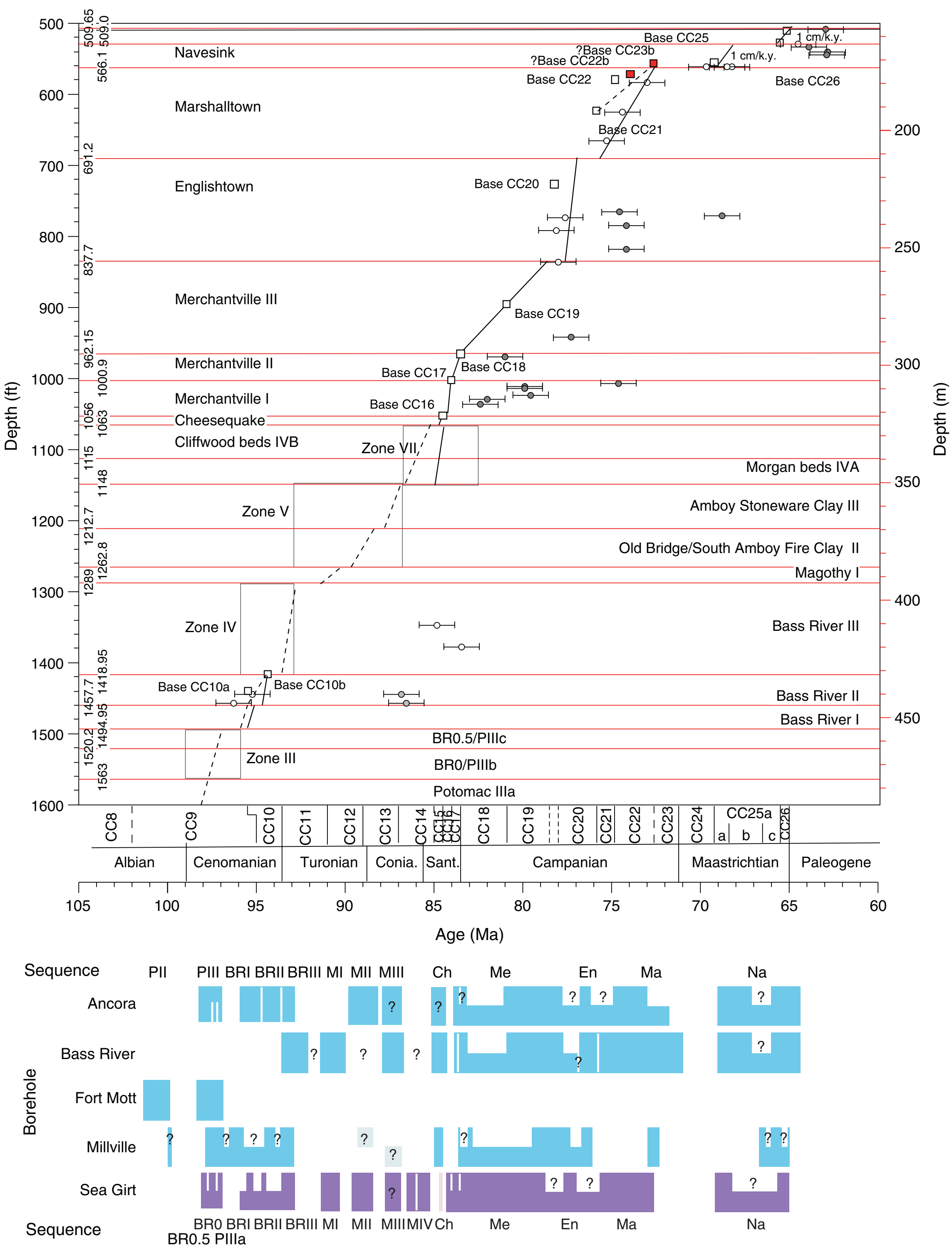

Figure F18. Cenozoic age-depth plot for the Sea Girt corehole. Black squares represent the tops and bottoms of calcareous nannoplankton zones. Red squares represent tops and bottoms of planktonic foraminiferal zones. Horizontal lines indicate sequence boundaries. Blue boxes along the bottom indicate time represented. Timescale after Berggren et al. (1995).

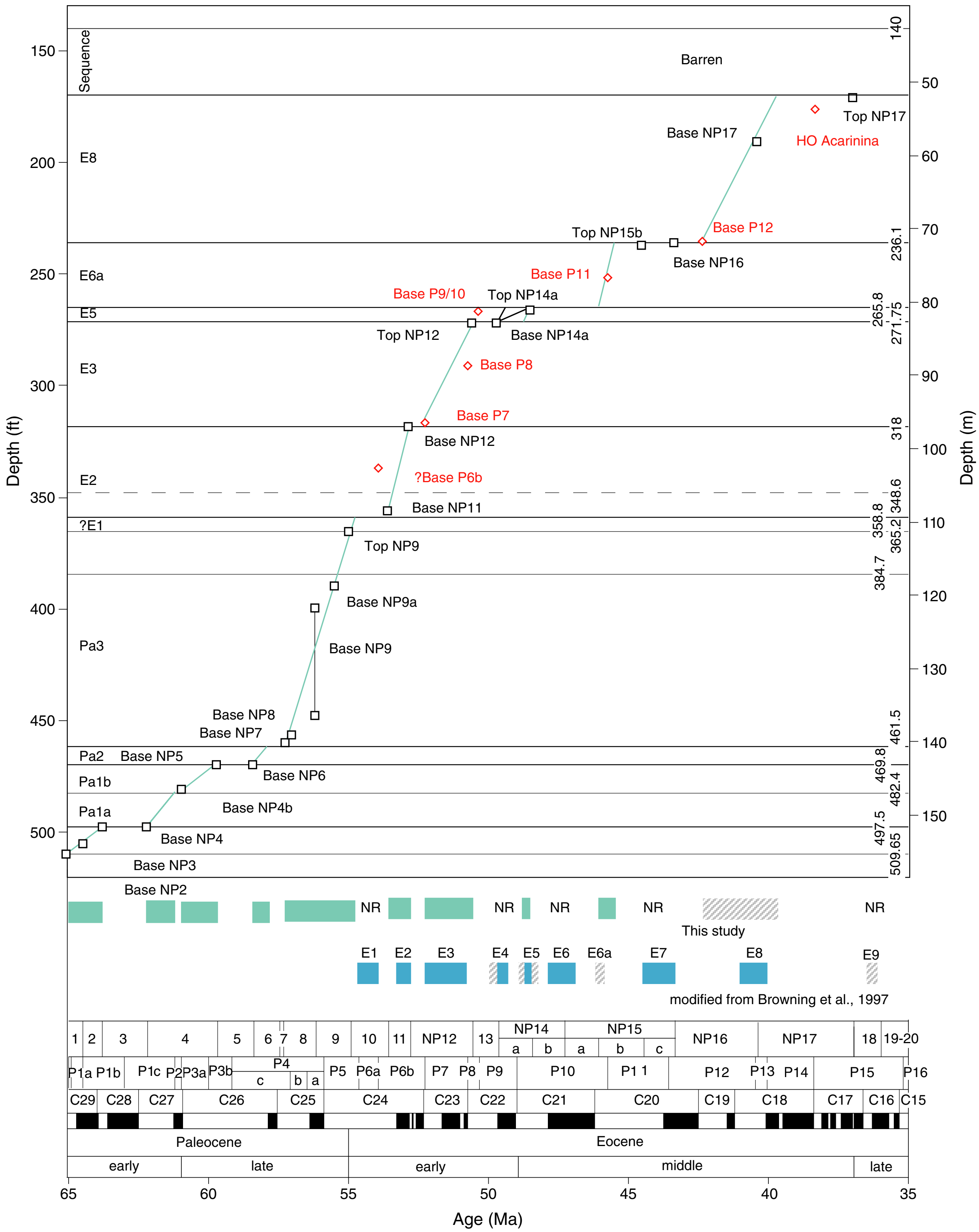

Table T1. Sea Girt core descriptions. (Continued on next two pages.)

Run number	Date (2003)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Lithology	Formation
1	24 Sep	1.–5.5	4.5	3.15	70	Coarse to very coarse sand	Cape May
2	24 Sep	5.5–10.5	5.0	2.2	44	Medium sand	Cape May
3	24 Sep	10.5–14	3.5	1.55	44	Coarse sand	Cape May
4	24 Sep	14–20	6.0	1.5	25	Medium sand	?Cape May
5	24 Sep	20–30	10.0	4.2	42	Medium sand	Kirkwood
6	24 Sep	30–35	5.0	1.0	20	Laminated silt and clay	Kirkwood
7	24 Sep	35–40	5.0	1.4	28	Clay	Kirkwood
8	24 Sep	40–45	5.0	3.1	62	Clay	Kirkwood
9	24 Sep	45–50	5.0	4.6	92	Sand	Kirkwood
10	24 Sep	50–60	10.0	9.2	24	Sand	Kirkwood
11	24 Sep	60–70	10.0	10.0	100	Sand	Kirkwood
12	24 Sep	70–80	10.0	6.7	67	Sand	Kirkwood
13	24 Sep	80–90	10.0	9.9	99	Sand	Kirkwood
14	25 Sep	90–100	10.0	6.5	65	Interlaminated sand, silt, and clay	Kirkwood
15	25 Sep	100–110	10.0	7.4	74	Interlaminated sand, silt, and clay	Kirkwood
16	25 Sep	110–120	10.0	1.7	17	Interlaminated sand, silt, and clay	Kirkwood
17	25 Sep	120–130	10.0	5.9	59	Interlaminated sand, silt, and clay	Kirkwood
18	25 Sep	130–140	10.0	6.3	63	Interbedded silt and clay, muddy sand	Kirkwood
19	25 Sep	140–150	10.0	6.85	69	Interbedded silt and clay, muddy sand	Upper Shark River
20	25 Sep	150–155	5.0	2.5	50	Interbedded silt and clay, muddy sand	Upper Shark River
21	25 Sep	155–160	5.0	5.2	104	Interbedded silt and clay, muddy sand	Upper Shark River
22	25 Sep	160–170	10.0	9.2	92	Muddy sand	Upper Shark River
23	26 Sep	170–180	10.0	10.0	24	Slightly glauconitic shelly clayey silt	Upper Shark River
24	26 Sep	180–190	10.0	10.0	100	Shelly glauconitic sandy clay silt	Upper Shark River
25	26 Sep	190–200	10.0	10.3	103	Shelly glauconitic sandy clay silt	Upper Shark River
26	26 Sep	200–210	10.0	10.15	102	Slightly glauconitic clay	Upper Shark River
27	29 Sep	210–215	5.0	2.4	48	Fossiliferous glauconitic slightly silty clay	Upper Shark River
28	29 Sep	215–220	5.0	4.2	84	Fossiliferous glauconitic slightly silty clay	Upper Shark River
29	29 Sep	220–230	10.0	10.7	107	Glauconitic clay and clayey glauconite sand; contact at 228.1 ft	Upper Shark River
30	29 Sep	230–240	10.0	6.5	65	Glauconitic clay and clayey glauconite sand; contact at 236.1 ft	Upper Shark River/Lower Shark River
31	29 Sep	240–250	10.0	7.4	74	Slightly silty, slightly glauconitic clay	Lower Shark River
32	29 Sep	250–260	10.0	9.45	95	Indurated slightly glauconitic clay	Lower Shark River
33	29 Sep	260–270	10.0	9.4	94	Glauconitic clay and clayey glauconite sand	Lower Shark River
34	29 Sep	270–280	10.0	10.0	100	Glauconitic sandy clay; contact at 271.75 ft	Lower Shark River/Manasquan
35	29 Sep	280–290	10.0	10.0	100	Silty clay	Manasquan
36	29 Sep	290–300	10.0	2.0	20	Clay and porcellanite	Manasquan
37	30 Sep	300–310	10.0	7.7	77	Foraminifer rich clay/porcellanite	Manasquan
38	30 Sep	310–320	10.0	7.8	78	Foraminifer rich clay	Manasquan
39	30 Sep	320–330	10.0	7.6	76	Foraminifer rich clay	Manasquan
40	30 Sep	330–340	10.0	9.6	96	Clay, laminated silt, glauconitic silty very fine sand	Manasquan
41	30 Sep	340–350	10.0	7.5	75	Silty clay/slightly glauconitic sandy (very fine) silt	Manasquan
42	30 Sep	350–360	10.0	10.2	102	Clay over glauconite sand	Manasquan
43	30 Sep	360–370	10.0	6.65	67	Glauconitic clay/clay; contact at 365.2 ft	Manasquan/Unnamed clay
44	30 Sep	370–380	10.0	7.15	72	Clay	Unnamed clay
45	30 Sep	380–390	10.0	7.0	70	Clay/glauconite silty clay; contact at 384.7 ft	Unnamed clay/Vincentown
46	30 Sep	390–400	10.0	9.6	96	clay/glauconite silty clay	Vincentown
47	1 Oct	400–410	10.0	9.9	99	Clayey silt	Vincentown
48	1 Oct	410–420	10.0	10.4	104	Clayey silt	Vincentown
49	1 Oct	420–430	10.0	7.3	73	Silty clay	Vincentown
50	1 Oct	430–440	10.0	10.4	104	Clayey silt to glauconitic clayey silt	Vincentown
51	1 Oct	440–450	10.0	9.9	99	Slightly glauconitic silty clay to glauconitic silty clay	Vincentown
52	2 Oct	450–460	10.0	7.2	72	Glauconitic clay silt/silty glauconite sand	Vincentown
53	2 Oct	460–465	5.0	4.35	87	Glauconite sand/silt	Vincentown
54	2 Oct	465–470	5.0	5	100	Glauconite sand and shell hash	Hornerstown
55	2 Oct	470–475	5.0	4.3	86	Silty glauconitic quartz sand with shells	Hornerstown
56	2 Oct	475–485	10.0	10.2	102	Silty glauconite sand; contacts at 478.1 and 484.4	Hornerstown
57	2 Oct	485–490	5.0	3.5	70	Interbedded glauconitic silty clay and sandy silt	Hornerstown
58	2 Oct	490–500	10.0	5.2	52	Interbedded glauconitic silty clay and sandy silt; contact at 499.6 ft	Hornerstown/Navesink
59	2 Oct	500–505	5.0	4.4	88	Interbedded glauconitic silty clay and sandy silt	Navesink
60	3 Oct	505–510	5.0	5	100	Glauconitic silt	Navesink
61	3 Oct	510–520	10.0	9.9	99	Glauconitic silt	Navesink
62	3 Oct	520–530	10.0	10.1	101	Glauconitic silt	Navesink
63	3 Oct	530–540	10.0	7.6	76	Glauconite silt/silty glauconite sand	Navesink
64	3 Oct	540–550	10.0	10.3	103	Silty glauconite sand	Navesink
65	3 Oct	550–560	10.0	10	100	Silty glauconite sand	Navesink

Table T1 (continued).

Run number	Date (2003)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Lithology	Formation
66	3 Oct	560–568.5	8.5	8.5	100	Clayey glauconite sand and quartz sand; contact at 565 ft	Navesink/Mount Laurel
67	3 Oct	568.5–575	6.5	2.5	38	Quartz sand	Mount Laurel
68	4 Oct	575–580	5.0	2.9	58	Bioturbated medium sand	Mount Laurel
69	4 Oct	580–590	10.0	10.2	102	Sand with some silt interbeds	Mount Laurel
70	4 Oct	590–600	10.0	10.35	104	Fine sand and interbedded clayey silt	Mount Laurel
71	4 Oct	600–605	5.0	2.35	47	Clayey silty very fine sand and interbedded medium sand	Mount Laurel
72	4 Oct	605–610	5.0	5.4	108	Fine sand and interbedded clay	Mount Laurel
73	5 Oct	610–620	10.0	4.8	48	Fine sand and interbedded clay	Mount Laurel
74	5 Oct	620–630	10.0	9.15	92	Fine sand and interbedded clay	Mt. Laurel/Wenonah
75	5 Oct	630–640	10.0	2.5	25	Interbedded silt and clay	Wenonah
76	5 Oct	640–650	10.0	3.4	34	Interbedded silt and clay	Wenonah
77	6 Oct	650–660	10.0	3.3	33	Micaceous silt with sand interbeds	Wenonah
78	6 Oct	660–667	7.0	6.9	99	Silt with sand laminae/glauconitic sand; contact at 666.5 ft	Wenonah
79	6 Oct	667–672	5.0	4.45	89	Glauconitic silt with sand laminae	Wenonah
80	6 Oct	672–677.5	5.5	5.5	100	Glauconitic silt with sand laminae/glauconite sand; contact at 675.7 ft	Wenonah/Marshalltown
81	6 Oct	677.5–682	4.5	4.05	90	Glauconitic silt to silty glauconitic sand	Marshalltown
82	6 Oct	682–690	8.0	9.2	115	Glauconitic silt/sandy silt; contact at 687.2 ft	Marshalltown/Englishtown
83	7 Oct	690–700	10.0	10	100	Fine to medium sand with interbedded thin silts and lignite	Upper Englishtown
84	7 Oct	700–710	10.0	10	100	Fine to medium sand with interbedded lignite, dark silts	Upper Englishtown
85	8 Oct	710–713	3.0	1.85	62	Interbedded sands and clays	Upper Englishtown
86	8 Oct	713–720	7.0	6.7	96	Lignitic sand with lignite and clay laminae	Upper Englishtown
87	8 Oct	720–730	10.0	9	90	Lignitic sand with lignite and clay laminae	Upper Englishtown
88	8 Oct	730–740	10.0	9.4	94	Lignitic sand with lithic clast beds and clay laminae	Upper Englishtown
89	8 Oct	740–750	10.0	5.9	59	Lignitic medium–fine sand with clay lamina, clay beds, and indurated zones	Upper Englishtown
90	9 Oct	750–760	10.0	0.6	6	Lignite, concretions, and clay	Upper Englishtown
91	9 Oct	760–760.4	0.4	0.4	100	Lignite, concretions, and clay	Upper Englishtown
92	9 Oct	760.4–770	9.6	6.3	66	Interbedded silt and clay	Upper Englishtown
93	9 Oct	770–780	10.0	4.8	48	Interbedded silt and clay	Upper Englishtown
94	9 Oct	780–790	10.0	7.1	71	Interbedded silt and clay	Upper Englishtown
95	9 Oct	790–800	10.0	10.4	104	Interbedded silt and clay	Upper Englishtown
96	10 Oct	800–810	10.0	7.9	79	Interbedded silt and clay	Upper Englishtown
97	10 Oct	810–820	10.0	9.7	97	Clay	Upper Englishtown
98	10 Oct	820–830	10.0	9.9	99	Clay and glauconitic clay	Upper Englishtown
99	11 Oct	830–840	10.0	9.3	93	Glauconitic clay/clayey glauconite–quartz sand; contact at 837.7 ft; sandstone/micaceous quartz sand	Upper Englishtown/Lower Englishtown
100	11 Oct	840–850	10.0	1.5	15	Micaceous, quartz sand with some shells	Lower Englishtown
101	11 Oct	850–860	10.0	4	40	Silty micaceous quartz sand	Lower Englishtown
102	12 Oct	860–861	1.0	0.9	90	Micaceous quartz sand	Lower Englishtown
103	12 Oct	861–870	9.0	9.5	106	Interbedded sand and silt	Lower Englishtown
104	12 Oct	870–880	10.0	2.9	29	Micaceous sand	Lower Englishtown
105	12 Oct	880–890	10.0	8.4	84	Micaceous sand	Lower Englishtown
106	12 Oct	890–900	10.0	8.15	82	Clayey silt	Woodbury
107	12 Oct	900–910	10.0	10.3	103	Silty clay	Woodbury
108	13 Oct	910–920	10.0	9.9	99	Micaceous, shelly silty clay	Woodbury
109	13 Oct	920–930	10.0	10.35	104	Micaceous, shelly silty clay	Woodbury
110	13 Oct	930–940	10.0	10	100	Slightly glauconitic clay, with some silt	Woodbury
111	16 Oct	940–950	10.0	7.1	71	Glauconitic clay; contact at 943.5 ft	Woodbury/Merchantville
112	16 Oct	950–960	10.0	5.1	51	Glauconitic clay and clayey glauconite sand	Merchantville
113	16 Oct	960–960.6	0.6	0.6	100	Glauconitic clay and clayey glauconite sand	Merchantville
114	16 Oct	960.6–970	9.4	3.9	41	Glauconitic clay and clayey glauconite sand	Merchantville
115	17 Oct	970–974	4.0	0	0	No recovery	Merchantville
116	17 Oct	974–980	5.9	6	98	Glauconitic silty clay	Merchantville
117	17 Oct	980–990	10.0	10.2	102	Glauconite sand	Merchantville
118	17 Oct	990–993	3.0	3.2	107	Glauconitic very fine sand	Merchantville
119	17 Oct	993–1000	7.0	7	100	Glauconitic very fine sandy silt	Merchantville
120	18 Oct	1000–1010	10.0	9.2	92	Glauconitic very fine sandy silt	Merchantville
121	18 Oct	1010–1020	10.0	5.7	57	Glauconitic very fine sand	Merchantville
122	18 Oct	1020–1030	10.0	10.1	101	Glauconitic very fine sand	Merchantville
123	18 Oct	1030–1033	3.0	2.6	87	Glauconitic very fine sand	Merchantville
124	18 Oct	1033–1037.5	4.5	4.3	96	Glauconitic very fine sand	Merchantville
125	18 Oct	1037.5–1047.5	10.0	0.4	4	Clayey glauconite sand	Merchantville
126	18 Oct	1047.5–1050	2.5	1.7	68	Clayey glauconite sand	Merchantville
127	19 Oct	1050–1060	10.0	0.6	6	Clayey glauconite sand	Merchantville

Table T1 (continued).

Run number	Date (2003)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Lithology	Formation
128	19 Oct	1060–1070	10.0	0.5	5	Micaceous silt with some glauconite sand	Cheesequake
129	23 Oct	1070–1074	4.0	4.4	110	Interbedded clay and sand	Magothy
130	2 Nov	1074–1080	6.0	4.4	73	Interbedded clay and sand	Magothy
131	2 Nov	1080–1090	10.0	5.7	57	Interbedded clay and sand	Magothy
132	2 Nov	1090–1100	10.0	3.1	31	Interbedded clay and sand	Magothy
133	2 Nov	1100–1110	10.0	9.35	94	Interbedded clay and sand	Magothy
134	3 Nov	1110–1120	10.0	0.65	7	Clay and sand	Magothy
135	3 Nov	1120–1130	10.0	10.2	102	Sand with clay interbeds	Magothy
136	3 Nov	1130–1140	10.0	10.2	102	Sand with clay interbeds	Magothy
137	4 Nov	1140–1150	10.0	9.75	98	Sand with clay interbeds	Magothy
138	4 Nov	1150–1160	10.0	9.25	93	Clay and interbedded sand	Magothy
139	4 Nov	1160–1170	10.0	8.7	87	Clay and interbedded sand	Magothy
140	4 Nov	1170–1180	10.0	10	100	Laminated sand and lignite	Magothy
141	5 Nov	1180–1190	10.0	6.25	63	Laminated sand, clay and lignite	Magothy
142	5 Nov	1190–1200	10.0	9.8	98	Sand with laminated clay and lignite	Magothy
143	5 Nov	1200–1210	10.0	4.7	47	Sand with laminated clay and lignite	Magothy
144	5 Nov	1210–1220	10.0	6.8	68	Medium to coarse sand	Magothy
145	5 Nov	1220–1230	10.0	0.4	4	Coarse to very coarse sand	Magothy
146	5 Nov	1230–1240	10.0	3.5	35	Medium to very coarse sand	Magothy
147	6 Nov	1240–1250	10.0	9.8	98	Interbedded sand and clay; contact at 2.05; mottled red and white clay	Magothy
148	6 Nov	1250–1260	10.0	4	40	Mottled red and white clay	Magothy
149	6 Nov	1260–1270	10.0	10	100	Sand with interbedded clay and sand	Magothy
150	6 Nov	1270–1280	10.0	3	30	Sand, lignitic medium–very coarse sand with interbedded clay	Magothy
151	6 Nov	1280–1289	9.0	6.5	72	Interbedded sand (granuliferous–medium) and sandy silty clays	Magothy
152	7 Nov	1289–1300	11.0	5.85	53	White/dark gray slightly sandy micaceous silt; contact at 1290.7 ft	Magothy/Bass River
153	7 Nov	1300–1310	10.0	4.85	49	Micaceous silt; sandy and clayey interbeds	Bass River
154	7 Nov	1310–1320	10.0	10.7	107	Micaceous silt to clayey silt	Bass River
155	7 Nov	1320–1330	10.0	8.1	81	Micaceous clayey silt to silty clay	Bass River
156	7 Nov	1330–1340	10.0	9.65	97	Clay with interbeds of lighter clay and lignite	Bass River
157	7 Nov	1340–1350	10.0	9.5	95	Interbedded clay, high shell concentration	Bass River
158	7 Nov	1350–1360	10.0	10.6	106	Slightly silty clay	Bass River
159	7 Nov	1360–1370	10.0	7.75	78	Slightly silty clay with thin sand bed	Bass River
160	8 Nov	1370–1380	10.0	10	100	Clay with common shell beds	Bass River
161	8 Nov	1380–1390	10.0	9.9	99	Clay with shells; 1.5 ft of calcarenite	Bass River
162	8 Nov	1390–1400	10.0	10.1	101	Clay with some sand and shell interbeds; 1 ft calcarenite bed	Bass River
163	8 Nov	1400–1410	10.0	10	100	Clay with sandy interbeds	Bass River
164	8 Nov	1410–1420	10.0	9.7	97	Interbedded silty sand/sandy clay with calcarenite	Bass River
165	8 Nov	1420–1430	10.0	10.4	104	Interbedded silty sand/sandy clay	Bass River
166	8 Nov	1430–1440	10.0	8.9	89	Interbedded silty sand/sandy clay	Bass River
167	8 Nov	1440–1450	10.0	10.45	105	Silt, lignitic, occasionally shelly, occasionally granuliferous, scattered lignite, laminae and bioturbated	Bass River
168	8 Nov	1450–1460	10.0	7.9	79	Clayey micaceous silt and shell bed; sequence boundary at ?1459 ft	Bass River
169	9 Nov	1460–1470	10.0	5.1	51	Slightly silty clay	Bass River
170	9 Nov	1470–1480	10.0	6.2	62	Silty clay to sandy silty clay; sand bed at base	Bass River
171	9 Nov	1480–1490	10.0	9.65	97	Clayey silt with distinct banding, an organic-rich bed in middle	Bass River
172	9 Nov	1490–1500	10.0	9.7	97	Clayey silt in upper half, changes to sand in lower half	?Bass River
173	9 Nov	1500–1510	10.0	7.5	75	Sand in upper part to clayey bioturbated silt at bottom	?Bass River
174	9 Nov	1510–1520	10.0	1.8	18	Clay, claystone layer	?Bass River
175	10 Nov	1520–1530	10.0	4.8	48	Clay; sequence boundary at 1520.2 ft; fine sand	?Bass River
176	10 Nov	1530–1540	10.0	4.8	48	Fine sand; contact at 1534.2 ft; clay with sand laminae	?Bass River
177	10 Nov	1540–1550	10.0	3.8	38	Clay and interbedded sand	?Bass River
178	10 Nov	1550–1560	10.0	6.4	64	Clay and interbedded sand	?Bass River
179	10 Nov	1560–1568.5	8.5	5.4	64	Lignitic silty clay/sugar sands/tight clays	Potomac
180	10 Nov	1568.5–1570	1.5	0.8	53	Gray clay	Potomac
181	10 Nov	1570–1580	10.0	9.65	97	Mottled gray lignitic clay, slightly clayey silt with sphaerosiderite, and silty clay	Potomac
182	10 Nov	1580–1590	10.0	10	100	Clayey silts to silty clay with root casts and sphaerosiderite	Potomac
183	11 Nov	1590–1600	10.0	8.1	81	Sand	Potomac

Table T2. Cumulative percent plot data. (See table notes. Continued on next four pages.)

Sample depth (ft)	Clay and silt (%)	Glauconite (%)	Fine quartz (%)	Medium and coarser quartz sand (%)	Sphaero-siderite (%)	Mica (%)	Other (%)
2.5	16.62	0	9	74	0	0	0
6.0	42.29	0	11	47	0	0	0
11.0	0.87	0	4	95	0	0	0
15.4	11.24	0	44	45	0	0	0
21.0	2.17	0	18	80	0	0	0
32.0	91.15	0	2	2	0	0	4
36.1	99.54	0	0	0	0	0	0
41.0	99.37	0	0	0	0	0	0
46.0	14.64	0	71	5	0	5	4
51.0	17.70	3	59	17	0	3	0
56.0	4.28	1	79	9	0	4	2
61.0	40.13	0	53	0	0	3	4
66.0	51.15	0	43	1	0	3	2
71.0	45.00	0	49	0	0	3	3
76.0	29.29	0	63	0	0	4	4
81.0	44.97	0	49	0	0	3	3
86.0	28.88	0	60	0	0	8	4
91.0	87.67	0	9	0	0	2	1
96.0	28.61	0	10	61	0	1	0
101.0	15.32	0	10	74	0	1	0
106.0	74.26	0	24	0	0	0	2
111.0	3.45	0	4	92	0	0	1
121.0	65.68	0	24	0	0	3	7
125.8	14.68	0	22	63	0	0	0
131.3	37.61	0	50	7	0	0	6
136.0	31.06	1	24	43	0	1	0
141.0	35.77	9	50	0	0	4	0
146.0	36.41	9	49	0	0	5	0
151.0	38.40	9	48	0	0	4	0
156.0	39.79	9	47	0	0	4	0
161.0	38.84	9	48	0	0	4	0
166.0	45.18	9	40	0	0	3	2
171.0	81.01	1	8	0	9	1	0
176.0	48.32	10	28	0	12	1	0
181.0	64.74	7	19	0	9	1	0
186.0	87.32	1	5	0	7	0	0
191.0	76.05	2	6	0	16	0	0
196.0	78.72	2	10	0	9	1	0
201.0	79.67	2	9	0	8	1	0
206.0	74.93	6	11	0	8	0	0
211.0	81.01	4	8	0	6	0	0
216.0	79.80	5	6	0	9	0	0
221.0	65.14	22	6	0	7	0	0
226.0	64.54	17	9	0	10	0	0
231.0	85.36	0	0	0	14	0	0
235.0	51.79	35	2	0	11	0	0
241.5	83.22	0	4	0	13	0	0
246.0	78.58	1	4	0	17	0	0
251.0	66.89	4	17	0	12	0	0
256.0	70.54	9	2	0	19	0	0
261.0	75.55	7	2	0	16	0	0
266.0	20.70	76	1	0	2	0	0
271.0	39.11	38	17	0	5	0	0
276.0	71.68	3	23	0	2	0	0
281.0	77.02	1	19	0	3	0	0
286.0	87.40	3	6	0	4	0	0
290.5	85.27	0	1	0	13	0	0
301.0	56.79	4	33	0	5	0	0
306.0	71.78	1	19	0	9	0	0
311.0	70.10	1	25	0	3	0	0
316.0	79.35	2	9	0	10	0	0
321.0	92.06	7	0	0	1	0	0
326.0	80.00	9	7	0	4	0	0
331.0	84.79	1	3	0	12	0	0
336.0	58.70	12	16	0	14	0	0
341.0	40.94	4	53	0	2	0	0

Table T2 (continued).

Sample depth (ft)	Clay and silt (%)	Glauconite (%)	Fine quartz (%)	Medium and coarser quartz sand (%)	Sphaero-siderite (%)	Mica (%)	Other (%)
346.0	51.76	7	41	0	0	0	0
351.0	96.49	0	3	0	0	0	0
356.0	73.86	2	24	0	1	0	0
361.0	37.85	40	20	0	0	2	0
366.0	99.91	0	0	0	0	0	0
371.0	99.83	0	0	0	0	0	0
376.0	99.57	0	0	0	0	0	0
381.0	99.71	0	0	0	0	0	0
386.0	62.30	21	16	0	0	0	0
391.5	57.09	27	16	0	0	0	0
396.0	51.63	39	5	0	0	5	0
401.0	48.50	41	5	0	0	5	0
406.0	57.62	8	33	0	0	1	0
411.0	77.67	4	16	0	0	2	0
416.0	74.80	5	19	0	0	2	0
421.0	80.89	4	14	0	0	1	0
426.0	93.01	1	5	0	0	0	1
431.0	83.62	3	12	0	0	1	0
436.0	76.62	9	12	0	0	2	0
441.0	90.67	4	5	0	0	1	0
446.0	77.36	14	7	0	0	1	0
451.0	70.60	25	5	0	0	0	0
456.0	41.48	54	3	0	1	0	0
461.0	25.64	63	11	0	1	0	0
466.0	20.34	76	4	0	0	0	0
471.0	21.17	46	27	0	3	3	0
476.0	11.09	63	26	0	0	0	0
481.0	22.26	72	5	0	0	0	0
486.0	42.54	25	27	0	0	5	0
491.0	46.90	35	14	0	0	5	0
494.7	32.69	63	4	0	0	0	0
501.0	24.87	74	1	0	0	0	0
506.0	22.73	75	3	0	0	0	0
507.0	22.17	78	0	0	0	0	0
508.0	23.25	76	0	0	0	0	0
509.0	27.80	72	0	0	0	0	0
510.0	23.74	76	0	0	0	0	0
510.5	41.04	59	0	0	0	0	0
511.0	35.98	64	0	0	0	0	0
512.0	39.90	60	0	0	0	0	0
513.0	41.28	58	1	0	0	0	0
514.0	30.44	68	1	0	0	0	0
515.0	41.71	57	1	0	0	0	0
516.0	50.14	48	2	0	0	0	0
517.0	40.24	59	1	0	0	0	0
518.0	44.82	54	1	0	0	0	0
525.0	48.52	47	3	0	1	0	0
530.0	42.06	52	4	0	2	0	0
535.0	44.59	53	1	0	1	0	0
540.0	45.44	49	1	0	4	0	0
545.0	43.30	49	2	0	6	0	0
550.0	42.02	50	0	0	8	0	0
555.0	51.73	33	0	0	15	0	0
560.0	39.68	50	1	0	9	0	0
565.0	33.57	18	9	33	6	0	0
570.0	7.91	1	5	85	0	0	0
576.0	12.06	2	8	78	0	0	0
581.0	14.11	1	6	78	0	0	0
586.0	22.40	21	22	35	0	0	1
591.0	20.25	4	67	4	0	5	0
596.0	37.79	4	48	3	0	4	3
601.0	34.35	3	49	7	0	4	3
606.0	19.19	8	58	0	0	9	5
611.0	25.79	4	39	24	0	4	4
614.2	5.64	3	33	57	0	1	1
621.2	42.88	1	47	0	0	4	5
626.0	63.18	2	26	0	0	4	5

Table T2 (continued).

Sample depth (ft)	Clay and silt (%)	Glauconite (%)	Fine quartz (%)	Medium and coarser quartz sand (%)	Sphaero-siderite (%)	Mica (%)	Other (%)
631.0	53.08	2	34	0	0	5	5
641.0	39.24	3	45	0	0	7	6
651.0	56.00	2	32	0	0	5	5
661.0	60.23	2	31	0	0	4	2
666.0	59.13	12	26	1	0	2	0
671.0	63.03	3	29	1	0	2	2
676.0	59.83	38	0	0	0	1	1
681.0	41.86	43	11	0	0	4	0
685.0	35.15	53	10	0	0	2	0
691.0	29.65	2	29	40	0	0	0
696.0	10.07	1	45	43	0	1	0
701.0	4.76	1	38	57	0	0	0
706.0	21.10	0	23	56	0	0	0
711.0	22.67	0	44	34	0	0	0
716.0	5.55	0	27	68	0	0	0
721.0	9.37	0	40	50	0	0	1
726.0	6.32	0	32	61	0	0	0
730.3	5.76	0	21	71	0	0	2
731.7	15.13	1	35	46	0	1	3
736.0	20.68	0	28	42	0	0	10
741.0	5.78	0	53	41	0	0	0
745.0	29.01	0	34	3	0	9	26
750.0	56.47	0	28	9	0	0	7
761.0	86.72	0	11	0	0	1	2
766.0	90.76	0	5	0	2	1	1
771.0	98.74	0	0	0	0	0	0
780.9	89.94	4	3	0	0	1	2
786.0	78.87	0	14	0	0	3	4
791.0	86.97	0	8	0	0	2	2
796.0	88.38	0	9	0	0	1	1
801.0	95.81	0	0	0	0	2	2
806.0	95.96	0	2	0	0	1	1
811.3	97.34	0	1	0	0	1	1
816.0	93.21	0	3	0	0	2	2
821.0	93.04	0	2	0	0	2	3
826.0	88.71	4	2	0	0	2	2
831.2	22.92	15	15	47	0	0	0
835.0	12.10	9	9	71	0	0	0
841.0	17.35	0	70	5	0	8	0
851.0	28.24	0	57	7	0	7	2
861.6	32.73	0	63	0	0	4	0
866.0	52.56	0	41	0	0	6	1
871.0	61.00	1	29	0	2	4	3
881.0	55.47	1	37	0	0	4	3
886.0	57.06	0	28	0	1	7	7
891.0	78.96	0	12	0	2	3	3
896.0	93.46	0	4	0	1	1	1
901.0	96.27	0	1	0	0	1	1
906.0	97.92	0	1	0	0	0	0
911.0	92.02	0	4	0	1	1	1
916.0	81.85	1	12	0	1	2	2
921.0	81.91	1	13	0	1	3	1
926.0	86.21	1	11	0	1	1	1
931.0	87.63	4	4	0	2	2	0
936.0	95.49	2	0	0	2	1	0
941.0	70.44	29	0	0	1	0	0
946.0	34.63	60	5	0	0	0	0
951.0	29.48	44	26	0	0	0	0
955.0	42.65	41	16	0	0	0	0
961.0	21.62	55	20	4	0	0	0
964.4	62.39	0	29	0	0	5	5
976.0	51.71	0	37	0	0	11	0
980.8	34.82	65	0	0	0	0	0
986.0	27.10	52	0	0	21	0	0
990.0	15.05	79	0	0	6	0	0
1001.0	93.20	0	3	0	0	2	2
1006.0	70.51	0	12	0	0	9	9

Table T2 (continued).

Sample depth (ft)	Clay and silt (%)	Glauconite (%)	Fine quartz (%)	Medium and coarser quartz sand (%)	Sphaero-siderite (%)	Mica (%)	Other (%)
1011.0	70.04	12	8	0	0	6	5
1015.0	36.49	59	5	0	0	0	0
1021.0	40.70	9	45	0	0	3	3
1026.0	26.17	54	19	0	0	0	0
1037.8	28.04	35	36	0	0	0	0
1047.5	34.60	33	32	0	0	0	0
1050.3	58.65	23	18	0	0	0	0
1071.0	36.55	6	26	32	0	0	0
1076.0	11.66	0	52	32	0	4	0
1081.0	36.08	0	52	0	0	6	6
1085.4	14.10	0	65	8	0	6	6
1090.0	73.75	0	11	0	0	3	13
1093.0	40.21	0	47	5	0	3	4
1101.0	8.27	0	14	77	0	0	1
1106.5	34.24	0	55	10	0	0	0
1121.0	9.51	0	74	4	0	4	8
1126.0	14.16	0	86	0	0	0	0
1131.0	6.25	0	87	1	0	5	0
1136.5	85.17	0	11	3	0	1	0
1141.0	5.31	0	59	36	0	0	0
1146.0	11.05	0	51	28	0	3	7
1151.0	59.39	0	40	0	0	0	0
1156.0	46.32	0	37	17	0	0	0
1161.0	5.56	0	7	87	0	0	0
1166.0	16.82	0	82	0	0	1	1
1171.0	34.94	0	50	0	0	7	9
1176.4	21.40	0	56	0	0	8	15
1181.2	92.12	0	6	0	0	1	1
1185.3	89.41	0	6	0	0	2	3
1191.0	52.30	0	27	0	0	9	11
1196.0	14.50	0	81	0	0	5	0
1201.0	17.33	0	75	0	0	4	3
1204.0	19.05	0	67	4	0	9	1
1211.0	31.38	0	34	5	0	15	15
1216.0	5.38	0	12	82	0	0	0
1231.0	30.65	0	3	66	0	0	0
1241.0	42.03	0	56	2	0	0	0
1246.0	58.78	0	41	0	0	0	0
1251.0	96.87	0	1	0	0	0	3
1261.0	49.63	0	50	0	0	0	0
1266.0	17.70	0	81	1	0	0	0
1271.0	7.00	0	5	59	0	0	29
1281.0	8.28	0	18	73	0	0	0
1286.0	7.86	0	26	66	0	0	0
1291.0	55.63	0	38	0	0	6	0
1294.2	29.21	0	55	12	0	4	0
1301.0	38.68	0	48	0	0	13	1
1304.4	29.15	0	58	0	0	12	1
1311.0	43.83	0	48	0	0	8	0
1316.0	30.75	0	60	0	0	9	0
1321.4	39.03	0	55	0	0	4	2
1326.0	78.97	0	17	0	0	3	1
1330.6	96.15	0	1	0	0	1	2
1336.0	88.77	0	10	0	0	1	0
1341.5	96.56	0	1	0	0	1	2
1346.0	63.95	0	30	0	2	4	0
1351.0	94.32	0	2	0	0	1	2
1356.0	98.85	0	0	0	0	0	1
1361.2	98.15	0	0	0	0	1	1
1366.0	99.65	0	0	0	0	0	0
1370.7	97.93	0	1	0	0	0	1
1376.8	95.21	0	0	0	0	3	2
1381.3	99.44	0	0	0	0	0	0
1386.0	58.96	0	38	0	1	2	0
1390.7	87.10	0	9	0	1	2	1
1396.0	55.69	0	28	0	11	4	1
1400.8	75.56	0	20	0	1	3	1

Table T2 (continued).

Sample depth (ft)	Clay and silt (%)	Glauconite (%)	Fine quartz (%)	Medium and coarser quartz sand (%)	Sphaero-siderite (%)	Mica (%)	Other (%)
1406.0	80.16	0	9	0	1	5	4
1411.9	85.39	0	7	0	0	4	3
1415.0	84.02	0	10	1	2	3	0
1421.0	53.98	0	40	0	1	5	0
1425.9	55.82	2	27	0	3	11	3
1431.0	38.17	0	53	0	5	3	0
1435.5	69.97	0	26	0	0	2	2
1441.0	94.19	0	3	0	0	1	1
1445.1	55.71	4	35	0	4	0	0
1451.0	97.09	0	2	0	0	0	0
1456.0	58.78	0	10	0	31	0	0
1461.0	98.83	0	1	0	0	0	1
1464.0	99.20	0	0	0	0	0	0
1471.0	83.58	0	12	0	0	1	3
1476.0	42.03	3	49	0	0	3	3
1481.0	98.49	0	1	0	0	0	0
1486.0	97.56	0	2	0	0	0	0
1491.4	93.10	0	6	0	0	0	0
1496.0	26.48	0	70	0	0	4	0
1500.7	13.19	0	85	0	0	2	0
1506.0	96.61	0	3	0	0	0	0
1510.9	99.76	0	0	0	0	0	0
1521.2	20.93	0	39	36	0	4	0
1524.7	17.33	0	63	20	0	0	0
1531.0	20.26	0	53	25	0	2	0
1534.7	75.76	0	24	0	0	0	0
1541.2	91.62	0	8	0	0	0	0
1551.0	83.47	0	15	0	0	1	1
1556.0	95.89	0	4	0	0	0	0
1561.0	82.89	0	1	0	0	0	16
1571.9	92.76	0	7	0	0	0	0
1576.0	73.69	0	22	0	0	1	3
1581.0	97.22	0	1	0	0	0	2
1586.0	93.43	0	3	0	0	0	3
1591.0	91.99	0	1	0	0	0	7
1596.0	64.12	0	32	0	0	4	0
1597.7	95.24	0	4	0	0	0	0

Notes: Percent silt and clay in each sample was quantitatively measured by weighing each sample before and after washing off the clay and silt. The weight of the remaining sand was compared to the weight of the original sample to calculate percent silt and clay. All other percentages were arrived at qualitatively by visually estimating the proportion of each constituent in the sand fraction (see **"Lithostratigraphy,"** p. 18).

Table T3. Eocene planktonic foraminiferal occurrences. (**See table note.** Continued on next page.)

Sample depth (ft)	*Acarinina angulosa*	*Acarinina broedermanni*	*Acarinina bullbrooki*	*Acarinina matthewsae*	*Acarinina nitida*	*Acarinina pentacamerata*	*Acarinina mckanni*	*Acarinina primitiva*	*Acarinina pseudotopilensis*	*Acarinina soldadoensis*	*Acarinina strabocella*	*Acarinina subsphaerica*	*Chiloguembelina cubensis*	*Eoglobigerina edita*	*Globanomalina chapmani*	*Globanomalina compressa*	*Globanomalina pseudomenardii*	*Globigerinitheka*	*Globigerinoides higginsi*	*Globconusa daubjergensis*	*Guembelina columbiana*	*Igorina pusilla*	*Morozovella acuta*	*Morozovella aequa*	*Morozovella angulata*
171.0																										
176.0																										
181.0																										
186.0			x																					
191.0																										
196.0																										
201.0																										
206.0			x																					
211.0																										
216.0			x																					
221.0																					x				
226.0		x		x									x					x								
231.0																					x				
235.0			x	x		x			x																	
241.0																										
246.0			x	x		x													x						
251.0		x	x	x														x			x				
256.0			x	x		x			x																	
261.0																										
266.0		x	x	x						x																	
271.0				x		x			x																	
276.0	x					x			x																	
281.0	x					x			x																	
286.0	x				x	x			x	x																
290.4	x				x	x		x	x	x																
301.0	x				x	x		x	x	x																
306.0	x				x	x		x	x	x																
311.0	x				x	x		x	x	x																
316.0	x				x	x		x	x	x																
321.0	x					x																				
326.0	x								x	x	x																
331.0	x				x	x		x	x	x														x	
336.0	x				x			x	x																x	
341.0	x					x				x																
346.0	B																									
351.0	B																									
356.0	B																									
361.0	B																									
366.0								x																			
376.0	B																									

Sample depth (ft)	*Morozovella apanthesma*	*Morozovella aragonensis*	*Morozovella spinulosa*	*Morozovella gracilis*	*Morozovella lehneri*	*Morozovella lensiformis*	*Morozovella quetra*	*Morozovella subbotina*	*Parasubbotina varianta*	*Praemurica pseudoinconstans*	*Pseudohastigerina micra*	*Pseudohastigerina sharkriverensis*	*Subbotina eocana*	*Subbotina inaequispira*	*Subbotina linaperta*	*Subbotina lozanoi*	*Subbotina senni*	*Subbotina triangularis*	*Subbotina triloculinoides*	*Subbotina trivialis*	*Subbotina velascoensis*	*Truncorotalites rohri*	*Truncorotalites topilensis*	*Turborotalia frontosa*	*Turborotalia pomeroli*
171.0																										
176.0																						x			
181.0																										
186.0												x	x										x	x		
191.0													x													
196.0																										
201.0																										
206.0			x										x													
211.0													x													
216.0													x									x	x		
221.0												x	x													
226.0			x		x						x		x	x								x	x		x
231.0											x	x														x
235.0			x								x		x				x						x		x
241.0											x															
246.0			x								x				x											
251.0											x	x	x			x								x	
256.0											x	x	x		x	x								x	
261.0																										
266.0											x		x		x	x									
271.0													x	x											
276.0		x										x	x	x	x	x									
281.0								x			x		x													
286.0						x					x		x	x												
290.4											x	x	x	x											
301.0								x			x	x														
306.0		x					x	x																	
311.0						x	x	x			x													
316.0		x					x	x																	
321.0							x				x															
326.0				x			x	x							x									
331.0				x			x	x			x				x									
336.0							x	x							x									
341.0								x							x									
346.0																										
351.0																										
356.0																										
361.0																										
366.0																										
376.0																										

Table T3 (continued).

Sample depth (ft)	*Acarinina angulosa*	*Acarinina broedermanni*	*Acarinina bullbrooki*	*Acarinina matthewsae*	*Acarinina nitida*	*Acarinina pentacamerata*	*Acarinina mckanni*	*Acarinina primitiva*	*Acarinina pseudotopilensis*	*Acarinina soldadoensis*	*Acarinina strabocella*	*Acarinina subsphaerica*	*Chiloguembelina cubensis*	*Eoglobigerina edita*	*Globanomalina chapmani*	*Globanomalina compressa*	*Globanomalina pseudomenardii*	*Globigerinitheka*	*Globigerinoides higginsi*	*Globconusa daubjergensis*	*Guembelina columbiana*	*Igorina pusilla*	*Morozovella acuta*	*Morozovella aequa*	*Morozovella angulata*	*Morozovella apanthesma*	*Morozovella aragonensis*	*Morozovella spinulosa*	*Morozovella gracilis*	*Morozovella lehneri*	*Morozovella lensiformis*	*Morozovella quetra*	*Morozovella subbotina*	*Parasubbotina varianta*	*Praemurica pseudoinconstans*	*Pseudohastigerina micra*	*Pseudohastigerina sharkriverensis*	*Subbotina eocana*	*Subbotina inaequispira*	*Subbotina linaperta*	*Subbotina lozanoi*	*Subbotina senni*	*Subbotina triangularis*	*Subbotina triloculinoides*	*Subbotina trivialis*	*Subbotina velascoensis*	*Truncorotalites rohri*	*Truncorotalites topilensis*	*Turborotalia frontosa*	*Turborotalia pomeroli*
386.0	B																																																	
396.0	B																																																	
406.0	B																																																	
416.0	B																																																	
426.0	B																																																	
436.0	B																																																	
446.0	B																																																	
451.0																																											x							
456.0											x						x							x	x	x																	x			x				
457.2							x					x										x	x	x																			x			x				
461.0												x					x							x	x																		x			x				
466.0												x																															x							
471.0	B																																																	
476.0																									x																			x						
481.0																																												x						
486.0																																												x						
491.0																x				x														x										x						
494.0														x		x				x														x	x								x		x					
495.2																				x															x															
504.4																																			x															

Note: B = barren.

Table T4. Maastrichtian and Danian planktonic foraminiferal occurrences.

Sample depth (ft)	Formation	Age	Cretaceous mixed	*Guembelitria cretacea*	*Hedbergella monmouthensis*	*Hedbergella holmdelensis*	*Heterohelix*	*Gansserina weidermeyeri*	*Globigerinelloides escheri*	*Globigerinelloides multispina*	*Globigerinelloides prairiehillensis*	*Globogerinita stuarti*	*Globotruncana*	*Globotruncana aegyptiaca*	*Globotruncana arca*	*Globotruncana bulloides*	*Globotruncana lapparenti*	*Globotruncana linneiana*	*Globotruncanella petaloidea*	*Globotruncanita angulata*	*Heterohelix globulosa*	*Heterohelix navaroensis*
560	Navesink	Maastrichtian									X					X	X	X		X	X	
555	Navesink	Maastrichtian									X					X	X	X	X	X	X	
550	Navesink	Maastrichtian						X			X			X		X	X	X	X	X	X	
545	Navesink	Maastrichtian								X	X				X				X	X	X	X
540	Navesink	Maastrichtian								X	X				X	?					X	X
535	Navesink	Maastrichtian		X						X	X			X							X	
530	Navesink	Maastrichtian		X		X			X	X											X	
525	Navesink	Maastrichtian								X											X	
519.9	Navesink	Maastrichtian								X											X	
519	Navesink	Maastrichtian								X					X					X	X	
518	Navesink	Maastrichtian								X											X	
517	Navesink	Maastrichtian								X											X	
516	Navesink	Maastrichtian		X						X											X	
515	Navesink	Maastrichtian								X											X	
514	Navesink	Maastrichtian		X										X							X	X
513	Navesink	Maastrichtian								X				X	X				X		X	
512	Navesink	Maastrichtian										X										
511	Navesink	Maastrichtian																				
510	Navesink	Maastrichtian	X	X			X						X									
509.5	Hornerstown	Maastrichtian	X	X			X															
509	Hornerstown	Danian		X			X															
508.5	Hornerstown	Danian		X			X															
508	Hornerstown	Danian		X																		
507.5	Hornerstown	Danian		X			X															
507	Hornerstown	Danian		X																		
506.5	Hornerstown	Danian		X			X															
506	Hornerstown	Danian		X																		
505.5	Hornerstown	Danian		X																		
505	Hornerstown	Danian		X																		

Sample depth (ft)	*Heterohelix punctulata*	*Laeviheterohelix dentata*	*Laeviheterohelix glabrans*	*Planoglobulina acervulinoides*	*Planoglobulina multicamerata*	*Pseudoguembelina hariaensis*	*Pseudotextularia elegans*	*Globotruncanella*	*Planoglobulina*	*Rosita fornicata*	*Rugoglobigerina hexacamerata*	*Rugoglobigerina reicheli*	*Rugoglobigerina rotundata*	*Rugoglobigerina macrocephala*	*Rugoglobigerina rugosa*	*Rugoglobigerina scotti*	*Rugoglobigerina*	*Raceguembelina intermedia*	*Globigerinelloides*	*Eoglobigerina edita*
560										X										
555	X				X		X			X										
550	X		X				X			X										
545	X		X								X		X	X						
540	X												X			X				
535	X	X																		
530	X		X																	
525																				
519.9																				
519												X			X					
518																				
517				X							X			X	X					
516																				
515																				
514	X					X						X		X						
513	X		X									X								
512									X		X	X						X		
511												X								
510																	X		X	
509.5																	X		X	
509																	X		X	
508.5																			X	
508																			X	
507.5																				
507																				X
506.5																				X
506																				X
505.5																				X
505																				X

Sample depth (ft)	*Eoglobigerina eobulloides*	*Globanomalina archeocompressa*	*Parasubbotina* aff. *pseudobulloides*	*Parvularugoglobigerina eugubina*	*Parvularugoglobigerina* cf. *eugubina*	*Praemurica pseudoinconstans*	*Praemurica taurica*	*Praemurica* cf. *taurica*	*Subbotina trivialis*	*Chiloguembelina midwayensis*	*Globoconusa daubjergensis*	*Woodringina claytonensis*	*Woodringina hornerstownensis*	*Woodringina* cf. *hornerstownensis*
560														
555														
550														
545														
540														
535														
530														
525														
519.9														
519														
518														
517														
516														
515														
514														
513														
512														
511														
510														
509.5														
509	X						X			X		X		
508.5												X		
508	X					X				X	X	X		
507.5	X					X	X			X	X			
507	X						X			X	X			
506.5	X		X				X			X	X			
506	X	X					X				X			
505.5	X						X				X			
505	X					X	X			X	X			

Table T5. Campanian Mount Laurel–upper Englishtown Formations planktonic foraminiferal occurrences.

Sample depth (ft)	Formation	*Archeoglobigerina blowi*	*Archeoglobigerina cretacea*	*Globigerinelloides multispina*	*Globigerinelloides prairiehillensis*	*Globigerinelloides subcarinatus*	*Globotruncana bulloides*	*Globotruncana linneiana*	*Guembelitria cretacea*	*Hedbergella holmdelensis*	*Heterohelix globosa*	*Rosita fornicata*
835.0	Upper Englishtown	R		A		R		R		F		R
831.2		R		A		R		R		F		R
826.0		R		A		R		R		F		R
821.0		R		A		R		R		F		R
811.3			VR									
801.0		R		A		R		R		F		R
791.0		R		A		R		R		F		R
781		R		A		R		R		F		R
771		R		A		R		R		F		R
766		R		A		R		R		F		R
761		R		A		R		R		F		R
731.7		R		A		R		R		F		R
711		R		A		R		R		F		R
685	Marshalltown	R		A		R		R		F		R
681					VR							
676			VR				VR					
671												
666											VR	
661											VR	
651	Wenonah		VR									
641			VR								VR	
631		VR	VR								F	
621.2			VR	VR	VR	VR					R	VR
611	Mount Laurel				R						R	
601											VR	
591					VR						VR	
581			R		F			R	VR		C–A	VR
570.4			VR		VR			VR	VR	VR	C	

Note: A = abundant, C = common, F = few, R = rare, VR = very rare.

Table T6. Cenomanian–Turonian Bass River Formation planktonic foraminiferal occurrences.

Sample depth (ft)	Age	*Guembelitria cenomana*	*Hedbergella delrioensis*	*Hedbergella planispira*	*Heterohelix moremani*	*Heterohelix reussi*	*Praeglobotruncana inornata*	*Whiteinella baltica*	*Whiteinella archeocretacea*
1499.6			R	A	R	R	F		
1477.05			R	A	R	R	F		
1464			R	A	R	R	F		
1460.3			R	A	R	R	F		
1456			R	A	R	R	F		
1450.3		VR							VR
1445	Cenomanian	F				F			R
1438.8		F						F	R
1435.5									VR
1431		B	A	R	R	F	N		
1430.3		R						F	F
1426			VR	R			VR		
1421									R
1415		F							
1406		R							
1396	Turonian	A	F	C	C		R		F
1386		VR	VR	VR					VR
1376.8			VR						VR
1346									

Note: A = abundant, C = common, F = few, R = rare, VR = very rare, B = barren.

Table T7. Eocene benthic foraminiferal occurrences. (Continued on next page.)

Sample depth (ft)	*Alabamina*	*Angulogerina*	*Anomalinoides auta*	*Anomalinoides midwayensis*	*Bolivina*	*Bulimina*	*Bulimina hornerstownensis*	*Bulimina midwayensis*	*Bulimina ovata*	*Cancris*	*Ceratobulimina*	*Ceratocancris*	*Chilostomella cylindroides*	*Cibicidina*	*Cibicidoides*	*Cibicidoides alleni*	*Cibicidoides baileyi*	*Cibicidoides eocenus*	*Cibicidoides speciosus*	*Cibicidoides subspiratus*	*Cibicidoides succedens*	*Cibicidoides* aff. *subspiratus*	*Cibicidoides* aff. *pseudoungerianus*	*Dentalina*	*Discorbis huneri*	*Ellipsonodosaria*	*Epistomina*	*Eponides*	*Frondicularia*	*Fursenkoina*	*Gavelinella capitatus*	*Glandulina*	*Globobulimina*	*Globulina*	*Guttulina*	*Gyroidinoides octocamerata*	*Hanzawaia*	*Hanzawaia blanpiedi*	*Lagena*	*Lagena dorbignyana*
171.0																																			x					
176.0						x								x																					x	x				
181.0											x			x																					x	x				
186.0	x				x	x					x			x													x								x	x				
191.0	x					x								x			x								x		x								x	x				
196.0						x						x		x											x								x		x	x	x		x	
201.0	x					x						x		x										x					x						x					
206.0	x				x							x		x					x					x						x			x		x	x	x	x	x	
211.0	x				x	x								x											x										x	x	x		x	
216.0					x	x					x			x			x		x					x	x								x			x			x	
221.0	x				x	x					x												x					x							x	x	x	x	x	
226.0	x					x				x	x			x			x		x				x	x	x								x		x	x	x	x		
231.0	x					x																	x		x		x											x		
235.0						x					x												x										x		x		x	x	x	x
241.0	x					x																	x	x								x			x	x				
246.0	x		x										x				x			x				x	x				x				x		x	x	x	x	x	
251.0										x							x			x				x	x	x			x				x	x	x	x	x		x	
256.0										x			x				x			x				x	x	x							x		x	x				
261.0			x																	x																				
266.0	x																	x				x	x					x							x					
271.0	x		x															x					x		x			x						x						
276.0	x		x															x						x				x						x						
281.0	x																	x					x					x												
286.0	x		x																			x						x												
290.4			x		x																	x	x	x				x												
301.0	x				x												x	x				x		x				x			x								x	
306.0			x														x	x				x	x	x				x			x		x							
311.0																		x				x		x							x									
316.0	x																					x	x	x									x							
321.0	x		x															x				x	x	x	x															
326.0			x											x				x				x	x														x			
331.0			x															x					x	x	x								x							
336.0			x															x				x	x																	
341.0			x			x																	x	x		x		x			x									
346.0																												x			x									
351.0			x																					x																
356.0																																								
361.0																																								
366.0	x	x	x												x	x					x			x			x													
371.0		x	x													x					x																			
376.0			x													x																								
386.0																																								
446.0																																								
456.0		x	x	x			x	x							x	x					x			x																
466.0		x	x				x		x							x								x																
476.0		x	x	x		x	x		x					x	x									x												x				
486.0			x																					x				x												
494.7			x													x								x																
501.0	x														x	x																								

Table T7 (continued).

Sample depth (ft)	*Lenticulina*	*Loxostomoides*	*Marginulina*	*Marginulinopsis*	*Massalina*	*Melonis*	*Nodosarella attenuata*	*Nodosaria*	*Nodosaria latejugata*	*Nonionellina*	*Oridorsalis*	*Osangularia*	*Pararotalia*	*Percultazonaria*	*Planulina*	*Pleurostomella*	*Polymorphina*	*Pullenia quinqueloba*	*Pulsiphonina prima*	*Quinqueloculina*	*Ramulina globulifera*	*Sigmoidella*	*Sigmomorphina*	*Siphonina claibornensis*	*Spiroplectammina*	*Spiroplectammina spectabilis*	*Stilostomella*	*Tappanina selmensis*	*Textularids*	*Trifarina*	*Turrilina robertsi*	*Uvigerina*	*Valvulineria*	*Virginullina*
171.0																																		
176.0	x												x							x													x	
181.0	x												x				x															x		
186.0	x					x							x																			x	x	x
191.0	x		x			x							x				x								x		x					x		
196.0	x					x							x												x		x		x			x	x	x
201.0	x																x					x	x				x		x					
206.0	x		x			x				x			x			x						x		x			x					x	x	x
211.0	x					x				x			x									x		x			x					x	x	
216.0	x					x				x			x									x		x								x	x	x
221.0	x					x							x									x		x			x					x	x	
226.0	x		x	x						x		x				x		x		x		x		x										
231.0	x					x				x		x													x		x		x			x	x	x
235.0	x	x			x	x							x							x				x	x		x					x		
241.0	x		x																	x					x		x		x					
246.0	x		x	x		x																	x		x		x		x					
251.0	x		x			x												x		x					x		x		x					
256.0	x		x	x		x														x					x		x		x					
261.0	x																																	
266.0	x													x									x											
271.0	x													x										x			x							
276.0	x													x										x	x				x					
281.0	x													x	x									x		x								
286.0	x													x	x		x							x			x							
290.4	x													x	x				x					x			x							
301.0	x					x								x	x			x									x		x	x	x			
306.0	x											x		x	x						x						x		x		x			
311.0	x		x			x						x		x	x												x							
316.0	x					x				x				x	x											x			x	x		x		
321.0	x													x	x												x			x	x			
326.0	x					x								x	x			x									x							
331.0	x													x	x	x					x				x		x		x					
336.0	x													x															x					
341.0												x		x	x												x		x					
346.0																																		
351.0																																		
356.0																																		
361.0																																		
366.0							x	x										x	x								x							
371.0																			x															
376.0																			x															
386.0																																		
446.0																																		
456.0							x	x										x									x	x						
466.0	x								x										x		x				x		x	x		x				
476.0	x																										x	x		x				
486.0																											x							
494.7	x								x		x																							
501.0								x																			x							

Table T8. Maastrichtian Navesink Formation benthic foraminiferal occurrences. (Continued on next page.)

Sample depth (ft)	*Alabamina midwayensis*	*Angulogerina naheolensis*	*Anomalinoides acuta*	*Anomalinoides midwayensis*	*Anomalinoides nobilis*	*Arenobulimina subsphaerica*	*Bolivinoides delicatulus*	*Bolivinoides giganteus*	*Bulimina arkadelphiana*	*Bulimina quadrata*	*Bulimina referata* type	*Buliminella carseyae*	*Chilostomella trinidadensis*	*Cibicides harperi*	*Clavulinoides trilatera*	*Coryphostoma plaitum*	*Dentalina alternata*	*Dentalina colei*	*Dentalina pseudoaculeata*	*Dorothea bulleta*
560				VR		R				VR		F		R	R	F		VR		
555				R		C				R		F		F	C	F		R		R
550						R				VR		F		F	R	R		VR		VR
545					VR	VR		R		C		A		F	VR	C	VR	VR	VR	
540				A						F		A		F	VR					
535				C						C	VR	A		C				VR		
530				C						C	VR	C		F				R		
525				F						F		F						F		
519.9				F												VR				
519				F					C	C		F				VR		VR		
518				F						C		F				R		VR		
517				F						R		R				R				
516				F						F	VR	R				R		VR		
515				X								R		F		F				
514	VR			F						VR		VR		F		VR		VR		
513			VR	F						R		R		F		R		VR		
512				C						F		F		F–C		F				
511				C						R		F		F	VR	F	VR	VR		
510	VR	VR	VR	F–C						VR		F–C		VR		R		R		
509.5	R			F			VR			VR		F		R		F				

Sample depth (ft)	*Dorothea conica*	*Dorothea monmouthensis*	*Eggerella trochoides*	*Eponides* sp.	*Frondicularia* sp.	*Fursenkoina* sp.?	*Gaudryina laevigata*	*Gaudryina navarroana*	*Gavelinella* cf. *neelyi*	*Gavelinella pinguis*	*Gavelinella monterelensis*	*Gavelinella* sp.	*Gavelinella spissocostata*	*Globulina gibba*	*Gyroidinoides globosa*	*Gyroidinoides imitata*	*Heterostomella americana*	*Lagena sulcata*	*Lagena hexagona*	*Lagena hispida*
560	VR									R	R		R	R	VR					
555	VR		VR		VR		VR			F	VR		R	R		R	VR			
550	VR		VR				VR			F	VR		R	R	VR	F	VR			
545		VR					VR			F			F			VR		VR		
540							VR			R				R		C		VR		
535		VR					VR			F				R		C				
530							VR	VR		F				F		C				
525		F								F		F				F				
519.9		VR								R						VR				
519		R					F			F				R		R				
518		F					F			F				R		R		VR		
517		R					R			F				R		VR				
516		VR					VR			R				VR		VR			VR	VR
515							F			F						F				
514		VR					VR			R				VR						
513		VR					R			VR				VR		R				
512								VR	VR	VR				VR		R				
511				VR				VR	VR	VR				VR		VR				
510						VR		VR	VR					VR		R				
509.5								R	VR	R				R		VR				

Note: A = abundant, C = common, F = few, R = rare, VR = very rare.

Table T8 (continued).

Sample depth (ft)	*Lenticulina*	*Neoflabellina reticulata*	*Nodosaria latejugata*	*Nodosaria* sp.	*Oolina hispida*	*Oridoralis* sp.	*Osangularia plummerae*	*Pseudoclavulina clavata*	*Pseudouvigerina seligi*	*Pullenia americana*	*Pullenia cretacea*	*Pullenia coryelli*	*Pulsiphonina prima*	*Quadrimorphina allomorphinoides*	*Rectonodosaria* sp.	*Siphogeneroides plummerae*	*Spirobolivina*	*Spiroplectammina laevis*	*Stilostomella alexanderi*	*Stilostomella pseudoscripta*	*Tappanina selmensis*	*Vaginulina cretacea*	*Valvulineria depressa*
560	VR				VR		VR		R	VR		VR		R									VR
555	R	VR	VR		VR		VR		VR		VR		VR	VR	VR			VR					VR
550	R				VR		R		R	VR	VR		VR					VR	VR		VR		
545	VR				VR		F		F	VR	VR		R	F					VR		R		
540	VR			VR	VR		R		C	R			R		VR				VR		VR		F
535	R				VR		F	VR	F	VR							VR			VR		VR	R
530	R		VR		R		F	VR	F	R			VR						VR	VR	VR		
525	VR		VR		R		F			R			VR										
519.9	VR							R	F					F								VR	
519	VR				VR	VR	VR	R	VR		VR			C					VR	VR		VR	VR
518	VR		VR	VR	VR	VR	VR	VR	VR	VR				R					VR				VR
517	VR						VR	R		VR	VR		R						VR				VR
516	VR		VR			VR		VR	VR		VR		VR							VR	VR		
515	VR					VR	VR	VR	VR	VR			VR										
514	VR						VR	R	VR	VR									VR		VR		
513	R						VR	R	F				R			VR			VR		C		VR
512	R							VR	C		VR		F			F		R?			F	VR	VR
511	VR						VR	VR	F	VR			R			F					VR	VR	R
510	R			VR			F-C	VR	VR	VR			F–C			VR			VR		VR	VR	R
509.5	VR						F	R	F–C				F–C	R		R					F–C		VR

Table T9. Campanian Mount Laurel–upper Englishtown Formations benthic foraminiferal occurrences.

Sample depth (ft)	Formation	*Arenobulimina* sp.	*Bulimina referata* type	*Buliminella carseyae*	*Buliminella fabilis*	*Cibicides harperi*	*Clavulinoides trilatera*	*Coryphostoma plaitum*	*Dentalina*	*Dentalina colei*	*Epistomina ripleyensis*	*Gaudrina laevigata*	*Gavelinella clementiana*	*Gavelinella compressa*	*Gavelinella dumblei*	*Gavelinella nelsoni*	*Gavelinella pinguis*	*Gavelinella stephensoni*	*Gavelinella tennessensis*	*Globorotalites* cf. *micheliniana*	*Globulina gibba*	*Gyroidinoides globosa*	*Heterostomella americana*	*Lenticulina*	*Lenticulina pseudosecans*	*Marginulina*	*Nodosaria*	*Nodosaria latejugata*	*Planulina correcta*	*Praebulimina evexa*	*Pullenia americana*	*Rosalina* sp.	*Valvulineria depressa*
835						R			A			R			R			E			N												
831.2													VR																				
826													F			VR																	
821										VR	VR		R			VR									R					R			
811.3										VR		VR													R					R			
801						R			A			R			R			E			N												
791	Upper Englishtown																								R								
781																									R								
771													VR												F								
766						R			A			R			R			E			N												
761						R			A			R			R			E			N												
731.7						R			A			R			R			E			N												
711						R			A			R			R			E			N												
685						R			A			R			R			E			N												
681							VR						F			VR	VR								R			VR		R			VR
676	Marshalltown									VR			C			F	C								F			VR		VR			
671																	VR		VR						VR					VR			
666				VR												VR		VR	VR						VR					VR	VR	VR	VR
661				VR						VR		VR		VR	VR			VR	VR						VR					VR			
651			VR														VR	VR			VR									VR			
641	Wenonah																	VR												VR			
631				VR	VR									VR					F		VR				VR					R			VR
621.2				R	VR							VR		R					F	VR	VR									VR			VR
611					VR								VR	VR				VR															
601					R								VR												VR								VR
591	Mount Laurel													VR				VR						VR			VR		VR				VR
581		VR				VR		R	VR	VR		R		R		R	VR	R			R	R	R	R	VR	VR				R			
570.4														F		R		C		F		C	VR	VR						F			VR

Note: A = abundant, C = common, F = few, R = rare, VR = very rare.

Table T10. Cenomanian–Turonian Bass River Formation benthic foraminiferal occurrences.

Sample depth (ft)	Age	*Ceratobulimina parva*	*Citharina kochii*	*Citharina siliquina*	*Dentalina*	*Dentatina colei*	*Epistomina chapmani*	*Epistomina lenticularis*	*Epistomina stelligera*	*Epistomina suturalis*	*Gaudryina* sp.	*Gavelinella cenomana*	*Gavelinella dakotensis*	*Globulina*	*Gyroidinoides* sp.	*Lagena sulcata*	*Lenticulina*	*Nodosaria*	*Palmula* sp.	*Praebulimina* sp.	*Quinqueloculina lirellangula*	*Valvulineria lotterlie*
1499.6				R			A			R			R			F						
1477.05				R			A			R			R			F						
1464				R			A			R			R			F						
1460.3				R			A			R			R			F						
1456																	VR					
1450.3													R									
1445	Cenomanian		VR	VR	VR	VR				R		C	F		C	VR	R		VR		VR	VR
1438.8										VR	F		F								F	
1435.5					VR		VR			VR							VR					
1431									VR	VR											VR	
1430.3			VR				R			F	VR		C		F						C	
1426			VR						R	C				VR		VR			VR		F	
1421							R		F	F			R					VR	VR		VR	
1415		R	R					VR	F				R							R		
1406		VR	VR																	R		
1396	Turonian	R	VR				A		A				C							C		
1386		R	VR				F		F											VR		
1376.8		R					C		C													
1346							VR															

Note: A = abundant, C = common, F = few, R = rare, VR = very rare.

Table T11. Cenozoic calcareous nannoplankton occurrences.

Species	LO	HO	Level (ft)	Stratigraphic level
Chiasmolithus grandis		X	171–166	Top Zone NP17
Chiasmolithus solitus		X	196–191	Top Zone NP16
Reticulofenestra umbilicus	X		235–241.5	In lower Zone NP16
Nannotetrina fulgens		X	241.5–235	Top in mid Zone NP16
Chiasmolithus gigas		X	241.5–235	Top Subzone NP15b
Chiasmolithus gigas	X		261–266	Base Subzone NP15b
Nannotetrina fulgens	X		261–266	Base Zone NP15
Discoaster. sublodoensis	X		271–276	Base Zone NP14
Discoaster. lodoensis		X	266–261	Top Subzone NP14a
Discoaster. kuepperi		X	271–266	Near Top Subzone NP14a
Tribrachiatus orthostylus		X	276–271	Top Zone NP12
Discoaster lodoensis	X		316–321	Base Zone NP12
Tribrachiatus orthostylus	X		356–361	In upper Subzone NP10c
Tribrachiatus contortus		X	—	Top Zone NP10
Discoaster multiradiatus	X		396–401	Base Zone NP9
Discoaster. anartios	X	X	376	Restricted to base Subzone NP9b
Heliolithus riedeli	X		461–456	Base Zone NP8
Heliolithus kleinpelli	X		471–466	Base Zone NP6
Fasciculithus tympaniformis	X		471–466	Base Zone NP5
Ellipsolithus macellus	X		501–494.7	Base Zone NP4
Sphenolithus primus	X		481–476	Base Subzone NP4b
Chiasmolithus danicus	X		501–494.7	Base Zone NP3
C. tenuis	X		505–501	Base Zone NP2
Cruciplacolithus primus	X		505–501	Base Zone NP1b

Notes: LO = lowest occurrence, HO = highest occurrence. — = not found.

Table T12. Pollen and dinocyst occurrences.

Sample number	Depth (ft)	Comments
		Miocene or Holocene extant pollen types; poor samples
28406	30.0–30.2	Modern pollen; no fusain
28407	64.5–64.7	Modern pollen; poor sample
28408	103.0–103.2	Modern pollen; poor sample
28409	120.0–120.4	Modern pollen; no fusain
		Barren Cretaceous lithotype
28410	1070.6–1070.8	Fusain; no palynomorphs
28411	1080.5–1080.7	Fusain; no palynomorphs
		Zone VII; Magothy; Santonian
28412	1106.7–1106.9	Magothy
28413	1136.3–1136.5	Good sample, no staining makes it hard to see
		Heidelbergipollis sp. A
		Trudopollis sp. B
		Zone V; lower Magothy; South Amboy Fire Clay
28414	1183.2–1183.4	Poor sample; ?Zone V SAFC
		Poropollenites sp. Doyle SAFC
28415	1241.2–1241.4	SAFC; Zone 5
		Complexipollis sp. E
		Complexipollis sp. B
		Poropollenites sp. as in Doyle
28416	1263.6–1263.8	Barren; fusain abundant; almost no palynomorphs
28417	1284.5–1284.7	Barren
		Zone IV; Raritan–Woodbridge; upper Cenomanian
28418	1317.0–1317.2	Dinoflagellate fragment (marine)
		Atlantopollis sp. as in Woodbridge Clay member
		Wilsonisporites woodbridgei
28419	1317.2–1317.4	Raritan–Woodbridge age
		Complexipollis sp. O; Raritan Formation
28420	1360.1–1360.3	Barren; very poor, mostly fusain
28421	1410.7–1410.9	Brackish water environment
		Microforaminifer linings of trochoid arenaceous types
		Complexipollis sp. P; index form for Raritan
		Momipites sp.; a triporate not known in Zone III
		Clavatipollenites sp.
		Ajatipollenites sp. A
		Tricolpites vulgaris
		Fragment of a dinocyst
Boundary between Zones III and IV is uncertain because Sample 28422 is almost barren.		
		Zone III; lower Cenomanian; upper Patapsco
28422	1511.0–1511.2	One pollen grain; Zone III; fusain abundant
28423	1541.3–1541.5	Good sample; Zone III; upper Patapsco
		Tricolpites vulgaris
		Tricolporites subtlus
28424	1560.3–1560.5	No diagnostic pollen; fusain abundant

Note: All samples terrestrial except Raritan–Woodbridge.

Table T13. Sr-isotopic data from shells.

Sample depth (ft)	Sample depth (m)	Sr value	Corrected standards	Error	Age	Average (Ma)
510.5	155.60	0.707853	0.000004	0.000004	62.83	
510.5	155.60	No signal				
510.5	155.60	0.707847		0.000005	63.16	
517.0	157.58	No signal				
530.8	161.79	0.707829	0.000004	0.000004	64.15	
530.8	161.79	0.707814	0.000004	0.000004	64.98	64.57
536.0	163.37	0.707833		0.000004	63.93	
541.9	165.16	0.707852		0.000005	62.89	
547.2	166.79	0.707851		0.000005	62.94	
562.7	171.51	0.707728		0.000005	69.73	
563.6	171.79	0.707754		0.000004	68.29	
563.6	171.79	0.707749		0.000004	68.57	68.43
585.8	178.55	0.707654		0.000004	73.81	
585.8	178.55	0.707672		0.000004	72.81	
585.8	178.55	0.707678		0.000005	72.48	73.03
627.2	191.17	0.707642		0.000006	74.47	
666.0	203.00	0.707629		0.000005	75.19	
766.0	233.48	0.707639		0.000005	74.63	
771.0	235.00	0.707746		0.000005	68.73	
774.6	236.10	0.707584		0.000004	77.67	
785.8	239.51	0.707646		0.000004	74.25	
792.7	241.61	0.707575		0.000005	78.16	
818.1	249.36	0.707646		0.000006	74.25	
836.6	255.00	0.707574		0.000006	78.22	
836.6	255.00	0.707581		0.000004	77.83	78.03
941.0	286.82	0.707592		0.000009	77.23	
960.0	292.61	0.707507		0.000004	81.91	
964.0	293.83	0.707524		0.000004	80.98	
1001.0	305.10	0.707640		0.000005	74.58	
1011.0	308.15	0.707545		0.000013	79.82	
1015.0	309.37	0.707545		0.000007	79.82	
1021.0	311.20	0.707551		0.000024	79.49	
1026.0	312.72	0.707507		0.000006	81.91	
1037.0	316.08	0.707496		0.000010	82.52	
1346.0	410.26	0.707453		0.000004	84.89	
1376.8	419.65	0.708073		0.000006	50.70	
1376.8	419.65	0.707478		0.000007	83.51	
1396.0	425.50	0.707572		0.000004	78.33	
1421.0	433.12	0.707815		0.000004	64.93	
1431.0	436.17	0.707991		0.000005	55.22	
1443.9	440.10	0.707417		0.000004	86.88	
1456.6	443.97	0.707422		0.000005	86.60	
1464.0	446.23	0.707596		0.000004	77.01	