Miller, K.G., Sugarman, P.J., Browning, J.V., et al.
Proceedings of the Ocean Drilling Program, Initial Reports Volume 174AX (Suppl.)

9. Double Trouble Site[1]

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INTRODUCTION

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

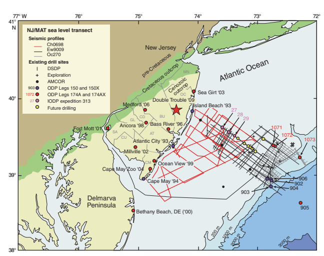
Chief Scientists: Browning, Miller, Sugarman
Operations: Browning, Miller, Sugarman
Lithostratigraphy: Browning, McLaughlin, Miller, Sugarman
Biostratigraphy:
- Foraminifers: Browning, Esmeray, Olsson
- Calcareous nannofossils: Aubry (Cenozoic), Bukry (Cretaceous)
- Dinocysts: Edwards

Logging: McLaughlin
Isotopic Stratigraphy: Browning, Feigenson, Miller

DOUBLE TROUBLE SITE SUMMARY

The Double Trouble site (October–November 2008) was the thirteenth continuously cored borehole drilled as part of the New Jersey Coastal Plain Drilling Project (NJCPDP) and the tenth site drilled as part of Leg 174AX (Fig. F1). Located ~5 mi (8 km) updip from the Leg 150X Island Beach site, drilling at Double Trouble (39°53′44.732″N, 74°13′23.346″W; elevation 36.8 ft [11.2 m]; Toms River U.S. Geological Survey [USGS] 7.5 min quadrangle; Berkeley Township, Ocean County,

F1. Location map, p. 39.



[1] Browning, J.V., Sugarman, P.J., Miller, K.G., Abdul, N.A., Edwards, L.E., Bukry, D., Esmeray, S., Feigenson, M.D., Graf, W., Harris, A.D., Martin, P.J., McLaughlin, P.P., Mizintseva, S.F., Monteverde, D.H., Montone, L.M., Olsson, R.K., Uptegrove, J., Wahyudi, H., Wang, H., and Syamsir, Z., 2012. Double Trouble Site. *In* Miller, Sugarman, Browning, et al., *Proc. ODP,* 174AX (Suppl.), College Station, TX (Ocean Drilling Program), 1–63. doi:2973/odp.proc.ir.174AXS.110.2012
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New Jersey) targeted Oligocene and late to middle Eocene sequences and aquifers and the Cretaceous/Paleogene boundary. Recovery was good (mean recovery = 74%), ending at a total depth (TD) of 858 ft (261.5 m) in Upper Cretaceous sediments. A full suite of slimline logs was obtained on the formation to 848.8 ft (258.7 m), and a gamma log was obtained to 844.6 ft (257.4 m). A team of scientists from the New Jersey Geological Survey (NJGS), Rutgers University, the Delaware Geological Survey (DGS), and the USGS collaborated in drilling and stratigraphic studies of this corehole, which was funded by the NJGS. Onsite and postdrilling studies of lithology, sequence stratigraphy, biostratigraphy, hydrostratigraphy, and Sr isotopes comprise the basic data sets on which this site report is based. The scientific team provided onsite descriptions of sedimentary textures, structures, colors, and fossil content and identified lithostratigraphic units, lithologic contacts, and sequences (unconformity-bounded units).

Beneath a thin (25.2 ft; 7.7 m) fluvial surficial (?Pleistocene) section, nearshore deposits of the upper to upper middle Miocene Cohansey Formation are 140.3 ft (42.8 m) thick and are only dated by regional correlations. The Cohansey Formation represents deposition in shoreface, foreshore, lagoonal, and tidal flat/channel environments and likely represents two sequences. The lower Miocene Kirkwood Formation (165.1–293.8 ft; 50.5–89.6 m) is 128.2 ft (39.1 m) thick and is also only dated by regional correlations; it represents deposition in shelf, prodelta, and delta front environments and can be divided into two sequences likely correlative to the Kw1a and Kw1b sequences of Miller and Synder (1997) **[AUTHOR: Please confirm reference; came in as Miller et al., 1997.]**.

The upper middle Eocene Toms River Member of the Shark River Formation (293.8–475.7 ft; 89.6–145.0 m) was a major target of this corehole. It consists of slightly muddy, glauconitic quartz sand. The sands are poorly sorted, ranging from very fine to coarse grained with granules and generally coarsen upsection. We interpret the environment of deposition as a "dirty" shoreface that shallows from lower to upper shoreface and that was proximal to a coarse sediment source. The Toms River Member at Double Trouble comprises the highstand systems tract (HST) of Sequence E8 of Browning et al. (1997 **[AUTHOR: 1997a or 1997b?]**). Age control on the unit is provided by dinocysts that suggest it is ~37–43 Ma (i.e., equivalent to nannofossil Zones NP16–NP17) and by superposition over sediments assigned to planktonic foraminiferal Zone E10 and nannofossil Zone NP16, all of which indicate it is upper middle Eocene. Regional studies documented here show that the sands of the Toms River Member are diachronous in the New Jersey coastal plain, becoming older downdip (i.e., comprising the HST of Sequences E8, E9, and E10 progressively downdip). The Toms River Member is an important aquifer in the Toms River, New Jersey, area and the Double Trouble corehole confirms that it is a thick (~161 ft; 49.1 m) water-bearing unit.

The middle Eocene lower Shark River Formation (475.8–572 ft; 145.0–174.3 m) is 96.2 ft (29.3 m) thick and can be divided into three sequences. The upper part of the unit is a fossiliferous, slightly micaceous, quartzose, glauconitic clayey silt, with glauconite increasing downsection to a sequence boundary at 517.4 ft (157.7 m). A maximum flooding surface (MFS) is placed near the top of the unit at ~485 ft (147.8 m). The HST of this Sequence E8 comprises the top of the lower Shark River and the Toms River Member. The bulk of the lower Shark River Formation consists of "ash colored marls": burrowed, very slightly glauconitic foraminiferal clays that become occasionally porcellanitic. A slightly sandy interval (517.4–541.1 ft; 157.7–164.9 m) marks the top of Sequence E6 or E6a, whereas a glauconitic interval (561–569.2 ft; 171.0–173.5 m) marks the base. Sequence E7 is not represented at Double Trouble. Sequence E6/6a is assigned to Zones E8–E9 (P10–P11) and NP15–N16. A thin Sequence E5 (570–572 ft; 173.7–174.3 m) consists of glauconitic clays assigned to Zone NP14a, which straddles the lower/middle Eocene boundary. Glauconitic clays are used to recognize the base of the formation.

The lower Eocene Manasquan Formation (572–706.5 ft; 174.3–215.3 m) is primarily a very slightly glauconitic carbonate clay that can be divided into three sequences. A thin Sequence E4 (572–583.6 ft; 174.3–177.9 m) is slightly sandy (10% quartz) with a basal thin glauconitic clay and is assigned to Zone NP13. Sequence E3 (583.6–673.6 ft; 177.9–205.3 m) is thick (90 ft; 27.4 m), very slightly sandy at the top, and assigned to Zones NP11 and E4–E7 (P6b–P9). It overlies a sandier HST of Sequence E2 (673.6–706.5 ft; 205.3–215.3 m) assigned to Zones NP11 and E4–E5; Sequence E2 consists of carbonate clays with quartz sands decreasing downsection from ~20% to a clay peak interpreted as an MFS (~706 ft; 215.2 m) and a basal glauconite sand that is also the base of the Manasquan Formation.

The section from 706.5 to 741.9 ft (215.3 to 226.1 m) is a heavily bioturbated, slightly micaceous, heavily burrowed clayey silt to silt deposited in a delta-influenced shelf environment and is assigned to the Vincentown Formation. This unit has discrepant biostratigraphic assignments likely due to reworking of Paleocene planktonic foraminifers into the lower lower Eocene section. The Marlboro Clay, which represents the Carbon Isotope Excursion (zones lower NP9b and E1) and subsequent recovery, is not represented at Double Trouble; it is similarly missing downdip at Island Beach but is otherwise well represented in other coastal plain coreholes. A sandy silt (741.9–751 ft; 226.1–228.9 m) may mark the HST of a sequence, with the contact at 741.9 ft (226.1 m) as a sequence boundary. A glauconitic-rich interval and surface at 810.3 ft (247.0 m) marks a basal sequence boundary. We tentatively interpret the entire section from 706.5 to 741.9 ft (215.3 to 226.1 m) and 741.9 to 810.2 ft (226.1 to 247 m) as two sequences correlated to Sequences E0 (defined herein) and Pa3a of Harris et al. (2010).

A thin sequence (810.3–818.8 ft; 247.0–249.6 m) straddles the contact with glauconite sands of the Hornerstown Formation (816–838.85 ft; 248.7–255.7 m), is assigned to Zone NP6, and is correlated with Sequence Pa2a of Harris et al. (2010). Below this, biostratigraphy suggests two thin Paleocene sequences: 818.8–822.95 ft (149.6–250.8 m), assigned to Zones P3 and NP5, and 822.95–832.65 ft (250.8–253.8 m), assigned to Zone P1c and NP3–NP4. A basal Paleocene sequence below 832.65 ft (253.8 m) straddles the Cretaceous/Paleogene boundary, with Zone P1b-Pα undifferentiated above and Upper Cretaceous below.

The Cretaceous/Paleogene boundary (838.35–838.65 ft; 255.5–255.6 m) appears to be biostratigraphically complete and has chalky clasts that may be carbonate accretionary lapilli and possible spherules, though a distinct spherule bed noted at Bass River (Olsson et al., 1997) is absent. Below the boundary are clayey glauconite sands of the Upper Cretaceous Navesink Formation.

The Double Trouble corehole penetrated several distinct water-bearing sands that comprise potential aquifers. Though no hydrologic studies were conducted at this site, sedimentological and log analyses suggest that the unconfined Kirkwood-Cohansey is shallow but a good aquifer (surface to ~185 ft; surface to 56.4 m). Prodelta fine silty sands and clayey silts (185–293.8 ft; 56.4–89.6 m) may confine the Toms River Member, the upper part of which comprises a major aquifer (293.8–~455 ft; 89.6–138.7 m).

BACKGROUND AND OBJECTIVES

This chapter is the site report for the Double Trouble corehole, the thirteenth continuously cored and logged onshore site drilled as part of the NJCPDP (Fig. F1). The NJCPDP began with drilling at Island Beach (March–April 1993; Owens et al., 1997), 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 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* during Leg 150 (Miller and Mountain, 1994; Miller et al., 1996b, 1998a). Leg 174AX continued onshore drilling at the following locations with specific objectives:

1. Bass River, New Jersey (October–November 1996) (Miller et al., 1998b), targeting Upper Cretaceous to Paleocene strata unsampled during Leg 150X.
2. Ancora, New Jersey (July–August 1998) (Miller et al., 1999), an updip, less deeply buried Cretaceous–Paleocene section complimentary to the Bass River.
3. Ocean View, New Jersey (September–October 1999) (Miller et al., 2001), focusing on middle Eocene–upper Miocene sequences.
4. Bethany Beach, Delaware (May–June 2000) (Miller et al., 2003), concentrating on thick Miocene sequences in the depocenter of the Salisbury Embayment.
5. Fort Mott, New Jersey (October 2001) (Sugarman et al., 2004), targeting the largely nonmarine Cretaceous Potomac Group and its contained aquifers.
6. Millville, New Jersey (May–June 2002) (Sugarman et al., 2005b), targeting upper Cretaceous sequences from southern New Jersey.
7. Sea Girt, New Jersey (September–November 2003) (Miller et al., 2006), targeting upper Cretaceous sequences from northern New Jersey.
8. Cape May Zoo, New Jersey (September–October 2004) (Sugarman et al., 2007), targeting middle Miocene through Pleistocene sequences. Continuing studies are helping to define the distribution of Miocene sequences and aquifers in the Cape May peninsula.
9. Medford, New Jersey (April–May 2007) (Sugarman et al., 2010), located to focus on improved correlations of Lower Cretaceous sequences and aquifers.

The Double Trouble site was located to focus on middle Eocene sequences and aquifers and to serve as a central tie point for correlation of aquifers between the southern and northern New Jersey coastal plain. In addition, the site was located to core the Paleocene/Eocene (PETM) and Cretaceous/Paleogene boundaries.

OPERATIONS

Drilling at the Double Trouble site (39°53′44.732″N, 74°13′23.346″W; elevation 36.8 ft (11.2 m); Toms River USGS 7.5 minute quadrangle; Berkeley Township, Ocean County, New Jersey) began on 10 October 2008. Drilling operations were superintended by Gene Cobbs III, Head Driller, USGS Eastern Earth Surface Processes Team (EESPT). Jeff Grey was the assistant driller. The Double Trouble State Park (Mark Pitchell, Superintendent) provided space, water, and electricity. The drillers arrived in the morning of 9 October and began rigging up. An onsite water well drilled by the USGS provided water. On 9 October, a field trailer was set up as a portable laboratory with hookups to the park's electricity. A Canon Power Shot G5 Zoom digital zoom camera (7.8–22 mm lens; 5 megapixel resolution), Macintosh Macbook Pro, and the Delaware Geological Survey photography stand were set up to photograph 2 ft (0.61 m) core segments; the camera's default settings with no flash were used.

All cores were measured in feet (all depths are given in feet below land surface with metric conversions provided). We continued to adopt the ODP convention of top justifying depths for intervals with incomplete recovery for all field notes and photos.

The first core was obtained on 10 October using a Christensen 94 mm (HQ) system, 4.5 inch Christensen CH bit. For unconsolidated sands, an extended "snout" shoe was used to contact the sample 1.5–2.5 inches (3.8–6.4 cm) ahead of the bit; core diameter is 2.5 inches (6.5 cm) with a rock shoe and 2.1 inches (5.3 cm) with the snout shoe. The uppermost 5 ft (1.5 m) was augured away while setting surface casing. The first core was obtained at 0850 h on 10 October with 1.2 ft (0.4 m) recovered (5–6.2 ft; 1.5–1.9 m) from 5 ft (1.5 m) run in very loose quartz sand. The second run (10–15 ft; 3–4.6 m) recovered 1.4 ft (0.4 m), also in very loose sand. The drillers put on the extended shoe to try to improve recovery, but poor recovery continued. Run 3 (15–20 ft; 4.6–6.1 m) had 40% recovery, and Run 4 (20–25 ft; 6.1–7.6 m) recovered 1.7 ft (0.5 m) of medium to very coarse sand. Run 5 (25–30 ft; 7.6–9.1 m) recovered 4.3 ft (1.3 m) in slightly siltier sand. Fast coring with poor to moderate recovery, especially in very wet coarser sands, continued through the day in the Cohansey Formation. Examples of poor recovery include Run 6 (30–35 ft; 9.1–10.7 m), which recovered 1 ft (0.3 m) of soupy coarse sand, Run 9 (45–50 ft; 13.7–15.2 m), which recovered 0.8 ft (0.2 m) of medium sand, and Run 12 (60–65 ft; 18.3–19.8 m), which recovered only 1.5 ft (0.5 m) of sand. The drillers intended to set surface casing in the first clay encountered. A fine-grained bed encountered the nearby Berkeley Township MUA hole at 50 ft (15.2 m) was not present at Double Trouble. The day ended at 70 ft (21.3 m) depth with 22.55 ft (7.8 m) recovered from 65 ft (19.8 m) drilled (39.3% recovery).

Recovery on 11 October improved in generally medium to coarse sand with 30 ft (9.1 m) (Runs 14–18, 70–100 ft; 21.3–30.5 m) drilled and 18.8 ft (5.7 m) recovered in the morning. Sticky clay at the bottom of Run 19 (100–105 ft; 2.3 ft recovered [30.5–32.0 m; 0.7 m]) blocked the bit and outer core barrel, preventing the inner core barrel from latching into place. The rods were pulled in order to clean off the clay. Normal coring resumed at 1500 h from 105 to 110 ft (Run 20, 32.0 to 33.5 m) with 4.3 ft (1.3 m) of recovery. Run 21 (110–120 ft; 33.5–36.6 m) is believed to have slipped out of the core barrel and only 0.1 ft (2.5

cm) of core was recovered. The day ended at 120 ft (36.6 m) depth with 26.15 ft (8.0 m) recovered from 50 ft (15.2 m) drilled (52% recovery).

On Sunday, 12 October, the drillers attempted to recover the rest of the core from Run 21. Run 21 recovered 0.65 ft (0.2 m), and Run 22 (120–125 ft; 36.6–38.1 m) recovered 4.75 ft (1.4 m; 95% recovery). Run 23 (125–130 ft; 38.1–39.6 m) recovered 4.6 ft (1.4 m), Run 24 recovered 3.7 ft (1.1 m; 64% recovery) from 130 to 135 ft (39.6 to 41.1 m), and Run 25 recovered 3 ft (0.9 m; 60% recovery) from 135 to 140 ft (41.1 to 42.7 m). Recovery was poor for Runs 26, 27, and 28, with 0.5 ft (0.2 m) from 140 to 150 ft (42.7 to 45.7 m), 0.9 ft (0.3 m) from 150 to 152 ft (45.7 to 46.3 m), and 0.35 ft (0.1 m) from 152 to 160 ft (46.3 to 483.8 m), respectively. Run 29 (160–165 ft; 48.8–50.3 m) recovered 2.7 ft (0.8 m; 54% recovery). Recovery improved to 96% on Run 30 (165–170 ft; 50.3–51.8 m). For Run 31, recovery was 90% (170–180 ft; 51.8–54.9 m; 9 ft [2.7 m] recovered), ending in granuliferous sand. The day ended at 180 ft (54.9 m) depth with 34.3 ft (10.5 m) recovered from 60 ft (18.3 m) drilled (57% recovery).

On Monday 13 October, the drillers washed the hole from the gravel penetrated at the end of the previous day. On the first run (Run 32; 180–182 ft; 54.9–55.5 m), the extended shoe could only penetrate 2 ft (0.6 m) into gravel, and 1.7 ft (0.5 m) was recovered. Run 33 (182–190 ft; 55.5–57.9 m) only recovered 0.7 ft (0.2 m) from gravel. On the next run the rods became sand locked and the drillers were forced to pull the rods. It took 2 hr to free the inner core barrel from the drill rod. The drillers had not advanced the rods below 190 ft (57.9 m); the gravel caving in the hole prevented coring. After clearing the barrel, the drillers reran the rods. They decided to run heavy mud in the hole and let it settle overnight. Examination of the gamma log from the nearby Berkeley Township MUA hole suggested that the gravel was thin (~5–6 ft; 1.5–1.8 m), which suggested that we may have penetrated the base of the gravel. Recovery for the day was 2.4 ft (0.7 m) from 10 ft (3.0 m) drilled (24%).

The drillers decided to run 6 inch (15.2 cm) PVC casing on Tuesday 14 October to case off the caving gravel. This depth is similar to where casing was set during drilling of the Transco Double Trouble well (drilled in 1951) that was cased at 207 ft (63.1 m). Despite repeated attempts on 14 and 15 October, the casing would not penetrate below 40 ft (12.2 m) in the Cohansey Formation sands. The drillers obtained 5 inch (12.7 cm) PVC casing on Thursday 16 October and ran it through the 6 inch (15.2 cm) casing to the bottom of the hole at 188 ft (57.3 m), successfully sealing off the Cohansey Formation sands and the caving gravel at ~180–185 ft (54.9–56.4 m).

The drillers ran the rods to the bottom of the hole on the morning of Friday 17 October. Coring resumed at 1000 h with good recovery in silty fine-to-medium sand. The drillers used the 10 ft (3.0 m) barrel for the day, although most runs were cut short because of difficult penetration. Run 40 (225–226 ft; 68.6–68.9 m) was sand locked, but the drillers were able to work the barrel free. Two groups of undergraduate students came to visit the site. The day ended at 250 ft (76.2 m; Run 43) depth with 46.9 ft (14.3 m) recovered from 60 ft (18.3 m) drilled (78% recovery).

Drilling on Saturday 18 October went very well. Ten foot (3.0 m) runs were undertaken between 250 and 310 ft (76.2 and 94.5 m), with recoveries of 85%, 37%, 91%, 93%, 98%, and 96%. A 7 ft (2.1 m) run was taken between 310 and 317 ft (94.5 and 96.6 m), with 4.8 ft (1.5 m) recovered. The next 3 ft (0.9 m) run recovered 0.9 ft (0.3 m), which was indurated in places. In the final run of the day from 320 to 330 ft (97.5 to 100.6 m), 6.1 ft (1.9 m) was recovered. The day ended at 330 ft (100.6 m) depth with 61.8 ft (18.8 m) recovered from 80 ft (24.4 m) drilled (77% recovery).

Cool (~45°F) temperatures greeted the drillers on Sunday 19 October. The first run (330–340 ft; 100.6–103.6 m) was blocked off by indurated sandy clay and only recovered 3.2 ft (1.0 m). The next run (340–345 ft; 103.6–105.2 m) went 5 ft (1.5 m) in alternating sands and indurated zones, recovering 2.0 ft (0.6 m) of solid core and 3 ft (0.9 m) of slop from adding the rods; the base of the run was indurated and had blocked off the core. The slop was discarded. The drillers shortened the shoe. The next run (345–350 ft; 105.2–106.7 m) was also blocked off by an indurated zone and recovered 2.6 ft (0.8 m). The drillers shortened the shoe to just shy of a rock shoe. Run 56 (350–337 ft; 106.7–108.8 m), Run 57 (357–360 ft; 108.8–109.7 m), and Run 58 (360–365 ft; 109.7–111.3 m) recovered 2.4, 1.35, and 2.2 ft (0.7, 0.4, and 0.7 m), respectively, as alternating hard and soft layers hindered recovery. The appearance of clay helped recovery on Run 59 (365–370 ft, 3.1 ft; 111.3–112.8 m, 0.9 m), Run 60 (370–375 ft, 3.4 ft; 112.8–114.3 m, 1.0 m), and Run 61 (375–380 ft, 4.1 ft; 114.3–115.8 m; 1.2 m). We returned to 10 ft cores on Run 62 (380–390 ft; 115.8–118.9 m) and Run 63 (390–400 ft; 118.9–121.9 m) and cored 10 ft (3.0 m), recovering 7.3 and 2.7 ft (2.2 and 0.8 m), respectively. Run 63 blocked off from a clay layer and major change in lithology. The day ended at 400 ft (121.9 m) depth with 34.35 ft (10.5 m) recovered from 70 ft (21.3 m) drilled (49% recovery).

On 20 October, the drillers ran 3 ft (0.9 m) on Run 64 to capture the possible contact with the upper Shark River Formation, but surprisingly ran back into sands of the Toms River Member. Recovery improved on Run 65 (2.8 ft from 403 to 406 ft; 0.9 m from 122.8 to 123.7 m) and Run 66 (2.85 from 406 to 410 ft; 0.9 m from 123.7 to 125.0 m) as the sediments became clayier. The next run (Run 67; 410–415 ft; 125.0–126.5 m) recovered water-rich sands with surprisingly good recovery (3.5 ft; 1.1 m). Run 68 (415–420 ft; 126.5–128.0 m) provided excellent (4.45 ft; 1.4 m) recovery of sands and a spectacular contact. Recovery dropped on Run 69 (420–425 ft, 1.55 ft; 128.0–129.5 m, 0.5 m) and Run 70 (425–430 ft, 3.6 ft; 129.5–131.1 m, 1.1 m) as we ran back into granuliferous sands. The drillers ran 10 ft (3.0 m) on Run 71 (430–440 ft; 131.1–134.1 m), recovering 2.45 ft (0.7 m). The day ended at 440 ft (134.1 m) depth with 22.4 ft (6.8 m) recovered from 40 ft (12.2 m) drilled (56% recovery).

On 21 October, the first run (Run 72) recovered 2.5 ft (0.8 m) of 10 ft (3.0 m). Recovery improved on the next two runs (Run 73 [450–460 ft; 137.2–140.2 m] and Run 74 [460–470 ft; 140.2–143.3 m]): 9.8 and 8.4 ft (3.0 and 2.6 m), respectively. Run 76 originally cored the interval 480–485 ft (146.3–147.8 m). The drillers recovered no core, as the core slipped out of the barrel. They went back and drilled 5 ft (1.5 m) more (485–490 ft; 147.8–149.4 m) and recovered 10 ft (3.0 m). The entire core is logged as Run 76. Run 77 again fell out of the bottom of the barrel, and only 4.5 ft (1.4 m) was originally recovered. On the next run (Run 78; 500–505 ft; 152.4–153.9 m) much more than 5 ft (1.5 m) was recovered, and we placed the upper 2.6 ft (0.8 m) into Run 77 and the rest (4.8 ft; 1.5 m) into Run 78. The day ended at 510 ft (155.4 m) depth with 53.1 ft (16.2 m) recovered from 70 ft (21.3 m) drilled (75.9% recovery). The drillers pulled up 70 ft (21.3 m) overnight because of swelling clays.

On 22 October, the drillers ran the rods back into the hole, but the inner core barrel became stuck. They eventually freed the barrel by rotating the rods and circulating mud. When the inner barrel surfaced at 1000 h, it was covered with sticky clay scraped off of the hole while the rods were lowered. The drillers drilled from 510 to 520 ft (Run 80; 155.4 to 158.5 m) and had difficulty freeing the inner core barrel; by pumping and twisting, they worked the inner barrel free but almost disengaged the overshot. The core arrived safely at the surface at 1200 h with full recovery. The drillers noticed that the quad latch was slightly wobbly. Run 81 (520–530 ft; 158.5–161.5 m) was made without incident, recovering 8.9 ft (2.7 m); Run 82 (530–539.5 ft; 161.5–164.4 m) picked up the 1 ft (0.3 m) lost on the previous run. We adjusted the depths in the field; photos and labels reflect recovery of 10.5 ft (3.2 m) from 529 to 539.5 ft (161.2 to 164.4 m). Run 83 ran 10.3 ft (3.1 m; 539.5–549.8 ft; 164.4–167.6 m) and recovered 9.9 ft (3.0 m). The day ended at 549.8 ft (167.6 m) depth with 39.2 ft (11.9 m) recovered from 39.8 ft (12.1 m) drilled (98% recovery).

On 23 October, drilling went exceptionally well. The lower Shark River Formation clay-silt cored very easily, allowing for exceptional recovery. Run 84 recovered 10.2 ft (3.1 m; 100% recovery) between 549.8 and 560 ft (167.6 and 170.7 m). Recovery was 92% from 560 to 570 ft (170.7 to 173.7 m; Run 85), 99% from 570 to 580 ft (173.7 to 176.8 m; Run 86), 98% from 580 to 590 ft (176.8 to 179.8 m; Run 87), 90% from 590 to 600 ft (179.8 to 182.9 m; Run 88), and 89% from 600 to 609 ft (182.9 to 185.6 m; Run 89). The drillers drilled to 610 ft (185.9 m) to finish the rod and try and retrieve the 1 ft (0.3 m) lost in the last run. They recovered 4 ft (1.2 m) of core. The bottom 2 ft (0.6 m) was added to the previous run, making recovery 100% for 600–610 ft (182.9–185.9 m). The top 2 ft (0.6 m) was labeled as 606–608b (184.7–185.3 m) until the higher cores can be corrected. The day ended at 610 ft (185.9 m) depth with 60.1 ft (18.3 m) recovered from 60.2 ft (18.3 m) drilled (99.8% recovery). The drillers pulled up 160 ft (48.8 m) of rods at the end of drilling.

On 24 October, the drillers ran the 160 ft (48.8 m) of rods that were removed the previous evening. They cleaned out the inner core barrel, pumped the hole, and commenced drilling at 1130 h. Run 91 (610–620 ft, 185.9–189.0 m) recovered 5.85 ft (1.8 m). The next run (Run 92, 620–627 ft; 189–191.1 m) cored 7 ft (2.1 m) and recovered 7.65 ft (2.3 m). The top of this core was probably left in the hole from the previous run. Run 93 recovered 4.05 ft (1.2 m) from 627 to 630 ft (191.1 to 192.0 m). Run 94 recovered only 5.55 ft (1.7 m) from 630 to 640 ft (192 to 195 m). The final run of the day (Run 95, 640–647 ft; 195.1–197.2 m) recovered 7.2 ft (2.2 m). The day ended at 647 ft (197.2 m) with 30.3 ft (9.2 m) recovered from 37 ft (11.3 m) drilled (82% recovery).

On 25 October, drilling from 647 to 655 ft (197.2 to 199.6 m; Run 96) recovered 4.3 ft (1.3 m), whereas the next run from 655 to 660 ft (199.6 to 201.2 m; Run 97) recovered 4.3 ft (1.3 m). On the following run, from 660 to 670 ft (201.2 to 204.2 m; Run 98), the drillers had problems catching the core. When the core was brought to the surface, 10.2 ft (3.1 m) was recovered. From 670 to 680 ft (204.2 to 207.3 m; Run 99), 8.1 ft (2.5 m) was recovered. Run 100 went 9 ft (2.7 m) with 8.5 ft (2.6 m) recovered. After the next run was completed from 688.5 to 698.5 ft (209.9 to 212.9 m; Run 101), the core fell out of the shoe. Recovery was excellent (92%), and the upper 2.1 ft (0.6 m) (688.5–690.6 ft; 209.9–210.5 m) and lower 1.3 ft (0.4 m; 696–697.3 ft; 212.1–212.5 m) were recovered in place, but the core in between is not in place. The final run of the day was from 698.5 to 708 ft (212.9 to 215.8 m; Run 102). The 10 ft (3.0 m) run could not be completed, as there was 0.5 ft (0.2 m) of core left in the hole from the last run. Recovery from this run was 9.5 ft (2.9 m). The day ended at 708 ft (215.8 m) depth with 55.1 ft (16.8 m) recovered from 60 ft (18.3 m) drilled (91.8% recovery).

The drillers ran the rods back into the hole and started drilling on the morning of 26 October. The first run (708–719 ft; 215.8–219.2 m) had almost full recovery (10.7 ft; 3.3 m). The second run (Run 104, 719–729.5 ft; 219.2–222.4 m) initially pulled 5.2 ft (1.6 m). The drillers went back in the hole for Run 105 (729.5–735 ft; 222.4–224.0 m) and recovered 10.5 ft (3.2 m). The core was apportioned between Runs 104 (5.1 ft; 1.6 m) and 105 (5.4 ft; 1.6 m). Drillers encountered problems with sticking rods, and they ceased drilling. They pulled all rods, cleaned the sticky clays off the outside of the rods, and put all but 60 ft (18.3 m) back in the hole, using the headlights of their truck to finish operations. The day ended at 735 ft (224.0 m) depth with 26.4 ft (8.0 m) recovered from 27 ft (8.2 m) drilled (98% recovery).

On the morning of 27 October, drillers added the remaining 60 ft (18.3 m) of rods and resumed drilling by 0900 h. After drilling a 5 ft (1.5 m) run (Run 106; 735–740 ft; 224.0–225.6 m), the inner core barrel stuck in the outer barrel and required pulling and pumping to free the core barrel. The inner barrel was freed, and core for Run 107 was up by 1100 h (1.4 ft [0.4 m] recovered). Run 107 drilled 8.5 ft (2.6 m; 740–748.5 ft; 225.6–228.1 m), short of the full 10 ft (3.0 m), and recovered 10.5 ft (3.2 m) of core including 2 ft from the previous run. We assigned the upper 2.0 ft (0.6 m; 738–740 ft; 224.9–225.6 m) of Run 107 to the bottom of Run 106. Run 108 drilled 7.5 ft (2.3 m; 748.5–756 ft; 228.1–230.4 m). However, the core barrel was empty when it came up at 1350 h, so drillers changed to the rock shoe and put the inner core barrel back in to attempt to recover the lost core. After 3.0 ft (0.9 m) of additional drilling (still referred to Run 108), the drillers successfully retrieved the core at 1430 h. In all, Run 108 (748.5–759.0 ft; 228.1–231.3 m) recovered 10.55 ft (3.2 m) from 10.5 ft (3.2 m) drilled. The drillers continued to run a rock shoe to reduce the chance of core loss from the bottom of the core barrel. The final run of the day, Run 109 (759.0–769.5 ft; 231.3–234.5 m), was completed at 1600 h with 10.7 ft (3.3 m) recovered. The drillers pulled up 40 ft (12.2 m) at the end of the day. The day ended at 769.5 ft (234.5 m) depth with 33.15 ft (10.1 m) recovered from 34.5 ft (10.5 m) drilled (96% recovery).

On 28 October, nasty, rainy, and windy conditions prevailed, and the drillers ran the 40 ft (12.2 m) to the bottom of the hole with an inner core barrel. The core barrel came up full as they recut the bottom section. The drillers then ran 10.5 ft (3.2 m) of new core on Run 110 (769.5–780 ft; 234.5–237.7 m), recovering 9.8 ft (3.0 m). The drillers reported that two sections were swelling, 480–510 ft (146.3–155.4 m; lower Shark River Formation) and 730–740 ft (222.5–225.6 m; Vincentown Formation). The next run (111, 780–785 ft; 237.7–239.5 m) encountered very high mud pressures, and the core in the shoe jammed the catcher, causing the run to be terminated after 5 ft (1.5 m). Trouble continued on the next run (112, 785–792 ft; 239.3–241.4 m), recovering 5.5 ft (1.7 m). The drillers reported very high mud pressures (800 psi) while drilling; when running for core, pressure dropped to 200 psi. Continued high drilling pressures, it was feared, would blow the pump, causing us to lose the rods and possibly the hole. The drillers believed the hole was not straight and the rods were shimming around the swelling clays at the base of the Shark River Formation (480–510 ft; 146.3–155.4 m). The drilling team considered three options:

1. Ream the hole with a 4-7/8 inch (12.4 cm) reaming bit (i.e., must be <5 inches [12.7 cm] to fit inside the casing), requiring 2–4 days.
2. Pull the rods out of the hole, clean the bit, and redrill with the coring bit.
3. Pull up to 450 ft (137.2 m) and ream with the coring bit down to the bottom to attempt a few more runs.

Co-Chief Scientists Sugarman and Miller favored option 3 with the following priorities: (1) save the hole for logging and (2) recover the Cretaceous/Paleogene (K/Pg) boundary. The drillers pulled the rods to 450 ft (137.2 m) and began to ream the hole with the idea of coring Thursday.

On Wednesday 29 October, the drillers successfully reamed the hole from 450 to 792 ft (137.2 to 241.4 m) and ran 8 ft (2.4 m) on Run 113 (792–800 ft; 241.4–243.8 m). The core was described by geologists onsite on 30 October.

Freezing conditions on 30 October delayed the first core until 0915 h. The drillers ran 5 ft (1.5 m) but only caught 1.1 ft (0.3 m) of slightly deformed core that may be from the previous run; the new core slipped out of the barrel. The next 5 ft run (1.5 m) recovered 8.6 ft (2.6 m) of core. We combined these two 5 ft (1.5 m) runs into Run 114 (800–810 ft; 243.8–246.9 m). We decided to keep making 10 ft (3.0 m) runs because the 5 ft (1.5 m) runs tended to slip out. The drillers had difficulty getting the inner barrel to release on Run 115 (810–820 ft; 246.9–249.9 m). Both Runs 115 and 116 (820–830 ft; 249.9–253.0 m) came up with virtually full recovery. Run 117 (830–840 ft; 253.0–256.0) recovered 10.6 ft (3.0 m), and the drillers noted a difference in drilling beginning 7–8 ft (2.1–2.4 m) into the run. Onsite, R. Olsson found Cretaceous planktonic foraminifers at the base of the core. The K/Pg boundary was interpreted to be at a surface in the core at 838.85 ft (255.7 m). We decided to run two more cores to get below the boundary for logging. Run 118 (840–850 ft; 256.0–259.1 m) recovered 7.6 ft (2.3 m) and Run 119 (850–858 ft; 259.1–261.5 m) recovered 10.6 ft (3.2 m), including 2.6 ft (0.8 m) from the previous run that had a thick rind on it. The day ended at 858 ft (261.5 m) depth with 57.5 ft (17.5 m) recovered from 60 ft (18.3 m) drilled (96% recovery).

On the morning of 31 October the mudlines were frozen and the drillers decided to forgo further drilling. Recovery for the hole was 635.2 ft (193.6 m) from 858 ft (261.5 m) drilled (74% recovery). Eighty-five core boxes were moved to the Rutgers Core Repository for further study.

On 31 October, P. McLaughlin (DGS) arrived onsite and obtained a gamma log through the rods to 844.6 ft (257.4 m) using the Rutgers University Department of Geology's Century Geophysical Corporation drawworks and the DGS's Century Geophysical slimline Natural Gamma Tool. The rods were pulled, and two logging runs were made on formation. The first was performed using the DGS's Century Gamma-Electric Multitool (Model 8144A). This logging tool simultaneously records a gamma ray log and a suite of electric logs, including spontaneous potential (SP), short normal resistivity (16N), long normal resistivity (64N), point resistance, and lateral resistivity. The first open-hole run was to 848.8 ft depth. Because the upper 200 ft of the hole is cased, a second run was made using the DGS's Century Gamma-Induction

Logging Tool to 845 ft; this tool simultaneously records gamma and magnetic induction conductivity logs in both the open and PVC-cased portions of the hole, and the induction log can be converted into a pseudoresistivity log.

The hole was plugged with concrete on 1 November, and the hole was abandoned.

LITHOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY

The on-site scientific team provided preliminary descriptions of sedimentary texture, structure, color, fossil content, identification of lithostratigraphic units (New Jersey Division of Water Resources, 1990), and lithologic contacts (Table T1; Figs. F2, F3, F4, F5, F6, F7). Subsequent studies integrated preliminary descriptions with additional descriptions, biostratigraphy, biofacies studies, isotopic stratigraphy, and the downhole gamma log. Unconformities were identified on the basis of physical stratigraphy, including irregular contacts, reworking, bioturbation, major facies changes, and gamma ray peaks. Paraconformities were inferred from biostratigraphic breaks. Core photographs (Figs. AF1, AF2, AF3, AF4, AF5) illustrate sequence-bounding unconformities and facies variation within sequences.

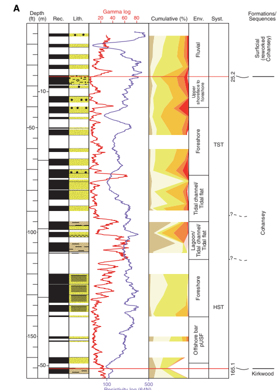
For the nonmarine and nearshore sections, lithofacies interpretations provide the primary means of recognizing unconformities and interpreting paleoenvironments and systems tracts. For the neritic sections, biostratigraphic studies and Sr isotopes provide an additional means of recognizing unconformities and interpreting paleoenvironments and systems tracts.

Cumulative percent plots of the sediments in the cores were computed from washed samples (Table T2). 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 on previous New Jersey coastal plain cores (Bass River, Island Beach, Atlantic City, and Cape May), in which the samples were not dried before washing.

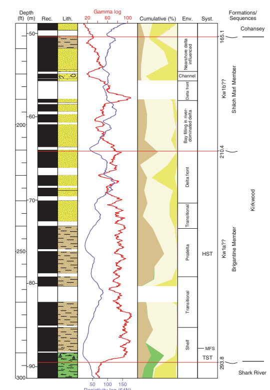
Facies changes within onshore sequences generally follow repetitive transgressive–regressive patterns (Sugarman et al., 1993, 1995) that consist of (1) a basal transgressive glauconite (particularly Paleogene–Upper Cretaceous sections) or quartz sands (particularly Miocene sections) equivalent to the transgressive systems tract (TST) of Posamentier et al. (1988) or (2) a coarsening-upward succession of regressive medial silts and upper quartz sands equivalent to the HSTs of Posamentier et al. (1988). Lowstand systems tracts (LSTs) are usually absent in the coastal plain and the TSTs are generally thin. Because the TSTs are thin, MFSs are difficult to differentiate from unconformities. Shell beds and gamma ray peaks can mark both TSTs and MFSs. Flooding surfaces, particularly MFSs, may be differentiated from sequence boundaries by the association of erosion and rip-up clasts at the latter, lithofacies successions, and benthic foraminiferal changes. The transgressive surface (TS), marking the top of the LST, represents a change from generally regressive to transgressive facies; because LST are generally absent, these surfaces are generally merged with the sequence boundaries. Where present, LSTs are recognized as generally thin, regressive, fluvial-estuarine sediments underlying TSTs and overlying sequence-bounding unconformities.

T1. Lithology, p. 48.

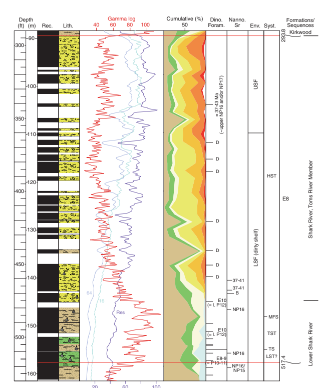
F2. Summary stratigraphic section, Cohansey Formation, p. 40.



F3. Summary stratigraphic section, Kirkwood Formation, p. 42.



F4. Summary stratigraphic section, Toms River Member, p. 43.



Surficial Deposits

Age: ?middle Pleistocene (?125,000 y)
Interval: 5–25.2 ft (1.5–7.7 m)

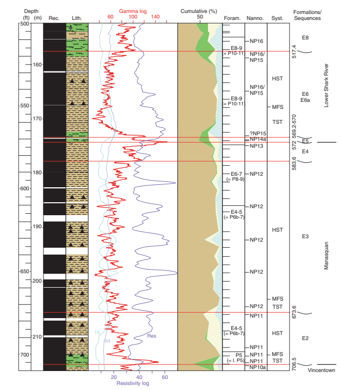
The upper 25.2 ft (7.7 m) is a fining-upward succession based on the on the gamma log, general core descriptions, and washed samples (Fig. F2). From 5 to 5.3 ft (1.5 to 1.6 m) is a gravelly sand (5%–10% very coarse sand and granules) that might represent slump into the hole or a lag gravel deposited as colluvium. From 5.3 to 25.2 ft (1.6 to 7.7 m) is a reddish yellow medium- to coarse-grained sand with 1%–2% opaque heavy mineral that fines upsection. No bedding is evident. The unit from 5 to 25.2 ft (1.5 to 7.7 m) was deposited in a channel, likely a fluvial one. The absence of clay and silt is likely due to the source being reworked from the marine Cohansey Formation sands below. The base of the unit is associated with a large gamma kick and an interval of no recovery (21.7–25.0 ft; 6.6–7.6 m); the contact is tentatively placed at 25.2 ft (7.7 m) at a change from fine sands above to gravely sands below. This surficial deposit is assigned to the upper stream terrace deposits with a likely age of ?125 ka (Newell et al., 2000).

Cohansey Formation

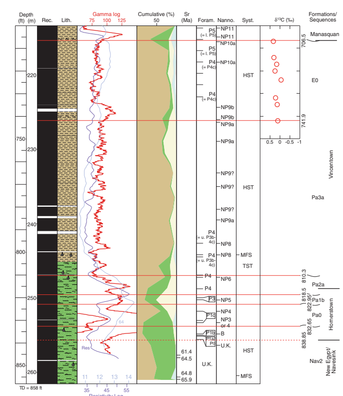
Age: ?uppermost middle to late Miocene
Interval: 25.2–165.1 ft (7.7–49.1 m)

The Cohansey Formation in the Double Trouble corehole (Fig. F2) is an aquifer sand deposited in inner neritic to nearshore (including shoreface and intertidal) environments. The Cohansey Formation is dominated by water-saturated medium to coarse quartz sand with gravel. Poor recovery (Fig. F2) of these unconsolidated sands makes detailed paleoenvironmental interpretation difficult. From 25.2 to 25.4 ft (7.68 to 7.74 m) is poorly sorted medium to coarse sand with abundant gravel (up to 14 mm) and 4% opaque heavy minerals. From 25.4 to 40.25 ft (7.74 to 12.3 m) the gamma log (Fig. F2) shows two coarsening-upward successions (the contact between the two was lost in a coring gap). The upper succession extends from 25.4 to 34 ft (7.74 to 10.4 m); the lower succession extends from 34 to 40.25 ft (10.4 to 12.3 m). From 25.4 to 27.3 ft (7.74 to 8.3 m) is coarse to very coarse sand with granules; 26.3–26.9 ft (8.0–8.2 m) has a concentration of granules and pebbles (up to 10 mm). Hints of bedding are defined by grain size differences. From 27.3 to 28.3 ft (8.3 to 8.6 m) there is a bedded interval with beds to 2 cm in thickness. This is mostly medium to very coarse sand that fines downward. Some of the beds are thin and dusky red with more common granules. The coarse beds from 25.4 to 28.3 ft (7.74 to 8.6 m) have a dusky red staining on coarser interbeds. From 28.3 to 31 ft (8.6 to 9.4 m) is medium to very coarse poorly sorted sand; there is a coring gap from 31.0 to 35.0 ft (9.4 to 10.7 m). There is an opaque heavy mineral concentration from 28.7 to 28.85 ft (8.7 to 8.8 m) in a finer grained bed. Another opaque heavy mineral concentration is in a coarser grained bed at 30.25–30.35 ft (9.2–9.3 m). There appears to be some bedding changes based on grain size changes. From 34 to 37.5 ft (10.4 to 11.4 m) is a better sorted medium to coarse sand dominated by quartz with few opaque heavy minerals. From 37.5 to 40.25 ft (11.4 to 12.3 m) the core is finer grained silty fine to medium sand and it gets slightly finer toward the base with more opaque

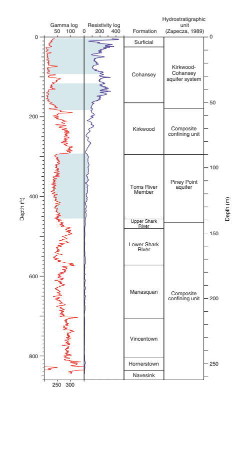
F5. Summary stratigraphic section, lower Shark River and Manasquan formations, p. 44



F6. Summary stratigraphic section, lower Shark River and Manasquan Formations, p. 45.



F7. Lithologic and hydrostratigraphic terminology, p. 46.



T2. Grain sizes, p. 51.

heavy minerals. This unit appears to represent an upper shoreface at the base overlain and prograded over by foreshore deposits.

A surface at 40.25 ft (40.25 m) separates silty fine sand above from a sandy gravel bed (40.25–40.55 ft; 12.3–12.4 m) below which in turn overlies a medium-coarse sand with more opaque heavy minerals below (Fig. F2). The gravel bed might be placed as a basal lag of the overlying succession or the top of the underlying succession; a sharp gamma log kick at 40 ft (12.2 m) suggests the latter.

The section from 40.55 to 41.1 ft (12.4 to 12.5 m) goes from gravelly very coarse sand at the base to medium sand at top. The unit is vaguely bedded with ~4–6 cm thick beds. From 41.1 to 43.1 ft (12.5 to 13.1 m) the core changes from medium on top to coarse to very coarse sand at the base with the boundary between the two lithologies at 42.2 ft (12.9 m). There is a coring gap from 42.2 to 50 ft (12.9 to 15.2 m). From 50 to 53.2 ft (15.2 to 16.2 m) is coarse to very coarse sand with a little fine sand matrix. At 53.2–53.5 ft (16.2–16.3 m) there is a change to a silty fine to medium sand with a possible silty burrow. There is a coring gap from 53.5 to 60 ft (16.3 to 18.3 m). The section from 60 to 72.75 ft (18.3 to 22.2 m) consists of alternating thinly bedded medium to medium-coarse sands with granuliferous zones; it is generally finer grained than above (Fig. AF1). We interpret this unit as foreshore/swash zone deposits representing a regressive foreshore barrier beach succession (succession A of Carter, 1978).

The section from 72.7 to 120 ft (22.2 to 36.6 m) is lithologically distinct from the section above and is interpreted to represent subtidal/intertidal environments (Fig. F2). A sharp surface at 72.7 ft (22.2 m; Fig. AF1) separates the nearshore sands with a thin gravel (as much as 10 mm in diameter) basal laminae (~2.5 cm thick) from a predominantly whitish gray clay with orangish laminae (liesegang banded) and areoles that might represent soil environments (72.5–75.2 ft; 22.1–22.9 m). The clay contains silty lenses 1–2 cm thick that are occasionally iron cemented. This was deposited in a protected nearshore environment behind a barrier island. Sand between 75.2 and 77.1 ft (22.9 and 23.5 m) is finely laminated with cross-laminae and may represent tidal environments. There seems to be two cycles of development in this interval. The top of the cycles consists of 0.2 ft of laminated fine sand with rare burrows. Sand from 77.1 and 95 ft (23.5 and 29 m) is bedded coarse to very coarse sand with rare granules. The sand is dominantly cross-bedded to 80.8 ft (24.6 m). Clay laminae are found at 77.65, 82.15, and 83.15 ft (23.7, 25.0, and 25.3 m). There is an ironstone concretion at 83.5–83.6 ft (24.45–25.48 m). The lower contact is missing in a coring gap between 89.7 and 95 ft (27.3 and 29.0 m). The entire unit from 72.7 to 95 ft (22.2 to 29.0 m) is interpreted to represent a tidal channel filling in to a tidal flat on top. These facies are similar to the tidal flat model of Carter (1978). Bidirectional cross beds within a core (e.g., 80–82 ft; 24.4–25.0 m) argue against a fluvial environment of deposition for this section.

The interval between 95 and 120 ft (29.0 and 36.6 m) is lithologically distinct from the section above (Fig. F2). The contact between the two units is lost in a coring gap between 89.7 and 95 ft (27.3 and 29.0 m). The gamma log has a positive inflection at 95 ft (29.0 m), where we placed the contact. From 95 to 96.3 ft (29.0 to 29.4 m) is laminated, kaolinitic clayey, silty fine to very fine sand with rare burrows. Laminations are highlighted by yellow iron staining, with thin and one thicker cross-laminae of medium-coarse sand. We interpret this as a tidal flat environment. The section grades down to 96.3–97.4 ft (29.4–29.7 m); it is kaolinitic at the top with kaolinite decreasing and grain size increasing to coarse downsection. From 97.4 to 101.35 ft (29.7 to 30.9 m) is a silty, clayey medium to coarse quartz sand that coarsens downsection. These two sections are interpreted as two fining-upward tidal channels well displayed on the gamma log (Fig. F2). From 101.35 to 101.7 ft (30.9 to 31.0 m) is a yellowish, laminated clayey, silty very fine sand. From 101.7 to 106.2 ft (31.0 to 32.4 m) is a micaceous yellowish clayey, sandy silt with organic-rich clay rip-up clasts (105.3 ft; 32.1 m); it is generally laminated with slight bioturbation. From 106.2 to 107.8 ft (32.4 to 32.9 m) is a gray micaceous, structureless, silty, very fine sand; there is an organic-rich layer from 106.45 to 106.6 ft (32.4 to 32.5 m; Fig. AF1). The unit appears gleyed. From 107.8 to 108.6 ft (32.9 to 33.1 m) is a gray, gleyed clay. From 108.6 to 110.75 ft (33.1 to 33.8 m) is a gray to blackish gray, organic-rich (?), well-sorted, fine–medium quartz sand with a few opaque heavy minerals. There is a coring gap from 110.75 to 120 ft (33.8 to 36.6 m). We interpret the section from 101.35 to 110.75 ft (30.9 to 33.8 m) as a lagoon environment (Fig. AF1). The lagoonal sediments have high but variable gamma log values. The gamma log suggests a change at ~112–113 ft (34.1–34.4 m) to more serrated log values of the sands below.

Sands from 120 to 140.4 ft (36.6 to 42.8 m) were deposited in foreshore (beach) environments, though the lower part may represent proximal upper shoreface environments (Figs. F2, AF1). The facies consist of laminated to cross-laminated medium sands with distinct dark ilmenite-rich laminae at 121.15, 126.8–127.9, 128.8–129.5, 130.9–131.9, and 132.4–132.6 ft (36.9, 38.6–39.0, 39.3–39.5, 39.9–40.2, and 40.4–40.4 m). The ilmenite-rich zones yield high gamma log values and a serrated log pattern. There are heavy mineral laminations in the section. The section is generally yellow, along with white, gray, and red (below 135 ft; 41.1 m) zones that may reflect minor grain size/sorting differences. There are some intensely burrowed (e.g., 120–120.3 ft; 36.6–36.7 m) intervals, but in general the section is laminated to cross-laminated, with some larger, spectacular cross-beds (e.g., 124.6 and 128.4 ft; 38.0–39.1 m **[AUTHOR: The first is not a range; the second is; please confirm.]**). Ilmenite is less observable below 135 ft (41.1 m), and the log values are low and constant. This section below 135 ft (41.1 m) may represent a proximal shoreface environment. There is a coring gap from 140.4 to 150 ft (42.8 to 45.7 m).

The lower part of the Cohansey Formation (150–162.05 ft; 45.7–49.4 m) consists of yellow structureless, moderately to poorly sorted medium to coarse sand. There is a yellow-white well-sorted, cross-laminated fine sand bed from 162.05 to 162.35 ft (49.4 to 49.5 m) and a yellowish fine–very coarse poorly sorted sand (162.35–162.7 ft; 49.5–49.6 m). These sediments (150–162.7 ft; 45.7–49.6 m) may represent an offshore bar in a proximal upper shoreface environment. There is a coring gap from 162.7 to 165.0 ft (49.6 to 50.3 m). Thus, the section from 162.7 to 120 ft (49.6 to 36.6 m) appears to shallow upsection.

From 165.0 to 165.1 ft (50.3 to 50.4 m) is a yellow sand (Fig. F2). This may be caved but appears to mark the base of the Cohansey Formation. There is a major sequence boundary at 165.1 ft (50.4 m) with a gray sand below to 165.55 ft (50.5 m). This sand is gray and medium-coarse with a few lithic fragments tentatively assigned to the Kirkwood Formation. Below 165.1 ft (50.4 m) appears fine–very fine lignitic sands typical of distal delta front deposits of the Kirkwood Formation.

There are two general trends in the Cohansey Formation at Double Trouble. First is a generally shallowing upward trend from the base to

110/120 ft (33.5/36.0 m), suggesting interpretation as an HST. The second is a retrogradational succession (tidal channel to foreshore to upper shoreface) from 25.2 to 95 ft (7.7 to 29.0 m; Fig. F2), suggesting interpretation as a TST. This change from progradational to retrogradational facies suggest a possible sequence boundary in the coring gap from 110 to 120 ft (33.5 to 36.6 m) or at the top of the kaolinite clays at 95 ft (29.0 m).

Kirkwood Formation

Age: early to middle Miocene
Interval: 165.1–293.8 ft (50.5–89.6 m)

The upper part of the Kirkwood Formation (Fig. F3) is characterized by sharply changing lithologies deposited in deltaic environments. From 165.1 to 165.55 ft (50.3 to 50.5 m) is a bed of poorly sorted, medium to very coarse quartz sand with minor amounts of silt and fine sand (Fig. AF2). The sediments are grayer than the yellowish brown sands of the Cohansey above. From 165.55 to 166.75 ft (50.5 to 50.8 m) is a darker silty, micaceous fine sand to very fine silt with abundant disseminated lignite within the sand and cross-laminations (to 1 cm) of lignite. From 166.75 to 168.15 ft (50.8 to 51.3 m) is laminated (0.25 cm) to thin bedded (1 cm) silty fine to medium sand. From 168.15 to 177.8 ft (51.3 to 54.2 m) is very micaceous, silty fine sand with some medium sand. The sand contains laminations (0.1–1 cm thick) to thin beds of silty clay and rare lignite laminations. The facies from 165.1 to 177.8 ft (50.3 to 54.2 m) again suggests deposition in a nearshore delta-influenced/delta front environment.

A gradational contact from 177.8 to 178.8 ft (54.2 to 54.5 m) contains brown slightly organic-rich, slightly granuliferous muddy sand (Fig. F3). Below 177.8 ft (54.5 m) the lithology changes to a slightly micaceous silty, gravelly, very poorly sorted sand. The amount of gravel and the size of the gravel (as large as 1 cm) increases to 182.7 ft (55.7 m). The interval from 182.7 to 190 ft (55.7 to 57.9 m) was lost. Gravel was screened from the drilling mud in this interval. The gamma log suggests that the base of the gravel is at 182.7 ft (55.7 m), with the sediments becoming increasingly clayey below. A gamma log minimum at ~180–183 ft (54.9–55.8 m) indicates the base of the fining-upward gravelly succession is at 182.7 ft (55.7 m) and the gravel found below was caved into the hole. The gravel (177.8–182.7 ft; 54.2–55.7 m) probably represents the base of a delta front channel. The section from 190 to 191.2 ft (57.9 to 58.3 m) is interlaminated (with numerous burrows interrupting laminations) lignitic and micaceous silty sand and medium sand deposited in a delta front environment. This finer grained material is associated with a major inflection in the gamma log that represents an important facies change that might be a sequence boundary or a change in environment in a delta front environment. The lack of evidence for deepening associated with the clays suggests a change in facies unrelated to sea level change.

The section from 192 to 205.95 ft (58.5 to 62.8 m) consists of structureless, well-sorted, silty fine sand (Fig. F3). The section from 205.95 to 210 ft (62.8 to 64.0 m) is muddier than above, consisting of micaceous clayey silty fine sand that appears bioturbated. The sand (192–210 ft; 58.5–64.0 m) contains fine lignite and abundant mica and may represent bay filling in a river-dominated delta. From 210 to 210.4 ft (64.0 to 64.1 m) there is a poorly sorted, clayey to granuliferous very coarse sand with possible phosphatic granules. A sequence boundary at 210.4 ft (64.1 m) separates the poorly sorted sand above from medium lignitic, micaceous sand below. The surface at 210.4 ft (64.1 m) is burrowed with burrows (0.4–1 cm in diameter) extending ~1 ft below the contact. The poorly sorted sand from 210 to 210.4 ft (64.0 to 64.1 m) is interpreted as a lag deposit on the sequence boundary. The lag deposit may be thicker, but the top of the lag was not recovered.

The section from 210.4 to 241.2 ft (64.1 to 73.5 m) is dominated by well-sorted medium to fine sand (Figs. F3, AF2). The section from 210.4 to 212.8 ft (64.1 to 64.9 m) is slightly micaceous, slightly sandy silty clay. From 212.8 to 230 ft (64.9 to 70.1 m) is a well-sorted micaceous fine sand with increasing medium sand downsection. Possible channel bases occur at 221.1 and 222.9 ft (67.4 and 67.9 m) where there is slightly cemented coarse sand. Below an unrecovered interval (230–231.3 ft; 70.1–70.5 m) is a change to laminated muddy fine sand (231.3–241.2 ft; 70.5–73.2 m). The sands are interpreted as delta from transitioning down to prodelta.

Fine-grained prodelta deposits appear at 241.2 ft (73.5 m; Fig. F3). From 241.2 to 245 ft (73.5 to 74.7 m) is slightly micaceous very fine sandy mud, which is laminated to thinly bedded (to 2.5 cm). Beds are disrupted by occasional burrows. From 245 to 260 ft (74.7 to 79.2 m) is dark gray to black, laminated to thin-bedded micaceous silty fine sand and clay silt deposited in a prodelta setting. At ~254 ft (77.4 m; Fig. AF2) clay content reaches a maximum. From 260 to 263.7 ft (79.2 to 80.4 m) is silty fine to medium sand representing a shelf environment. There is coring gap from 263.7 to 270 ft (80.4 to 82.3 m), below which the sediments (270–278.8 ft; 82.3–85.0 m) change back to laminated to thin-bedded, slightly burrowed, micaceous silty fine sand probably representing environments transitional between a shelf and a prodelta (Fig. AF2). Below a minor coring gap, the sediments change from 280 to 285 ft (85.3 to 86.9 m) to laminated slightly micaceous clayey silt with burrows containing micaceous very fine sand (Fig. AF2). Glauconite sand beds occur at ~285 ft (86.9 m; Fig. F3). Slightly micaceous, slightly glauconitic, slightly sandy muddy silt appears from 285 to 285.7 ft (86.9 to 87.1 m). From 285.7 to 293.8 ft (87.1 to 89.6 m) is interbedded dark gray silty quartz glauconite sand, with glauconite sand likely reworked from the sequence below. We interpret the environments as delta front (210–231 ft; 64.0–70.4 m), distal delta front (231–241 ft; 70.4–73.5 m), prodelta clays (241–260 ft; 73.5–79.2 m), transitional between shelf and prodelta (260–280 ft; 79.2–85.3 m), and shelf sand (280–285 ft; 85.3–86.9 m) (Fig. AF2). We place the TST from 285 to 293.8 ft (86.9 to 89.6 m), the MFS at ~285 ft (86.9 m) at the glauconite sands, and an HST from 165.1 to 285 ft (50.3 to 86.9 m).

There is no age control on the Kirkwood Formation at Double Trouble. Regional correlations suggest that the sequences from 165.1 to 210.4 and 210.4 to 293.8 ft (50.3 to 64.1 and 64.1 to 89.6 m) correlate with the Kw1b (Shiloh Marl Member) and Kw1a (Brigantine Member) sequences of Miller and Snyder (1997) **[AUTHOR: Please confirm reference; came in as Miller et al., 1997.]**, respectively. This is similar to the Miocene sequence stratigraphy at Island Beach, although the Kw3 sequence is represented there, but not at Double Trouble.

Upper Shark River Formation, Tom River Member

Age: upper middle Eocene
Interval: 293.8–475.7 ft (89.6–145.0 m)

A sharp contact at 293.8 ft (89.6 m; Fig. AF3) separates the shelfal facies of the Kirkwood Formation above from dark green slightly glauconitic quartz sand of the Shark River Formation, Toms River Member, below. The sands oxidize to brown. The facies from 293.8 to 350 ft (89.6 to 106.7 m) are an interesting mix of glauconitic poorly sorted quartz sand ranging from very fine to coarse grained with granules.

The section generally coarsens up from 350 ft (106.7 m) and consists of thick beds of glauconitic medium–very coarse quartz sand (up to 30 cm thick). There are indurated (iron-cemented) zones (Fig. F4) starting at 309 ft (94.2 m) that are a maximum of 20 cm thick and consist of siltstones with some sandy matrix (e.g., 317.0–317.9, 325.6–325.9, 332.9–333.1, and 341–341.1 ft; 96.6–96.9, 99.2–99.3, 101.47–101.53, and 103.9–104.0 m). These punctuations of finer, indurated beds may signify minor flooding surfaces. There are rare shell molds (e.g., 350.7 ft; 106.9 m), though there does not appear to be primary shell material. Some of the section is heavily burrowed (e.g., 312–314 ft; 95.1–95.7 m), indicating likely marine deposition. Below 350 ft (106.7 m) there are distinct thin brown clay beds (2–7 cm thick) and overall sand size decreases and the section is slightly better sorted. The environment of deposition of the section from 293.8 to 350 ft (89.6 to 106.7 m) is uncertain but appears to be a generally coarsening-upward succession on top of lower shoreface shelf clays, and thus the shallower, higher energy marine section above is interpreted as deposited in upper shoreface environments (Fig. AF3).

Mud increases generally downsection from 360 to 466.75 ft (109.7 to 142.3 m), and there are more clay beds (as thick as 30 cm; Fig. F4). Clays with thin interbedded sands occur from 366.4 to 371.4 ft (111.7 to 113.2 m) and represent the transition from distal lower shoreface to offshore deposits. There are common gypsum needles (e.g., 365.1–367.9 ft; 111.3–112.1 m), possibly replacing carbonate. There is a return to glauconitic granuliferous medium to coarse quartz sand from 371.4 to 410 ft (113.2 to 125.0 m), with a granule-rich coarse sand bed from 371.8 to 372.1 ft (113.3 to 113.4 m). The section from 385.1 to 385.5 ft (117.4 to 117.5 m) is clearly bioturbated, though bioturbation in much of the section is not clear. A sand bed from 410 to 415.4 ft (125.0 to 126.6 m) consists of cleaner glauconitic medium to coarse quartz sand that coarsens upsection. Clayey, slightly granuliferous cross-bedded glauconitic quartz occurs from 415.4 to 420 ft (126.6 to 128.0 m). From 420 to 421.5 ft (128.0 to 128.5 m) is bioturbated glauconitic medium to coarse quartz sand with clay-lined burrows. The interval from 421.5 to 454.8 ft (128.5 to 138.6 m) consists of slightly granuliferous clayey glauconitic medium-coarse quartz sand with sandy clay interbeds up to 5 cm thick. There is an indurated siltstone at 426.4–426.6 ft (129.97–130.03 m). The section from 454.8 to 466.75 ft (138.6 to 142.3 m) is also slightly granuliferous clayey glauconitic medium-coarse quartz sand, but is more clay-rich, heavily bioturbated, and very slightly shelly, with a downsection decrease in quartz grain size and increase in glauconite to ~25%. There is a large pyrite nodule at the base of the section, and there is a faint contact at 466.75 ft (142.3 m) with *Thalassinoides* burrows from ~466.9 to 467.9 ft (142.3 to 142.6 m). Common gypsum occurs on the core surface below 465 ft (141.7 m), and planktonic foraminifers occur in a sample at 466 ft (142.0 m). Below the interbedded sand/clay contact is a heavily bioturbated, slightly micaceous, clayey, silty, slightly shelly, glauconitic quartz sand. Silt and clay increase downsection to 476 ft (145.1 m). Below a minor coring gap (476–480 ft; 145.1–146.3 m), the section is sandy silt to clayey silt with 5%–

10% glauconite, thin shells, and shell fragments. We place the base of the Toms River Member at 475.7 ft (145.0 m) at a transition from the sand above to more carbonate-rich clay below (Fig. F4); there is also a downhole increase in gamma log values at this depth.

The depositional environment of the section from 360 to 475.7 ft (109.7 to 145.0 m) is enigmatic. The co-occurrence of quartz and glauconite argues for recycled glauconite, and the coarseness of the quartz sand argues for a fairly high-energy environment (shoreface or estuarine). Cross-beds (e.g., 380–380.6 and 416–418 ft; 115.8–116.0 and 126.8–127.4 m) and clay beds are common, though wood/lignite is generally absent and mica, though present, is rare. Bioturbation varies from extensive to obscure. One tentative interpretation is lower shoreface on a muddy shelf. Another interpretation is an estuary, with numerous thin clays, channels, and cross-beds. We favor the former, with the sequence from 293.8 to 517.5 ft (89.6 to 157.7 m) comprising one thick sequence comprising all of the Toms River Member and the upper part of the lower Shark River Member.

The unusual nature of the Toms Rivers Member warrants discussion. It is a very poorly sorted unit with reworked acarininids at the ACGS#4 corehole (Poore and Bybell, 1988; Miller et al., 1990); at that site it is essentially the same age as the Exmore Breccia in the Chesapeake Bay Impact Structure (CBIS) (35.4 Ma; Pusz et al., 2009) that results from resurge and tsunamis associated with impact. However, there is evidence that the Toms River Member is not a tsunamite or resurge deposit at Double Trouble: (1) we note that burrowing occurs throughout; (2) there are repetitive patterns of lithologies that can best be ascribed to normal marine processes; (3) there are no reworked taxa other than the acarininids and other uppermost middle Eocene forms (i.e., tsunamites and resurge deposits in the CBIS represent a full Cretaceous through middle Eocene suite of fossils); and (4) the unit is clearly older at Double Trouble (>37 Ma) than it is at ACGS#4 and is thus older than the CBIS (see **"Regional Correlations of the Toms River Member,"** below).

Lower Shark River Formation

Age: middle Eocene
Interval: 475.8–572 ft (145.0–174.3 m)

The middle Eocene lower Shark River Formation is first encountered at 475.8 ft (145.0 m), immediately below a minor coring gap (Fig. F4). The top of the lower Shark River Formation consists of very fossiliferous and heavily bioturbated, slightly micaceous, quartzose, glauconitic clayey silt. Glauconite is more concentrated between 495 and 500.8 ft (150.9 and 152.6 m). An MFS is placed at ~485 ft (147.8 m) at a clay peak associated with high gamma log values (Fig. F4). Below a coring gap (497.1–500 ft; 151.5–152.4 m), the section returns to slightly glauconitic silt (500.8–505.6 ft; 152.6–154.1 m). Glauconite increases downsection at 505.6 ft (154.1 m). There is a large sandy, pyritized burrow from 506 to 506.4 ft (154.2 to 154.4 m) that may mark a sequence boundary. An alternate interpretation is that this is a TS, with a coarsening upward LST from 506 to 517.4 ft (154.2 to 157.7 m; Fig. F4). Glauconitic shelly silty clay returns from 506.4 to 513 ft (154.4 to 156.4 m). Glauconite and shells increase downsection to an irregular contact and major sequence boundary at 517.4 ft (157.7 m). The sequence above 517.4 ft (157.7 m) is assigned to Zone NP16 (511 ft; 155.8 m) and Zone E10 (P12) above 506 ft (154.2 m) and Zone E8–E9 (P10–P11) below 511 ft (155.8 m). It is possible that there is a thin sequence between 506.4 and 517.4 ft (154.4 and 157.7 m) that is Zones E8–E9 (P10–P11), though regional correlations suggest that there is one sequence, E8 of Browning et al. (1996), from 293.8 to 517.4 ft (89.6 to 157.7 m).

The top of the sequence below 517.4 ft (157.7 m; Figs. **F5, AF4**) contains a subequal mixture of ~20% fine–very fine quartz sand, with glauconite (~15%), shells, and rare wood to 524.1 ft (159.7 m) that all sharply decrease in abundance below 524.1 ft (159.7 m). This thin section (517.4–524.1 ft; 157.7–159.7 m) is a slightly sandier HST of the E6/E6a sequence (Fig. **F5**) deposited in offshore-distal lower shoreface environments.

The section from 524.1 to ~560 ft (159.7 to 170.7 m) is an "ash-colored marl" (5GY4/1): burrowed, very slightly glauconitic, foraminiferal clay typified by "wormy" horizontal burrows and generally uniform except as follows. There a slightly sandy bed from 525.6 to 525.9 ft (160.2 to 160.3 m; Fig. **F5**). Porcellanitic zones appear at 534.4 ft (162.9 m) and continue downsection (e.g., 549.2–549.3 ft; 167.40–167.43 m). A slightly sandy (10%) bed observed in the washed samples and single-point resistivity at 541 ft (164.9 m) is associated with a slightly sandy interval from 540.8 to 541.5 ft (165.0 m) and a slight difference in bioturbation (not as "wormy"). The interval from 541.5 to 551.4 ft (165.0 to 168.1 m) shows a low in single-point resistivity values. Washed samples show a clear change in glauconite; though low in abundance, glauconite shows a distinct, progressive decrease downsection from ~2% at 526 ft (160.3 m) to 0% at 550 ft (167.6 m), increases to 3% at 561 ft (171.0 m), and then shows a sharp, large (>10%) increase at 566 ft (172.5 m). We identify a surface at 551.4 ft (168.1 m) as the MFS, with interbedded dark green wormy clays above with whiter clay with larger burrows below. A major increase in glauconite occurs from 561 to 562 ft (171.0 to 171.3 m; Fig. **AF4**). The "ash-colored marls" below 562 ft (171.3 m) consist of highly bioturbated silty clay that slightly coarsens downsection to clayey silt at 569 ft (173.4 m; Fig. **AF4**), with intervals of fine glauconite sand-filled burrows. The clay contains thin porcellanitic zones. A sequence boundary occurs in a coring gap between 569.2 and 570 ft (173.5 and 173.7 m), with a heavily burrowed zone containing up to 50% glauconite immediately above the coring gap **[AUTHOR: There was a note here in the manuscript to check this.]**.

The base of the Shark River Formation represents another sequence. The section from 570 to 570.8 ft (173.7 to 174.0 m) is an indurated, slightly glauconitic, very fine quartz sand that represents a thin HST (Fig. **F5**). Glauconite increases from 570.8 to 571.9 ft (174.0 to 174.3 m) and is concentrated in burrows, with a hard nodule at 571.9–572.0 ft (174.3–174.3 m). There is another sequence boundary at 572 ft (174.36 m) at the top of a bed of light brown clay. Thus, there are two sequence boundaries associated with the glauconite sands at 569.2/570.0 and 572 ft (173.5/173.7 and 174.3 m). Nannofossils date the thin sequence between these levels as Zone NP14a in Samples 570.3 and 571 ft (173.8 and 174.0 m); nannofossils confirm the interpretation of the two sequences boundaries by the absence of Zone NP14b and the presence of Zone NP13 at 574 ft (175.0 m). The sequence above 569.2 ft (173.5 m) is correlated to Sequence E6 or E6a of Browning et al. (1996), the thin sequence from 570 to 572 ft (173.7 to 174.3 m) to Sequence E5, and the sequence below 572 ft (174.3 m) to Sequence E4.

Manasquan Formation

Age: lower Eocene
Interval: 572–706.5 ft (174.3–215.3 m)

We place the top of the Manasquan Formation at the base of the glauconite bed at 572 ft (174.3 m; Fig. **F5**). The Manasquan Formation at the Double Trouble corehole consists of yellowish greenish gray, very slightly glauconitic, carbonate-rich (average ~9% of sand fraction), very slightly sandy silty clay to clay, with occasional thin silty and sandy beds and porcellanitic zones. Quartz sand is particularly low from 572 to 671 ft (174.3 to 204.5 m) (0.3%–15%; average = ~5%) and is higher (average = ~20%) from 675.3 to 706.5 ft (205.8 to 215.3 m; Table **T2**). Glauconite is generally rare in the formation (0%–4%, average and median 2%, including several zones with no glauconite) (Table **T2**).

Sequences and lithologic changes are subtle in the Manasquan Formation at Double Trouble (Fig. **F5**). The top of the formation is slightly sandier, with ~10% fine quartz sand above 600 ft (182.9 m). Glauconite content is higher in burrows from 578 to 580.6 ft (176.2 to 177.0 m) and there is a burrowed contact at 581.5–583.6 ft (177.2–177.9 m; Fig. **AF5**) with glauconite infilled burrows. This level is associated with a major gamma log kick and is possibly a sequence boundary separating Sequence E4 from E3 of Browning et al. (1996).

The section from 583.6 to 675.3 ft (177.9 to 205.8 m) is relatively uniform silty clay to clay, occasionally porcellanitic with traces of glauconite, sparse fine quartz sand, and common porcellanitic zones (notably 620–626 and 660–670 ft; 189.0–190.8 and 201.2–204.2 m). Downhole log resistivity peaks at ~595, ~610, ~630, and ~650 ft (~181.4, ~185.9, ~192.0, ~198.1 m; Fig. **F5**) appear to correspond to minor peaks (~10%) in quartz sand. The section from 583.6 to 675.3 ft (177.9 to 205.8 m) appears to be one sequence assigned to Zones NP12 and E4–E7 (P6b–P8) and thus correlates with Sequence E3 of Browning et al. (1996). Slightly sandy clays above 600 ft (182.9 m) are likely the HST. The MFS might be in the finest grained sediments at 666 ft (203 m; Fig. **F5**).

There is a contact at 673.3–673.6 ft (205.2–205.3 m) with porcellanitic silty clay above and a sandy clayey silt below associated with a minor gamma ray peak. The contact is subtle and is recognized as a possible sequence boundary by the change from progradational facies below to retrogradational facies and a change to deeper water facies above and a nannofossil boundary between Zones NN11 and NN12 (see **"Calcareous Nannoplankton";** Fig. **F5**). This change suggests correlation of the section from 673.6 to 706.5 ft (205.9 to 215.3 m) with Sequence E2 of Browning et al. (1996). Quartz sand is higher (average = ~20%) in Sequence E2 than other Manasquan Formation sequences in the Double Trouble corehole (Table **T2**). It is particularly high from 675.6 to 689.7 ft (205.9 to 210.2 m) and drops off below this interval at a downhole increase in gamma log values. Sand occurs in burrows from 689.5 to 695 ft (210.2 to 211.8 m), though the section is primarily silty clay. Clay generally increases downsection from 689.5 to ~706 ft (210.2 to ~215.2 m). Glauconite appears at 704.5 ft (214.7 m), becomes prominent at 705 ft (214.9 m), and increases to a glauconite sand down to a contact at 706.5 ft (215.3 m; Fig. **AF5**). The contact is sharp and abrupt, with a few small circular burrows just below the contact. Thus, Sequence E2 consists of carbonate clays with quartz sands decreasing downsection from ~20% to a clay peak interpreted as an MFS (~706 ft; 215.2 m) and a basal glauconite sand.

Vincentown Formation

Age: upper Paleocene
Interval: 706.5–816 ft (215.3–248.7 m)

The Vincentown Formation contains several sequences. The section from 706.5 to 735 ft (215.3 to 224.0 m) is a heavily bioturbated, slightly micaceous, heavily burrowed clayey silt (to 719 ft; 219.2 m) and silt (719–735 ft; 219.2–224.0 m; Fig. F6). Calcispheres assigned to the Vincentown Formation are found in abundance between 711 and 731.4 ft (216.7 and 222.9 m) and are unusual in the Vincentown Formation (Table T3). Silty glauconitic clay (735–736 ft; 224.0–224.3 m) overlies glauconitic silt (736–741.9 ft; 224.3–226.1 m) and clayey, slightly glauconitic sandy silt that is heavily burrowed (743.8–769.5 ft; 226.7–234.5 m). This silty unit represents shelf deposits with a deltaic influence. Lithologically it differs from the "ash marls" of the Eocene above and is assigned to the Paleocene Vincentown Formation. The age assignment of this unit is uncertain. Foraminifers (e.g., *Globanomalina pseudomenardii*, found at 714.6 ft; 217.8 m) assign it to Paleocene Zones P5 and P4c (Berggren and Pearson, 2005), suggesting that the unit predates the carbon isotope excursion (CIE). Nannofossils assign it to the post-CIE portion of Eocene Zone NP9b and Zone NP10. Two possibilities exist: (1) it correlates with the Eocene, indicating Paleocene planktonic foraminifers are reworked, or (2) it correlates with the upper Paleocene Vincentown Formation, indicating the calcareous nannoplankton are contaminated. In either case, it appears that the CIE and carbon isotope recovery section associated with kaolinite-rich clays (Marlboro Clay) is missing from Double Trouble as it is at Island Beach (Pak et al., 1997). The absence of the Marlboro Clay appears to be restricted to the region between this updip-downdip pair of sites because it is well-represented at Sea Girt to the north (Miller et al., 2006) and Bass River to the south (Cramer et al., 1999). We name this Sequence E0, which postdates the PETM and predates the basal Manasquan E1 sequence boundary, which is younger than 54.6 Ma.

T3. Planktonic foraminifers, p. 54.

There is a contact at 741.9 ft (226.1 m; Fig. AF5) with a glauconitic clayey slightly sandy silt above and slightly clayey, slightly glauconitic sandy silt below (Fig. F6). The contact has glauconite sand concentrated (up to 20%) in burrows and no evidence of rip-up clasts. Quartz sand peaks below the contact at 751 ft (228.9 m; up to 30% in burrows) and decreases below this. This pattern looks like a regressive HST to a sequence boundary at 741.9 ft (226.1 m), but the similarities of lithologies above and below and lack of evidence for erosion at the contact could indicate a flooding surface rather than a sequence boundary. Nannofossils suggest a gap, and thus we interpret this contact as a sequence boundary with Sequence E0 above and Sequence Pa3a (Harris et al., 2010) below.

Below 741.9 ft (226.1 m) the section fines down to slightly micaceous, slightly glauconitic clayey silt and silty clay (to 785 ft; 239.3 m) and coarsens again to very micaceous very fine sandy glauconitic clayey silt (to 792 ft; 241.4 m; Fig. F6). The section fines again to silty clay (792–799.4 ft; 241.4–243.7 m), with slightly sandy, slightly silty, slightly glauconitic clay (800–803 ft; 243.8–244.8 m) and glauconite increasing downsection to ~30% from 806 to 810.3 ft (245.7 to 247.0 m;

note that there appears to be a registry issue on the gamma log of 2.5 ft; 0.8 m). The peak in clay content at 796–801 ft (242.6–244.1 m) may be the MFS. There is a sideritized shell at 805 ft (245.4 m) and a large burrow from 807.5 to 807.55 ft (246.13 to 246.14 m), filled with glauconitic, silty very fine quartz sand. There is a sequence boundary at 810.3 ft (247 m), with a shift from the glauconite clay to a slightly silty, sandy glauconitic clay; the contact is heavily burrowed with clay chips (2 mm × 5 mm) burrowed 6 cm below the contact. There is a nannofossil break from Zone NP6 (811 ft; 247.2 m) to Zone NP8 (801.9 ft; 244.4 m), which correlates the sequence below 810.3 ft (247.0 m) with Pa2a of Harris et al. (2010). The section from 810.3 to 814 ft (247.0 to 248.1 m) is glauconitic, quartzose sandy clayey silt that is heavily bioturbated, with sand concentrated in burrows. Glauconite increases downsection to 814–816 ft (248.1–248.7 m).

Hornerstown Formation

Age: lower Paleocene
Interval: 816–838.85 ft (248.7–255.7 m)

We place the top of the Hornerstown Formation at 816 ft (248.7 m) where glauconite becomes dominant in a sandy, clayey, silty glauconite sand, with scattered shells and shell fragments (Fig. F6). Shell beds occur at 817.7–817.85, 818.1–818.2, 820–820.1, 820.3–820.4, 820.5–820.6, and 821.55–821.6 ft (249.23–249.28, 249.36–249.39, 249.94–249.97, 250.03–250.06, 250.09–250.12, and 250.41-250.42 m). As at other sites, there are several closely spaced sequences in the Hornerstown Formation. We place a sequence boundary at 818.5 ft (249.5 m) below the first shell bed separating glauconite clay above from clayey glauconite sand, both with abundant quartz sand. The sequence from 810.3 to 818.5 ft (247.0 to 249.5 m) is assigned to Zones NP6–NP7, whereas the sequence below (818.5–822.95 ft; 249.6–250.8 m) is assigned to Zone P3. The abundance of quartz sand is unusual for the Hornerstown Formation.

A thick shell bed at 820 ft (249.9 m) is likely the *Gryphaea dissimilis* bed observed throughout the coastal plain. Samples at 820 and 821 ft (249.9 and 250.2 m) are assigned to Zone P3 (820 ft; 249.9 m) based on *Morozovella angulata*. The unit becomes slightly silty glauconitic quartz sand from 820 to 822.1 ft (249.9–250.6 m), where there is a contact at 822.95 ft (250.8 m) interpreted as a sequence boundary. Below this sequence boundary (Fig. F6) is a clayey quartzose, glauconitic clay (822.9–828 ft; 250.8–252.37 m) that coarsens downsection from 828 to 831 ft (252.37 to 253.29 m). Clayey silty glauconite sands from 831 to 834.65 ft (253.29 to 254.4 m) contain disseminated shell debris and pyrite concretions, and rare mica occurs in the section. A sample at 830 ft (253.0 m) contains *Parasubbotina bulloides*, *Subbotina triloculinoides*, and *Globoconusa daubjergensis* and is assigned to the Danian (Zone P1c). A zone containing clay rip-up clasts (832.25–832.65 ft; 253.7–253.8 m) marks a sequence boundary separating the Zone P1c sequence above from the lowermost Danian. Below the sequence boundary at 832.65 ft (253.8 m; Fig. F6) is a glauconite sand, with quartzose (10%–15%) glauconite sandy burrowed zones (836.25–836.4 and 837.3–837.9 ft; 254.89–254.93 and 255.2–255.4 m). There is a shell concentration at 837.3–837.4 ft (255.2–255.25 m). The Cretaceous/Paleogene boundary occurs at 838.35–838.65 ft (255.5–255.6 m), with possible spherules observed. There are two white chalky clasts at 838.9 and 839.1 ft (255.7 and 255.8

m) that may be carbonate accretionary lapilli. Below this are clayey glauconite sands of the Navesink Formation.

Navesink Formation

Age: Maastrichtian
Interval: 838.85–858 ft (total depth; 255.7–261.5 m)

A very dark greenish gray clayey glauconitic sand (~50%–60% glauconite) to glauconite clay occurs from 838.85 to 852.6 ft (255.7 to 259.9 m). The section is heavily burrowed and is very slightly quartzose (~1% very fine sand). The sand has pyritized or sulfur-rich burrows that are common from 840.35 to 851.1 ft (256.1 to 259.4 m). The section becomes very slightly micaceous from 848 to 851 ft (258.5 to 259.4 m). There are brown carbonate clay clasts that are likely altered shells (840.7, 844.8, 844.5, 853.2, and 854.0 ft; 256.2, 257.5, 257.4, 260.1, and 260.3 m). There is a contact at 852.6 ft (259.9 m; adjusted core depth), with very dark gray glauconite clay below. The clay is heavily burrowed with glauconite-filled burrows. The main upsection change in the Navesink Formation is a decrease in clay content (Fig. F6). We interpret the Navesink to basal Hornerstown Formation (to 832.65 ft; 253.8 m) as one shallowing upward sequence across the K/Pg boundary, with increasing glauconite and quartz sand above 852.6 ft (259.9 m). We tentatively place an MFS at 854.0–854.2 ft (260.3–260.4 m) at a concentration of clay clasts that was likely a shell layer. This unit is uppermost Cretaceous, with Sr ages of ~65 Ma.

BIOSTRATIGRAPHY

Planktonic Foraminifers

Planktonic foraminifers were generally abundant below 475.9 ft (145.1 m) in the Double Trouble corehole (Tables T3, T4, T5) and were used to assign ages in the lower middle Eocene through Maastrichtian section. Preservation was good in most of the section, but often important marker species were not present, making precise age assignments difficult. Planktonic foraminiferal zones used are those of Berggren and Pearson (2005) with references to the older Berggren et al. (1995) zonation and timescale.

T4. Biozones, p. 55.

T5. Cretaceous species, p. 56.

The Double Trouble corehole was barren of planktonic foraminifers above 475.9 ft. The section from 475.9 to 506 ft (145.1 to 154.2 m), in the Toms River Member and uppermost lower Shark River Formation, was assigned to planktonic foraminiferal Zone E10 (lower P12 of Berggren et al., 1995) based on the highest occurrence of *Acarinina cuneicamerata* at 511 ft (155.8 m), which is not generally found above lower Zone E9. The section from 511 to 571 ft (155.8 to 174.0 m) is assigned to undifferentiated Zones E8–E9 encompassing the lower part of the lower Shark River Formation. The two zones could not be differentiated because of the near absence of *Globigerinatheka* in the core (the first occurrence of *Globigerinatheka kugleri* marks the base of Zone E9). The fauna is typified by the presence of *Acarinina mcgowrani*, *Jenkinsina columbiana*, *Morozovelloides coronatus*, *Subbotina corpulenta*, and *Turborotalia frontosa*.

The upper Manasquan Formation (576–614 ft; 175.6–187.1 m) is assigned to Zones E6–E7. The lower/middle Eocene boundary is difficult to place in the absence of *Hantkenina* and the delayed first occurrence of *Guembelitrioides nuttalli* at 521 ft (158.8 m). The Zone E7/E8 boundary (lower/middle Eocene) is placed at the highest occurrence of *Acarinina pentacamerata* at 576 ft (175.6 m) below the lowest occurrence of *T. frontosa* at 566 ft (172.5 m). The age of the sample at 571 ft (174.0 m) is not certain.

The lower Manasquan Formation (626–696 ft; 190.8–212.1 m) is assigned to Zones E4–E5 based on the first occurrence of *Morozovella formosa* at 696 ft (212.1 m). Zones E4 and E5 could not be subdivided because *Morozovella aragonensis*, the marker for the base of Zone E5, is not present in the core. The presence of *A. pentacamerata* in these samples suggests the section might be all Zone E5.

The two samples from the base of the Manasquan Formation (701 and 706 ft; 213.7 and 215.2 m) are difficult to date. The sediments appear to be conformable with those above but contain a planktonic foraminiferal fauna that is anomalously older than the overlying sediments. The samples do not contain *Pseudohastigerina wilcoxensis*, the marker species for the base of Zone E2, which is usually common in New Jersey Eocene sediments. A sample at 701 ft (213.7 m) contains a single specimen of *Globanomalina pseudomenardii* (whose range defines Zone P4 but might be reworked) and *Globanomalina imitata* that are generally not found above Zone P4. Other species, such as *Morozovella occlusa*, *Morozovella apanthesma*, and *Morozovella velascoensis* (whose highest occurrence defines the top of E2), are not found above Zone E2. This would imply that the sediments at the base of the Manasquan Formation at Double Trouble are Zone E2 or older and that there is an unconformity with a hiatus equal in time to at least Zone E3 between 696 and 701 ft (212.1 and 213.7 m). However, there is no physical expression of an unconformity in the cores (see **"Lithostratigraphy and Sequence Stratigraphy"**), and this finding is in disagreement with the calcareous nannoplankton biostratigraphy (Zone NP11 [planktonic foraminiferal Zone E4]; see **"Calcareous Nannoplankton"**). Thus, we conclude that the older ages are due to reworking.

The highest occurrence of *G. pseudomenardii* is at 714.6 ft (217.8 m; i.e., this assumes that the specimen of *G. pseudomenardii* at 701 ft [213.7 m] is reworked). A sample at 711 ft (216.7 m) is assigned to Paleocene Zone P5, and samples at 714.6–731 ft (226.1–222.8 m) are assigned to Paleocene Zone P4. However, nannofossils indicate that this section is lower Eocene Zones NP9b and NP10a (see **"Calcareous Nannoplankton"**) and that the specimens of *G. pseudomenardii* at both 714.6 ft (217.8 m) and 701 ft (213.7 m) are reworked.

Samples between 736.3 and 786 ft (224.4 and 239.6 m) were either barren or had poor preservation. The section from 796 to 816 ft (242.6 to 248.7 m) is assigned to Zone P4 based on the occurrence of *G. pseudomenardii*. Zone P4 could not be subdivided because of the absence in the core of *Acarinina soldadoensis* and *Parasubbotina variospira*. The presence of *Morozovella aequa* in most of the Zone P4 samples to 811 ft (247.2 m) suggests that interval should be assigned to Zone P4c.

Paleocene sediments (Table **T4**) below 821 ft (250.2 m) generally contain thin sequences. A sample at 821 ft (250.2 m) is assigned to Zone P3 because of the presence of *Morozovella angulata* and the absence of *G. pseudomenardii*. Zone P3 could not be subdivided because of the absence in the core of *Igorina albeari*. Other species typical of Zone P3 include *Acarinina strabocella* and *Igorina pusilla*. Samples at 826, 830, and 831 ft (251.8, 253.0, and 253.3 m) are assigned to Zone P1c because of the presence of *Globanomalina compressa* and *Praemurica inconstans*. In addition, the presence of *Eoglobigerina eobulloides* at 826 ft (251.8 m) suggests the samples are not younger than Zone P1c. Thus, planktonic foraminiferal biostratigraphy suggests an unconformity between 821 and 826 ft (250.2 and 251.8 m) and that Zone P2 is represented by a hiatus, consistent with placement of an unconformity at 822.95 ft (250.8 m; Fig. F6). Samples from 836 and 836.35 ft (254.8 and 254.9 m) are assigned to Zone P1b because of the presence of *Subbotina triloculinoides* that defines the base of the zone and *Praemurica taurica*, which does not generally range above Zone P1b. Samples between 836.65 and 838.65 ft (255.0 and 255.6 m) contain few specimens and are assigned to Zones P0 to P1a undifferentiated because they are below the first occurrence of *Subbotina triloculinoides*. Planktonic foraminiferal biostratigraphy is thus consistent with an unconformity recognized in the cores at 832.65 ft (253.8 m), implying that a portion of Biochron P1c or P1b is not represented.

Samples below 839 ft (839–856 ft; 255.7–260.9 m; Table T5) contain an abundant and diverse assemblage of Upper Cretaceous species, including members of the genera *Globotruncana*, *Heterohelix*, *Racemiguembelina*, and *Rugoglobigerina*, among others.

Dinoflagellate Cysts

A sample (340.6–340.7 ft; 103.83 m) from the Toms River Member of the Shark River Formation was analyzed qualitatively for dinoflagellate cyst biostratigraphy. The dinoflagellate cysts place the sample in the upper part of the middle Eocene and indicate approximate correlation with calcareous nannofossil Zones NP16–N17. Important species include *Pentadinium goniferum* and *Pentadinium polypodum*. A sample from 458.4 ft (139.7 m) has dinocysts that also indicate equivalence of nannofossil Zone NP16 or higher.

Calcareous Nannofossils

Samples were examined for biostratigraphic dating by means of calcareous nannofossils in the interval between 470.0 and 841 ft (143.3 and 256.3 m). The resolution was low (up to 20 ft [6 m] between samples) except between 707 and 742 ft (215.5 and 226.2 m), where samples were taken at a 2 ft (0.6 m) interval. The abundance and preservation of nannofossils fluctuate considerably in this upper Paleocene–middle Eocene sedimentary section. In some samples, small coccoliths are abundant, as if recovered from a chalk. Preservation may be exceptionally good at some levels, whereas dissolution hampers confident biozonal assignment at other levels.

A sample at 470.0 ft (143.3 m) was barren. Samples at 481 and 511 ft (146.6 and 155.8 m) are assigned to mid-Zone NP16 based on the co-occurrence of *Chiasmolithus solitus*, *Helio-discoaster distinctus*, *Reticulofenestra floridana*, and *Reticulofenestra reticulata*. Calcareous nannofossils were abundant and very well preserved in these samples.

Samples at 521 and 541 ft (158.8 and 164.9 m) also yielded abundant and well-preserved coccoliths. They yielded *Chiasmolithus solitus*, *Sphenolithus furcatolithoides*, and *Reticulofenestra* cf. *R. samodurovi* and are assigned to the NP15–NP16 zonal interval.

A sample at 568 ft (173.1 m) yielded common but poorly preserved nannofossils due to dissolution. Diversity was low, and no marker taxa were found. Because of stratigraphic position it is questionably assigned to Zone NP15.

A sample at 571 ft (174.0 m) yielded abundant, moderately preserved nannofossils. The assemblage includes *Discoaster sublodoensis* and *Discoaster lodoensis*, indicating Subzone NP14a. A sample at 570.3 ft (173.8 m) also yielded these two species (*D. sublodoensis* being very rare), but coccoliths and discoasters are few and very poorly preserved at this level (reworking cannot be ruled out).

A sample at 574 ft (175.0 m) belongs to the lower part of Zone NP13, as indicated by the occurrence of *Discoaster cruciformis*. An unconformity likely occurs between this level and 571 ft (174.0 m). Likewise, we note the absence of Subzone NP14b, implying an unconformity between samples at 571 and 570.3 ft (174.0 and 173.8 m) or between the latter and a sample at 568 ft (173.1 m) (additional samples would resolve this uncertainty).

The interval between 574 and 740 ft (175.0 and 228.9 m) consists of lower Eocene sediments extending from lowermost Eocene Subzone NP9b (post-CIE) to upper lower Eocene Zone NP13. A stratigraphic gap including Subzones NP10b–NP10d (as well as the upper part of Subzone NP10a and the lower part of Zone NP11) occurs between 705 and 707 ft (214.9 and 215.5 m). The NP12/NP13 zonal boundary is placed between 574 and 591 ft (175.0 and 180.1 m); the NP11/NP12 zonal boundary is placed between levels 671.6 and 676 ft (204.7 and 206.0 m).

The NP9b/NP10 zonal boundary is extremely difficult to locate because of the scarcity of *T. bramlettei* **[AUTHOR: Please spell out genus in first occurrence.]** in the section. It is provisionally placed between levels 726 and 728 ft (221.3 and 221.9 ft). In general, the lowest occurrence (LO) of *T. bramlettei* and the highest occurrence (HO) of *Fasciculithus* spp. are in stratigraphic proximity. This is not the case here, where fasciculiths occur continuously, albeit in low and variable frequency, up to 707 ft (215.5 m). This is interpreted as evidence of reworking, as supported by the rare occurrence of *Helio-discoaster araneus* at 714 and 742 ft (217.6 and 226.2 m). This also supported by the consistent occurrence of lower Eocene markers such as *Chiasmolithus eograndis* between 707 and 712 ft (215.5 and 217.0 m).

An unconformity between 740 and 742 ft (228.9 and 226.2 m) is inferred from calcareous nannofossil stratigraphy, and based on the HO of *Fasciculithus alanii* in a sample at 742 ft (226.2 m) and the LOs of *Fasciculithus involutus*, *H. araneus*, *Pontosphaera plana*, and *Rhomboaster calcitrapa*. The HO of *F. alanii* marks the top of Zone NP9a just below the CIE; the LO of *P. plana* occurs above the CIE (e.g., the Global Stratotype Section and Point for the base of the Eocene; Aubry et al., 2007). *H. araneus* is sporadic (see above) and *R. calcitrapa* is rare at 740 ft (228.9 ft) and above, not abundant as in the CIE interval in which the two species form the "*Rhomboaster* spp.-*Discoaster araneus*" (RD) assemblage specific to the CIE.

The interval between samples at 786 and 836 ft (239.6 and 254.8 m) is Paleocene. A sample at 786 ft (239.6 m) yielded no discoasters, but the occurrence of *F. alanii* characterizes Subzone NP9a. Nannofossils were abundant and well preserved in samples at 796 and 801.9 ft (242.6 and 244.4 m), which belong to Zone NP8 (with the marker *Heliolithus riedeli* exceptionally common and well preserved). A sample at 811 ft (247.2 m) yielded *Heliolithus kleinpelli* without *Discoaster mohleri*; it belongs to Zone NP6. A sample at 821 ft (250.2 m) yielded *Fasciculithus tympaniformis* without *H. kleinpelli*; it belongs to Zone NP5. A sample at 826 ft (251.8 m) yielded *Ellipsolithus macellus*, *Cruciplacolithus tenuis*, *Er-*

icsonia subpertusa, and *Prinsius minutus*. It is assigned to the lower part of Zone NP4. A sample at 836 ft (254.8 m) was barren.

A sample at 846 ft (257.9 m) yielded Cretaceous assemblages. A sample at 843.7 ft (257.2 m) contains *Nephrolithus frequens*, the marker for upper Maastrichtian Zone CC26.

ISOTOPIC STRATIGRAPHY

Sr isotopic age estimates were obtained from mollusk shells. Approximately 4–6 mg of shells was cleaned in an ultrasonic bath and HCl and then 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 Isoprobe for the data set averaged 0.000007, and the external precision is approximately ±0.000008 (based on replicate analyses of standards). National Bureau of Standards (NBS) 987 is measured for these analysis at 0.710241 normalized to $^{86}Sr/^{88}Sr$ of 0.1194.

Carbonate shells were first encountered in the Double Trouble corehole at 461 ft (140.5 m). Two Sr isotopic ages were attempted at 461.0 and 467.8 ft (140.5 and 142.6 m). Strontium ratios for both of these samples (Table T6) indicate Eocene ages older than 37 Ma. More precise ages are not obtainable because of the low rate of change of Sr isotopes older that ~35 Ma.

T6. Sr isotope data, p. 57.

Cretaceous ages were assigned (Table T6) 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 ±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.). For comparison, Table T6 also shows ages derived from the look-up tables of McArthur et al. (2001).

Four Sr isotopic ages were obtained on shell material in the Navesink Formation. The sample at 845.6 ft (257.7 m) obtained an age of 61.4 Ma, which is too young for the Maastrichtian Navesink and is assumed to have been affected by diagenesis. The other three samples (246.1, 855, and 856 ft; 257.9, 260.6, and 260.9 m) gave ages between 64.5 and 65.9 Ma, consistent with the Navesink II sequence of Miller et al. (2004).

Eight bulk oxygen and carbon isotopic measurements were made on the sequence from 706.5 to 741.9 ft (215.3 to 226.1 m) to aid in correlation of this section. In particular, we were interested to determine if this sequence postdated the global CIE (Kennett and Stott, 1989 **[AUTHOR: Please provide full citation for reference list.]**), as suggested by nannofossil biostratigraphy (see **"Nannofossil Biostratigraphy"**), or predated the CIE (i.e., Paleocene age), as suggested by the presence of the planktonic foraminifer *Globanomalina pseudomenardii* (see **"Planktonic Foraminiferal Biostratigraphy"**). Small "chip" samples were obtained, dried, ground, and analyzed on a Fisions Optima mass spectrometer at Rutgers University supervised by J.D. Wright. Carbon isotopic values obtained (~0.0‰–0.5‰) (Fig. F6) are consistent with post-CIE values in other New Jersey coastal plain coreholes (e.g., Cramer et al., 1999).

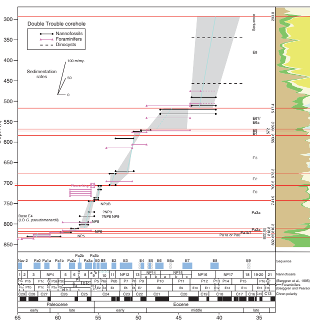
This implies reworking of Paleocene planktonic foraminiferal specimens in the sequence from 706.5 to 741.9 ft (215.3 to 226.1 m) to explain the Zone 9b assignment.

CHRONOLOGY

The sequences of the Double Trouble corehole were dated using integrated strontium isotopic stratigraphy and calcareous nannoplankton, dinocyst, and planktonic foraminiferal biostratigraphy (Fig. F8; Table T7). The sequences in the Double Trouble corehole can, generally, be correlated to sequences previously identified on the New Jersey coastal plain. Sediments between 293.8 and 741.9 ft (89.6 and 226.1 m) are assigned to the Eocene. The sequence between 293.8 and 517.4 ft (89.6 and 157.7 m) is likely equivalent to Sequence E8 of Browning et al. (1996), but definitive age markers are absent. The sequence between 517.4 and 569.2 ft (157.7 and 173.5 m) is lower middle Eocene and can be assigned to either Sequence E6 or E6a. Sedimentation rates in the Eocene range from ~9 to 35 m/m.y. The slower sedimentation rates are likely minimum rates, as the sequences are thin and obtaining precise ages for tops and bottoms is difficult. Sedimentation rates for the Eocene average 26 m/m.y.

Sediments between 741.9 and 832.65 ft (226.1 and 253.8 m) are assigned to the Paleocene. The sequence between 818.8 and 822.95 ft (249.6 and 250.8 m) is slightly younger than the previously described Sequence Pa1b of Harris et al. (2010). The sequence deposited between 822.95 and 832.65 ft (250.8 and 253.8 m) is equivalent to either Sequence Pa1a or Pa0 of Harris et al. (2010). Sedimentation rates for the Paleocene average 15 m/m.y.

F8. Age relations, p. 47.



T7. Recovered sequences, p. 58.

REGIONAL CORRELATIONS OF THE TOMS RIVER MEMBER

One of the major objectives of the Double Trouble corehole was to understand the distribution and environment of deposition of the Toms River Member (TRM) of the Shark River Formation. The TRM is an important aquifer in the coastal plain, but it has been difficult to determine whether the aquifer is a single unit or is slightly different units in different parts of the state.

The TRM was first named by Enright (1969), and the type locality was designated as 160–240 ft (48.8–73.2 m) below sea level (225–240 ft [68.6–73.2 m] below ground surface) in well no. 84 of the Toms River Chemical Company, Toms River, New Jersey (LM# 492; permit number 290085J). Enright (1969) described the unit as a slightly clayey, shelly, fine to medium quartz sand. The TRM is recognized as a coarse quartz-glauconite sand of middle Eocene age. Downdip it is found between the carbonate-rich clay of the Shark River Formation Squankum Member (also known as the “Blue Marl”; referred to in other ODP 174AX reports as the lower Shark River; see, e.g., Miller et al., 1998b) below and the clay-rich upper Eocene Absecon Inlet Formation above. At some sites the TRM is distinguished from the upper Shark River Formation. Neither the TRM nor the Absecon Inlet Formations have been recognized in outcrop.

In the Double Trouble corehole the TRM is coarse to very coarse glauconitic quartz sand. Above a basal glauconite at 517.4 ft (157.7 m), the

TRM coarsens upsection from predominantly clay below 475 ft changing to medium quartz sand between 365 and 475 ft (111.3 and 144.8 m) and to coarse to very coarse sand with granules and pebbles from 365 ft (111.3 m) to the top of the sequence at 293.8 ft (89.6 m). It is interpreted to have been deposited on a lower shoreface shallowing upsection to upper shoreface environments.

The TRM is found in other ODP New Jersey coastal plain wells. Analysis of these wells allows us to recognize the TRM on gamma logs in the absence of core control. The TRM is different thicknesses and different ages in different parts of the state. Browning et al. (1997 **[AUTHOR: 1997a or 1997b?]**) recognized the TRM at Island Beach and found it represented two sequences, designated E8 and E9. Sequence E8 is planktonic foraminiferal Zone P12 and calcareous nannoplankton Zone NP16. Sequence E8 is thickest (~250 ft; 76.2 m) and coarsest at Double Trouble. At Sea Girt the sequence is ~100 ft (30.5 m) thick and predominantly marl at the base deposited in inner middle neritic environments below storm wave base grading up to muddy fine sand on top deposited in a lower shoreface environment. At Ancora, Millville, ACGS, Bass River, and Island Beach, Sequence E8 consists of 20–40 ft (6.1–12.2 m) of glauconite quartz sand. At Atlantic City and Ocean View, Sequence E8 consists of 40 ft (12.2 m) of carbonate-rich clay with little quartz or glauconite.

Sequence E9 has a distribution similar to E8. Sequence E9 is not present at the updip Sea Girt or Double Trouble coreholes. Sequence E9 is thickest at Ancora, where it consists of ~100 ft (30.5 m) of shelly medium quartz sand (Miller et al., 1999). It is the HST of a sequence that includes finer grained mud and glauconite at its base. Sequence E9 is also found at Millville, where it consists of ~70 ft (21.3 m) of medium- to coarse-grained glauconitic quartz sand. The sequence is finer at the base and contains progressively less mud upsection. The environments change from offshore middle neritic at the base grading to distal lower shoreface to proximal lower shoreface on top. At Island Beach, Sequence E9 consists of 30 ft (9.1 m) of pebbly medium to coarse glauconite quartz sand. At the ACGS#4 and Bass River coreholes, Sequence E9 is finer grained and consists of 20 ft (6.1 m) of glauconite sand with abundant fine quartz. At Atlantic City and Ocean View, Sequence E9 consists of ~30–40 ft (9.1–12.2 m) of slightly glauconitic clay.

Sequence E10 follows a similar pattern to E8 and E9. Sequence E10 is thickest at Millville, where it consists of 140 ft (42.7 m) of fine to medium quartz sand with scattered coarse to very coarse grains (Sugarman et al., 2005b). At ACGS#4 corehole, Sequence E10 consists of 40 ft (12.2 m) of very muddy glauconite quartz sand that coarsens upsection above a basal glauconite, suggesting it is a sequence. At Bass River, Sequence E10 is 150 ft (45.7 m) thick and is glauconite sandy mud with minor amounts of fine to very fine quartz sand. At Island Beach, Sequence E10 consists of ~40 ft (12.2 m) of glauconite sandy mud. Sequence E10 is finer grained and thicker at Cape May (>140 ft; 42.7 m), Ocean View (300 ft; 91.4 m), and Atlantic City (170 ft; 51.8 m), where it consists of slightly sandy mud.

Sequence E11 is only found thick and well exposed at the ACGS#4 corehole, where it consists 80 ft (24.4 m) of very fine grained silty clay. It represents a much deeper water facies than the underlying quartz and glauconite sands.

The pattern of facies outlined here is similar to that described for the Oligocene of New Jersey by Pekar et al. (2000). The coarse-grained quartz facies known as the TRM is the foreshore and upper shoreface deposits. The glauconite- and quartz-rich facies, informally known as the upper Shark River Formation, is transitional between the lower shoreface and the offshore middle neritic environment, and the thick slightly sandy to sandy clay, generally referred to as the Absecon Inlet Formation, represents middle to outer neritic clays. These units are then time transgressive and represent the first prograding sequences across the shelf. This is a very different environment from that of the underlying lower Shark River that accumulated as carbonate-rich marls on a ramp setting. The changeover from carbonate to marl to prograding siliciclastics occurred at ~40–42 Ma on the New Jersey coastal plain (Browning et al., 1996).

SUMMARY AND CONCLUSIONS

Hydrogeologic Summary

The Double Trouble corehole penetrated several currently used or potential aquifer sand bodies. Though no hydrologic studies were conducted at this site, sedimentological and log analyses suggest that the unconfined Kirkwood-Cohansey aquifer system is divided into an upper and lower aquifer at Double Trouble. The upper aquifer is 94 ft (0–94 ft; 28.7 m) thick at Double Trouble and consists of medium to coarse quartz sand deposited in nearshore and inner neritic environments. Thin (<5 ft, 1.5 m) finer-grained units, shown on the gamma log at 40 and 73 ft (12.2 and 22.3 m), consist of fine to very fine quartz sand. A 21 ft thick (6.4 m) unit from 94 to 115 ft (28.7 to 35.1 m) contains >50% silt and clay deposited originally in lagoonal or tidal flat environments and likely acts as a leaky confining unit dividing the Kirkwood-Cohansey aquifer system. The lower aquifer is 70 ft (21.3 m) thick (115–185 ft; 35.1–56.4), comprising the lower Cohansey and upper Kirkwood Formations. The section consists of fine to medium sand. The section from 115 to 165.6 ft (35.1 to 50.5 m) was deposited in foreshore and offshore bar environments, and the section from 165.6 to 185 ft (50.5 to 56.4 m) was deposited in a delta-influenced inner neritic environment. The lower Kirkwood Formation (185–293.8 ft; 56.4–89.6 m) is a confining unit with the finest parts deposited mostly as bay fill and prodelta environments.

The Eocene Piney Point aquifer (Nemickas and Carswell, 1976) was a target at this corehole, where it is represented by the Toms River Member of the Shark River Formation at Double Trouble; it is 161.2 ft (49.1 m) thick (293.8–455 ft; 89.6–138.7 m) and was deposited in lower to upper shoreface environments. The aquifer is coarser at the top, consisting of poorly sorted coarse to very coarse sand and fining downsection to medium to coarse sand. Granules are found throughout the aquifer. The Piney Point is an excellent aquifer in the Toms River area. The installed pump capacity for various wells screened in this aquifer has ranged between 160 and 1900 gpm (~600 and 7200 L/min). At Double Trouble, the Piney Point aquifer is equivalent to middle Eocene Sequence E8 of Browning et al. (1996). Below 455 ft (138.7 m), the core consists of the middle Eocene lower Shark River Formation through the Upper Cretaceous Navesink Formation and is part of the composite confining unit.

Geologic Summary

Double Trouble proved to be one of the more challenging coreholes drilled as part of Leg 174AX because of coring issues in the sandy Cohansey Formation and dating issues in the targeted Toms River Member and the Vincentown Formation. The K/Pg boundary appears to be biostratigraphically relatively complete, though it lacks a distinct spherule layer found at the most complete New Jersey coastal plain sections (Bass River and Ancora; Olsson et al., 1997, 2002; Miller et al., 2010 **[AUTHOR: Please provide full citation for reference list.]**). The Paleocene Hornerstown Formation is thin (<25 ft; 7.6 m). The overlying Vincentown Formation lacks the Marlboro Clay Member that includes the CIE and carbon isotopic recovery. However, the upper Vincentown Formation consists of a ~35 ft (10.7 m) thick sequence that has proven to be a Rosetta Stone for deciphering sea level history associated with the Paleocene/Eocene boundary. This sequence (706.5–741.9 ft; 215.3–226.1 m) is here named E0 (E-zero) and is assigned to upper Zone NP9b and NP10 and is overlain by Eocene Sequence E2 at this corehole. A major sea level lowering occurred before the deposition of Sequence E0 and eroded the Marlboro Clay, which is represented in other Leg 174AX New Jersey coastal plain coreholes but not in Double Trouble and the nearby Leg 150X Island Beach corehole. Eocene sequences at Double Trouble follow a familiar (Browning et al., 1997 **[AUTHOR: 1997a or 1997b?]**) pattern of "marly" slightly glauconitic clays of the lower Eocene Manasquan Formation (Sequences E2–E4) and more glauconitic clays of the middle Eocene lower Shark River Formation (Sequences E5–E8). The Toms River Member at Double Trouble is a 223.6 ft (66.2 m) thick unit that comprises the HST of Sequence E8 and was deposited at high sedimentation rates (~34 m/m.y.). The Double Trouble corehole provides a means of evaluating the age and geological relationships of the Toms River Member. The Kirkwood and Cohansey Formations proved difficult to date at Double Trouble, though the Kirkwood appears to represent two sequences that are likely correlated to the Kw1a and Kw1b (Miller et al., 1997 **[AUTHOR: Miller and Snyder?]**). The ?Kw1a is a classic prograding shelf–prodelta–delta front succession, whereas the ?Kw1b is a less complete bay–delta front succession. The Cohansey Formation appears to be a lower prograding shoreface succession (?HST) and an upper retrogradational tidal-shoreface succession (?TST). Surficial deposits apparently represent reworked Cohansey lithology in a fluvial terrace setting.

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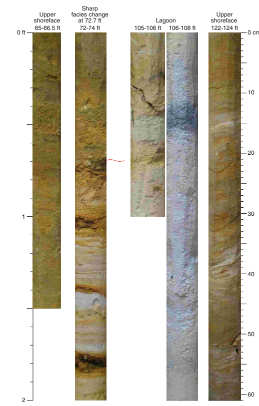
Appendix

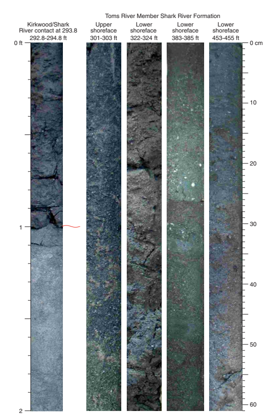
Representative lithofacies are shown in Figures AF1, AF2, AF3, AF4, and AF5.

AF1. Cohansey and Kirkwood Formations, p. 59.

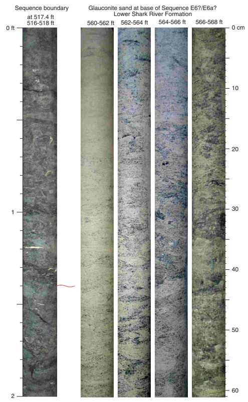


AF2. Kirkwood/Cohansey contact and Kirkwood Formation, p. 60.

AF3. Kirkwood/Shark River contact and Toms River Member, p. 61.



AF4. Sequence E7, p. 62.



AF5. Sequence boundaries, p. 63.

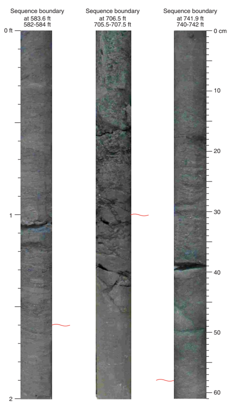


Figure F1. Location map showing the Double Trouble site (red star), existing Deep Sea Drilling Project (DSDP), Atlantic Margin Coring Project (AMCOR), Ocean Drilling Program (ODP), and Integrated Ocean Drilling Program (IODP) coreholes analyzed as a part of the New Jersey (NJ)/Mid-Atlantic (MAT) sea level transect. Also shown are multichannel seismic data from *Ewing* (EW9009), *Oceanus* (Oc270), and *Cape Hatteras* (Ch0698) cruises. 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.

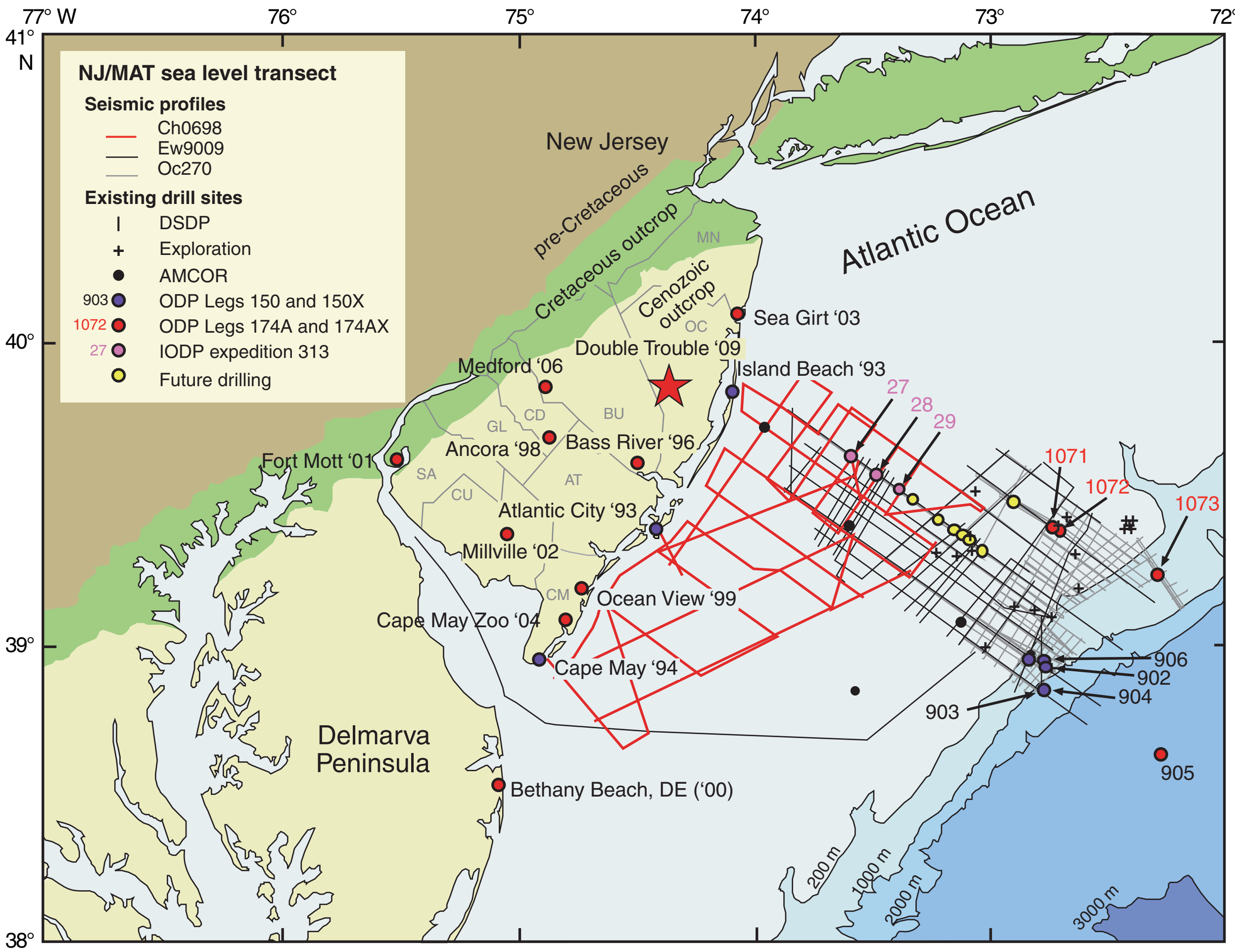


Figure F2. A. Summary stratigraphic section for the Cohansey Formation (?uppermost middle to late Miocene) in the Double Trouble borehole, with core recovery (Rec.), lithology (Lith.), gamma ray and resistivity log signatures, age, and environments (Env.). Syst. = systems tract. pUSF = See part B for legend. (**Continued on next page.**)

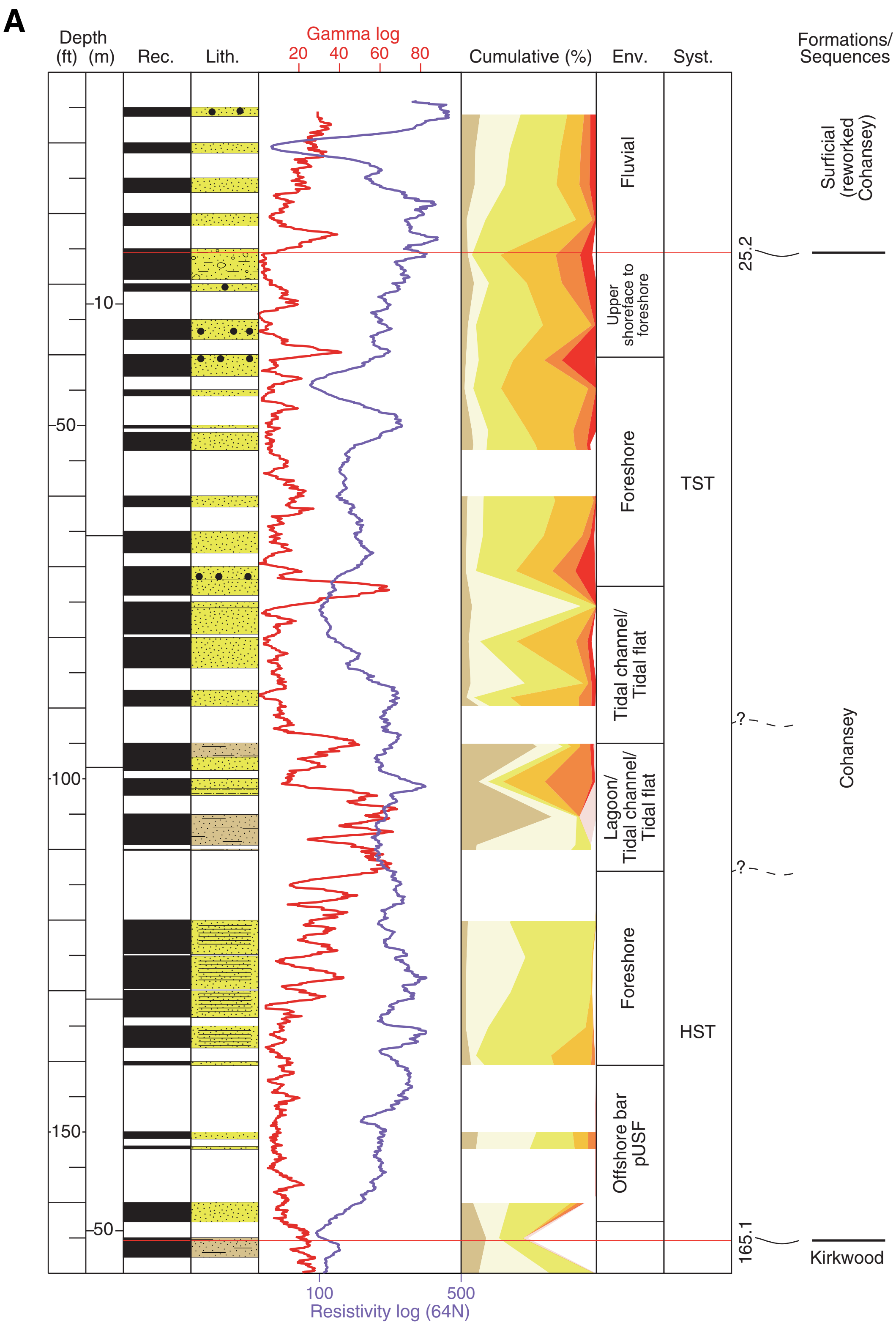


Figure F2 (continued). B. Legend of lithology symbols and abbreviations used on summary stratigraphic sections.

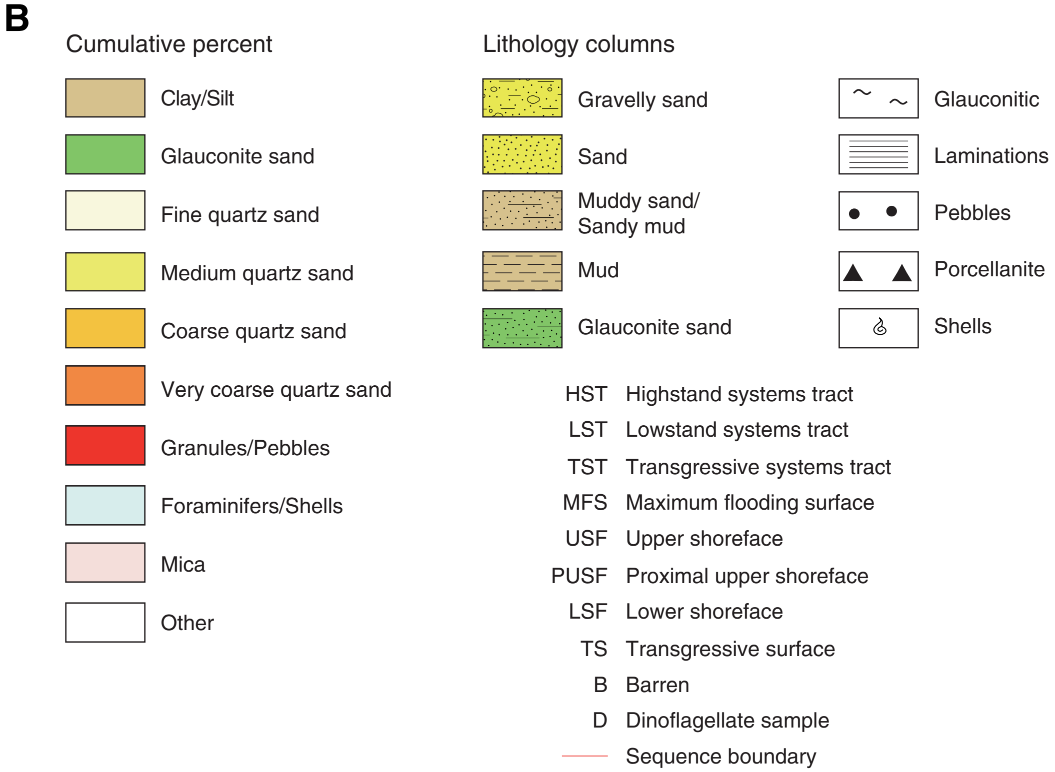


Figure F3. Summary stratigraphic section for the Kirkwood Formation (?lower to middle Miocene) in the Double Trouble borehole, with core recovery (Rec.), lithology (Lith.), gamma ray and resistivity log signatures, age, and environments (Env.). Syst. = systems tract. Kw1a and K1b are sequences defined by Sugarman et al. (1993). See Figure F2B for legend.

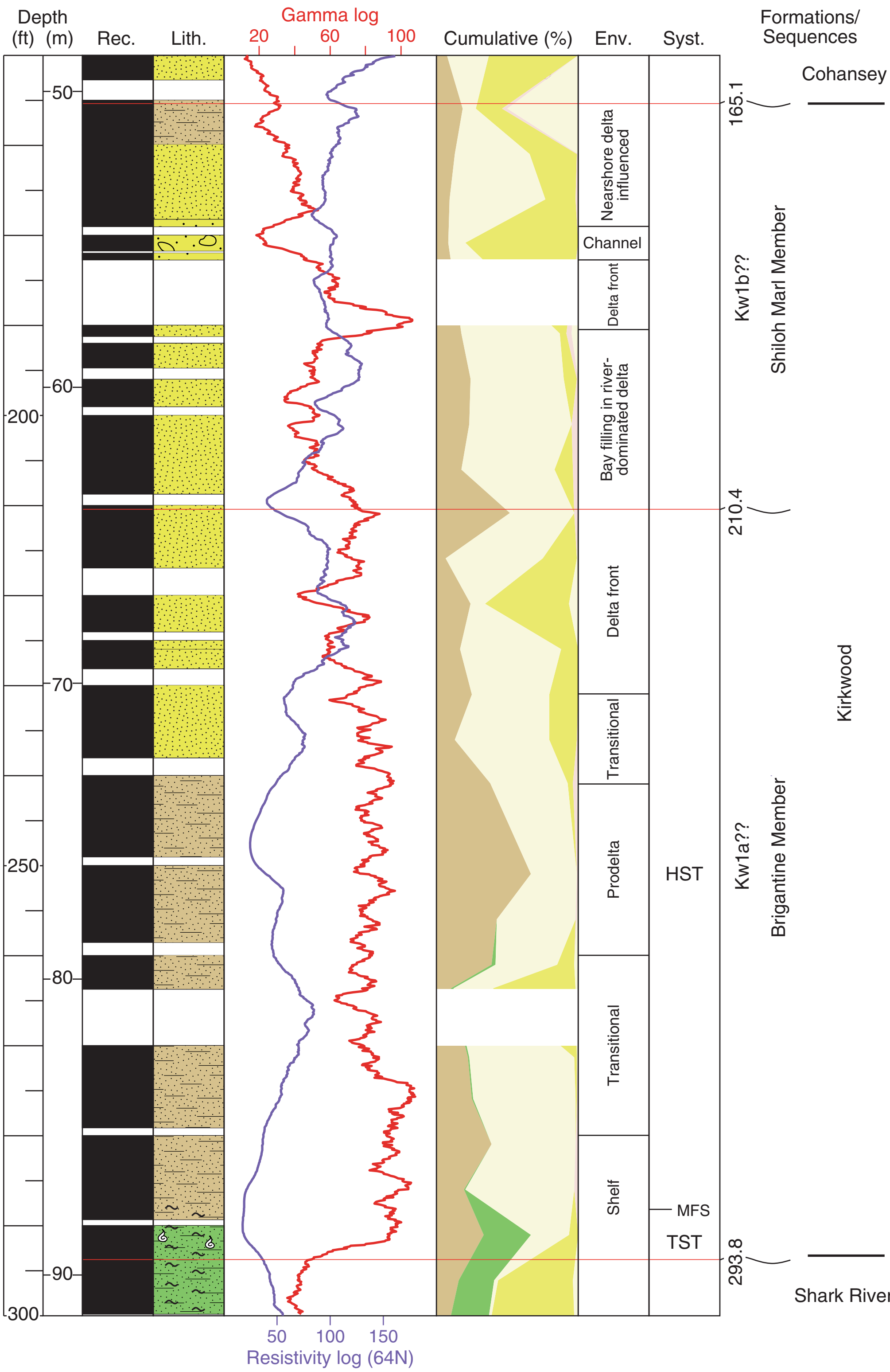


Figure F4. Summary stratigraphic section for the Toms River Member of the Shark River Formation (upper middle Eocene) from the Double Trouble borehole. with core recovery (Rec.), lithology (Lith.), gamma ray and resistivity log signatures, age, and environments (Env.). Dino. = Dinocyst zone, Foram. = foraminifer zone, Nanno. = nannofossil zone, Sr = strontium age estimate, Syst. = systems tract. Lines Res, 16, and 64 are all resistivity logs. NP Zones are from Martini (1971) and Martini and Müller (1986). E and P Zones are from Berggren et al. (1995). E8 is a sequence defined by Browning et al. (1997a, 1997b). See Figure F2B for legend.

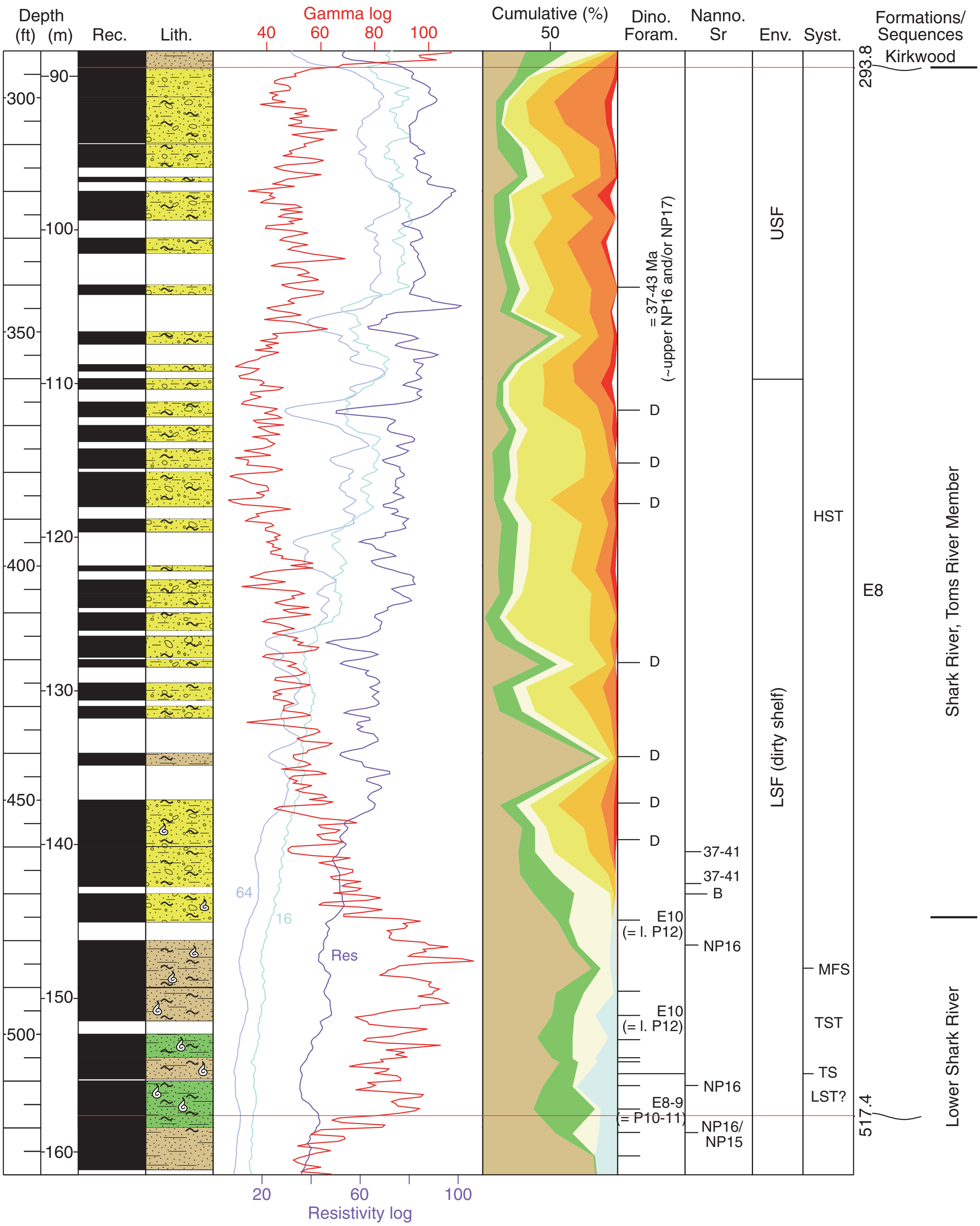


Figure F5. Summary stratigraphic section for the lower Shark River (middle Eocene) and Manasquan (lower Eocene) Formations from the Double Trouble borehole, with core recovery (Rec.), lithology (Lith.), gamma ray and resistivity log signatures, and age. Foram. = foraminifer zone, Nanno. = nannofossil zone, Syst. = systems tract. Lines Res, 16, and 64 are all resistivity logs. E and P Zones are from Berggren et al. (1995). NP Zones are from Martini (1971) and Martini and Müller (1986). E2–E5 and E7 **[AUTHOR: E8?]** are sequences defined by Browning et al. (1997a, 1997b). See Figure **F2B** for legend.

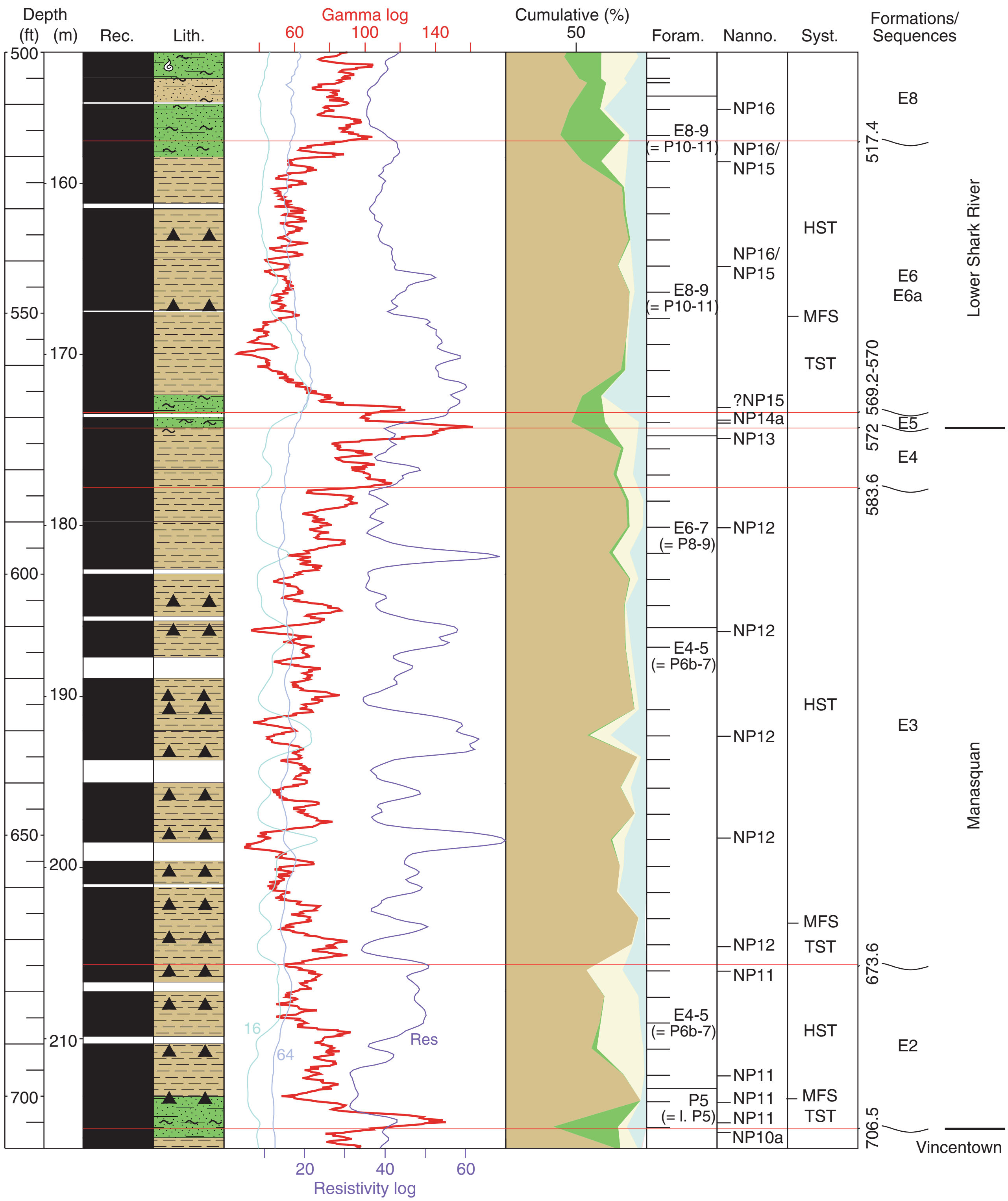


Figure F6. Summary stratigraphic section for the Vincentown (upper Paleocene), Hornerstown (lower to lowermost upper Paleocene), and New Egypt/Navesink Formations from the Double Trouble borehole, with core recovery (Rec.), lithology (Lith.), gamma ray and resistivity log signatures, and age. Foram. = foraminifer zone, Nanno. = nannofossil zone, Syst. = systems tract. P Zones are from Berggren et al. (1995). NP Zones are from Martini (1971) and Martini and Müller (1986). U.K. = [AUTHOR: Please define.]. Pa0–Pa3a are sequences defined by Liu et al. (1997) and Harris et al. (2010). See Figure F2B for legend.

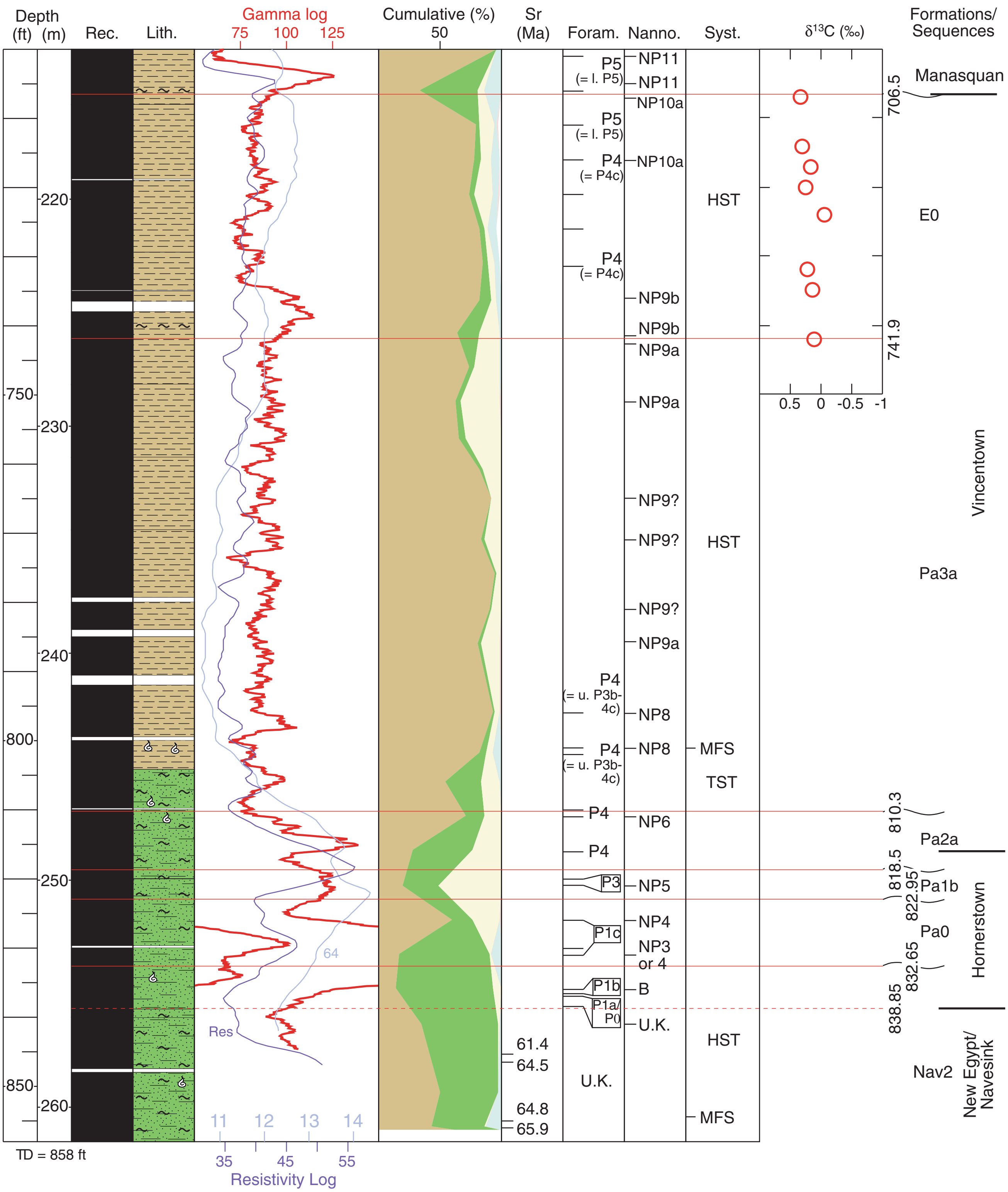


Figure F7. Lithologic and hydrostratigraphic terminology for units recovered from the Double Trouble corehole. Shaded areas in the gamma and resistivity log columns indicate aquifers.

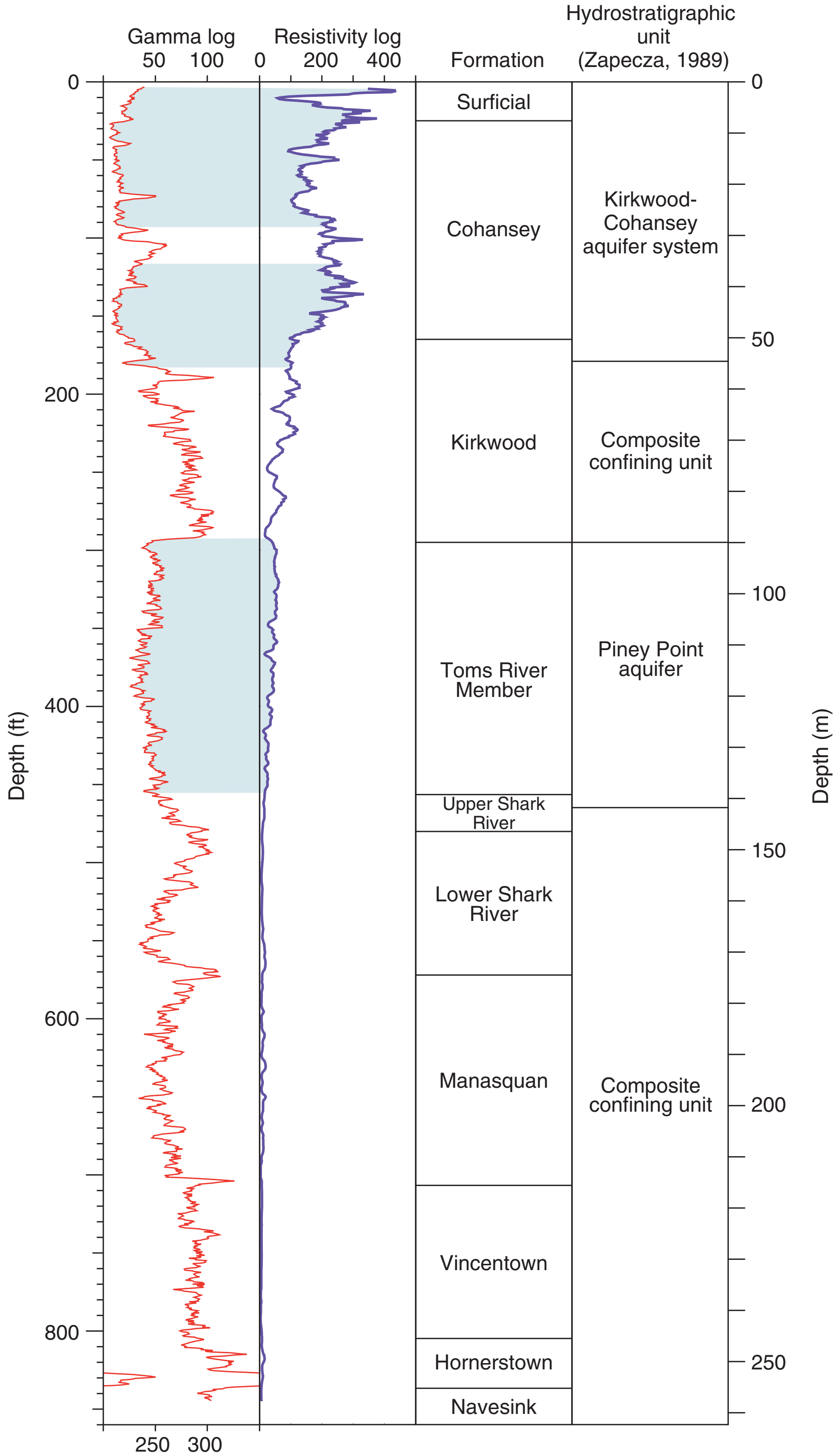


Figure F8. Age relations for Double Trouble corehole sediments. See Figure F2B for legend. LO = last occurrence.

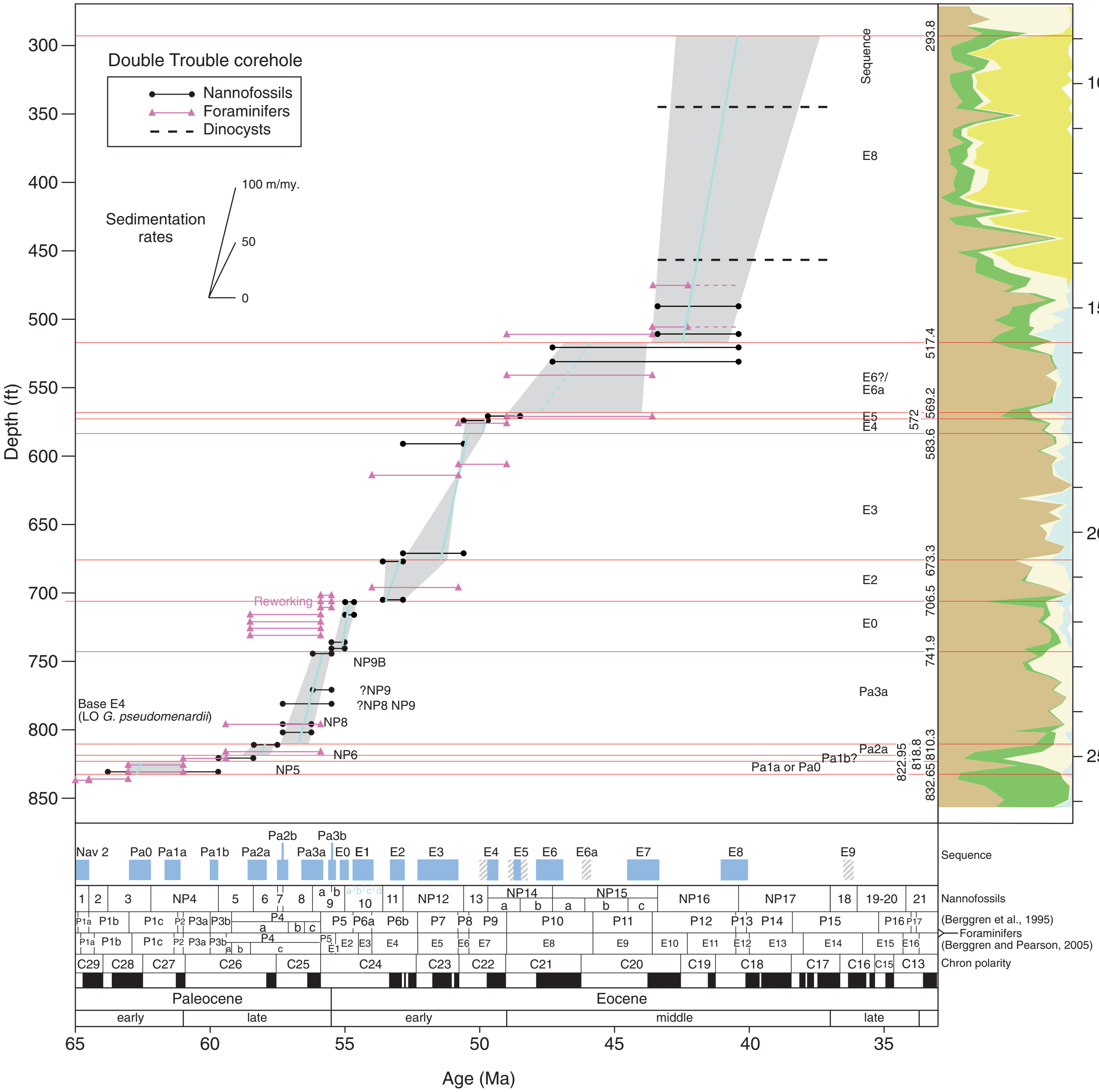


Table T1. Lithology at Double Trouble site. (**Continued on next two pages.**)

Run number	Date (2008)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Lithology	Formation	Color
1	10 Oct	5–10	5	1.2	24	Medium to coarse sand	Cohansey	7.5YR 7/6 (reddish yellow)
2	10 Oct	10–15	5	1.4	28	Medium to coarse sand	Cohansey	7.5YR 7/6 (reddish yellow)
3	10 Oct	15–20	5	2	40	Medium to coarse sand	Cohansey	7.5YR 7/6 (reddish yellow)
4	10 Oct	20–25	5	1.7	34	Medium to coarse sand	Cohansey	7.5YR 7/6 (reddish yellow)
5	10 Oct	25–30	5	4.3	86	Medium to coarse sand	Cohansey	10R 3/3 (dusky red)
6	10 Oct	30–35	5	1	20	Medium to coarse sand	Cohansey	7.5YR 7/8 (reddish yellow)
7	10 Oct	35–40	5	2.8	56	Medium to coarse sand	Cohansey	10YR 7/6 (yellow)
8	10 Oct	40–45	5	3	60	Medium to coarse sand	Cohansey	10YR 7/6 (yellow)
9	10 Oct	45–50	5	0.8	16	Medium to coarse sand	Cohansey	7.5YR 8/3 (pink)
10	10 Oct	50–51	1	0.35	35	Medium to coarse sand	Cohansey	7.5YR 8/3 (pink)
11	10 Oct	51–60	9	2.5	28	Medium to coarse sand	Cohansey	10YR 7/6 (yellow) 7.5 YR 7/8 (reddish yellow)
12	10 Oct	60–65	5	1.5	30	Medium to coarse sand	Cohansey	10YR 7/6 (yellow)
13	10 Oct	65–70	5	3	60	Fine to medium sand	Cohansey	7.5YR 7/6 (reddish yellow)
14	11 Oct	70–75	5	4	80	Medium sand, silty clay at bottom	Cohansey	7.5YR 7/6 (reddish yellow)
15	11 Oct	75–80	5	4.5	90	Fine to medium sand	Cohansey	7.5YR 6/6 (reddish yellow)
16	11 Oct	80–87.5	7.5	4.3	57	Medium to coarse sand	Cohansey	10YR 5/8 (yellowish brown)
17	11 Oct	87.5–95	7.5	2.2	29	Medium to coarse sand	Cohansey	10YR 6/6 (brownish yellow)
18	11 Oct	95–100	5	3.8	76	Silt and interlaminated sand	Cohansey	2.5 YR 7/2 (light gray)
19	11 Oct	100–105	5	2.3	46	Coarse sand, silty sand at bottom	Cohansey	2.5Y 8.6 (yellow)
20	11 Oct	105–110	5	4.3	86	Silt, clay, and sand	Cohansey	10YR 7/1 (light gray)
21	11 Oct	110–120	10	0.75	8	Clay, silt, and sand	Cohansey	2.5Y 6/2 (light brownish yellow)
22	12 Oct	120–125	5	4.75	95	Fine to medium sand	Cohansey	10YR 6/6 (brownish yellow)
23	12 Oct	125–130	5	4.6	92	Fine to medium sand	Cohansey	10YR 5/8 (yellowish brown)
24	12 Oct	130–135	5	3.7	74	Medium sand	Cohansey	10YR 7/8 (yellow)
25	12 Oct	135–140	5	3	60	Fine to medium sand	Cohansey	10YR 6/3 (pale brown)
26	12 Oct	140–150	10	0.5	5	Medium to coarse sand	Cohansey	2.5Y 2.5/3 (dark reddish brown)
27	12 Oct	150–152	2	0.9	45	Medium sand	Cohansey	2.5Y 6/6 (olive yellow)
28	12 Oct	152–160	8	0.35	4	Fine to medium sand	Cohansey	10YR 6/6 (brownish yellow)
29	12 Oct	160–165	5	2.7	54	Fine to medium sand/Very fine sand	Cohansey	10YR 5/8 (yellowish brown)
30	12 Oct	165–170	5	4.8	96	Lignitic sand and silt interbedded with medium to coarse sand	Kirkwood	2.5Y 5/3 (light olive brown)/ 2.5Y 3/1 (very dark gray)
31	12 Oct	170–180	10	9	90	Fine to medium sand	Kirkwood	2.5Y 3/1 (very dark gray)
32	13 Oct	180–182	2	1.7	85	Granuliferous sand to sandy gravel	Kirkwood	2.5Y 5/1 (gray)
33	13 Oct	182–190	8	0.7	9	Granuliferous sand to sandy gravel	Kirkwood	2.5Y 5/1 (gray)
34	17 Oct	190–192	2	1.2	60	Lignitic silty sand interbedded medium sand	Kirkwood	10GY 2.5/1 (greenish black)
35	17 Oct	192–196	4	2.7	68	Fine to medium sand	Kirkwood	10Y 2.5/1 (greenish brown)
36	17 Oct	196–200	4	3	75	Fine to medium sand	Kirkwood	10GY 3/1 (very dark greenish gray)
37	17 Oct	200–210	10	8.7	87	Fine to medium sand	Kirkwood	7.5YR 3/1 (very dark gray)
38	17 Oct	210–220	10	6.9	69	Fine to medium sand	Kirkwood	5Y 3/1 (very dark gray)
39	17 Oct	220–225	5	4	80	Fine to medium sand	Kirkwood	5Y 3/1 (very dark gray)
40	17 Oct	225–226	1	1.3	130	Fine to medium sand	Kirkwood	5Y 2.5/1 (black)
41	17 Oct	226–230	4	2.1	53	Fine to medium sand	Kirkwood	7.5YR 2.5/1 (black)
42	17 Oct	230–240	10	8	80	Fine to medium sand	Kirkwood	5Y 2.5/1 (black)
43	17 Oct	240–250	10	9	90	Fine to medium sand	Kirkwood	5Y 2.5/1 (black)
44	18 Oct	250–260	10	8.5	85	Micaceous clayey silts and very fine sand	Kirkwood	2.5Y 3/1 (very dark gray)
45	18 Oct	260–270	10	3.7	37	Micaceous clayey silts and very fine sand	Kirkwood	2.5Y 3/1 (very dark gray)
46	18 Oct	270–280	10	9.1	91	Micaceous clayey silts and very fine sand	Kirkwood	2.5Y 3/1 (very dark gray)

Table T1 (continued). (Continued on next page.)

Run number	Date (2008)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Lithology	Formation	Color
47	18 Oct	280–290	10	9.3	93	Micaceous clayey silts and very fine sand and glauconite sand	Kirkwood/Kw0	2.5Y 3/1 (very dark gray)
48	18 Oct	290–300	10	9.8	98	Glauconitic clay and sand	Kw0/Oligocene	10GY 2.5/1 (greenish black)
49	18 Oct	300–310	10	9.6	96	Glauconitic quartz sand	Toms River Member	5Y 6/2 (light olive gray
50	18 Oct	310–317	7	4.8	69	Glauconitic quartz sand	Toms River Member	5GY 2.5/1 (greenish black)
51	18 Oct	317–320	3	0.9	30	Glauconitic quartz sand, indurated	Toms River Member	5GY 2.5/1 (greenish black)
52	18 Oct	320–330	10	6.1	61	Glauconitic quartz sand, indurated	Toms River Member	5GY 2.5/1 (greenish black)
53	19 Oct	330–340	10	3.2	32	Glauconite-quartz sand, indurated in spots	Toms River Member	5G 2.5/2 (very dark grayish green)
54	19 Oct	340–345	5	2	40	Glauconite-quartz sand, indurated in spots	Toms River Member	5G 2.5/2 (very dark grayish green)
55	19 Oct	345–350	5	2.6	52	Quartzose glauconite sand, glauconitic clay beds	Toms River Member	5GY 4/1 (dark greenish gray)
56	19 Oct	350–357	7	2.4	34	Quartzose glauconite sand, glauconitic clay beds	Toms River Member	5G 2.5/2 (very dark grayish green)
57	19 Oct	357–360	3	1.35	45	Quartzose glauconite sand, glauconitic clay beds	Toms River Member	5G 3/2 (very dark grayish green)
58	19 Oct	360–365	5	2.2	44	Quartzose glauconite sand, glauconitic clay beds; cross-beds	Toms River Member	5G 2.5/2 (very dark grayish green)
59	19 Oct	365–370	5	3.1	62	Quartzose glauconite sand, glauconitic clay with interbedded sands	Toms River Member	Sand: 5GY 3/1, clay: 5GY 5/1 (greenish gray)
60	19 Oct	370–375	5	3.4	68	Quartzose glauconite sand, glauconitic clay beds	Toms River Member	5G 2.5/2 (very dark grayish green)
61	19 Oct	375–380	5	4.1	82	Glauconite-quartz sand, silt and clay beds	Toms River Member	5G 2.5/2 (very dark grayish green)
62	19 Oct	380–390	10	7.3	73	Glauconite-quartz sand, thin clay beds	Toms River Member	5GY 2.5/1 (greenish black)
63	19 Oct	390–400	10	2.7	27	Granuliferous glauconite-quartz sand; ash marl	Toms River Member	5GY 2.5/1 (greenish black) 2.5Y 4/2 (dark grayish brown)
64	20 Oct	400–403	3	1	33	Glauconite-quartz sand, thin clay bed	Toms River Member	5GY 2.5/1 (greenish black) 10GY 3/1 (very dark greenish gray)
65	20 Oct	403–406	3	2.8	93	Granuliferous glauconite-quartz sand	Toms River Member	5G 3/1 (very dark grayish green)
66	20 Oct	406–410	4	2.85	71	Granuliferous glauconite-quartz sand	Toms River Member	5G 3/1 (very dark grayish green)
67	20 Oct	410–415	5	3.8	74	Glauconitic quartz sand; very water rich	Toms River Member	5G 3/1 (very dark grayish green)
68	20 Oct	415–420	5	4.45	89	Glauconitic quartz sand; clayey glauconitic quartz sand; sequence boundary; glauconitic clay	Toms River Member	5G 3/1 (very dark grayish green) 5GY 4/1 (dark greenish gray)
69	20 Oct	420–425	5	1.55	31	Granuliferous clayey, glauconitic quartz sand and glauconitic clay	Toms River Member	5G 3/1 (very dark grayish green) 5GY 4/1 (dark greenish gray)
70	20 Oct	425–430	5	3.6	72	Granuliferous clayey, glauconitic quartz sand and glauconitic clay	Toms River Member	5G 3/1 (very dark grayish green) 5GY 4/1 (dark greenish gray)
71	20 Oct	430–440	10	2.45	25	Granuliferous clayey, glauconitic quartz sand and glauconitic clay	Toms River Member	5G 3/1 (very dark grayish green) 5GY 4/2 (olive gray)
72	21 Oct	440–450	10	2.5	25	Granuliferous clayey, glauconitic quartz sand and glauconitic clay	Toms River Member	5Y 4/2 (olive gray) 10Y 4/1 (dark greenish gray)
73	21 Oct	450–460	10	9.8	98	Granuliferous clayey, glauconitic quartz sand and glauconitic clay	Toms River Member Shark River	10Y 3/1 (very dark greenish gray)
74	21 Oct	460–470	10	8.4	84	Glauconite, quartz silt with interburrowed brown clay	Upper Shark River	10Y 4/1 (dark greenish gray)
75	21 Oct	470–480	10	6	60	Glauconite, quartz silt with interburrowed brown clay	Shark River	10Y 4/1 (dark greenish gray)
76	21 Oct	480–490	10	10	100	Slightly sandy silt	Lower Shark River	10Y 4/1 (dark greenish gray)
77	21 Oct	490–500	10	7.1	71	Slightly sandy silt	Lower Shark River	10Y 4/1 (dark greenish gray)
78	21 Oct	500–505	5	4.8	96	Glauconitic silt	Lower Shark River	10Y 4/1 (dark greenish gray)
79	21 Oct	505–510	5	4.5	90	Glauconitic silt	Lower Shark River	10Y 4/1 (dark greenish gray)
80	22 Oct	510–520	10	10	100	Glauconitic silty clay	Lower Shark River	5GY4/1 (dark greenish gray) 5GY6/1 (greenish gray)
81	22 Oct	520–530	10	8.9	89	Glauconitic foraminiferal clay; contact 521.7; slightly glauconitic foraminifer-rich clay	Lower Shark River	5GY4/1 (dark greenish gray) 5GY 5/1 (greenish gray)
82	22 Oct	530–539.5	9.5	10.4	109	Slightly glaucontic foraminiferal clay and porcellanitic clay	Lower Shark River	5GY 5/1 (greenish gray)
83	22 Oct	539.5–549.8	10.3	9.9	96	Slightly glaucontic foraminiferal clay and porcellanitic clay; MFS?	Lower Shark River	5GY 5/1 (greenish gray)

Table T1 (continued).

Run number	Date (2008)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Lithology	Formation	Color
84	23 Oct	549.8–560	10.2	10.2	100	Slightly glaucontic foraminiferal clay and porcellanitic clay	Lower Shark River	5GY 5/1 (greenish gray)
85	23 Oct	560–570	10	9.2	92	Slightly glaucontic foraminiferal clay and porcellanitic clay	Lower Shark River	5GY 5/1 (greenish gray)
86	23 Oct	570–580	10	9.9	99	Glaucontic foraminiferal clay and porcellanitic clay	Shark River/Manasquan	10GY 5/1 (greenish gray)
87	23 Oct	580–590	10	9.8	98	Slightly glaucontic foraminiferal clay and porcellanitic clay	Manasquan	10GY 5/1 (greenish gray)
88	23 Oct	590–600	10	9	90	Silty clay, porcellanite very fine sand, slightly glauconite	Manasquan	10GY 5/1 (greenish gray)
89	23 Oct	600–609	9	8	89	Silty clay, porcellanite very fine sand	Manasquan	5GY 5/1 (greenish gray)
90	23 Oct	609–610	1	4	400	Silty clay, porcellanite very fine sand	Manasquan	
91	24 Oct	610–620	10	5.85	59	Slightly glaucontic foraminiferal porcellanitic silty clay	Manasquan	5GY 5/1 (greenish gray)
92	24 Oct	620–627	7	7.65	109	Slightly glaucontic foraminiferal porcellanitic silty clay	Manasquan	5GY 5/1 (greenish gray)
93	24 Oct	627–630	3	4.05	135	Slightly glaucontic foraminiferal porcellanitic silty clay	Manasquan	5GY 5/1 (greenish gray)
94	24 Oct	630–640	10	5.55	56	Slightly glaucontic foraminiferal porcellanitic clayey sand	Manasquan	5GY 5/1 (greenish gray)
95	24 Oct	640–647	7	7.2	103	Slightly glaucontic foraminiferal porcellanitic silty clay	Manasquan	5GY 5/1 (greenish gray)
96	25 Oct	647–655	8	4.3	54	Slightly glaucontic foraminiferal porcellanitic silty clay	Manasquan	5GY 5/1 (greenish gray)
97	25 Oct	655–660	5	4.3	86	Slightly glaucontic foraminiferal porcellanitic silty clay	Manasquan	5GY 5/1 (greenish gray)
98	25 Oct	660–670	10	10.2	102	Porcellanitic silty clay and clayey silt	Manasquan	5GY 5/1 (greenish gray)
99	25 Oct	670–680	10	8.1	81	Porcellanitic silty clay with very fine sand filled burrows	Manasquan	5GY 5/1 (greenish gray)
100	25 Oct	680–688.5	8.5	9	106	Clayey silt with burrowed fine sand	Manasquan	5GY 5/1 (greenish gray)
101	25 Oct	688.5–698.5	10	9.7	97	Silty clay to clay with sand filled burrows	Manasquan	5GY 5/1 (greenish gray)
102	25 Oct	698.5–708	9.5	9.5	100	Clay, glauconite sand, and micaceous silt	Manasquan/Vincentown	5GY 5/1 (greenish gray)
103	26 Oct	708–719	11	10.7	97	Clayey silt	Vincentown	10Y 2.5/1 (greenish black)
104	26 Oct	719–729.5	10.5	10.3	98	Clayey silt	Vincentown	5GY 2.5/1 (greenish black)
105	26 Oct	729.5–735	5.5	5.4	98	Clayey silt	Vincentown	10GY 3/1 (very dark greenish gray)
106	27 Oct	735–740	5	1.4	28	Silty clay, glauconitic	Vincentown	10Y 3/1 (very dark greenish gray)
107	27 Oct	740–748.5	8.5	10.5	124	Silt with glauconite and very fine sand	Vincentown	10Y 3/1 (very dark greenish gray)
108	27 Oct	748.5–759.0	10.5	10.55	100	Silt with glauconite and very fine sand	Vincentown	10Y 3/1 (very dark greenish gray)
109	27 Oct	759.0–769.5	10.5	10.7	102	Silt with very fine sand, some glauconite	Vincentown	10Y 3/1 (very dark greenish gray)
110	28 Oct	769.5–780	10.5	9.7	92	Clayey silt to silty clay, some glauconite	Vincentown	3/N (very dark gray) 10Y 3/1 (very dark greenish gray)
111	28 Oct	780–785	5	3.9	78	Silty clay, some glauconite	Vincentown	3/N (very dark gray) 10Y 3/1 (very dark greenish gray)
112	28 Oct	785–792	7	5.5	79	Very micaceous very fine sandy clayey silt	Vincentown	10GY 2.5/1 (greenish black)
113	29 Oct	792–800	8	7.4	93	Sandy silty clay	Vincentown	10Y 3/1 (very dark greenish gray)
114	30 Oct	800–810	10	9.7	97	Silty clay over clayey, silty quartzose glauconite sand; contact 804.1 ft	Vincentown/Hornerstown	5GY 4/1 (dark greenish gray) 5G 4/1 (dark greenish gray)
115	30 Oct	810–820	10	9.9	99	Clayey, slightly micaceous glauconite sand to glauconitic clay	Hornerstown	10Y 4/1 (dark greenish gray)
116	30 Oct	820–830	10	9.6	96	Slightly silty, glauconitic quartz sand; contact zone 822.1–824.3 ft; clayey glauconite sand	Hornerstown	10Y 3/1 (dark greenish gray) 10YR 3/2 (very dark grayish brown)
117	30 Oct	830–840	10	10.7	107	Clayey glauconite sand; K/Pg 838.85 ft; glauconitic clay	Hornerstown/New Egypt–Navesink	5GY 4/1 (dark greenish gray) 2.5Y 3/1 (very dark gray)
118	30 Oct	840–850	10	7.6	76	Glauconitic clay	Navesink	10Y 3/1 (very dark greenish gray)
119	30 Oct	850–858	8	10	125	Clay, glauconite sand	Navesink	2.5Y 3/1 (very dark gray)

Table T2. Percentages of grain sizes at Double Trouble site. (See table notes.) (Continued on next two pages.)

Sample depth (ft)	Clay and silt (%)	Glauconite† (%)	Quartz sand (%)†				Granules and pebbles† (%)	Carbonate† (%)	Mica† (%)	Other† (%)
			Fine	Medium	Coarse	Very coarse				
6	14.0	0.0	30.0	34.6	12.3	4.6	4.4	0.0	0.0	0.0
11.3	10.5	0.0	25.5	37.3	15.1	7.0	4.6	0.0	0.0	0.0
16	9.8	0.0	22.7	38.0	16.9	7.6	5.0	0.0	0.0	0.0
21	4.1	0.0	13.8	67.0	12.0	2.2	1.0	0.0	0.0	0.0
26	4.9	0.0	3.1	21.2	40.8	18.1	8.7	0.0	0.0	3.1
30.9	9.5	0.0	10.9	28.2	25.7	17.8	7.9	0.0	0.0	0.0
36	4.9	0.0	6.2	49.3	35.9	2.5	1.3	0.0	0.0	0.0
41	3.7	0.0	9.2	25.8	23.0	12.9	25.1	0.0	0.0	0.3
45.7	2.6	0.0	6.3	20.7	64.5	5.9	0.0	0.0	0.0	0.0
51	8.2	0.0	11.7	29.3	33.6	11.8	5.4	0.0	0.0	0.0
53.4	9.0	0.0	10.1	35.9	29.0	9.0	2.6	0.0	0.0	4.3
61	4.5	0.0	12.0	52.8	28.7	1.7	0.3	0.0	0.0	0.0
66	3.9	0.0	12.2	44.7	28.9	5.8	3.2	0.0	0.7	0.7
71	3.3	0.0	7.9	29.2	27.0	17.1	14.7	0.0	0.4	0.4
76	8.1	0.0	80.3	11.4	0.2	0.0	0.0	0.0	0.0	0.0
81	5.6	0.0	8.5	26.9	43.8	8.6	2.9	0.0	0.0	3.7
87.5	6.8	0.0	40.0	43.4	4.0	2.4	3.5	0.0	0.0	0.0
89.6	4.0	0.0	5.5	27.2	50.2	9.5	3.0	0.0	0.3	0.3
96	55.9	0.0	19.0	6.2	6.7	7.7	2.4	0.0	1.1	1.1
101	13.0	0.0	6.8	11.4	30.6	35.4	2.0	0.0	0.4	0.4
106	66.9	0.0	18.4	1.6	0.4	0.1	0.0	0.0	12.6	0.0
110.65	11.6	0.0	72.9	11.6	0.0	0.1	0.0	0.0	0.0	3.8
121	4.8	0.0	31.1	63.6	0.3	0.1	0.1	0.0	0.0	0.0
126	3.8	0.0	43.8	49.1	1.0	0.0	0.0	0.0	0.0	2.3
131	3.6	0.0	32.9	59.7	0.8	0.0	0.0	0.0	0.0	3.0
136	3.6	0.0	16.4	71.8	5.8	0.6	0.0	0.0	0.0	1.8
140.4	6.6	0.0	4.5	55.6	30.0	2.5	0.0	0.0	0.0	0.8
150.8	13.0	0.0	44.6	24.6	11.7	5.4	0.8	0.0	0.0	0.0
160.9	7.1	0.0	30.0	50.8	5.7	5.2	1.2	0.0	0.0	0.0
166	18.7	0.0	9.4	17.8	0.0	0.0	0.0	0.0	3.7	50.3
171	12.9	0.0	52.8	33.2	0.0	0.0	0.0	0.0	1.1	0.0
176	9.4	0.0	67.3	21.2	0.0	0.0	0.0	0.0	2.1	0.0
181	8.1	0.0	11.9	80.0	0.0	0.0	0.0	0.0	0.0	0.0
191	18.0	0.0	68.8	4.5	0.0	0.0	0.0	0.0	4.4	4.4
196	24.2	0.0	65.4	9.8	0.0	0.0	0.0	0.0	0.5	0.0
201	23.3	0.0	71.9	0.0	0.0	0.0	0.0	0.0	4.7	0.0
206	17.5	0.0	66.2	12.8	0.0	0.0	0.0	0.0	3.5	0.0
211	51.6	0.0	45.9	0.0	0.0	0.0	0.0	0.0	2.4	0.0
216	6.1	0.0	69.2	24.0	0.0	0.0	0.0	0.0	0.0	0.7
221	24.1	0.0	10.4	58.6	0.0	0.0	0.0	0.0	0.0	6.9
226	16.8	0.0	71.0	12.2	0.0	0.0	0.0	0.0	0.0	0.0
231	24.6	0.0	54.8	20.7	0.0	0.0	0.0	0.0	0.0	0.0
236	12.7	0.0	67.0	18.9	0.0	0.0	0.0	0.0	1.4	0.0
241	37.8	0.0	54.4	4.2	0.0	0.0	0.0	0.0	3.0	0.6
251	66.2	0.0	33.1	0.0	0.0	0.0	0.0	0.0	0.7	0.0
256	42.5	0.0	55.2	0.0	0.0	0.0	0.0	0.0	1.1	1.1
261	38.8	2.4	44.0	12.2	0.0	0.0	0.0	0.0	0.0	2.4
263.6	10.4	1.5	27.8	58.7	0.0	0.0	0.0	0.0	0.0	1.5
271.4	22.3	0.8	73.9	2.2	0.0	0.0	0.0	0.0	0.0	0.8
276	24.9	0.7	72.8	0.4	0.0	0.0	0.0	0.0	1.2	0.0
281	38.5	0.6	59.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0
286	19.9	0.8	76.9	0.0	0.0	0.0	0.0	0.0	2.4	0.0
291	32.9	31.9	25.9	5.9	3.4	0.0	0.0	0.0	0.0	0.0
296	23.8	10.3	1.6	15.3	21.9	24.4	2.7	0.0	0.0	0.0
301	9.7	7.6	2.2	12.7	21.2	38.3	5.5	0.0	0.0	2.9
306	9.9	5.1	1.1	19.0	26.4	30.9	4.2	0.0	0.4	3.0
311	11.6	18.5	3.3	24.6	28.2	12.1	0.8	0.0	0.2	0.7
317	27.6	6.7	12.9	21.4	19.5	11.0	1.0	0.0	0.0	0.0
321	9.0	10.7	2.0	21.8	22.8	18.7	10.9	0.0	0.1	4.1
325.9	8.7	12.6	3.0	27.3	31.0	16.4	0.9	0.0	0.1	0.0
331	10.6	7.3	2.2	18.0	25.1	25.4	3.0	0.0	0.0	8.3
341	18.1	11.0	6.0	18.4	27.2	19.3	0.0	0.0	0.0	0.0
346	13.0	8.7	3.1	22.3	32.5	15.7	1.7	0.0	0.0	3.1
351	49.3	7.4	4.5	13.6	11.4	11.7	2.1	0.0	0.0	0.0
357	21.2	5.0	4.2	14.2	22.9	27.6	4.0	0.0	0.0	0.9
361	11.2	4.9	4.3	26.2	22.1	19.1	8.0	0.0	0.0	4.1
366	10.7	5.1	4.3	25.7	39.4	13.4	0.4	0.0	0.0	1.0

Table T2 (continued). (Continued on next page.)

Sample depth (ft)	Clay and silt (%)	Glauconite† (%)	Quartz sand (%)†				Granules and pebbles† (%)	Carbonate† (%)	Mica† (%)	Other† (%)
			Fine	Medium	Coarse	Very coarse				
371	19.6	6.2	8.1	39.4	17.8	6.1	2.8	0.0	0.0	0.0
376	7.0	13.0	6.3	50.2	17.4	4.9	1.1	0.0	0.0	0.2
381	9.0	12.1	6.4	47.9	22.0	2.2	0.4	0.0	0.0	0.0
386	8.4	8.0	7.8	25.8	38.6	9.5	1.9	0.0	0.0	0.0
391	14.4	12.8	9.9	37.5	19.6	4.6	1.2	0.0	0.0	0.0
400.9	11.3	12.3	11.0	31.1	18.4	10.4	5.2	0.0	0.0	0.3
406	13.0	9.9	7.3	50.8	12.8	3.9	2.3	0.0	0.0	0.0
411	1.9	11.6	3.1	62.6	20.4	0.3	0.0	0.0	0.0	0.0
416	11.0	14.2	9.2	45.1	15.8	3.5	1.1	0.0	0.0	0.0
421	42.3	14.3	11.5	24.8	5.4	1.4	0.0	0.0	0.3	0.0
426	7.6	15.1	9.4	32.4	25.8	8.7	1.1	0.0	0.0	0.0
431	13.3	16.7	9.8	39.0	16.8	4.3	0.2	0.0	0.0	0.0
441	84.5	4.1	5.5	4.2	1.3	0.4	0.0	0.0	0.0	0.0
451	13.6	12.0	9.6	21.7	31.4	10.1	1.7	0.0	0.0	0.0
456	29.5	10.2	8.8	26.8	17.6	5.2	1.9	0.0	0.0	0.0
461	27.6	12.3	14.0	26.2	15.7	2.7	1.2	0.3	0.0	0.0
466	28.0	24.8	22.8	17.6	5.6	0.7	0.0	0.2	0.2	0.0
470	38.4	30.0	26.5	3.4	1.3	0.1	0.0	0.1	0.1	0.0
475.9	56.2	9.0	30.7	0.1	0.0	0.0	0.0	4.0	0.1	0.0
481	66.5	5.2	23.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0
486	81.1	7.1	7.4	0.0	0.0	0.0	0.0	4.0	0.4	0.0
491	55.3	20.1	22.3	0.0	0.0	0.0	0.0	2.2	0.0	0.0
496	52.7	15.8	15.2	0.0	0.0	0.0	0.0	16.3	0.0	0.0
500.5	41.5	26.3	26.3	0.0	0.0	0.0	0.0	5.8	0.0	0.0
505	52.1	15.8	16.3	0.0	0.0	0.0	0.0	15.8	0.0	0.0
506	57.7	14.0	14.4	0.0	0.0	0.0	0.0	14.0	0.0	0.0
511	45.4	21.9	2.7	0.0	0.0	0.0	0.0	30.1	0.0	0.0
516	38.7	46.0	3.1	0.0	0.0	0.0	0.0	12.3	0.0	0.0
521	54.2	13.7	18.3	0.0	0.0	0.0	0.0	13.7	0.0	0.0
526	82.7	1.7	0.2	0.0	0.0	0.0	0.0	15.4	0.0	0.0
531	84.0	1.6	0.2	0.0	0.0	0.0	0.0	14.2	0.0	0.0
536	87.2	1.3	0.1	0.0	0.0	0.0	0.0	11.4	0.0	0.0
541	79.6	0.4	10.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0
546.1	87.9	0.2	3.6	0.0	0.0	0.0	0.0	8.2	0.0	0.0
551	87.5	0.0	0.6	0.0	0.0	0.0	0.0	11.9	0.0	0.0
556	85.1	0.3	1.5	0.0	0.0	0.0	0.0	13.1	0.0	0.0
561	81.8	3.3	0.4	0.0	0.0	0.0	0.0	14.5	0.0	0.0
566	54.2	13.7	0.9	0.0	0.0	0.0	0.0	31.2	0.0	0.0
571	46.4	24.1	24.1	0.0	0.0	0.0	0.0	5.4	0.0	0.0
576	81.9	1.8	9.1	0.0	0.0	0.0	0.0	7.3	0.0	0.0
581	76.5	2.3	11.7	0.0	0.0	0.0	0.0	9.4	0.0	0.0
586	85.3	2.2	10.3	0.0	0.0	0.0	0.0	2.2	0.0	0.0
591	86.7	1.3	9.3	0.0	0.0	0.0	0.0	2.7	0.0	0.0
596	73.3	2.7	12.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0
601	87.8	0.6	6.1	0.0	0.0	0.0	0.0	5.5	0.0	0.0
606	84.2	0.3	0.8	0.0	0.0	0.0	0.0	14.7	0.0	0.0
614.1	85.0	0.4	3.7	0.0	0.0	0.0	0.0	10.8	0.0	0.0
626	91.4	0.3	3.1	0.0	0.0	0.0	0.0	5.2	0.0	0.0
631	57.9	1.7	15.2	0.0	0.0	0.0	0.0	25.3	0.0	0.0
635.4	93.6	0.1	2.4	0.0	0.0	0.0	0.0	3.8	0.0	0.0
641	81.7	0.4	7.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0
646	91.6	0.0	0.8	0.0	0.0	0.0	0.0	7.5	0.0	0.0
650.5	74.7	0.8	9.3	0.0	0.0	0.0	0.0	15.2	0.0	0.0
656	81.0	0.0	2.8	0.0	0.0	0.0	0.0	16.1	0.0	0.0
661	79.2	0.0	1.0	0.0	0.0	0.0	0.0	19.7	0.0	0.0
666	94.3	0.0	0.3	0.0	0.0	0.0	0.0	4.3	0.0	1.1
671	89.8	0.0	0.5	0.0	0.0	0.0	0.0	9.2	0.0	0.5
676	57.4	0.0	25.6	0.0	0.0	0.0	0.0	17.0	0.0	0.0
681	69.7	0.6	24.3	0.0	0.0	0.0	0.0	5.5	0.0	0.0
686	66.9	0.7	28.1	0.0	0.0	0.0	0.0	4.3	0.0	0.0
691	60.9	3.9	33.2	0.0	0.0	0.0	0.0	2.0	0.0	0.0
696	83.5	0.5	14.9	0.0	0.0	0.0	0.0	1.2	0.0	0.0
701	95.8	0.1	0.2	0.0	0.0	0.0	0.0	3.9	0.0	0.0
706	33.5	46.5	6.3	0.0	0.0	0.0	0.0	13.7	0.0	0.0
711	78.6	3.0	12.6	0.0	0.0	0.0	0.0	2.0	1.0	2.9
716	78.2	5.4	8.6	0.0	0.0	0.0	0.0	5.9	1.1	0.8
721	74.0	3.9	15.5	0.0	0.0	0.0	0.0	4.5	1.3	0.8
726	81.9	3.6	3.5	0.0	0.0	0.0	0.0	7.3	0.0	3.7
731	84.2	5.2	5.4	0.0	0.0	0.0	0.0	4.0	0.0	1.3

Table T2 (continued).

Sample depth (ft)	Clay and silt (%)	Glauconite† (%)	Quartz sand (%)†				Granules and pebbles† (%)	Carbonate† (%)	Mica† (%)	Other† (%)
			Fine	Medium	Coarse	Very coarse				
736.3	82.3	9.1	4.1	0.0	0.0	0.0	0.0	4.4	0.0	0.1
741	63.4	18.8	16.8	0.0	0.0	0.0	0.0	1.0	0.0	0.0
746	74.3	3.1	21.8	0.0	0.0	0.0	0.0	0.3	0.5	0.0
751	62.3	4.5	32.0	0.0	0.0	0.0	0.0	0.4	0.8	0.0
756.4	65.9	5.1	28.7	0.0	0.0	0.0	0.0	0.0	0.3	0.0
760.9	81.4	2.8	15.6	0.0	0.0	0.0	0.0	0.0	0.2	0.0
765	91.1	0.9	7.9	0.0	0.0	0.0	0.0	0.0	0.2	0.0
770.9	83.9	1.6	14.2	0.0	0.0	0.0	0.0	0.0	0.3	0.0
776	94.9	0.5	4.4	0.0	0.0	0.0	0.0	0.0	0.1	0.1
781	90.9	0.9	7.8	0.0	0.0	0.0	0.0	0.0	0.2	0.2
786	81.0	1.9	16.4	0.0	0.0	0.0	0.0	0.0	0.4	0.4
796	93.4	0.7	5.2	0.0	0.0	0.0	0.0	0.1	0.1	0.7
801.9	81.2	6.2	6.2	0.0	0.0	0.0	0.0	6.3	0.0	0.0
806	53.8	30.1	14.5	0.0	0.0	0.0	0.0	1.6	0.0	0.0
811	71.4	14.3	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
816	27.7	49.1	23.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
821	18.9	29.2	51.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
826	59.8	16.1	22.1	0.0	0.0	0.0	0.0	0.0	2.0	0.0
831	16.9	73.6	0.8	0.0	0.0	0.0	0.0	8.7	0.0	0.0
836	14.2	78.4	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
841	35.1	62.6	1.2	0.0	0.0	0.0	0.0	1.2	0.0	0.0
851	49.3	47.3	1.1	0.0	0.0	0.0	0.0	1.6	0.7	0.0
856	42.7	43.1	1.4	0.0	0.0	0.0	0.0	12.5	0.3	0.0
856.4	61.4	37.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: † = Obtained by visual best estimate. See **"Lithostratigraphy and Sequence Stratigraphy."**

Table T3. Planktonic foraminifers at Double Trouble site. This table is available in an **oversized format.**

Table T4. Biozones at Double Trouble site. (See table note.)

Depth (ft):	801	801.9	809.8	811	816	820	821	826	830	831	836	836.35	836.65	837	837.35	837.4	837.65	838	838.35	838.65
Biozone:	P4	P4	P4	P4	P4	P3	P3	P1c	P1c	P1c	P1b	P1b	P0–P1a	P0–P1a	P0–P1a	P0–P1a	P0–P1a	P0–P1a	P0–P1a	P0–P1a
Remarks:			No foraminifers												No foraminifers	Clay nodule	No foraminifers		Small spheres-spherules (?)	
Acarinina coalingensis	x																			
Acarinina strabocella							x													
Acarinina mckannai	x	x		x	x															
Acarinina nitida	x	x																		
Chiloguembelina midwayensis		x																		
Chiloguembelina crinata	x	x																		
Chiloguembelina morsei																				
Eoglobigerina edita								x		x	x									
Eoglobigerina eobulloides									x		x	x		x				x		
Globanomalina archeocompressa											x			x						
Globanomalina chapmani	x	x		x																
Globanomalina compressa								x		x										
Globanomalina imitata																				
Globanomalina planocompressa										x	x									
Globanomalina pseudomenardii				x	x															
Globoconusa daubjergensis										x	x	x	x							
Hedbergella monmouthensis																		x		
Heterohelix sp.																				x
Igorina pusilla							x													
Morozovella aequa	x	x		x																
Morozovella angulata					x		x													
Morozovella conicotruncata							x													
Morozovella praeangulata							x													
Parasubbotina pseudobulloides										x										
Parasubbotina varianta							x													
Parasubbotina sp.						x														
Parvularugoglobigerina alabamensis										x										
Praemurica inconstans								x		x										
Praemurica pseudoinconstans										x	x									
Praemurica taurica											x	x								
Subbotina cancellata					x															
Subbotina triangularis	x			x																
Subbotina triloculinoides					x	x	x	x	x	x		x								
Subbotina trivialis										x										
Subbotina velascoensis	x	x		x																
Woodringina claytonensis													x							
Woodringina hornerstownensis											x									
Zeauvigerina waiparaensis											x									

Note: x = present.

Table T5. Cretaceous species at Double Trouble site. **[AUTHOR: Please define quotation marks in first header row.]** (**See table note.**)

Depth (ft):	839	839.4	839.65	840	"840.35"	"840.65"	840	841	851	856
Biozone:					Cretaceous					
Globotruncana aegpytiaca			x	x						
Globigerinelloides alvarezi	x	x	x		x	x		x		x
Globigerinelloides messinae	x	x						x		x
Globigerinelloides prairiehillensis						x				x
Globigerinelloides spp.	x		x	x	x	x		x	x	x
Globotruncana arca				x						x
Globotruncana sp.				x		x				
Globotruncanella minuta	x	x	x		x					
Globotruncanella petaloidea										x
Globotruncanella sp.	x									
Globotruncanita angulata										x
Globotruncanita pettersi					x			x		
Globotruncanita stuarti										
Globotruncanita stuartiformis										x
Globotruncanita sp.						x				
Guembelitria cretacea	x	x		x	x	x		x	x	
Hedbergella holmdelensis		x								x
Hedbergella monmouthensis		x			x			x		x
Heterohelix globulosa	x	x	x	x	x	x		x	x	x
Heterohelix labellosa			x	x	x	x				
Heterohelix navarroensis					x	x		x		x
Heterohelix planata	x							x		
Heterohelix punctulata						x				x
Heterohelix sp.							x			
Laeviheterohelix dentata				x	x	x			x	x
Laeviheterohelix glabrans			x		x					
Pseudoguembelina sp.				x						
Pseudotextularia elegans			x	x	x			x		x
Pseudotextularia nuttalli			x	x	x			x		x
Pseudotextularia sp.				x						x
Racemiguembelina sp.						x				
Rugoglobigerina hexacamerata	x	x			x					x
Rugoglobigerina macrocephala			x	x				x		x
Rugoglobigerina pennyi										
Rugoglobigerina rugosa	x	x	x	x	x	x		x		x
Rugoglobigerina sp.										x

Note: x = present.

Table T6. Sr isotope data at Double Trouble site. **[AUTHOR: Please confirm table note.]** (**See table note.**)

Depth (ft)	Depth (m)	Material	Sr value	Corrected standards	Error	Age (Ma)	McArthur	McArthur corrected
461	140.5	Shell	0.707739	0.707753	0.000008		0.707746	37–41
467.8	142.6	Shell	0.707724	0.707738	0.000005		0.707731	39–41
845.6	257.7	Shell	0.707940	0.707954	0.000008	61.4	0.707947	31.1
846.1	257.9	Shell	0.707871	0.707885	0.000006	64.5	0.707878	32.8
855	260.6	Shell	0.707863	0.707877	0.000007	64.8	0.707870	33
856	260.9	Shell	0.707840	0.707854	0.000007	65.9	0.707847	33.3

Note: McArthur = McArthur et al., 2001.

Table T7. Sequences recovered at Double Trouble site.

Sequence	Depth (ft)		Depth (m)		Thickness (m)	Age (Ma)		Sedimentation rate (m/m.y.)
	Top	Bottom	Top	Bottom		Top	Bottom	
E8	293.8	517.4	89.6	157.7	68.2	40.5	42.5	34
E6/E6a	517.4	569.2	157.7	173.5	15.8	46.9	47.7	20
E5	569.2	572	173.5	174.3	0.9	48.6	48.7	9
E4	572	583.6	174.3	177.9	3.5	49.8	49.9	35
E3	583.6	673.3	177.9	205.2	27.3	50.5	51.5	27
E2	673.3	706.5	205.2	215.3	10.1	53.0	53.5	20
E0	706.5	741.9	215.3	226.1	10.8	54.8	55.1	36
Pa3a	741.9	810.3	226.1	247.0	20.8	55.8	56.8	21
Pa2a	810.3	818.8	247.0	249.6	2.6	58.0	58.2	13
Pa1b?	818.8	822.95	249.6	250.8	1.3	59.5	59.6	13
Pa1a or Pa0	822.95	832.65	250.8	253.8	3.0	62.5	62.7	15
							Eocene average:	26
							Paleocene average:	15

Figure AF1. Representative lithofacies from the Double Trouble corehole: upper shoreface sediments from the Cohansey Formation (65–66.5 ft; 19.8–20.3 m); sharp surface at 72.7 ft (22.2 m) in the Cohansey Formation; lagoonal facies in the Cohansey Formation (105–106 ft and 106–108 ft; 32.0–32.3 and 32.3–32.9 m); and upper shoreface facies in the Kirkwood Formation (122–124 ft; 37.2–37.8 m).

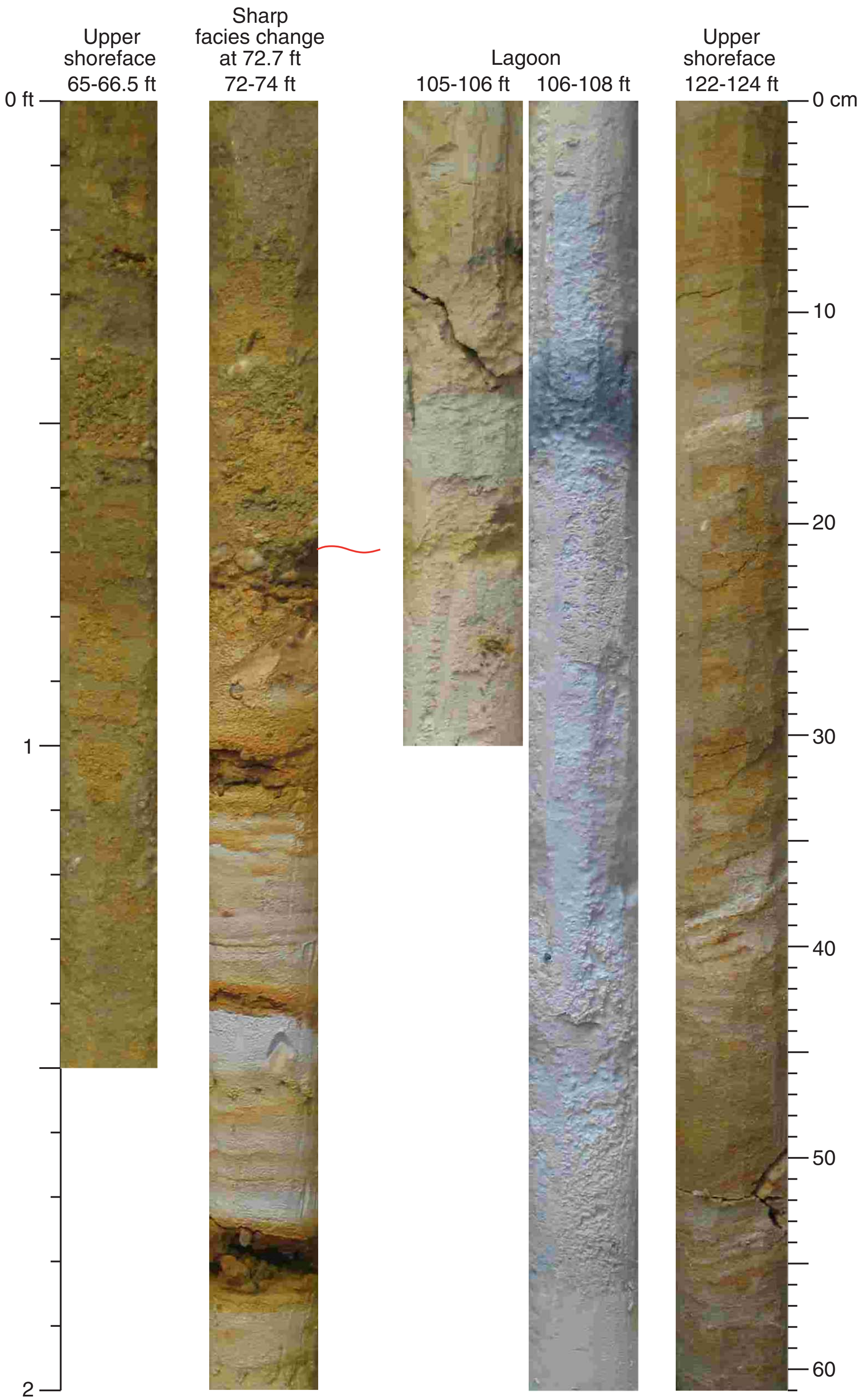


Figure AF2. Representative lithofacies from the Double Trouble corehole: Kirkwood/Cohansey contact at 165.1 ft (50.3 m) and cores showing a progression from delta front to middle neritic sand in the Kirkwood Formation: delta front (214–216 ft; 65.2–65.8 m), prodelta (254–256 ft; 77.4–78.0 m), shelf to prodelta (271.4–273.4 ft; 82.7–83.3 m), and middle neritic sand (280.5–282.5 ft; 85.5–86.1 m).

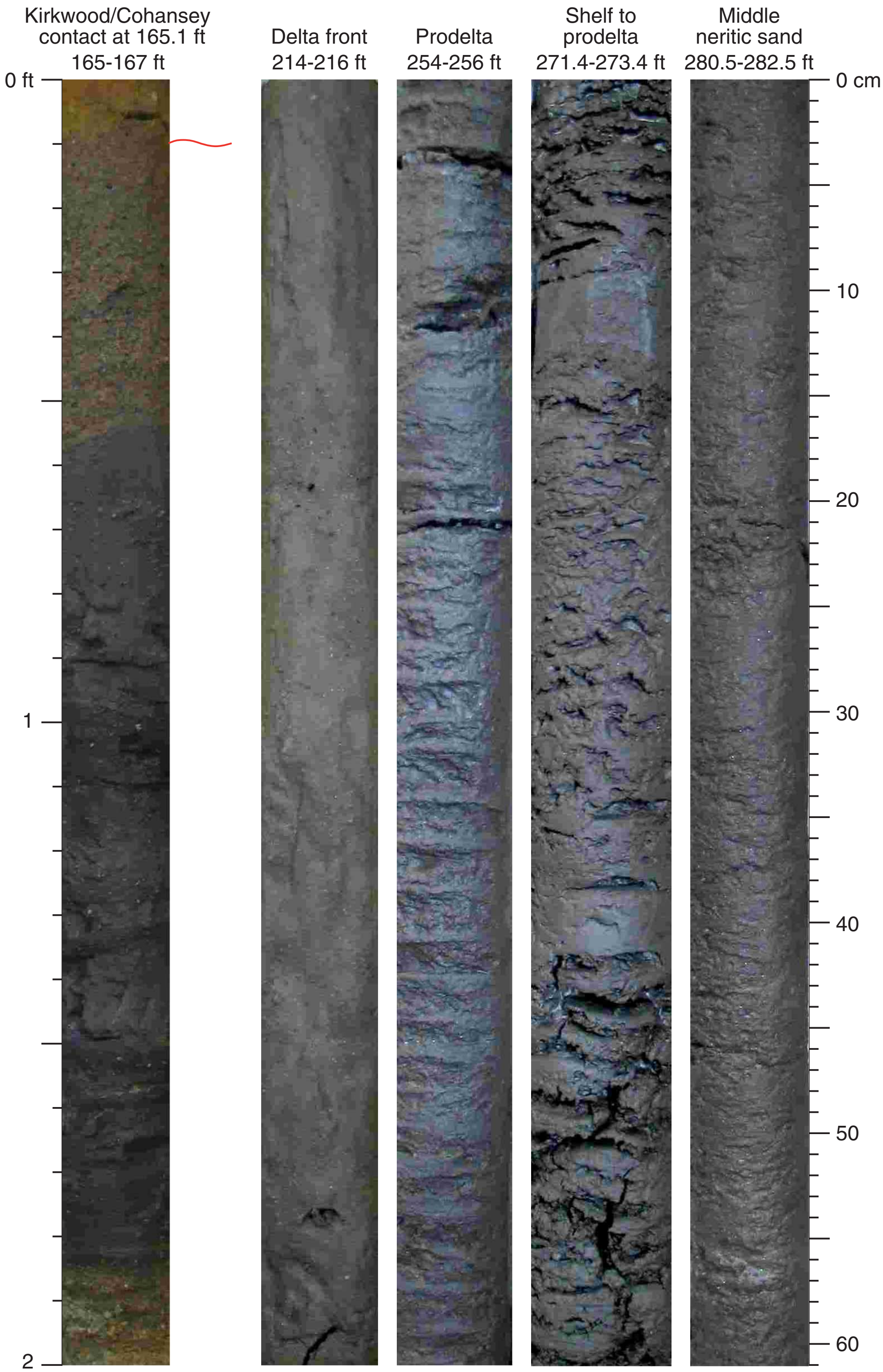


Figure AF3. Representative lithofacies from the Double Trouble corehole: Kirkwood/Shark River contact at 293.8 ft (89.6 m) and Toms River Member of the Shark River Formation: upper shoreface (301–303 ft; 91.7–92.4 m), lower shoreface (322–324 ft; 98.1–98.8m), lower shoreface (383–385 ft; 116.7–117.3 m), and lower shoreface (453–455 ft; 138.1–138.7 m).

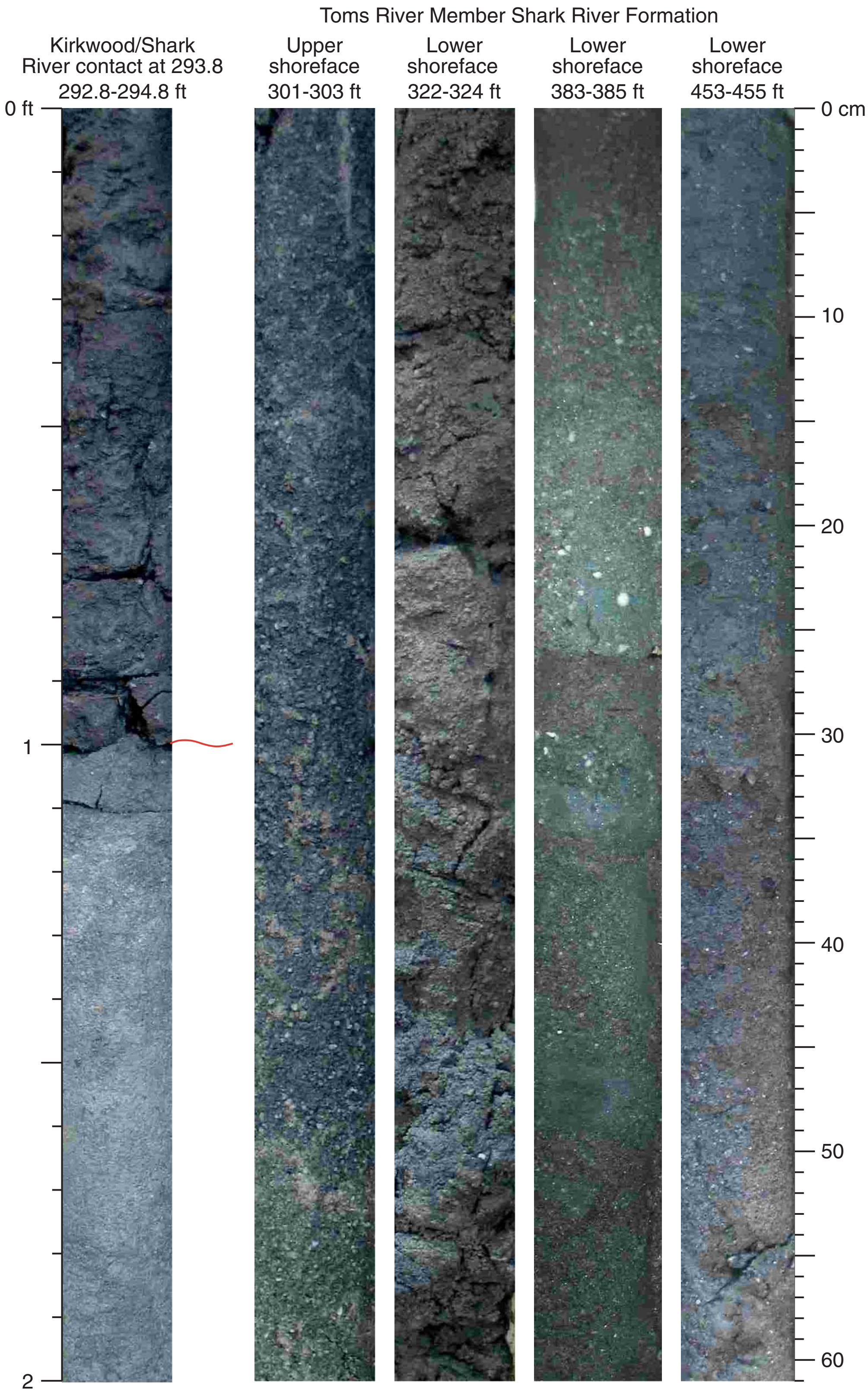


Figure AF4. Representative lithofacies from the Double Trouble corehole: sequence boundary at 517.4 ft (157.6 m) and gradual increase in glauconite sand at the base of Sequence E7 (560–568 ft; 170.7–173.1 m).

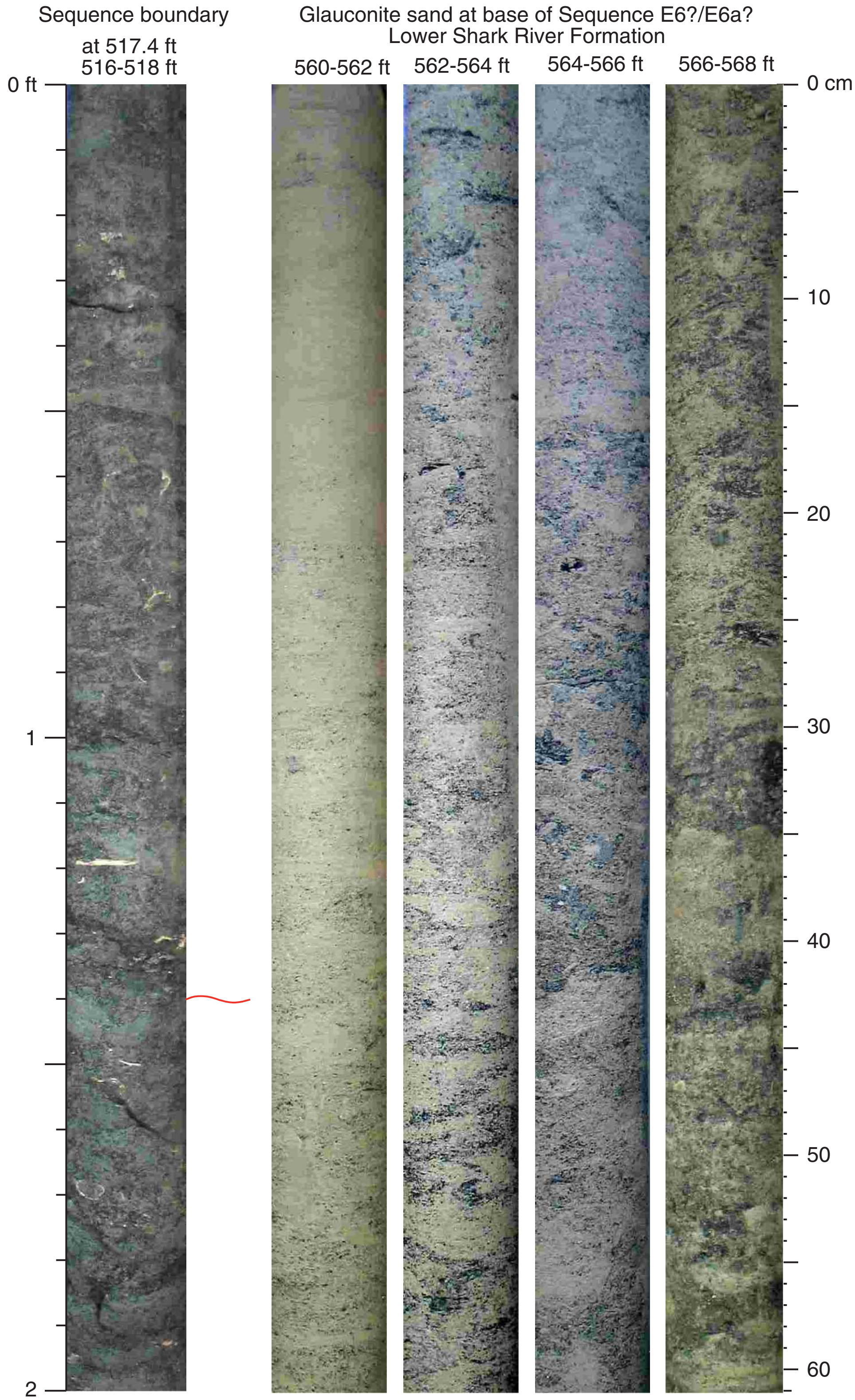


Figure AF5. Representative lithofacies from the Double Trouble corehole: sequence boundaries at 583.6 ft (177.9 m), 706.5 ft (215.3 m), and 741.9 ft (226.1 m).