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

4. Fort Mott Site[1]

Peter J. Sugarman, Kenneth G. Miller, Peter P. McLaughlin Jr., James V. Browning, John Hernandez, Donald Monteverde, Jane Uptegrove, Stefanie J. Baxter, Thomas E. McKenna, A. Scott Andres, Richard N. Benson, Kelvin W. Ramsey, Todd Keyser, Miriam E. Katz, Alicia Kahn, Andrea Friedman, Matt Wojtko, Mark D. Feigenson, Richard K. Olsson, Gil Brenner, Jean M. Self-Trail, and Gene Cobbs III[2]

INTRODUCTION

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

Chief scientists: McLaughlin, Miller, Sugarman
Staff scientist: Browning
Operations: Cobbs III
Lithostratigraphy: Andres, Baxter, Benson, Browning, Hernandez, Kahn, Katz, Keyser, McKenna, McLaughlin, Miller, Monteverde, Ramsey, Sugarman, Uptegrove
Biostratigraphy:
  Calcareous nannofossils: Self-Trail
  Palynomorphs: Brenner, McLaughlin
Logging: Baxter, McLaughlin

FORT MOTT SITE SUMMARY

Fort Mott was the eighth site drilled as part of the New Jersey Coastal Plain Drilling Project and the fifth site drilled as part of Leg 174AX. Drilling at Fort Mott State Park, New Jersey (75°33′07.175″N, 39°36′19.956″W; elevation = 3.79 ft [1.2 m]; Delaware City, Delaware, 7.5′ quadrangle, Salem County, New Jersey) targeted Upper and Lower Cretaceous sequences and aquifers with an 820-ft (249.9 m) corehole

[1] Sugarman, P.J., Miller, K.G., McLaughlin, P.P., Jr., Browning, J.V., Hernandez, J., Monteverde, D., Uptegrove, J., Baxter, S.J., McKenna, T.E., Andres, A.S., Benson, R.N., Ramsey, K.W., Keyser, T., Katz, M.E., Kahn, A., Friedman, A., Wojtko, M., Feigenson, M.D., Olsson, R.K., Brenner, G., Self-Trail, J.M., and Cobbs, G., III, 2004. Fort Mott Site. *In* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX (Suppl.), 1–50 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/174AXSIR/VOLUME/CHAPTERS/174AXS_4.PDF>. [Cited YYYY-MM-DD]
[2] Scientific Party addresses.

Ms 174AXSIR-105

drilled 3–23 October, 2001. At Fort Mott, we recovered 638.85 ft (194.7 m); mean recovery was 78% for the 820 ft (249.9 m) cored. Gamma ray, conductivity, spontaneous potential, and resistivity downhole logs were collected from the borehole. Cretaceous sediments lie beneath a 27.7-ft (8.4 m) veneer of Quaternary sediments. A thin (8.4 ft; 2.6 m), weathered, basal transgressive systems tract (TST) of an uppermost Cretaceous (Campanian?) sequence is preserved beneath the Quaternary sediments; its stratigraphic correlation is unclear, although it probably correlates to the upper Englishtown or Marshalltown sequences of Miller et al. (2004). A thick Campanian (CC19) sequence is found below this truncated sequence. It is a typical New Jersey Cretaceous sequence with a thin glauconite sand TST at the base (Merchantville Formation), a thick clay-silt to silty very fine sand lower high-stand systems tract (HST) in the middle (Woodbury Formation), and a silty sandy upper HST at the top (Englishtown Formation). Previous mapping of this area was incorrect in not recognizing the Woodbury Formation (sediments were assigned to the Englishtown Formation), which is 30.7 ft (9.36 m) thick. Beneath the Merchantville sequence, a thin, predominantly silty upper Santonian? sequence is tentatively correlated with the Cheesequake Formation, although no age was determined because of lack of calcareous fossils. The Magothy Formation is thin at Fort Mott (16.1 ft; 4.9 m) and appears to be a single nonmarine Turonian sequence (Magothy II? of Miller et al., 2004). This formation is thicker and composes a major aquifer to the northeast and downdip. For example, at the Leg 174AX Ancora site, the Magothy Formation is 105.1 ft (32.03 m) thick and consists of two separate sequences (Magothy II and Magothy III).

The majority of the sediments recovered (678.9 ft; 206.93 m) at Fort Mott were from the Potomac Formation. Fort Mott coring collected one of the most detailed updip sedimentary records from the Potomac Formation, including strata from Potomac Formation Units 1–3 (Lower to Upper Cretaceous; Barremian (?)–lower Cenomanian). The Potomac section is composed primarily of nonmarine fluvial/upper delta plain deposits that have commonly been overprinted by ancient soil-forming processes, leaving thick intervals of paleosols. The overall depositional model for the Potomac Formation is interpreted as an anastomosed fluvial system. However, the possibility exists that laterally pervasive sands at the bases of Potomac Units 2 and 3 in New Jersey are marine delta front deposits. The Potomac Formation is dated using a palynological zonation developed in the Atlantic coastal plain continental Cretaceous sections. Pollen Zone I (?Barremian–Aptian), Pollen Zone II (Albian) and its subzones, and Pollen Zone III (Albian–lower Cenomanian) were recognized in the Fort Mott core, and these zones generally correspond to lithologic units defined in the hole. However, the exact stratigraphic contacts between these pollen zones in the core were difficult to place because of non-fossiliferous intervals produced by the destruction of organic material by soil-forming processes.

The highest subdivision, Potomac Unit 3 (141.1–363.6 ft; 43.01–110.83 m), is a thick section (222.5 ft; 67.8 m) of paleosols and fluvial sediments (channel and overbank facies). The interval is dominated by deeply weathered clays and silts, with an ~60-ft (18.3 m)-thick section of sand at its base. This sand is the largest aquifer in this region.

Potomac Unit 2 (363.6–599.7 ft; 110.83–182.79 m; 236.1 ft [71.96 m] thick) is well defined at the top contact but poorly defined at its lower contact with Potomac Unit 1. The upper part of Unit 2 has more stratigraphic intervals that are less severely weathered than Unit 3, allowing better interpretation of sedimentary facies and more detailed pollen analysis. This more detailed analysis allowed recognition of Subzones IIC and IIB within Unit 2. Within Potomac Unit 2, sediments correlated with pollen Zone IIC are organic rich and are interpreted to be deposits from an anastomosed fluvial system. Common facies include flood-basin, lacustrine, and overbank deposits. Zone IIB contains similar facies (along with crevasse splay) and a thick channel sand, although deeply weathered paleosols are also present, making it extremely difficult to accurately map the Zone II/Zone I boundary. Therefore, the interval between 599.7 and 644.1 ft (182.79 and 196.32 m) is assigned to undifferentiated Units 1–2, although we favor assignment to Unit 2.

Potomac Unit 1 (644.1–820 ft; 196.32–249.94 m) is 109.4 ft (33.3 m) thick in this borehole. It is also interpreted as sediments deposited in an anastomosed fluvial system, with channel fill, overbank, and swamp deposits. Intervals of colluviated material are also present. Deeply weathered paleosols are formed on this ancient fluvial sediment.

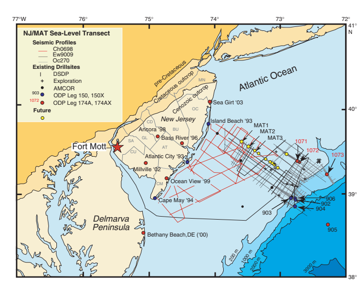
Hydrogeologic Summary

Three of the units penetrated in the Fort Mott corehole contain aquifer-quality sands in the coastal plain of New Jersey and Delaware: the Englishtown Formation, the Magothy Formation, and the Potomac Formation. The Englishtown Formation contains too high a percentage of clay and silt and is too thin to be used as an aquifer in this area. The Magothy Formation is also too thin at Fort Mott (13–18.3 ft; 3.96–5.58 m) to constitute a potential major aquifer; it is correlative with the upper Potomac-Raritan-Magothy (PRM) aquifer of Zapecza (1989). There are several sand intervals in the Potomac Formation that may make high-quality aquifers. The best aquifer is ~73 feet (22 m) thick and is found at the base of Potomac Unit 3. It is tentatively correlated with the middle PRM aquifer of Zapecza (1989). The gross thickness of the Unit 3 aquifer is significant, and it can be subdivided into thinner upper and lower aquifer subunits. The upper subunit, screened at the nearby Finns Point National Cemetery well at 282–319 ft (85.95–97.23 m), appears at Fort Mott at 291.4–310.6 ft (88.82–94.67 m) and is separated from the lower subunit at 320.4–364.25 ft (97.66–111.02 m) by a thin confining bed at 310.6–320.4 ft (94.67–97.66 m). Hydrologic testing would be required to establish the effectiveness of this confining bed. Another potential aquifer appears below a thick confining bed in Potomac Unit 2 from 565.1 to 596.8 ft (172.24 to 181.90 m). Because the sediment is composed of very fine to fine sand, this potential aquifer requires testing to determine its output.

BACKGROUND AND OBJECTIVES

Drilling onshore by Ocean Drilling Program (ODP) Legs 150X (Island Beach and Atlantic City, New Jersey [Miller et al., 1994], Cape May, New Jersey [Miller et al., 1996a]) and 174AX (Bass River, New Jersey [Miller et al., 1998], Ancora, New Jersey [Miller, Sugarman, Browning, et al., 1999, 2000], Oceanview, New Jersey [Miller, Sugarman, Pekar, Browning, et al., 2001], and Bethany Beach, Delaware [Miller, McLaughlin, Browning, et al., 2003]) (Fig. F1) has focused to date on global sea level and regional tectonic changes. The mid-Atlantic U.S. coastal plain that encompasses New Jersey and Delaware is a natural laboratory for teasing out the influences of global sea level (Miller et al., 1996b, 1997), regional tectonic, and sediment supply changes (Browning et al., submit-

F1. Location map, p. 35.



ted [N1]). This region is also inhabited by over 10 million people (2 million in southern New Jersey, 0.8 million in Delaware [0.5 million depend on groundwater], and 8 million in Maryland and northern Virginia), many of whom rely on groundwater for their day-to-day sustenance. Because of this, drilling at Bass River, Ancora, and Oceanview, New Jersey, was partially funded by the New Jersey Geological Survey (NJGS). Similarly, drilling at Bethany Beach, Delaware, was partially funded by the Delaware Geological Survey (DGS). Both the NJGS and the DGS have endeavored to understand the relationship among groundwater resources (aquifers), their confining units, and sequence stratigraphy.

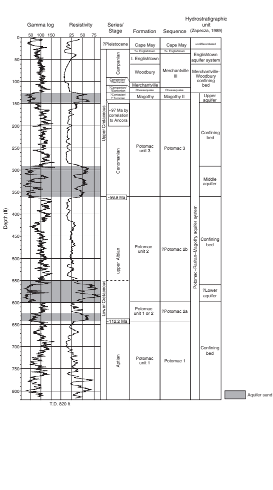
Sequence stratigraphy was pioneered by Exxon Production Research Company in their quest to understand the geological controls on oil-bearing units (e.g., Vail et al., 1977; Posamentier et al., 1988). Sequences are unconformity-bounded units that provide a predictable pattern for not only oil but also water-bearing beds (aquifers). In the New Jersey and Delaware coastal plains, marine sequences consist of basal unconformities, thin lower TST sands, thick medial lower HST silty clays and silts, and thick upper HST sands (Sugarman et al., 1993). Lowstand systems tracts are largely missing in the onshore coastal plain. The upper HST sands generally compose aquifers, whereas the silty lower HST units compose confining units (Sugarman and Miller, 1997). Understanding the sequence stratigraphy of the coastal plain provides a predictability for the distribution of groundwater resources.

With this in mind, the NJGS funded drilling targeting aquifers in the southern part of the state, namely Salem and Cumberland Counties (Fig. F1). This region currently derives nearly all of its drinking water supplies from groundwater (Cauller et al., 1999). This is especially true for southwestern Cumberland County, where surface water supply is nonexistent. Critical issues face water resource planners in this area, as in many areas of New Jersey, where the demand for water is projected to increase significantly over the next 20 yr. The Salem/Cumberland area is projected to be one of the five fastest growing areas in New Jersey, highlighting the need for additional water resources and intelligent water resource planning. Continuous coring of sequences in this region is needed to help determine the areal distribution of aquifers to allow efficient use of water resources.

In addition to water use, planners must consider saltwater intrusion and regulatory issues. One of the major aquifers in this region, the PRM aquifer system (Fig. F2), is susceptible to saltwater intrusion because of proximity to the Delaware estuary and heavy pumping in surrounding areas. Regulatory issues include the existence of water supply Critical Area No. 2 in northern Gloucester, Camden, and Burlington Counties, where pumpage is regulated, and its proximity to the Pinelands, a protected region. The resulting scenario is one of numerous restrictions coupled with vulnerable aquifers. These concerns have resulted in the initiation of a Water Supply Action Plan for the Salem/Gloucester/Cumberland area calling for a focus on evaluating the effect of proposed PRM withdrawals. The PRM is the major aquifer of focus because other regional confined aquifers, including the Wenonah–Mount Laurel and the Piney Point, have relatively low yields based on aquifer testing and are therefore inadequate to satisfy anticipated future demands in Salem and Gloucester Counties (note: the PRM is too deep to presently be considered in Cumberland County).

Planning and regulation of aquifers in this region are additionally complicated by the fact that New Jersey shares the PRM aquifer system

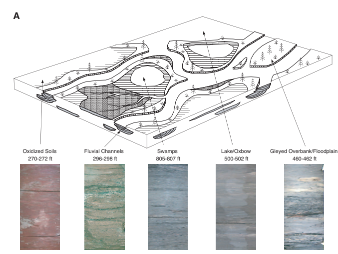
F2. Lithologic and hydrostratigraphic terminology, p. 36.



with Delaware. Current and future PRM withdrawals in Delaware may have significant potential effects on the quantity and quality of the PRM aquifer system in New Jersey and vice versa. A coordinated study of the hydrogeology of the PRM between New Jersey and Delaware is needed to develop strategies to protect and restore the PRM and to help ensure the availability of freshwater to meet future needs in the Lower Delaware Basin.

One of the primary objectives of NJGS-funded coastal plain drilling is to evaluate the geologic framework of Salem and Cumberland Counties, with a main emphasis on the PRM aquifer system. To this end, two stratigraphic control coreholes were proposed by the NJGS. The first, at scenic Fort Mott State Park on the Delaware River (Fig. F1), was completed in October 2001 and was the eighth continuously cored borehole drilled in New Jersey as part of the New Jersey Coastal Plain Drilling Project. The second was drilled in 2002 at Millville, New Jersey (Fig. F1), and will be reported in a subsequent site report. The Fort Mott corehole was drilled to a depth of 820 ft (249.94 m) and provides a continuously sampled borehole to investigate the water resource potential of two critical water-bearing units (aquifers) within the Magothy and Potomac Formations. These are two of the primary aquifers in the New Jersey coastal plain in a belt that parallels the Delaware River from Monmouth through Salem Counties. These units are made up of clay-silt and interbedded sands deposited in riverine and nearshore paleoenvironments (Fig. F3) during the middle part of the Cretaceous, ~125–84 m.y. ago. Our understanding of the distribution of these clays and sands is critical for prediction of water resources and pollution remediation in the southern part of the state, but it is limited by lateral facies changes and poor sampling of the formations in both outcrop and discontinuously sampled water wells. Continuous geological samples obtained at Fort Mott provide new insights into the complex environments of deposition, especially in the Potomac Formation (e.g., Fig. F3), and their impact on the distribution of water resources.

F3. Facies models, p. 37.



Drilling and study of the Fort Mott borehole was a collaborative project: the NJGS provided scientific personnel and funds to drill the borehole; the DGS provided scientific personnel and downhole logging support; Rutgers, The State University of New Jersey, provided science personnel and logistical support; the U.S. Geological Survey (USGS) drilled the hole; and ODP provided publications support. The Fort Mott site is the most updip location drilled to date by this team. Recovery was good (78%), with 639 of 820 ft (194.77 of 249.94 m) recovered. A full suite of wireline logs was obtained to 800 ft (243.84 m). The on-site scientific team provided preliminary descriptions of sedimentary texture, structure, color, and fossil content and identified lithostratigraphic units, lithologic contacts, and sequences.

OPERATIONS

Drilling at Fort Mott State Park, New Jersey (75°33′07.175″N, 39°36′19.956″W; elevation = 3.79 ft [1.2 m]; Delaware City, Delaware, 7.5′ quadrangle, Salem County, New Jersey) began in early October 2001. Drilling operations were superintended by Gene Cobbs, USGS Eastern Earth Surface Processes Team; Gene Cobbs III was the driller. Space, water, and electricity were provided by the New Jersey Department of Parks at the Fort Mott State Park maintenance yard (courtesy of Fort Mott State Park Chief Ranger Patricia Cianflone). On 1 October, an onsite laboratory was established in a garage bay and P. Sugarman and J. Browning (Staff Scientist) moved equipment on site. A Kodak DC260 digital zoom camera (38.4–115.2 mm lens; 1536 × 1024 megapixel resolution), Power Macintosh 7200, and photography stand were set up to photograph 2-ft (0.61 m) core segments; default settings (including flash) with wide angle (38.4 mm) were used, yielding the truest colors and ensuring uniformity among photographs. On 2 October, the USGS team arrived on site and began rigging up, testing the water well on site, and connecting electrical hookups.

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

The first core was obtained on 3 October 2001 using a Christensen 94-mm (HQ) system, with a 4.5-in (11 cm) Christensen drill bit, creating a 2.5-in (6.4 cm) core diameter. For unconsolidated sands, an extended shoe was used to contact the sample 1.5–2.5 in (3.8–6.4 cm) ahead of the bit. A coal-rich fill was encountered in the upper 0.5 ft (0.15 m). Drilling was smooth through the surficial units on the first day. A gravel unit at 19–24 ft (5.79–7.32 m) was difficult to recover, and it destroyed the shoe. In all, 39 ft (11.89 m) was drilled with 24.7 ft (7.53 m) recovered (recovery = 63%).

On 4 October, 5-in (13 cm) polyvinyl chloride surface casing (to be removed after completion of the drilling) was set to 32 ft (9.75 m) into a tight clay. Drilling resumed promptly at 0930 hr. The first run (40–45 ft; 12.19–13.72 m) came up empty. Because it was possible that the core had slipped out of the rock shoe, the inner core barrel was placed back in the hole to try to retrieve it but nothing more was recovered. Run 10 (40–45.5 ft; 12.19–13.87 m) hit a hard layer that flared the shoe. Although 2.8 ft (0.85 m) was recovered between 40 and 45.5 ft (12.19 and 13.72 m), the top 2.1 ft (0.64 m) was drilling slurry and the bottom 0.7 ft (0.21 m) was clay mixed with drilling mud. An attempt to push the hard layer into the softer sediments resulted in no recovery on run 11 (45–50 ft; 13.72–15.24 m) and poor to moderate recovery (1.4 ft; 0.43 m) on run 12 (50–55 ft; 15.24–16.76 m). Recovery improved (4.0 ft; 1.22 m) on run 13 (55–60 ft; 16.76–18.29 m), but the cores still showed heavy scoring and intrusion of drilling mud and a new shoe was destroyed. It appeared that indurated material was blocking the hole and it was decided to pull the rods. A cobble was extracted from the hole along with 3.4 ft (1.04 m) of good core by jamming the drill string without a bit on its end over the cobble and pushing through the sediment below the cobble to trap it. The cobble is believed to have fallen into the hole during reaming and casing. This core was logged as run 15 (60–63.6 ft; 18.29–19.39 m). The day ended with 11.8 ft (3.60 m) recovered from 23.6 ft (7.19 m) drilled (40–63.6 ft; 12.19–19.39 m; recovery = 50%).

No major problems were encountered on 5 October, coring from 63.6 to 140 ft (19.39 to 42.67 m). Run 22 (120–130 ft; 36.58–39.62 m) was blocked by a chert pebble at 4.8 ft (1.46 m), and the lower 5.2 ft (1.58 m) was lost. For the day, we recovered 55.45 ft (16.90 m) from 76.4 ft run (23.29 m; recovery = 72.6%).

Coring was slowed by rain on the morning of 6 October. Moderate recovery in interbedded sand and clay (140–180 ft; 42.67–54.86 m) changed to excellent recovery in clays (180–200 ft; 54.86–60.96 m). The top 3 ft (0.91 m) of run 29 (170–180 ft; 51.82–54.86 m) was chewed up, with 6.6 ft (2.01 m) of solid core, whereas core 30 (180–190 ft; 54.86–

57.91 m) had 1 ft (0.92 m) of "chew" at top. The day ended with 45.9 ft (13.99 m) recovered from 60 ft run (18.29 m; recovery = 76.5%).

Recovery on 7 October was excellent. We drilled from 200 to 245 ft (60.96 to 74.68 m), with 90% recovery (40.3 ft [12.28 m] recovered of 45 ft [13.72 m] drilled). Excellent recovery continued during the first 3 runs on 8 October (245–270 ft drilled; 25.15 ft recovered; 74.68–82.30 m drilled; 7.66 m recovered), but recovery dropped sharply on runs 40 and 41 (270–290 ft; 82.30–88.39 m). There were no obvious problems in run 40 (270–280 ft; 82.30–85.34 m), with 4.8 ft (1.46 m) of clay recovered. The core was lost from the barrel in the next coring run (280–290 ft; 85.34–88.39 m), but 3.1 ft (0.94 m) was recovered on 9 October by running the inner core barrel back in for the core. This core may represent material from anywhere between the bottom of the overlying recovered interval at 274.8 ft (83.76 m) and the bottom of this run at 290 ft (88.39 m), but its top is hung at 280 ft (85.34 m).

Coring continued on 9 October with a change from mottled clay to coarse sand and some gravel. Drilling was limited to 25 ft (7.62 m) for the day (19.45 ft [5.93 m]; recovery = 78%) because the inner core barrel became stuck ~100 ft (30.48 m) from the bottom of the hole. The core from run 44 (300–303.5 ft; 91.44–92.51 m) was intruded with drilling mud. The top 2 ft (0.61 m) of the core from run 45 (303.5–310 ft; 92.51–94.49 m) may be drilling slurry.

On 10 October we cored 50 ft (15.24 m) from 315 to 365 ft (96.01 to 111.25 m). Below 330 ft (100.58 m) the drillers added bentonite to the drilling mud to equalize the pressure inside and outside the core barrel. For all subsequent coring runs on this day, drilling was slightly faster to minimize drilling mud invasion into sands and extra care was taken to pump long enough to clear drilled sand from the hole. A hard bed was encountered during the drilling of the last core (run 53; 360–365 ft; 109.73–111.25 m), destroying a coring shoe. The day ended with 40.5 ft (12.34 m) recovered from 50 ft run (15.24 m; recovery = 81%). Pumping after each run to clean out sand, as well as increasing the mud weight, probably helped contribute to the excellent recovery in a sand-dominated interval.

Recovery on 11 October was excellent, although the dominant mottled clay lithology kept the drilling rate slow. The drillers had been using a modified shoe with long springs inside to help capture the core. Using the modified shoe allowed them to move the shoe back up inside of the bit, allowing the bit to cut faster. All of these modified shoes were expended and we were relegated to using a regular rock shoe. The rock shoe contacts the clay just behind the carbide cutters and in front of the diamonds, reducing the speed at which clay is cut. The lack of modified shoes resulted in slower drilling. Recovery was 100% for the day (45 ft [13.72 m] from 375 to 410 ft [114.3 to 124.97 m]).

On 12 October, clay gave way to sand and drilling speeds increased. Below 418 ft (127.41 m), the sand content increased in the core and drilling was much quicker to 474 ft (144.48 m). At 474 ft (144.48 m) the drillers encountered a lithified zone or large nodule in the hole, and they stopped the run after 5 ft (1.52 m) in a gray clay. The day ended with 59.2 ft (18.04 m) recovered from 65 ft run (21.33 m; recovery = 91%).

Coring in clay continued on 13 October from 475 to 530 ft (144.78 to 161.54 m), with 52.15 ft (15.90 m) recovered (95%). Coring was faster in the morning in gray, slightly micaceous silty clays, but slowed in the afternoon as we reencountered mottled red, green, and gray clays.

Drilling was suspended on 14 October as the drillers returned to Reston, Virginia, to get additional supplies. The rods were turned in the morning and in the evening to prevent binding in the hole. No problems were encountered on return from Reston and smooth coring resumed on 15 October. Drilling became easier on runs 73–74 (540–560 ft; 164.59–170.69 m) as we penetrated silts. Easy drilling continued, but recovery dropped in sands on runs 75–77 (560–590 ft; 170.69–179.83 m). The day ended at 590 ft (179.83 m) with 41.7 ft (12.71 m) recovered (69.5%).

On 16 October, run 78 (590–598 ft; 179.83–182.27 m) penetrated a harder zone at the top of the run and was stopped at a hard layer at 598 ft (182.27 m). Run 79 (598–605 ft; 182.27–184.40 m) recovered only 2 ft of sand and interbedded clay, whereas run 80 (605–610 ft; 184.40–185.93 m) became plugged with clay, blowing away the underlying sand. The interbedded sands and clays hindered recovery. Run 81 (610–616 ft; 185.93–187.76 m) slipped out of the core barrel. We went down with the 10-ft (3.05 m) barrel and drilled another 4 ft (1.22 m; 610–620 ft; 185.92–188.98 m), recovering 8.4 ft (2.56 m). The final run (620–630 ft; 188.98–192.02 m) obtained 8.1 ft (2.47 m). For the day, 26.9 ft (8.20 m) was recovered from 40 ft (12.19 m) drilled (recovery = 67.3%).

At the beginning of the day on October 17, runs 83–84 (630–650 ft; 192.02–198.12 m) penetrated silty sands. Drilling slowed near the end of run 84 at 644.1 ft (196.32 m) when we penetrated a very hard clayey silt. The drillers stopped the run after drilling 6.5 ft (1.98 m); only 4.7 ft (1.43 m) was recovered. The hard lithology continued in run 85, which was stopped after 4.5 ft (1.37 m) at 651 ft (198.42 m) with 6.0 ft (1.83 m) recovered. We believe the top 1.5 ft (0.46 m) of run 85 represents material from the bottom of run 84. Run 86 drilled very slowly, and the core catcher was destroyed during the run. Only 1.85 ft (0.56 m) of 9.0 ft (2.74 m) run was recovered (with the remainder probably still in the bottom of the hole, having slipped out of the core catcher). The same interval was re-run as run 86A, and an additional 1.2 ft (0.37 m) of core was recovered, likely from the bottom part of the run interval, making a total of 3.05 ft (0.93 m) recovered for this 9.0-ft (2.74 m) interval. For the day, 21.9 ft (6.68 m) was recovered from 30 ft (9.14 m) drilled (recovery = 73%).

On 18 October, drilling was slow with good recovery (>96.5%) as the mottled clays become harder. The drilling ended with 30 ft (9.14 m) drilled to 690 ft (210.31 m). The core was dropped on the last 10 ft (3.05 m) run, but completely recovered.

On 19 October, the rods were stuck in the hole because of swelling clays, so the mud was thinned and circulated until about 0900 hr. Drilling resumed with a 4-ft (1.22 m) run, with a recovery of 2.15 ft (0.66 m). The core was mangled (undercut) because the material was very hard. A 6-ft (1.83 m) run followed, and 6.1 ft (1.86 m) of core was recovered (693.9–700 ft; 211.50–213.36 m). The day finished with a 10-ft (3.05 m) run (700–710 ft; 213.36–216.41 m), from which 10.25 ft (3.12 m) was recovered. The drillers pulled the rods up 200 ft (60.96 m) at the end of the day to avoid the swelling clays that caused the rods to stick that morning. For the day, 16.5 ft (5.03 m) was recovered from 20 ft (6.10 m) drilled (recovery = 83%).

On 20 October, a first attempt to core 5 ft (710–715 ft; 216.41–217.93 m) yielded no recovery. A rock shoe was used in this interval, and the core likely slipped through the metal core catcher because of undercutting. After some modification of the catcher, drilling resumed for an additional 5 ft (1.52 m; 715–720 ft; 217.93–219.46 m), targeted at recovering the lost core (710–715 ft; 216.41–217.93 m) as well as the additional footage (715–720 ft; 217.93–219.46 m). On attempting to retrieve this interval, the core again slipped through the catcher. The core barrel was lowered, this time with a short snout shoe and plastic core catcher, and the interval was drilled again, finally recovering 2.9 ft (0.88 m) of the 10-ft (3.05 m) interval cored (recovery = 29%). The following coring run (720–725 ft; 219.46–220.98 m) went fairly smoothly and recovered 2.8 ft (0.85 m) of 5 ft (1.52 m) drilled (recovery = 56%). The interval from 725 to 730 ft (220.98 to 222.50 m) was very hard; 5.5 ft (1.68 m) of core was recovered of 5 ft (1.52 m) drilled (recovery = 110%), including the bottom of the previous coring run. The final core for the day, 730–740 ft (222.50–225.55 m), began with a hard interval and concluded with a softer interval at its base. Recovery was 9.2 ft (2.80 m). For the day, 20.4 ft (6.22 m) was recovered from 30 ft (9.14 m) drilled (recovery = 68%).

There was no drilling on Sunday, 21 October. Drilling resumed on 22 October. Approximately 50% of the first run (740–748 ft; 225.55–227.99 m) was recovered. Recovery improved to 84% on the next run (748–753.5 ft; 227.99–299.67 m); this core cut faster than the previous run. Recovery between 753.5 and 760 ft (299.56 and 231.65 m) was 5.15 ft (1.57 m; recovery = 79%); the last 0.5 ft (0.15 m) was very hard. Recovery from 760 to 765 ft (231.65 to 233.17 m) was perfect. The last 0.7 ft (0.21 m) was much harder, resulting in a new shoe being fitted for the next run. The day concluded with a 10-ft (3.05 m) run from 765 to 775 ft (233.17 to 236.22 m) and 75% recovery (7.5 ft; 2.29 m). For the day, 26.35 ft (8.03 m) of core was recovered from 35 ft (10.67 m) drilled (recovery = 75%).

The final day of coring was 23 October, as we reached our target depth of 800 ft (243.84 m). The first run of the day had no recovery from 775 to 780 ft (236.22 to 237.74 m). When the core barrel was retrieved, we discovered that the core catcher was inside out. The next run (780–785 ft; 237.74–239.27 m) recovered 5.1 ft (1.55 m) of core, (recovery = 102%). Run 105 (785–795 ft; 239.27–242.32 m) recovered 7.7 ft (2.35 m). Another 10-ft (3.05 m) run (795–805 ft; 242.32–246.36 m) was attempted as penetration was easy, but only 4.5 ft (1.37 m) was recovered. The next 5-ft (1.52 m) section was drilled from 805 to 810 ft (245.36 to 246.89 m), with 5.2 ft (1.58 m) recovered. The run was stopped at 5 ft (1.52 m) to switch back to a hard rock shoe for the next run. The final core run (810–820 ft; 246.89–249.94 m) recovered 4 ft (1.22 m) of core. Drilling was easy, and basement saprolite or rock was never encountered.

At Fort Mott, we recovered 638.85 ft (194.7 m) from a total hole of 820 ft (249.9 m); mean recovery was 78% for the 820 ft (249.9 m) cored. Lithologies were described on site and subsequently at the Rutgers core facility; these descriptions form the basis for the preliminary lithologic descriptions. Samples were obtained at ~5-ft (1.52 m) intervals for biostratigraphic and coarse-fraction lithologic studies. Cores were cut into 2-ft (0.61 m) sections, labeled at top and bottom of each section, placed into split PVC pipe (3-in [7.6 cm] diameter), wrapped in plastic sheeting, and stored in 2-ft (0.61 m) wax boxes. A total of 119 core boxes were moved to permanent storage at the Rutgers University core library for further study.

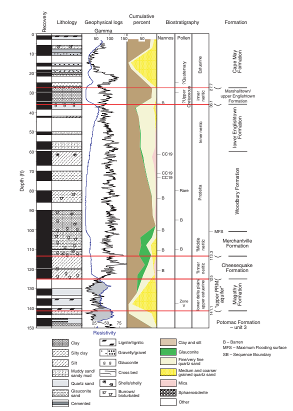
LITHOSTRATIGRAPHY

Summary

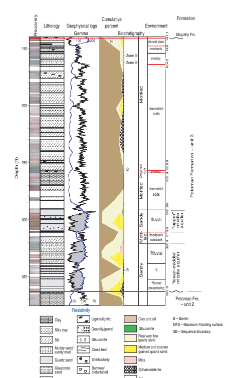
The on-site scientific team provided preliminary descriptions of sedimentary texture, structure, color, fossil content, identification of lithostratigraphic units (NJGS Information Circular 1, 1990), and lithologic contacts (Table T1; Figs. F4, F5, F6, F7). Subsequent studies integrated preliminary descriptions with additional descriptions, biostratigraphy (nannoplankton and pollen), and the gamma ray log. Unconformities were identified on the basis of physical stratigraphy, including irregular contacts, reworking, bioturbation, major facies changes, gamma ray peaks, and paraconformities inferred from biostratigraphic breaks. For the nonmarine and nearshore sections in the Potomac and Magothy Formations, lithofacies interpretations provide the primary means of recognizing unconformities and interpreting paleoenvironments; this information is supplemented by palynostratigraphy.

Cumulative percent plots of the sediments in the cores were computed from washed samples. Each sample was dried and weighed before washing, and the dry weight was used to compute the percentage of sand. This differs from the method used in previous New Jersey coastal plain cores (Bass River, Island Beach, Atlantic City, and Cape May), in which the samples were not dried before washing.

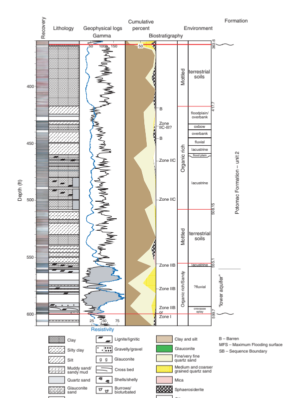
T1. Core descriptions, Fort Mott borehole, p. 43.



F4. Stratigraphy for various formations, p. 39.



F5. Stratigraphy for Potomac Unit 3, p. 40.



F6. Stratigraphy for Potomac Unit 2, p. 41.

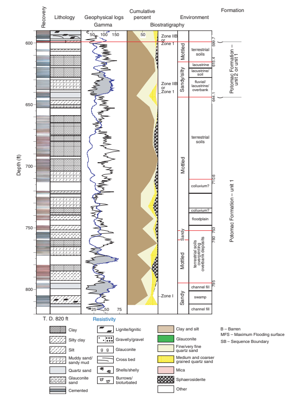
Facies Model

New Jersey coastal plain strata were deposited on the trailing edge of a passively subsiding continental margin (e.g., Grow and Sheridan, 1988). Thermoflexural subsidence and sediment loading along a hinged margin has dominated the creation of accommodation space (e.g., Kominz et al., 1998). The depositional environment of the Lower Cretaceous to basal Upper Cretaceous (Barremian–lowermost Cenomanian) Potomac Formation was predominantly terrestrial, whereas the Upper Cretaceous to Miocene was primarily marine. Previous studies have interpreted the sediments of the Potomac Formation as having been deposited in a nearshore delta plain or coastal plain setting, and this deltaic influence continued into the marine sediments of the Late Cretaceous and Miocene (Owens et al., 1970).

Potomac Formation sediments in the Fort Mott borehole and elsewhere are predominantly fine grained (clays, silty clays, and clayey silts), with a few critical sand bodies. The finer-grained units are in many intervals heavily overprinted by soil-forming processes. These range from light blue and gray gleyed soils indicating soil formation in reduced conditions to dark red (lateritic?) soils indicating oxidized conditions. These silty clays and clayey silts were probably deposited as heavily vegetated overbank deposits. Variations in color and downhole logs (Figs. F4, F5, F6, F7) are found on the 2- to 3-ft (60–90 cm) and 10-ft (3 m) scales; these cycles appear to reflect differences in evaporation and precipitation with red oxidized sediments (high gamma log values) alternating with gray or gleyed reduced sediments (low gamma log values). This cyclicity not only reflects regional climate changes, its regularity implies a global imprint on climate and precipitation (e.g., Milankovitch periodicities).

Owens et al. (1970) interpreted the facies of the Potomac Formation as being deposited in a delta plain and delta front. His facies model for the Potomac Formation interpreted sand facies as fluvial-dominated delta front deposits (Fig. F3B). We consider that the Potomac Formation was deltaically influenced but also propose that the depositional environment encompasses elements of an anastomosing river environment, (Fig. F3A) corresponding well with much of the observed Potomac facies (Figs. F3A, F5, F6, F7).

F7. Stratigraphy for Potomac Units 2 and 1, p. 42.



Anastomosed systems are streams that are divided into multiple coexistent channels that have stable islands or bars separating the channels (Smith and Smith, 1980). Bar stability is provided by either vegetation or fine-grained sediments or both working together (Makaske, 2001). Anastomosed systems differ from braided systems in that the channel and bar stability in the anastomosed system prevents the river from reworking sediments and organic-rich sediments. As a result, anastomosed systems are dominated by fine floodplain deposits and organic-rich sediments or coals. Channel sands in the anastomosed system are generally more confined and tend to aggrade (Makaske, 2001). Anastomosing rivers are believed to form by avulsion splitting the primary flow into two or more channels. Avulsion is facilitated by a low-gradient floodplain and by rapidly elevating baselevel control downstream (Smith and Smith, 1980). Rapid sea level rise in the Holocene is considered a factor in elevating base level, leading to anastomosis (Makaske, 2001), and such a model may be applicable to the mid-Cretaceous at Fort Mott. Because anastomosing rivers are aggradational features, their chances for preservation are good.

Major environments and sedimentary facies for the anastomosing river system were described by Smith and Smith (1980), and we follow their classification (Fig. F3A). Two major environments are found in an anastomosed system. The channel facies consists of gravel and coarse sand (Fig. F3A). In contrast, fine-grained overbank deposits compose the majority of the sediments (Fig. F3A). Levees flanking the rivers consist of sandy silt and silty sand containing roots. Low areas between levees have lakes and peat bogs or back swamps; they are differentiated based upon the frequency with which they receive water and their connection to the main channels. Lakes are intermittently supplied with fine sediment including laminated clay and silty clay with sparse organic matter. Peat bogs and back swamps have no direct connection to the main channels and may receive clastic sediments only during times of flood. Sediments are organic-rich (up to 98% organic matter) silty clay and clayey silt. Finally, crevasse splays are recognized as thin layers of sand and fine gravel rarely more than 40 cm thick (Smith and Smith, 1980).

An outstanding question is the extent to which the anastomosing environment includes the upper delta plain environments. Many modern workers now consider the channels in a deltaic environment to be fundamentally similar to anastomosing channels in a continental setting (see Makaske, 2001, for discussion). Thus, the contrast with the deltaic model outlined by Owens et al. (1970) is minor except for the interpretation of the sand bodies.

The anastomosing model (Fig. F3A) does not adequately explain the thick sand bodies at the base of the Potomac Formation Units 3 and 2 (290.65–363.6 ft [88.59–110.83 m] and 555.1–599.7 ft [169.19–182.79 m], respectively). These sand bodies appear to be laterally continuous and may extend from New Jersey into Delaware. They can be traced on gamma logs within New Jersey a distance of 24 mi (40 km). Such widespread sand sheets are difficult to explain using the anastomosing stream model. The thick widespread nature of sands at the base of Potomac Unit 3 have the geometry of a delta front shoreline sand, although no direct marine evidence has been uncovered within them. If this interpretation is correct, then at least for Potomac Unit 3 the sediments may represent a transgressive–regressive cycle, with delta front sands (Fig. F3B) being prograded over by an anastomosed river system or delta plain deposits, including lower delta plain interdistributary lakes, marshes and swamps, and upper delta plain deeply weathered soils.

Cape May Formation

Interval: 1.5–27.7 ft (0.46–8.44 m)
Age: ?middle–late Pleistocene–?Holocene

Below a fill typified by coal (1.0–1.5 ft; 0.30–0.45 m), fine–medium laminated silty quartz sand (1.5–2.1 ft; 0.45–0.64 m) and heavily burrowed sandy silt (6.0–7.85 ft; 1.83–2.39 m) were deposited in estuarine environments (Fig. F4) similar to the adjacent Delaware River estuary. Fine sands with interbedded silty clays appear from 7.85 to 8.7 ft (2.39 to 2.65 m) and overlie a gravelly sand (9.9–11.1 ft; 3.02–3.38 m) that coarsens downsection to gravel (16.2–16.4 ft; 4.93–5.00 m). This pattern of gravel grading up to sand repeats at 16.4–19.6 ft (5.00–5.97 m) based on the gamma log and is interpreted as channels in an estuary. A soft twisted clay (20–20.9 ft; 6.10–6.37 m), reflecting some coring disturbance, overlies orange-colored slightly sandy silt (20.9–21.4 ft; 6.37–6.52 m), returning to gray silty clay (21.4–21.6 ft; 6.52–6.58 m). Silty clay (25.0–26.4 ft; 7.62–8.05 m) grades down to silty, slightly clayey, micaceous laminated sand that becomes coarser downsection from 26.95 to 27.7 ft (8.21 to 8.44 m) to a gravel channel fill at 27.5–27.7 ft (8.38–8.44 m). A sharp contact at 27.7 ft (8.44 m) separates the gravel from laminated silty clay of the Cretaceous below.

The complex juxtaposition of channel gravels, cross-bedded to laminated sands, sandy silts, and burrowed clays is typical of estuarine environments. The burrowed clays, silts, sands, and gravels between 1.5 and 27.7 ft (0.46 and 8.44 m) at Fort Mott, New Jersey, are interpreted as highstand "Delaware Bay" deposits. In New Jersey, these sediments are generally assigned to the Cape May Formation (Newell et al., 2000). Across the Delaware River, this unit would be assigned to the Lynch Heights or Scotts Corner Formation (Ramsey, 1993).

Marshalltown?/Upper Englishtown? Formation

Interval: 27.7–36.1 ft (8.44–11.00 m)
Age: Campanian

A major lithologic change appears at an erosional surface at 27.7 ft (8.44 m), separating poorly sorted sands above (the Pleistocene–Holocene? Cape May Formation) from silty, micaceous, laminated Cretaceous clays below (Fig. F4). Clays from 27.7 to 32 ft (8.44 to 9.75 m) are weathered to a light gray from the typical dark greenish clays below 32 ft (9.75 m); they are slightly siltier in the top 0.5 ft (0.15 m). The color difference appears to be because of subaerial exposure of these marine clays. The clays continue to 35.9 ft (10.94 m), contain rare pyrite and flakes of plant debris, display faint silty laminae, are slightly micaceous, and are burrowed with 2- to 10-mm-diameter sand-filled burrows. The clays are siltier and slightly sandier near the base. A thin glauconite sand (35.9–36.1 ft; 10.94–11.00 m) is mixed with silty clay and concretions.

A distinct contact at 36.1 ft (11.00 m) separates glauconite sand above from quartz sand below and is interpreted as a prominent Upper Cretaceous sequence boundary separating a glauconitic clay from silty upper HST sand. The section from 27.1 to 36.1 ft (8.26 to 11.00 m) appears to represent a distinct sequence (Figs. **F2, F4**). It overlies sands assigned to the Englishtown Formation and clays assigned to the Woodbury Formation below, and thus could be the equivalent of the lower clayier facies of the "upper" Englishtown Formation, or a clayey, less glauconitic facies of the Marshalltown Formation.

Englishtown Formation

Interval: 36.1–60 ft (11.00–18.29 m)
Age: Campanian

Micaceous, clayey-silty fine to medium quartz sand with plant debris (36.1–38.7 ft; 11.00–11.80 m) composes the HST of a sequence that is assigned to the lower Englishtown Formation. Burrowed, micaceous, very silty sands to sandy silts (upper HST; 50–60 ft; 15.24–18.29 m) appear below an interval of poor recovery (38.7–50.0 ft; 11.80–15.24 m). These finer-grained sediments reflect a downward-fining succession. The boundary with the underlying Woodbury Formation is tentatively placed at the downhole appearance of >50% silt and clay (Fig. **F4**) at ~60 ft (18.29 m), although this contact is admittedly gradational and could be placed slightly higher upsection.

Woodbury Formation

Interval: 60–100.7ft (18.29–30.69 m)
Age: Campanian

Micaceous silts and clays with sand laminae below 60 ft (18.29 m) are tentatively assigned to the Woodbury Formation, although previous mapping suggested that the Woodbury pinches out along strike north of Fort Mott (Owens et al., 1970). Silts and clays that we assign to the Woodbury Formation at Fort Mott may be equivalent to a finer-grained facies of the Englishtown Formation (Owens et al., 1970) (Fig. **F4**); this facies has been previously assigned to the Merchantville Formation in New Jersey at outcrop (Owens et al., 1970) (Fig. **F4**) and Delaware (Benson and Spoljaric, 1996). The assignment of this unit at Fort Mott to Zone CC19 (Fig. **F4**) agrees with correlations to the Woodbury sequence (Miller et al., 2004).

A trace of shells appears in the very micaceous, slightly clayey silts with burrowed sand laminae, between 60 and 63.6 ft (18.29 and 19.39 m). The sediments continue to fine downsection, with very clayey silts with scattered sand laminae (70–90 ft; 21.34–27.43 m) to predominantly silty clay with fewer sand laminae (below 90 ft; 27.43 m) and a trace of shell material; the mica also becomes finer grained downsection. The sediments are highly bioturbated, with burrows filled with very fine sand. Traces of glauconite appear at 94 ft (28.65 m) and become common (2%–5% of the core) below 99 ft (30.18 m). Glauconite sand increases at 100.7 ft (30.69 m), where there is concentration of gypsum on the core surface (100.5–100.6 ft; 30.63–30.66 m), an ammonite? fragment (100.7 ft; 30.69 m), and a minor gamma ray peak (Fig. **F4**); the contact with the underlying Merchantville Formation is gradational and a maximum flooding surface (MFS) is placed at this point.

The Woodbury Formation at Fort Mott was deposited in a prodelta environment. Calcareous nannoplankton Zone CC19 (Campanian) was identified from the Woodbury Formation at 61.5, 71.1, and 73.6 ft (18.8, 21.67, and 22.43 m; see **"Biostratigraphy,"** p. 28).

Merchantville Formation

Interval: 100.7–113.3 ft (30.69–34.53 m)
Age: Campanian [Santonian?]

The Merchantville Formation in the Fort Mott borehole is mainly a glauconitic, slightly quartzose silt to glauconite silty clay to glauconite-quartzose silty sand (Fig. **F4**). The section from 100.7 to 108 ft (30.69 to 32.92 m) consists of glauconitic-rich clay layers interbedded with less glauconitic clay. The unit is heavily burrowed with prominent large clay-lined burrows. Between 100.7 and 105 ft (30.69 and 32.00 m), large (5 mm–5 cm) indurated brown clay burrows/clay blebs (weathered shell material?) yield a mottled brown-green aspect to the core; less common, smaller brown burrows are found from 105 to 108 ft (32.00 to 32.92 m), and scattered, small brown burrows continue below this. Below 104.0 ft (31.70 m), the section consists of glauconitic, quartzose, very silty, slightly clayey sand with sandy burrow fills that continues to 113.3 ft (34.53 m); the section is heavily burrowed and has less glauconite, less clay, and fewer brown clay burrows than above. This suggests a general transgression from 104 to 113.3 ft (31.70 to 34.53 m), a condensed section from 104 to 100.7 ft (31.70 to 30.69 m), and an MFS at 100.7 ft (30.69 m). The Merchantville Formation at Fort Mott was deposited in neritic (middle?) environments. No age-diagnostic nannofossils or pollen were identified.

Cheesequake Formation

Interval: 113.3–125 ft (34.53–38.10 m)
Age: ?Campanian or ?Santonian

At 113.3 ft (34.53 m), there is a shift from glauconitic silt/silty sand above to glauconite-free silt below (Fig. **F4**). Glauconite is burrowed down to 114.25 ft (34.82 m), and it was difficult to pick out a distinct contact until the core was split. This silt is assigned to the Cheesequake Formation of Litwin et al. (1993) based on lithologic similarity and stratigraphic position between the Merchantville and Magothy Formations. The Cheesequake Formation consists of a single sequence containing a very micaceous, highly bioturbated "blue" silt; traces of glauconite appear downsection at 118.5 ft (36.12 m) and increase downsection to a highly burrowed, slightly glauconitic silt with clay-lined burrows at the base. Small granules and pebbles on the outside of the core appear to be washed downhole except for pebbles at the base of the succession below 119 ft (36.27 m). These pebbles were probably reworked from the Magothy Formation. (A shark tooth was found at 121.6 ft; 37.06 m.) The Cheesequake Formation at Fort Mott was deposited in neritic (inner–middle?) environments. It composes a truncated sequence with a thin (<5 ft; 1.52 m) TST consisting of glauconitic silt and a thicker (>7 ft; 2.13 m) lower HST consisting of silt; upper HST sands are absent at Fort Mott. In this region sands reported from the "lower Merchantville Formation" near Camden (Farlekas et al., 1976) are considered HST deposits. A chert pebble that blocked the core barrel at 124.8 ft (38.04 m) may mark the contact with the underlying Magothy Formation.

Magothy Formation

Interval: 125–141.1 ft (38.10–43.01 m)
Age: Coniacian/Turonian?

The Magothy Formation was first encountered at 130 ft (39.62 m) below a coring gap (124.8–130 ft; 38.04–39.62 m), where it consists of moderately well sorted, lignitic, medium quartz sand. We place the contact at 125 ft (38.10 m) based on the gamma and resistivity log signature (Fig. F4) that indicates sands below ~125 ft (38.10 m). Sands are broken by a thin gray clay (136.0–137.0 ft; 41.45–41.76 m) with thin sand interbeds and lignite beds (136.1–136.3 and 136.8–136.85 ft; 41.48–41.54 and 41.70–41.71 m). A pyrite nodule is present at 136.7 ft (41.67 m). Sands similar to above recur at 137.0–137.3 ft (41.76–41.85 m), with a dark gray clay layer from 137.3 to 137.9 ft (41.85 to 42.03 m), switching back to sands from 137.9 to 138.2 ft (42.03 to 42.12 m), a clay from 138.2 to 138.4 ft (42.12 to 42.18 m), a coring gap from 138.4 to 140 ft (42.18 to 42.67 m), interlaminated lignitic clay and fine–medium sand from 140 to 140.9 ft (42.67 to 42.95 m), and a granular medium–very coarse sand bed (140.9–141.1 ft; 42.95–43.01 m) with lignitic chunks at a distinct contact at 141.1 ft (43.01 m).

The very thin Magothy Formation (16.1 ft; 4.91 m) here appears to compose one sequence (Magothy II) (Miller et al., 2004) deposited in fluvial (lower delta plain?) or upper estuarine environments. The Raritan Formation and its downdip equivalent, the Bass River Formation, are cut out at Fort Mott, with the Magothy Formation directly overlying the Potomac Formation. The Magothy Formation at Fort Mott is assigned to pollen Zone V of Christopher (1982), which is generally correlated with the upper Turonian–Santonian; the absence of stratigraphically higher advanced Normapolles suggests late Turonian.

Potomac Formation

Interval: 141.1–820 ft (43.01–249.94 m)
Age: earliest Cenomanian to Aptian (possibly Barremian)

The Potomac Formation can be lithostratigraphically subdivided into at least three distinct units based on successions of medium to fine quartz sands overlain by fine-grained units (clay and silty clay). The highest, Potomac Unit 3, is well defined at its base (363.6 ft; 110.83 m) by the contact of the "middle aquifer" sands with an underlying confining unit (Figs. F2, F5). The base of the middle unit, Potomac Unit 2, could be placed at the base of the "lower aquifer" (599.7 ft; 182.79 m) or slightly lower at the base of an unnamed sand (644.1 ft; 196.32 m). The lowest, Potomac Unit 1, also has a medium to fine quartz sand that represents the lowest section recovered at Fort Mott.

The Potomac Formation elsewhere in the Atlantic coastal plain is biostratigraphically subdivided using palynology into Zone I (?Barremian–Aptian), Zone II (Albian), and Zone III (Albian–lower Cenomanian). At Fort Mott, there is a general correspondence of the lithostratigraphic zones defined in this study to the biostratigraphic zones of the same number. The possible exception is the placement of the base of Unit 2 and with respect to the base of Zone II. The base of lithostratigraphic Unit 2 is most readily placed using lithostratigraphic criteria at the base of the distinct "lower aquifer" sands (599.7 ft; 182.79 m). However, pollen suggestive of Subzone IIB (see **"Pollen,"** p. 28, in "Biostratigraphy") is found below the "lower aquifer" sands to 641.1 ft (195.41 m). Based on this pollen evidence, the boundary between Units 1 and 2 is placed at a lithologic break at 644.1 ft (196.32 m), where the lithology shifts from sandy overbank deposits above to paleosols below.

Potomac Formation—Unit 3

Interval: 141.1–363.6 ft (43.01–110.83 m)
Age: early Cenomanian (possibly late Albian)

The top of the Potomac Formation was placed at 141.1 ft (43.01 m) at an abrupt contact between gray granular lignitic sands of the Magothy Formation and underlying very fine to fine, silty, slightly micaceous sands. There is little evidence of reworking at the contact, although the basal Magothy sands appear to be a lag deposit and irregular laminations in the basal Magothy Formation appear to result from bioturbation. The contact shows a minor increase in gamma log values at 141 ft (42.98 m), with the largest increase present at ~148 ft (45.11 m) (Fig. **F5**). At Fort Mott, clays and silty clays with subordinate silts, clayey silts, and very fine sands dominate the Potomac Formation. The clays are generally gray with red mottling. The general environment of deposition is interpreted as an anastomosing river system (Fig. **F3A**) with various subenvironments represented, including levee, lake, swamp, crevasse splay, and fluvial channel deposits (in order of decreasing abundance). The thicker sand deposits may also have formed in a delta front environment; based on their thickness (~60 ft or 18.29 m) and lateral extent (over 24 mi or 40 km), these deposits may represent distributary-mouth bar deposits. If this interpretation is correct, the overall facies model may be reinterpreted as fluvial-deltaic environments, with delta front deposits underlying lower and upper delta plain deposits (Fig. **F3B**).

The top of the Potomac Formation at Fort Mott consists of laminated sands (141.1–148 ft; 43.01–45.11 m). The section from 141.1 to 141.4 ft (43.01 to 43.10 m) consists of whitish tan, very fine grained, slightly micaceous, laminated sand, whereas the section between 141.4 and 141.6 ft (43.10 and 43.16 m) consists of interlaminated clayey silty red and white laminated sands. Laminated fine sands from 141.6 to 143.3 ft (43.16 to 43.68 m) are slightly coarser and cleaner than above, with clay rip-up clasts appearing at 143.0–143.3 ft (43.59–43.68 m). Whitish tan, very fine grained, slightly micaceous, laminated sands (145.0–148.0 ft; 44.20–45.11 m) return below a coring gap (143.3–145.0 ft; 43.68–44.20 m), with thin reddish clay laminae (145–146 ft; 44.20–44.50 m) and cross-bedded laminae in rusty sand (146–146.3 ft; 44.50–44.58 m); below 145.6 ft (44.38 m), the sand becomes slightly siltier and sphaerosiderite nodules appear, perhaps reworked from below. From 146.3 to 147.5 ft (44.58 to 44.96 m), the section consists of tan, reddish, and gray sand that has an increasing abundance of sphaerosiderite nodules downsection to 147.8 ft (45.05 m); the sphaerosiderite nodules are fused into larger concretions at 147.4 ft (44.93 m). From 147.8 to 148.0 ft (45.05 to 45.11 m), sphaerosiderite nodules decrease and clay increases down to a clay layer at 148.0 ft. This contact has small concretions, thin bands of rusty stain, and is associated with a major gamma ray decrease upsection (Fig. **F5**).

The sequence and environmental significance of these laminated sands is unclear: (1) it is unclear if this sand is a local overbank environment (e.g., crevasse splay), a local fluvial meandering sand, or a regionally significant sand; and (2) although the sands are bracketed by abrupt erosional contacts, the lower surface may be a local erosional feature of a fluvial/alluvial plain environment, whereas the upper surface is clearly the contact with the Magothy Formation and has regional significance. The interval at 125–148 ft (38.10–45.11 m) is correlative with the upper aquifer within the PRM aquifer system (Fig. F2). This aquifer, a major water producer to the north–northeast in Salem and Gloucester Counties, is a minor aquifer here, as well as to the south. For example, wells at Fort Mott and adjacent Finns Point are screened in the aquifer below (291.4–310.6 ft; 88.82–94.67 m), within the Potomac Formation (middle aquifer of the PRM aquifer system).

Slightly silty clay with hard concretions present from 148 to 149 ft (45.11 to 45.42 m), and 150 to 153 ft (45.72 to 46.63 m) is mostly light gray with mottling of greenish gray and dusky red. A gray clay (153–153.5 ft; 46.63–46.79 m) and very fine sand with orange mottling (153.5–154.3 ft; 46.79–47.03 m) overlie a thicker interval of interlaminated silty clay and very fine sand with scattered cross laminations (154.3–164.2 ft; 47.03–50.05 m) and indications of deformed laminae (soft sediment deformation?) (155–158 ft; 47.24–48.16 m). The section at 157–158 ft (47.85–48.16 m) is darker gray than above or below with scattered lignite and may be more organic rich. The mottled clays and interlaminated clay-sands were deposited in subaerial overbank and subaqueous overbank (e.g., swamp) environments, respectively.

A thick interval of interfluvial mottled clay paleosols appears below the interlaminated clay and sand. Whitish gray to light gray silty clay with clayey silt laminae and red mottles are present from 164.2 to 256.8 ft (50.05 to 78.27 m). The silty clay contains dusky red zones with concretions (172.6, 173.5, and 175.0 ft; 52.61, 52.88, and 53.34 m), which include features resembling root traces and drab halos around root traces (164–172.6 ft; 49.99–52.61 m; spanning a coring gap from 167–170 ft; 50.9–51.82 m). From 180 to 182 ft (54.86 to 55.47 m), the light gray silty clay contains thin olive and red bands and sphaerosiderite nodules with reddish rinds (?hematite). From 182 to 195.7 ft (55.47 to 52.61 m), the whitish gray silty clay is banded with hematitic red silty clays with sphaerosiderite nodules and a few root traces (190–191, 192.5–193.5, and 195–195.3 ft; 57.91–58.22, 58.67–58.98, and 59.44–59.53 m). The section at 195.7–197.7 ft (59.65–60.26 m) is a mostly red and olive-brown mottled silty clay, whereas that at 197.7–200.2 ft (60.26–61.02 m) is a banded light gray and olive-gray silty clay. Mottled red and gray very fine sandy silt with sphaerosiderite nodules with reddish rinds (201.8–203 ft; 61.51–61.87 m) breaks an otherwise monotonous series of clays. The interval from 203.8 to 215.2 ft (62.12 to 65.59 m) is a banded to mottled red (orange and dusky) and white silty clay with sphaerosiderite nodules. Red silty clay with thin whitish bands (215.3–217.2, 219.4–220.0, and 223–223.7 ft; 65.62–66.20, 66.87–67.06, and 67.97–68.18 m) alternate with the banded to mottled red (orange and dusky) and white silty clay with sphaerosiderite nodules. At 223.7 ft (68.18 m), there is a surface overlying intensely mottled whitish silty clay that shows signs of breccia-like fabric (223.7–225.6 ft; 68.18–68.76 m). Red and white mottled silty clays that persist from 225.6 to 248.2 ft (68.76 to 75.65 m) can be split into more intensively mottled redder intervals (227.0–230.3, 234.0–236.5, and 247.7–248.2 ft; 69.19–70.20, 71.32–72.09, and 75.50–75.65 m), whiter intervals with sphaerosiderite nodules (230.3–234 and 241.5–245.5 ft; 70.20–71.32 and 73.61–74.83 m), and mottled gray and red intervals (236.5–241.5 and 245.5–247.7 ft; 72.09–73.61 and 74.83–75.50 m). A contact at 248.2 ft (75.65 m) separates red clay from brown, white, and red mottled silty clay where the mottles extend over 0.5 ft (0.15 m; 248.2–250.2 ft; 75.65–76.26 m). There is transition from 250.2 to 256.8 ft (76.26 to 78.27 m) that changes downsection from alternating light gray and olive-gray mottled silty clay with sphaerosiderite nodules to darker gray silty clay (254–256.0 ft; 77.42–78.03 m) to organic-rich (lignitic) clayey silt (256.0–256.8 ft; 78.03–78.27 m) to a contact at 256.8 ft (78.27 m). This darkening downsection reflects a change in environmental oxidation from mottled paleosols above to swampy subaqueous environments below.

A thin break of very fine to fine sandy clayey silt with common lignite and disseminated pyrite (256.8–259.9 ft; 78.27–79.22 m) underlies the paleosols and overlies an erosional contact with another interval of paleosols at 259.9 ft (79.22 m). Rusty mottling at 258.0–259.0 ft (78.64–78.94 m) and rare reddish clay mottles at 259.3 ft (79.03 m) document incipient soil formation in this predominantly subaqueous environment. Otherwise, the section from 259 to 259.9 ft (78.94 to 79.22 m) is gray with abundant charcoal (the charcoal may document dry season forest fires). There are granules at the irregular contact at 259.9 ft (79.22 m). This section represents deposition in a swampy floodplain environment and a possible rise/fall of baselevel.

Mottled paleosol clays return from 259.9 to 274.8 ft (79.22 to 83.76 m). From 259.9 to 262 ft (79.22 to 79.86 m), oxidized sediments reappear, characterized by predominantly light gray to light olive-tan silty clay with minor red mottling and sphaerosiderite nodules with hematite rinds. The interval at 262–265 ft (79.86–80.77 m) is predominantly red mottled silty clay with light gray to light olive-tan mottles, decreasing sphaerosiderite nodules, and increasing dusky red mottling downsection. From 265 to 270 ft (80.77 to 82.30 m), the lithology returns to light gray to light olive-tan clay with common dusky red mottles, whereas that at 270–274.8 ft (82.30–83.76 m) returns to red silty clay with extensive light gray to light olive mottles. The mottles cross cut, suggesting multiple generations of formation; some follow cracks whereas other halos are probably root traces. This lithology continues from 280 to 280.8 ft (85.34 to 85.59 m) below a coring gap (274.8–280 ft; 83.76–85.34 m). The section from 280.8 to 281 ft (85.59 to 85.65 m) is a light gray silty clay, whereas that at 281–283.3 ft (85.65–86.35 m) is medium gray silty clay with reddish mottles near the bottom. The section below 282.8 ft (86.20 m) is a slightly sandy clay. Below a coring gap (283.3–290 ft; 86.35–88.39 m) are gray silts with very fine to fine sand and common sphaerosiderite nodules with hematite rinds (290–290.65 ft; 88.39–88.59 m) that overlie a distinctive bright red slightly sandy clayey silt (290.65–290.95 ft; 88.59–88.68 m). The clays from 259.9 to 290.95 (79.22 to 88.68 m) represent terrestrial soils developed on an overbank.

A shift in sediment type to a predominantly sand section with a few mud breaks characterizes the core from 290.65 to 363.6 ft (88.59 to 110.83 m). Sands and silty sands are present from 290.65 to 296.7 ft (88.59 to 90.43 m). These whitish, very fine "sugar" sands include siltier zones (290.95–291.1 and 293.6–293.7 ft; 88.68–88.73 and 89.49–89.52 m), with silt lamina, mica, disseminated sphaerosiderite nodules, and opaque heavy mineral laminae common throughout. The sands at 293.65–296.7 ft (89.50–90.43 m) are fine–medium grained, have less silt, are laminated to cross laminated in places (including opaque mineral lamination), and are slightly brownish (because of intrusion of drilling mud). A very coarse sand with gravel appears below a sharp contact at 296.7 ft (90.43 m). The gravel is coarsest from 297.0 to 297.3 ft (90.53 to 90.62 m), with grains up to 1 cm in diameter. The change from this gravelly sand to progressively finer clasts up to 290 ft (88.39 m) appears to represent a fining-upward fluvial succession. This gravelly sand is underlain by a structureless medium to coarse quartz sand at 297.3–298.5 ft (90.62–90.98 m).

The underlying section consists of several fining-upward fluvial successions from pebbly granule beds to fine–medium sands: 300–300.4, 300.4–302.5, 302.5–306.7, and 306.7–310.6 ft (91.44–91.56, 91.56–92.20, 92.20–93.48, and 93.48–94.67 m). Opaque black mineral laminae are present in the sands. It is not clear if these sands are meandering, anastomosing, or delta front; the repetitive reasonably thick (2–4 ft; 0.61–1.22 m) successions of granules to fine sand with inclined laminations indicative of trough cross beds may have been deposited in anastomosing (or possibly meandering) environments. The base of the sand–granule succession is at 310.6 ft (94.67 m) where clays return.

The sand from 290.65 to 310.6 ft (88.59 to 94.67 m) composes an aquifer screened at nearby Finns Point. This is the “upper sand” of the middle aquifer of the PRM aquifer system; this “upper middle” sand can be identified at Artificial Island near Salem, New Jersey (well 33–401; 10 mi [16 km] to the south) (Cauller et al., 1999), at Clayton, New Jersey (24 mi [40 km] to the east) (Owens et al., 1998), and Delaware City, Delaware (3 mi [5 km] to the southwest) (Benson and McLaughlin, 2001; McLaughlin and Benson, 2002) and is thus laterally persistent. It is absent at New Castle, Delaware (3 mi [5 km] to the north) (Benson and McLaughlin, 2001; McLaughlin and Benson, 2002). This lateral persistence suggests that the sands may be part of a larger deltaic system and possibly a delta front sand.

From 310.6 to 320.3 ft (94.67 to 97.63 m), the core consists of micaceous clayey silts characterized by an alternation between light bluish gray, gray with purple mottles (including banding and halos around root traces), and gray with red clayey mottles. The environment is interpreted as floodplain/overbank altered by soil-formation processes. The micaceous silts probably reflect provenance, with a source from the nearby Piedmont.

The section recovered from 320.4 to 337.9 ft (97.66 to 102.99 m) is predominantly sand. The sands fine upsection from slightly micaceous medium–coarse at the base (337.9 ft; 102.99 m) to micaceous, silty, very fine sand with laminations of opaque heavy minerals at the top. A thin clay interval indicated on the gamma log was poorly recovered (328–330 ft; 99.97–100.58 m), although the section at 327.8–328 ft (99.91–99.97 m) is slightly clayey silty sand. Silty clay appears at 337.9 ft (102.99 m) as shown by higher gamma log values (Fig. F5). Between 337.9 and 352.15 ft (102.99 and 107.34 m), there are interbedded fine sands and sandy clayey silts. The sand beds are very fine to medium grained, between 0.4 and 1.1 ft (12 and 34 cm) thick, and in many places are invaded by red drilling mud. The silts commonly have interlaminated clays and are light greenish gray.

The section is again dominated by sand from 352.15 to 363.6 ft (107.34 to 110.83 m). The sands range from medium to fine grained, have a few slightly silty zones, and display clay rip-up clasts (355–355.5 and 361–361.5 ft; 108.20–108.36 and 110.03–110.19 m) and, in places, show fining-upward packages. The coarser sands are red owing to drilling mud invasion. An irregular cemented sand appears at 355.9 ft (108.48 m). The base of the section consists of crumbly granular sands (362.8–363.6 ft; 110.58–110.83 m), iron cemented intervals (363.3–363.4 ft; 110.73–110.76 m), and charcoal (363.5–363.6 ft; 110.79–110.83 m). They are tentatively interpreted as meandering river deposits, partly based on the lack of any evidence of marine deposition, although it is possible they are delta front. The contact at the base of the sands at 363.6 ft (110.83 m) may be a sequence boundary.

The sands from 320.4 to 363.6 ft (97.66 to 110.83 m) compose the "middle" (320.4–337.9 ft; 97.66–102.99 m) and "lower" (352.15–365 ft; 107.34–111.25 m) part of the middle aquifer of the PRM aquifer system. Elsewhere (Owens et al., 1998), this aquifer has been assigned to pollen Zone III (Cenomanian) (Benson and McLaughlin, 2001) and the confining unit below has been assigned to Zone II (Albian). Most of Potomac Unit 3 is barren of pollen at Fort Mott (Fig. **F5**).

Potomac Formation—Unit 2

Interval: 363.6–599.7 ft (110.83–182.79 m)
Age: Albian

The interval at 363.6–599.7 ft (110.83–182.79 m) is assigned to the Potomac Unit 2 (Figs. **F6, F7**). From 363.6 to 417.7 ft (110.83 to 127.31 m), the interval is a gray silty clay, frequently mottled red, with common root structures throughout; these are interpreted as paleosols. Four lithologic types are recognized in this interval based on the color and nature of mottling:

1. Light gray silty clays with subvertical 20- to 30-mm red mottles interpreted as root traces (365–367.5, 401–404, and 408–416 ft; 111.52–112.01, 122.22–123.14, and 124.36–126.80 m); the section from 410 to 416 ft (124.97 to 126.801 m) has sphaerosiderite nodules with hematite oxidation rims;
2. A similar lithology with abundant orange and dusky red small mottles (approaching a breccia fabric) that appear to be intense root traces and soil cracks (e.g., 376–390 and 416–417.7 ft; 114.60–118.87 and 126.80–127.31 m);
3. A more intensely mottled zone with subequal gray and red to a predominantly red mottled interval with thick root traces ranging from 30 to 40 mm and sphaerosiderite nodules (with hematite oxidation rims) (390–401 and 406–408 ft; 118.87–122.22 and 123.75–124.36 m); and
4. Banded red and light gray silty clay (404–406 ft; 123.14–123.75 m).

A transition to coarser, less oxidized facies appears below 417.7 ft (127.31 m). At 417.7–419 ft (127.31–127.71 m), the silty clays become tannish gray with increasing amounts of silt. Interbeds of very silty, very fine sands appear at 419 ft (127.71 m), and the interlaminated silty clays/clayey silts grade down to predominantly silty, very fine sands at 420 ft (128.02 m). The gamma log shows low values from 417 to 438 ft (127.10 to 133.50 m), consistent with the higher sand content, although this interval is too silty to compose an aquifer. At 424–426 ft (129.24–129.84 m) the sands gradually coarsen downsection from very silty, very fine sand to silty fine sand to clean fine sand. The sand from 425.5 to

426 ft (129.69 to 129.84 m) contains reddish silty and organic-rich laminae with hints of cross bedding. From 426.0 to 426.3 ft (129.84 to 129.94 m) the fine sand is siltier. The interval at 430–430.6 ft (131.06–131.25 m) is a light gray clayey sandy silt with common small charcoal fragments. A charcoal-rich bed (430.6–431.1 ft; 131.25–131.40 m) consists of a clayey, sandy silt matrix and charcoal up to 10 mm, a pyrite nodule (431.0 ft; 131.37 m), and almost pure charcoal at the base. Below this is a bed (431.1–431.35 ft; 131.40–131.48 m) with interlaminated clayey silt and charcoal flake layers. The interval at 431.35–432.1 ft (131.48–131.70 m) consists of two charcoal clast layers (431.35–431.45 and 431.55–431.65 ft; 131.48–131.51 and 131.54–131.57 m) within a zone dominated by clay rip-up clasts that include fragments of hematite(?), cemented and pyritic concretions, and charcoal, as well as common very fine mica. The features evident from 425.5 to 432.1 ft (129.69 to 131.70 m) indicate subaqueous overbank deposition within the floodplain and, hence, more humid conditions in contrast to soil/subaerial deposition in the section above. A surface in the core at 432.1 ft (131.70 m) separates grayish brown lignite-rich clay above from laminated sandy silt and sand below.

The section at 432.1–438.0 ft (131.70–133.50 m) consists of medium–dark gray silty clay with a few interlaminated sands. Mica and charcoal are common in both the silts and sands, with charcoal concentrations at 433.5, 433.7, and 434.8 ft (132.13, 132.19, and 132.53 m) and a zone at 436.5–438 ft (133.05–133.50 m). In a few places there are reddish concretions and red clays (432.3 and 437.15 ft; 131.77 and 133.24 m), with other scattered red clay beds. These interlaminated silts and sands probably represent cutoff channel/oxbow lake sedimentation adjacent to a soil-forming floodplain.

More uniform finer-grained sediments return below a coring gap (438–440 ft; 133.50–134.11 m) associated with a gamma kick (439 ft; 133.81 m). The section from 440 to 445 ft (134.11 to 135.64 m) consists of fairly homogeneous light gray slightly clayey silt with common sphaerosiderite nodules. This section probably represents an incipient soil on the levee/overbank. Below this, the section becomes more laminated, more micaceous, darker gray slightly clayey silt with scattered dark (?organic rich) laminae (445–447.5 ft; 135.64–136.40 m). In situ sphaerosiderite nodules are lacking from 445 to 446.3 ft (135.64 to 136.03 m). This section probably represents more subaqueous influence than above. Darker micaceous clayey silts with common scattered very fine charcoal fragments and scattered very fine sand beds, sand-filled burrows or root traces, and very dark gray clay (447.5–452 ft; 136.40–137.77 m) appear to represent deposition in a fluvial-lacustrine environment (?oxbow lake). The unit below this (452–458.15 ft; 137.77–139.64 m) is similar, although slightly darker and lacking sand; it appears to be a lacustrine deposit.

An interesting contact is present at 458.8 ft (139.84 m). From 458.15 to 458.8 ft (139.64 to 139.84 m), the lithology consists of an organic-rich clayey silt with graded, abundant dispersed charcoal (ranging in size from silt sized to 2 mm diameter) beds at its base. A yellowish tan clayey sandy silt below the contact (458.8–458.95 ft; 139.84–139.89 m) appears to represent subaerial weathering of the underlying subaqueous silts (458.95–469.05 ft; 139.89–142.97 m). The contact at 458.8 ft (139.84 m) may represent a transition from a desiccated lake/overbank deposit to a deeper-water lake above (i.e., a change to wetter conditions), although in marine facies this would be interpreted as a sequence boundary.

Complex gray silt and clay facies deposited in subaqueous floodbasins appear below the 458.8 ft (139.84 m) contact: light gray clayey silts (458.95–459.05 ft; 139.89–139.92 m), laminated clays with clay rip-up clasts and scattered charcoals (459.05–459.4 ft; 139.92–140.03 m), and dark grayish brown clayey silt with common dispersed charcoal fragments (459.4–460.0 ft; 140.03–140.21 m). The section from 460 to 461 ft (140.21 to 140.51 m) is a clay that has been disturbed by coring. Interbedded gray clayey silt to silty clay with charcoal zones (461–466 ft; 140.51–142.04 m) include clay rip-up clasts (e.g., 461.5 ft; 140.67 m).

Between 461 and 508.15 ft (140.51 and 154.88 m) the cores are predominantly dark gray silty clay with dispersed fine plant debris, interbedded silty very fine sands, and scattered charcoal fragments. Special features include: (1) thin sand laminae; (2) slightly sandy, heavily bioturbated sandy zones; and (3) cemented red lithified concentrations (Table T2). These red zones and concretions appear to be plinthites (cemented concretions) in an overbank/desiccated lake setting. Pyrite concretions appear at 463.8 ft (141.37 m).

T2. Cumulative percent data, p. 45.

Color varies in the clayey beds because of changing oxidation. From 461 to 471 ft (140.51 to 143.56 m), they are light to medium gray; from 471 to 471.5 ft (143.56 to 143.71 m), a lavender hue is present; at 471.5–475 ft (143.71–144.78 m), the clays are light to medium gray; and brownish gray hues become common from 475 to 480 ft (144.78 to 146.30 m). Color laminations of gray, light brown, and red dominate the interval from 480 to 498.4 ft (146.30 to 151.91 m). The color changes at 498.4 ft (151.91 m) to a darker distinctly laminated dark gray with olive-gray bands. From 500.0 to 507.6 ft (152.40 to 154.72 m), the section is interlaminated gray and tan. The color boundaries tend to be more gradational than sharp.

These fine-grained sediments appear to have been deposited in small lakes in a fluvial setting. The paucity of sand and lack of abundant organic matter/pyrite argues against cutoff channel/oxbow lake subenvironments and points toward larger floodplain standing lakes. Although the burrowed sands are suggestive of estuarine environments, occasional soil concretions indicate subaerial exposure, consistent with ephemeral lakes. There are hints of cyclicity on a small (2–3 ft; 60–90 cm) scale in the gamma logs and cores and ~10-ft (3.05 m) cyclicity on the gamma logs.

The section returns to red and light gray silts and clays at 508.25 ft (154.91 m) at a sharp contact. An indurated yellowish to blackish clayey silty sand (508.2–508.25 ft; 154.90–154.95 m) overlies the irregular contact; this indurated interval is overlain by blebs of red clay (508.15–508.2 ft; 154.88–154.90 m), apparently reworked from below, and a return to blackish clayey silty sand (507.6–508.15 ft; 154.72–154.88 m). This contact could either be a sequence boundary or a facies shift from soils in an alluvial floodplain to a lake in the floodplain. There is a change in gamma log signature at ~508.25 ft (154.95 m) from smaller, thinner variations above to thicker, large-scale variations below.

Mottled clays and silts deposited as soils appear below the 508.25 ft (154.95 m) surface and continue to a surface at 555.1 ft (167.98 m). The section at 508.25–508.55 ft (154.95–155.01 m) is banded red and light olive-gray clay with sparse sphaerosiderite nodules overlying a coring gap. The section below this (510–512 ft; 155.45–156.06 m) consists of a light gray, slightly micaceous silty clay with common sphaerosiderite nodules and red mottles following what appear to be large root traces. The interval from 512 to 515 ft (156.06 to 156.97 m) is a light gray, very silty micaceous clay with small circular sand zones that may be root fills and common sphaerosiderite nodules with hematite rinds that increase in abundance downsection.

The section is silty overall down to 515 ft (156.97 m), predominantly clay from 517 to 520 ft (157.58 to 158.50 m), and returning again to silt at 520–529.9 ft (158.50–161.51 m). From 515.0 to 519.5 ft (156.97 to 158.34 m) the section is a mottled, orange-red, light olive-gray silty clay. The section at 519.15–520.35 ft (158.24–158.60 m) is an olive-gray silty clay with small reddish brown mottles and a trace of mica. From 520.35 to 523.5 ft (158.60 to 159.56 m) the section consists of light olive-gray, slightly micaceous clayey silt with 1-cm-thick red mottles and abundant small sphaerosiderite nodules (very fine sand size). The section from 523.5 to 529.3 ft (159.56 to 161.33 m) consists of a return to light gray, very silty micaceous clay with common sphaerosiderite nodules and small cracks with black (?manganese) infill. The interval at 529.3–530.9 ft (161.33–161.82 m) is light olive-gray and brown mottled clay with sphaerosiderite nodules transitioning downsection to 538.3 ft (164.07 m) to mostly brown, mottled, slightly silty, slightly micaceous clays with some reddish and grayish mottles and scattered sphaerosiderite nodules. From 538.3 to 546.0 ft (164.07 to 166.42 m) the section returns to a light olive-gray clay with orange-red and dusky red mottles and sphaerosiderite nodules, abundant in places. The mottles appear to follow traces of large roots. The section at 546.0–550.4 ft (166.42–167.76 m) is light gray to light brownish gray very silty clay with brown mottles. The section from 550.4 to 550.5 ft (167.76 to 167.79 m) is a light gray to olive-green banded silty clay. The interval between 550.5 and 551.1 ft (167.79 and 167.98 m) is a brown and light gray silty clay. At 551.1–555.2 ft (167.98–169.22 m) is a light olive-gray silty clay with light brown mottles and thin sand. A sharp contact at 555.1 ft (169.19 m) separates silty clay above from very charcoal rich, medium to dark gray clay below; reworked charcoal laminae continue up above the contact to 555.0 ft (169.16 m). The underlying clay continues with rare sand laminae to 558 ft (170.08 m) and is interpreted as a lacustrine deposit. The contact at 555.1 ft (167.98 m) is marked by a gamma log kick (Fig. **F6**) and could be either a sequence boundary or a shift to paleosols above from lacustrine deposits below.

From 558 to 560.3 ft (170.08 to 170.78 m), the clay becomes increasingly sandy downsection. The section between 560.3 and 560.8 ft (170.78 and 170.93 m) is interbedded fine–very fine sand and sandy dark gray clay with common charcoal. The underlying bed (560.8–563.7 ft; 170.93–171.82 m) is very fine micaceous sand with scattered thin interlaminated clay layers and abundant charcoal. At 563.7–563.8 ft (171.82–171.85 m) is a thin silty clayey very fine micaceous sand. Sands from 560.3 to 563.7 ft (170.78 to 171.82 m) appear to have too much interlaminated clay and charcoal to compose a good aquifer. There is a coring gap at 563.8–570 ft (171.85–173.74 m).

Sands continue from 570 to 596.8 ft (173.74 to 181.90 m), constituting a potential aquifer. The sands from 570 to 580.5 ft (173.74 to 176.94 m) are generally very fine to fine grained, lignitic, and slightly silty, with thin clay interbeds at 574.0–574.9, 577.1–580.5, and 580.9–581.1 ft (174.96–175.23, 175.90–176.94, and 177.06–177.12 m). Interbedded sands and clays continue below this: very fine carbonaceous sands (581.1–581.8 ft; 177.12–177.33 m), a silty clay layer (581.8–582 ft; 177.33–177.39 m), and a very fine sand with scattered carbonaceous material (582–582.3 ft; 177.39–177.49 m). Below a coring gap (582.3–590 ft; 177.49–179.83 m), the sediments coarsen downward to 593.3 ft

(180.84 m) from fine sand with scattered charcoal fragments (up to 4 cm long) to granuliferous sand. An irregular contact at 593.3 ft (180.84 m) with a rip-up clast of underlying material appears to be the base of a channel. Thus, the section from 581.1 to 593.3 ft (177.12 to 180.84 m) appears to be fluvial channel fill; however, a marine channel interpretation cannot be precluded. The section at 593.3–596.0 ft (180.84–181.66 m) is very charcoal rich (fragments from 2–3 mm to 6 cm across), micaceous, very fine sand with cross beds and soft-sediment deformation features probably deposited in a fluvial overbank/crevasse splay setting. Interbedded fine–very fine sands and clays with abundant charcoal compose the section from 596.0 to 599.7 ft (181.66 to 182.79 m): a clayey sandy silt with soft-sediment deformation features and abundant charcoal fragments (596.8–598.4 ft; 181.90–182.39 m), a fine–very fine sand with charcoal (598.4–599.0 ft; 182.39–182.58 m), a sandy charcoal bed (599.0–599.2 ft; 182.58–182.64 m), a clay (599.2–599.4 ft; 182.64–182.70 m), and a fine–very fine sand (599.4–599.7 ft; 182.70–182.79 m). These are also tentatively interpreted as crevasse splay environments.

The sands and interbedded clays from 560.3 to 599.7 ft (170.78 to 182.79 m) are assigned to pollen Zone IIB (Albian) (556.2 and 577 ft; 169.53 and 175.87 m) (see **"Biostratigraphy,"** p. 28) or Zone IIB/I (Aptian or older) (599 ft; 182.58 m).

Potomac Formation—Unit 2 or Unit 1

Interval: 599.7–644.1 ft (182.79–196.32 m)
Age: Aptian or Albian

A sharp irregular contact at 599.7 ft (182.79 m) separates sand above from paleosols below. The contact may be a sequence boundary. The section below includes a silty clay (599.7–600.0 ft; 182.79–182.88 m), sandy silt (below a coring gap; 600–605 ft; 182.88–184.40 m), with scattered sphaerosiderite nodules with hematite rinds (605–606.2 ft; 184.40–184.77 m), and gray and heavily mottled, red, slightly silty clay with abundant sphaerosiderite nodules representing interfluvial paleosols (606.2–615.4 ft; 184.77–187.57 m) (Fig. **F7**). These clays become slightly sandy and less mottled below 613.5 ft (186.99 m). A contact at 615.4 ft (187.57 m) separates the light gray sandy clay with sphaerosiderite nodules above from dark gray (?organic rich) slightly silty clay below.

The gray clays (615.4–620.1 ft; 187.57–189.01 m) contain small charcoal fragments, lack sphaerosiderite nodules, and have thin micaceous sand interbeds below 617 ft (188.06 m). They are interpreted as lacustrine. This facies continues to 620.1 ft (189.01 m), where there is a return to lighter gray mottled silty clays.

Different clays appear from 620.1 to 628.1 ft (189.01 to 191.44 m). At 620.1–625.7 ft (189.01–190.71 m) the section contains variably light to medium gray sandy clayey silts with olive mottling and evidence of bioturbation in places. Between 621.7 and 622.5 ft (189.49 and 189.74 m) this mottled interval is relatively hard, with obvious root casts and/or desiccation cracks; below this the mottling is less intense and bioturbation is more obvious. This passes downward into a slightly darker, laminated, medium gray sandy clayey silt with scattered charcoal fragments at 625.7–626.4 ft (190.71–190.93 m). Interbedded dark and light gray clay and sandy clay is present from 626.4 to 628.1 ft (190.93 to 191.44 m), with a coring gap to 630 ft (192.02 m). The environment of deposition of the section from 620.1 to 628.1 ft (189.01 to 191.44 m) is uncertain; the facies are consistent with cutoff channel/floodplain lakes, although slight mottling of the section indicates incipient soil formation.

Sands and silts predominate from 630.0 to 644.1 ft (196.32 to 198.99 m). Silty sand with white rip-up clasts (630.0–630.3 ft; 192.02–192.12 m) overlies an erosional contact (630.3 ft; 192.12 m). Interbedded micaceous, gray sandy silt alternates with burrowed silty fine sand to 637.6 ft (194.34 m); sphaerosiderite nodules appear sporadically from 630.5 to 632.0 ft (192.18 to 192.63 m), again suggesting incipient soil formation on a fluvial (proximal levee?)-lacustrine (cutoff channel?) environment. Bedding is obscured above 632 ft (192.63 m) and laminated below. Another sharp, irregular contact at 637.6 ft (194.34 m) separates the silty sand above from clayey fine sand below. Soft, silty, very fine sand (637.6–638.2 ft; 194.34–194.52 m) passes downsection to a series of fining-upward successions of medium sand to fine sand to clay with variably abundant charcoal, possibly representing overbank deposits, that are present to 644.1 ft (196.32 m).

As discussed above, the lithologic assignment of the section from 599.7 to 644.1 ft (182.79 to 196.32 m) is problematic. It may constitute a distinct sequence (Subunit 2a or 1b), be part of the larger Unit 2 sequence, or be part of the Unit 1 sequence. Based on the distinct facies successions from sand to clay upsection, we favor this being a distinct sequence.

Potomac Formation—Unit 1

Interval: 644.1–820 ft (196.32–249.94 m)
Age: Aptian (possibly Barremian)

From 644.1 ft to 649.2 ft (196.32 to 197.88 m) the section consists of an extremely hard, clayey, light gray silt with an interval of burrowed silty sand (648.3–648.8 ft; 197.60–197.75 m). At 649.2–652.7 ft (197.88–198.94 m) is a succession that passes from mottled orange and light gray slightly sandy, slightly clayey silt downsection to darker grayish brown slightly sandy clayey silt with abundant sandy burrows/rootlet fills; this appears to be the same lithology decreasingly affected by soil processes downsection. Sporadic sphaerosiderite nodules appear from 649 to 651 ft (197.82 to 198.42 m). The environment appears to be fluvial overbank swamp with common organic matter overprinted by soil processes exemplified by root casts.

Below 652.7 ft (198.94 m) the section returns to a heavily mottled character, which persists through 710.6 ft (216.59 m). The section alternates between clay and silt and between zones of extensive mottling and grayer gleyed zones. The mottling below 652.7 ft (198.94 m) becomes particularly intense compared to upper sections of the borehole, suggesting intense soil weathering under tropical–subtropical conditions of varying seasonal precipitation. The section between 652.7 and 652.85 ft (198.94 and 198.99 m) consists of light gray silty clay above a coring gap (652.85–658.8 ft; 198.99–200.80 m). From 658.8 to 660 ft (200.80 to 201.17 m), the lithology is light gray clay with sphaerosiderite nodules and red mottling and banding. The mottled zones are commonly characterized by intensely mottled and cracked red, brown, and olive fine-grained lithologies with scattered concretions. The interval at 660–665 ft (201.17–202.69 m) is predominantly clay with sphaerosiderite nodules; the mottles are red and appear rootlike and commonly become narrower downward. From 665 to 676 ft (202.69 to 206.04 m), the section is siltier with fine micaceous sand at 670.1–671 ft (204.25–

204.52 m) and contains sphaerosiderite nodules altered to hematite throughout; gamma log values are distinctly lower in this section. From 670.1 to 673.6 ft (204.25 to 205.31 m) the core is mostly orange-red with olive, orange, and gray mottles with small (up to 5 mm) dusky red concretions (hematite cemented sand). The interval at 673.6–676.1 ft (205.31–206.08 m) is slightly sandy to clayey light gray micaceous silt with common sphaerosiderite nodules with hematite rinds and small hematite concretions. A dramatic change appears at an uneven contact at 676.1 ft (206.08 m) to a deeply mottled red to dusky red to olive to light gray extensively cracked, slightly silty clay that continues to 685.2 ft (208.85 m) with a few zones of small (up to 1 cm) hematite concretions. From 685.2 to 690.2 ft (208.85 to 210.37 m), large orange to olive mottles are present on light gray to pinkish clay with little silt and small hematite concretions (up to 2 mm) concentrated in the orange-olive mottles. Deeply mottled, red, intensely cracked clay continues at 690.2–703.9 ft (210.37–214.55 m) with scattered sphaerosiderite nodules, common small hematite concretions in deeper red zones, and orange to olive mottles from 703 to 703.9 ft (214.27 to 214.55 m). An abrupt change to light pinkish purple clayey, slightly sandy, micaceous silt is present at 703.9 ft (214.55 m) with scattered hematite grains after sphaerosiderite. Light pinkish purple clay continues to 705.55 ft (215.05 m), where the section changes to light gray slightly clayey micaceous silt (705.55–710.6 ft; 215.05–216.59 m) that becomes increasing sandy downsection with a few red and olive mottles and sphaerosiderite nodules. The bottom of this section (710.3–710.6 ft; 216.50–216.59 m) has abundant small holes filled with very fine sands that are probably root casts.

A heterolithic interval appears at 710.6–722.8 ft (216.59–220.31 m) (Fig. F7). From 710.6 to 712.9 ft (216.59 to 217.29 m) the lithology is heterogeneous, with mottled red and gray very clayey sandy silt and blebs of other lithologies (silty clay and very sandy clayey silt) lacking sphaerosiderite nodules; this facies may be colluvium. Below a coring gap (712.9–720 ft; 216.59–219.46 m), is a heterolithic bed (720–722 ft; 219.46–220.07 m) with mottled micaceous sandy clayey silt with clasts up to 7 mm that is more deeply cracked and redder at the top. At 722 ft (220.07 m), the section becomes sandy, with very silty micaceous sand to 722.8 ft (220.31 m) followed by a coring gap (722.8–725 ft; 220.31–220.98 m). The sand is poorly sorted, fines upward from medium to very fine grained, and is marked at its base by a few angular pebbles up to 1 cm in diameter.

The section from 725 to 732.2 ft (220.98 to 223.17 m) consists of spectacularly mottled, poorly sorted sandy silt. The section has large (1–5 cm) light gray mottles on a deep red base lithology. The light gray mottles frequently have olive rims from 1 to 10 mm wide; at the core of some of the light gray mottles are areas of weak red color. The mottling may represent alteration in a rooted soil zone affected by an alternation of oxidizing and gleying (reducing) conditions because of water table rise and fall over a century- to millennial-scale time interval.

An interval of gray poorly sorted silty sand appears from 732.2 to 734.4 ft (223.17 to 223.85 m) with scattered sphaerosiderite nodules and hematite concretions. This is underlain by another extensively mottled zone between 734.4 and 738.3 ft (223.85 and 225.03 m), but this zone is different than that at 725–732.2 ft (220.98–223.17 m). It is mostly clay to silty clay, dominated by deep red colors and olive-yellow patches with isolated light gray zones. The dusky red clay areas are discrete and appear to be individual clay pieces that may have physically moved into this deposit by soil or slope processes (e.g., colluvium). A very hard silt/siltstone appears at 738.3–738.6 ft (225.03–225.13 m). This indurated zone is underlain by a very soft interval of interlaminated whitish sand and clay from 738.6 to 739.1 ft (225.13 to 225.28 m), probably representing overbank deposition.

Laminated deep red clays are present from 739.1 to 743.9 ft (225.28 to 226.59 m) with scattered white mottles and subordinate interbedded micaceous white clayey silts. These laminated clays and silts were apparently deposited under subaqueous conditions (?floodplain).

Below a coring gap (743.9–748 ft; 226.59–227.99 m) is an intensely mottled, variably micaceous deep red and pinkish white sandy, slightly clayey silt (748–752.8 ft; 227.99–229.45 m) with dusky red irregular concretions and some olive mottles and light olive-brown mottling predominating in a slightly sandier zone (e.g., 751.5–752 ft; 229.06–229.21 m). The lower part of the section (752–752.8 ft; 229.21–229.45 m) has extensive “wormy” mottling and cracks.

A major lithologic change appears in a coring gap (752.8–753.5 ft; 229.45–229.67 m). The section at 753.5–758.15 ft (229.67–231.08 m) is a predominantly medium–dark gray zone with interbedded silty fine–coarse sand, silty clay, sandy silts with scattered lignite, mica, sand-filled root casts or burrows in the lower part, and soft-sediment deformation (756–756.5 ft; 230.43–230.58 m). This section may represent a wet fluvial overbank environment (perhaps swamp subenvironment).

Clays and clayey silts return at 760–765.6 ft (231.65–233.35 m). Brown silty clay and clayey silt (760–762.9 ft; 231.65–232.53 m) and mottled red orangish tan and gray slightly silty clay with cracks and sphaerosiderite nodules (762.9–“765.05” ft; 232.53–“233.19” m) represent intense paleosol formation. Dark gray silty clay with charcoal (765.05–765.6 ft; 233.19–233.35 m) represents a wet floodplain environment.

A coarse-grained unit found from 765.6 to 769.2 ft (233.35 to 234.45 m) is expressed as a distinct low on the gamma log. Mottled tan and olive sandy silt with organic flecks (765.6–767 ft; 233.35–233.78 m) overlies a very sandy silt to very silty sand (767–769.2 ft; 233.78–234.45 m) that is predominantly fine to medium grained. The sand is mottled red and olive near the top to light gray near the base and appears to be coarser near the base. The silts and sands may represent overbank deposits altered into soil near the top.

An abrupt change is present at 769.2 ft (234.45 m) to mottled olive-yellow and light gray hard, waxy clayey silt (769.2–771.6 ft; 234.45–235.18 m) with cracks and scattered red mottles that represents another paleosol. It passes downward into a sandy silt at 771.6 ft (235.18 m) and to a poorly sorted fine–coarse silty sand at 772.3 ft (235.40 m) that again probably represents an overbank deposit.

Below a coring gap (772.5–780 ft; 235.46–237.74 m), slightly silty clay returns (780–789 ft; 237.74–240.49 m) as a deep red mottled interval. The upper part (780–783 ft; 237.74–238.66 m) has abundant small mottles of various shades of red. Tan and light gray mottles appear at 783 ft (238.66 m). Deep dusky red and black-red mottles appear at 785.5 ft (239.42 m) (manganese-iron oxide?). The section becomes increasingly indurated and slightly sandy downsection. Olive-colored mottles contain scattered small (<1 mm) hematite nodules, probably after sphaerosiderite. The sediments represent multiple generations of paleosols as indicated by multiple generations of mottling with different-colored rims and cores.

The section from 789 to 790.5 ft (240.49 to 240.94 m) is a fining-upward succession from a fine- to medium-grained quartz with coarse-grained sphaerosiderite nodules to a silty medium- to fine-grained sand to slightly sandy silt. It probably represents a crevasse splay deposit within the overbank.

Red mottled clay with root casts (790.5–791.5 ft; 240.94–241.25 m) grades down to into a light gray sphaerosiderite nodule-rich slightly micaceous silt (791.8 ft; 241.34 m) that coarsens downward to a silty sand (795 ft; 243.32 m) and a slightly silty sand (797 ft; 242.93 m) to a medium–coarse sand (798.05 ft; 243.25 m). Mottled material at the top is a deep red with small, "wormy," whitish mottles. The sand is micaceous and in the basal part contains very angular quartz grains that suggest proximity to source. The entire succession probably represents a channel-fill deposit.

Another cycle from 798.05 to 799.5 ft (243.25 to 243.69 m) consists of a fining-upward succession from slightly micaceous fine–medium sand to a clayier, siltier, mostly fine-grained sand. Below a coring gap (799.5–805 ft; 243.69–245.36 m), a dark gray lignitic micaceous clayey silt (805–808.65 ft; 245.36–246.48 m) abruptly overlies a silty clay. The silt probably represents a swamp environment.

From 808.65 to 808.9 ft (246.48 to 246.55 m) the section coarsens downsection from a soft, light medium gray, slightly silty clay that overlies a very hard, medium light gray, slightly sandy clayey silt (808.9–811 ft; 246.55–247.19 m) to sandy silt (811–812 ft; 247.19–247.50 m) to whiteish gray slightly silty medium sand (813–814 ft; 247.80–248.11 m). The section becomes progressively darker and purplish upsection above the bottom of the hole (814 ft; 248.11 m). Thus, from the bottom of the hole to 808.65 ft (246.48 m) the cores trace a fining-upward succession deposited as a channel fill.

BIOSTRATIGRAPHY

Calcareous nannoplankton

Samples were taken at 35.4 ft (10.8 m), 61.5 ft (18.8 m), 71.1 ft (21.7 m), 73.6 ft (22.4 m), 84 ft (25.6 m), 100.3 ft (30.6 m), 110.4 ft (33.7 m), and 120.7 ft (36.8 m) in the marine section above the Magothy Formation. The only samples that contained nannoplankton were 61.5 ft (18.8 m), 71.1 ft (21.7 m), and 73.6 ft (22.4 m). These samples contained *Aspidolithus parcus constrictus* (first occurrence [FO] in Zone CC18) but lack *Marthasterites furcatus* (last occurrence at top of Zone CC18) and *Ceratolithoides aculeus* (FO at the base of CC20), which places them firmly in Zone CC19. The background assemblage is Campanian.

Pollen

Eleven nonmarine samples were analyzed from the Fort Mott corehole by G. Brenner for palynomorphs, pollen, and spores (Table T3), and preliminary examination was made of 16 samples from the Potomac Formation by P.P. McLaughlin. Sample recovery was variable (5 of 16 examined by McLaughlin were barren), but several samples recovered a well-preserved flora. Samples are assigned ages using the zonations of Brenner (1967) (Figs. F2, F4, F5, F6, F7) and Doyle and Robbins (1977). A sample at 137.5 ft (41.91 m) is assigned to Zone V; because it lacks advanced Normapolles, it is interpreted as late Turonian. Samples

T3. Pollen occurrences, p. 48.

between 157 and 162.8 ft (47.85 and 49.62 m) are assigned to Zone III and interpreted as early Cenomanian. Zonal assignment of the sample at 435.4 ft (132.71 m) may be either Subzone IIC (late Albian) or possibly Zone III (early Cenomanian). Samples between 465.4 and 500 ft (141.85 and 152.4 m) were assigned to Subzone IIC (late Albian). Samples between 556.2 and 577.2 ft (169.53 and 175.93 m) were assigned to Subzone IIB (Albian). The biostratigraphic assignment of samples from 599.3 ft (182.67 m) and 641.1 ft (195.41 m) is equivocal and could be either to Subzone IIB or to Zone I. Brenner (this study) assigned both samples to Zone I (Aptian) based on the apparent absence of tricolpate pollen, tricolporate pollen, and pteridophyte spores typical of Zone II in the Patapsco Formation of Maryland. In addition, he notes an increase in the pollen of *Classopollis, Eucommiidites, Cicatricosisporites,* and smooth triangular trilete spores of *Cyatheaceae* that are characteristic of the Patuxent-Arundel succession (Zone I) (?Barremian–Aptian) in Maryland. McLaughlin (this study) additionally reports very small (12 µm) faintly reticulate tricolpoiroidate angiosperm pollen (aff. *Tricolpites albiensis*) and another small angiosperm pollen similar to *Retitricolpites virgius* in these two samples, suggesting assignment to Subzone IIB (Albian). Assignment to Subzone IIB is consistent with log correlations that suggest the 599.3 ft (182.67 m) level at Fort Mott should correspond to ~515 ft (156.97 m) in Dc53-07 to ~590 ft (179.83 m) or so at Ec14-01 in Delaware, both of which were recognized as Subzone IIB by Doyle and Robbins (1977). The sample at 806.0 ft (245.7 m) is placed in Zone I (Aptian).

STRONTIUM ISOTOPE CHRONOSTRATIGRAPHY

Sr isotopic age estimates were obtained from mollusk shells. Approximately 4–6 mg of shells or foraminiferal tests were cleaned ultrasonically and dissolved in 1.5-N HCl. Sr was separated using standard ion-exchange techniques (Hart and Brooks, 1974) and analyzed on a VG Sector mass spectrometer at Rutgers University (New Jersey). Internal precision on the sector for the data set averaged 0.000009 and the external precision is approximately ±0.000020 (Oslick et al., 1994). NBS 987 is measured for these analysis at 0.710255 (2σ standard deviation 0.000008; n = 22) normalized to ^{86}Sr/^{88}Sr of 0.1194.

Cretaceous ages were assigned using linear regressions developed for upper Coniacian through Maastrichtian sections by Miller et al. (2004). Using a similar upper 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 ±1 m.y. (i.e., the external precision of ~0.000020 divided by the slopes of the regressions of ~0.000020/m.y.)

Strontium isotopic ages were obtained from three samples in the Woodbury Formation in the Fort Mott borehole (Fig. F4). The sample at 61 ft (18.59 m) (^{86}Sr/^{87}Sr = 0.707678 ± 12) yielded an age estimate of 73.8 Ma; the sample at 62.6 ft (19.08 m) (^{86}Sr/^{87}Sr = 0.707622 ± 7) yielded an age estimate of 75.6 Ma; and a sample at 84.2 ft (25.66 m) (^{86}Sr/^{87}Sr = 0.707620 ± 6) yielded an age estimate of 75.7 Ma. These ages are substantially younger than the ages that would be expected based on calcareous nannofossil biostratigraphy, and it is concluded that these samples have been altered by diagenesis.

SUMMARY AND FUTURE WORK

Drilling at Fort Mott was successful in providing data to evaluate local and regional aquifers. It also was an important site for understanding the regional and global significance of the Aptian–lowermost Cenomanian (~120–98 Ma) Potomac Formation (possibly Barremian in part). This unit can comprise more than one half of the entire thickness of the coastal plain section; for example, at Cape May it is nearly 1100 m of a total coastal plain section of 1900 m (Olsson et al., 1988). Understanding age, porosity, and thickness of the Potomac Formation is important for improving backstripping of the Upper Cretaceous and younger section for sea level studies. This constituted the primary impetus for including this site as part of Leg 174AX, which has as a major objective of obtaining a sea level record by backstripping Cretaceous sections at Ancora, Bass River, Millville, and Sea Girt. However, drilling at Fort Mott also yielded surprising new insights into the depositional history of the coastal plain and potentially provides a key record for deciphering the climate and chronology of deposition of the mid-Cretaceous on this margin.

The Potomac Formation has been previously interpreted as a fluvial unit deposited in a delta plain or coastal plain setting. Our examination of the Potomac Formation at Fort Mott yields the following observations:

1. Potomac Formation sediments in the Fort Mott borehole and elsewhere are predominantly fine grained (clays, silty clays, and clayey silts), with a few critical sand bodies. Many of the finer-grained intervals are heavily overprinted by soil-forming processes. These range from light blue and gray gleyed soils formed in poorly drained, reducing conditions to dark red soils indicating highly oxidized conditions. These silty clays and clayey silts were probably deposited as heavily vegetated levee deposits. Variations in color appear to reflect differences in evaporation and precipitation. The general depositional environment of the Potomac Formation best fits an anastomosing river system characterized by extremely low topographic gradients. Lakes are a common subenvironment of such systems, and we interpret several organic-rich fine-grained intervals as lacustrine deposits, some as oxbow lakes and some as larger alluvial plain lakes.
2. Sand bodies at the bases of Potomac Units 3 (lowermost Cenomanian) and 2 (Albian) appear laterally continuous in southernmost New Jersey; these sands may be present on top of previously unrecognized sequence boundaries. These sequence boundaries potentially reflect baselevel (in this case related to sea level) lowerings. Two other sands in Unit 1 are also candidate sequence boundaries.
3. These thick, apparently continuous sands have the geometries of delta front shoreline sands, although no direct marine evidence has been uncovered within them. If this interpretation is correct, then these sands may constitute the transgressive systems tracts and the anastomosing river facies model represents the highstand systems tracts. Thus, the basal delta front sands were pro-

graded over by delta plain deposits, including lower delta plain interdistributary lakes, marshes, and swamps and upper delta plain deeply weathered soils.

4. Cyclicity is evident in both the color and downhole logs (Figs. F4, F5, F6, F7). In particular, cyclicity is noted on the 2- to 3-ft (60–90 cm) and 10-ft (3 m) scales. Red oxidized sediments (high gamma log values) alternate with gray or gleyed reduced sediments (low gamma log values), providing colorful bar codes for spectral analysis. This cyclicity not only reflects regional climate changes, but its regularity implies a global imprint on climate and precipitation (e.g., Milankovitch periodicities). Future work is needed to test the assumption that these cycles represent precession and short eccentricity cycles, with hints of the long eccentricity cycle.
5. Identification of precessional and eccentricity cycles may, in the future, provide a potential means to parse time in these largely nonmarine units. Pollen biostratigraphy only allows coarse correlation to the stage level, suggesting that the age of these sediments are is ~98–120 Ma. Further investigation may allow us to provide an astronomical correlation for these sediments.

Recognizing that possibly global processes of eustatic change (e.g., the sequence boundaries) and evaporation–precipitation cycles with possible Milankovtich periodicities sheds new light onto these otherwise monotonous soils and sands. Like the Newark Basin Upper Triassic–Lower Jurassic redbeds, the stratigraphic record should reveal entirely new stories by integrating continuous coring with new tools and new insights.

REFERENCES

Benson, R.N., and McLaughlin, P.P., 2001. New perspectives on correlation of nonmarine depositional packages in the Cretaceous Potomac Formation, Delaware coastal plain. *Geol. Soc. Am. Bull.,* 33:100. (Abstract)

Benson, R.N., and Spoljaric, N., 1996. Stratigraphy of the post-Potomac Cretaceous and Tertiary rocks of central Delaware. *Bull.—Del., Geol. Surv.,* Vol. 20.

Brenner, G.J., 1967. Early angiosperm pollen differentiation in the Albian to Cenomanian deposits of Delaware (U.S.A.). *Rev. Paleobot. Palynol.,* 1:219–227.

Cauller, S.J., Carleton, G.B., and Storck, M.J., 1999. Hydrogeology of, water withdrawal from, and water levels and chloride concentrations in the major coastal plain aquifers of Gloucester and Salem Counties, New Jersey. *U.S. Geol. Surv. Water-Resour. Invest. Rep.,* 98–4136.

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

Doyle, J.A., and Robbins, E.I., 1977. Angiosperm pollen zonation of the continental Cretaceous of the Atlantic Coastal Plain and its applications to deep wells in the Salisbury Embayment. *Palynology,* 1:43–78.

Farlekas, G.M., Nemickas, B., and Gill, H.E., 1976. Geology and ground-water resources of Camden County, New Jersey. *U.S. Geol. Surv. Water-Resour. Invest. Rep.,* 76.

Grow, J.A., and Sheridan, R.E., 1988. U.S. Atlantic continental margin: a typical Atlantic-type or passive continental margin. *In* Sheridan, R.E., and Grow, J.A. (Eds.), *The Geology of North America* (Vol. I-2): *The Atlantic Continental Margin: U.S.:* Boulder (Geol. Soc. Am.), 1–7.

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

Howarth, R.J., and McArthur, J.M., 1997. Statistics for strontium isotope stratigraphy: a robust LOWESS fit to the marine Sr-isotope curve for 0 to 260 Ma, with look-up table for the derivation of numerical age. *J. Geol.,* 105:441–456.

Kominz, M.A., Miller, K.G., and Browning, J.V., 1998. Long-term and short-term global Cenozoic sea-level estimates. *Geology,* 26:311–314.

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

Makaske, B., 2001. Anastomosing rivers: a review of their classification, origin and sedimentary products. *Earth-Sci. Rev.,* 53:149–196.

McLaughlin, P.P., and Benson, R.N., 2002. Application of palynomorph biostratigraphy to correlation of aquifer units in nonmarine facies of the Cretaceous Potomac Formation, Delaware coastal plain. *Palynology,* 26:270. (Abstract)

Miall, A.D., 1996. *The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology:* Berlin (Springer).

Miller, K.G., Newell, W., Snyder, S.W., et al., 1994. *Proc. ODP, Init. Repts.,* 150X: College Station, TX (Ocean Drilling Program).

Miller, K.G., Browning, J.V., Pekar, S.F., and Sugarman, P.J., 1997. Cenozoic evolution of the New Jersey coastal plain: changes in sea level, tectonics, and sediment supply. *In* Miller, K.G., Newell, W., and Snyder, S.W. (Eds.), *Proc. ODP, Sci. Results,* 150X: College Station, TX (Ocean Drilling Program), 361–373.

Miller, K.G., Liu, C., Browning, J.V., Pekar, S.F., Sugarman, P.J., Van Fossen, M.C., Mullikin, L., Queen, D., Feigenson, M.D., Aubry, M.-P., Burckle, L.D., Powars, D., and Heibel, T., 1996a. Cape May site report. *Proc. ODP, Init. Repts.,* 150X (Suppl.): College Station TX (Ocean Drilling Program), 5–28.

Miller, K.G., McLaughlin, P.P., Browning, J.V., Benson, R.N., Sugarman, P.J., Hernandez, J., Ramsey, K.W., Baxter, S.J., Feigenson, M.D., Aubry, M.-P., Monteverde, D.H., Cramer, B.S., Katz, M.E., McKenna, T.E., Strohmeier, S.A., Pekar, S.F., Uptegrove, J., Cobbs, G., Cobbs, G., III, and Curtin, S.E., 2003. Bethany Beach site. *In* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX (Suppl.), 1–85 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

Miller, K.G., Mountain, G.S., and Leg 150 Shipboard Party and Members of the New Jersey Coastal Plain Drilling Project, 1996b. Drilling and dating New Jersey Oligocene–Miocene sequences: ice volume, global sea level and Exxon records. *Science,* 271:1092–1995.

Miller, K.G., Sugarman, P.J., Browning, J.V., Cramer, B.S., Olsson, R.K., de Romero, L., Aubry, M.-P., Pekar, S.F., Georgescu, M.D., Metzger, K.T., Monteverde, D.H., Skinner, E.S., Uptegrove, J., Mullikin, L.G., Muller, F.L., Feigenson, M.D., Reilly, T.J., Brenner, G.J., and Queen, D., 1999. Ancora site. *In* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX (Suppl.), 1–65 [Online]. Available from World Wide Web: http://www-odp.tamu.edu/publications/174AXSIR/VOLUME/CHAPTERS/174AXS_1.PDF. [Cited 2004-08-24]

Miller, K.G., Sugarman, P.J., Browning, J.V., Kominz, M.A., Olsson, R.K., Feigenson, M.D., and Hernandez, J.C., 2004. Upper Cretaceous sequences and sea-level history, New Jersey coastal plain. *Geol. Soc. Am. Bull.,* 116:368–393.

Miller, K.G., Sugarman, P.J., Browning, J.V., Olsson, R.K., Pekar, S.F., Reilly, T.J., Cramer, B.S., Aubry, M.-P., Lawrence, R.P., Curran, J., Stewart, M., Metzger, J.M., Uptegrove, J., Bukry, D., Burckle, L.H., Wright, J.D., Feigenson, M.D., Brenner, G.J., and Dalton, R.F., 1998. Bass River site. *In* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX: College Station, TX (Ocean Drilling Program), 5–43.

Miller, K.G., Sugarman, P.J., Browning, J.V., Pekar, S.F., Katz, M.E., Cramer, B.S., Monteverde, D., Uptegrove, J., McLaughlin, P.P., Jr., Baxter, S.J., Aubry, M.-P., Olsson, R.K., Van Sickel, B., Metzger, K., Feigenson, M.D., Tiffin, S., and McCarthy, F., 2001. Ocean View site. *In* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX (Suppl.), 1–72 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

Miller, K.G., Sugarman, P.J., Browning, J.V., Cramer, B.S., Olsson, R.K., de Romero, L., Aubry, M.-P., Pekar, S.F., Georgescu, M.D., Metzger, K.T., Monteverde, D.H., Skinner, E.S., Uptegrove, J., Mullikin, L.G., Muller, F.L., Feigenson, M.D., Reilly, T.J., Brenner, G.J., Queen, D., 2000. Ancora site. *In* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., *Proc. ODP, Init. Repts.,* 174AX (Suppl.), 1–85 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station TX 77845-9547, USA.

Newell, W.L., Powars, D.S., Owens, J.P., Stanford, S.D., and Stone, B.D., 2000. Surficial geologic map of central and southern New Jersey, 1:100,000. *U.S. Geol. Surv. Map Ser.,* I-2540-D.

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

Olsson, R.K., Gibson, T.G., Hansen, H.J., and Owens, J.P., 1988. Geology of the northern Atlantic coastal plain: Long Island to Virginia. *In* Sheridan, R.E., and Grow, J.A. (Eds.), *The Geology of North America* (Vol. I-7): *The Atlantic Continental Margin: U.S.:* Boulder (Geol. Soc. Am.), 87–105.

Oslick, J.S., Miller, K.G., Feigenson, M.D., and Wright, J.D., 1994. Oligocene–Miocene strontium isotopes: stratigraphic revisions and correlation to an inferred glacioeustatic record. *Paleoceanography,* 9(3):427–443.

Owens, J.P., Minard, J.P., Sohl, N.F., and Mello, J.F., 1970. Stratigraphy of the outcropping post-Magothy Upper Cretaceous formations in southern New Jersey and northern Delmarva Peninsula, Delaware and Maryland. *U.S. Geol. Surv. Prof. Pap.,* 674.

Owens, J.P., Sugarman, P.J., Sohl, N.F., Parker, R.A., Houghton, H.F., Volkert, R.A., Drake, A.A., Jr., and Orndorff, R.C., 1998. Bedrock geologic map of central and southern New Jersey, 1:100,000. *Misc. Invest. Ser. Map,* I-2540-B.

Posamentier, H.W., Jervey, M.T., and Vail, P.R., 1988. Eustatic controls on clastic deposition, I. Conceptual framework. *In* Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., and Van Wagoner, J. (Eds.), *Sea-Level Changes: An Integrated Approach.* Spec. Publ.—Soc. Econ. Paleontol. Mineral., 42:109–124.

Ramsey, K.W., 1993. Geologic map of the Milford and Mispillion River Quadrangles, 1:24,000. *Del., Geol. Surv., Geol. Map,* 8.

Reading, H.G., 1986. *Sedimentary Environments and Facies:* Boston (Blackwell Scientific Publ.).

Smith, D.G., and Smith, N.D., 1980. Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta. *J. Sediment. Petrol.,* 50:157–164.

Sugarman, P.J., and Miller, K.G., 1997. Correlation of Miocene sequences and hydrogeologic units, New Jersey Coastal Plain. *In* Segall, M.P., Colquhoun, D.J., and Siron, D.L. (Eds.), *Evolution of the Atlantic Coastal Plain–Sedimentology, Stratigraphy, and Hydrogeology.* Sediment. Geol., 108:3–18.

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

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

Vail, P.R., Mitchum, R.M., Jr., Todd, R.G., Widmier, J.M., Thompson, S., III, Sangree, J.B., Bubb, J.N., and Hatlelid, W.G., 1977. Seismic stratigraphy and global changes of sea level. *Mem.—Am. Assoc. Pet. Geol.,* 26:49–212.

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

Figure F1. Location map showing existing ODP boreholes analyzed as a part of the New Jersey/Mid-Atlantic (MAT) sea level transect. Also shown are multichannel seismic data (MCS) from *Ewing* cruise 9009 (Ew9009), *Oceanus* cruise (Oc270), and *Cape Hatteras* cruise (CH0698). Fort Mott borehole location is shown as a star. 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.

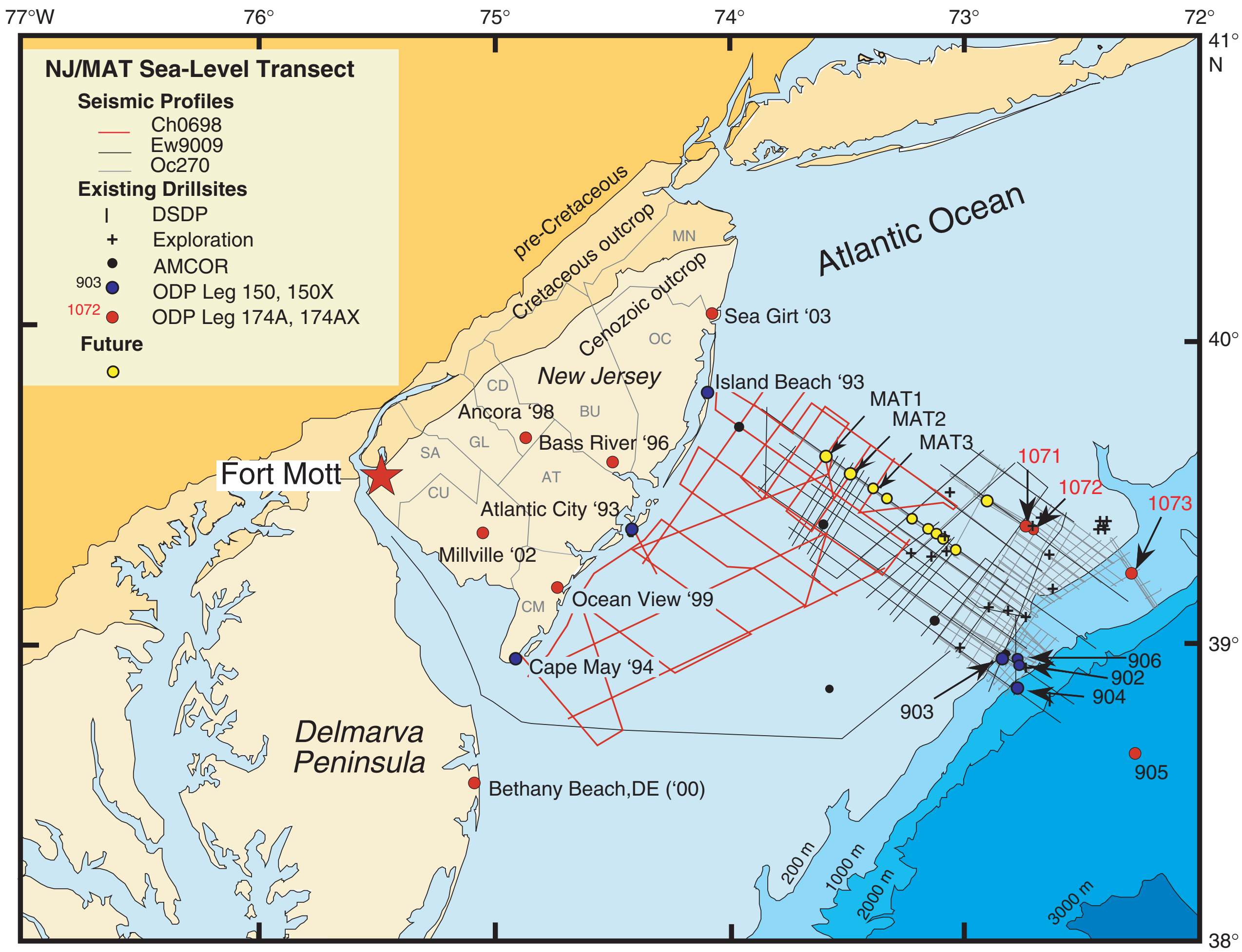


Figure F2. Lithologic and hydrostratigraphic terminology for units recovered from the Fort Mott borehole. Gray areas in the gamma and resistivity log columns indicate aquifers.

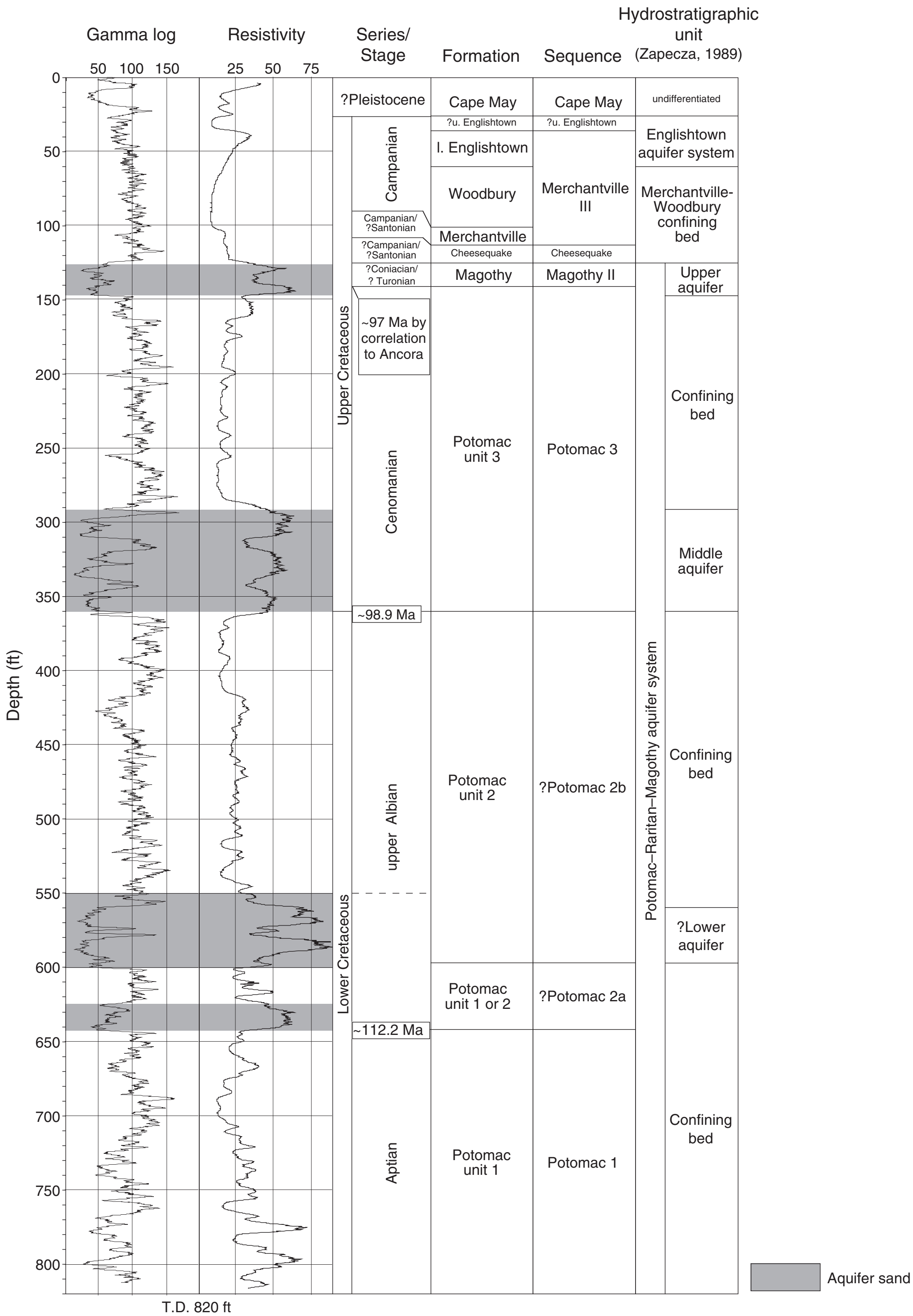


Figure F3. A. Facies model for anastomosed river sedimentation from the Potomac Formation (modified from Miall, 1996). Photographs are examples of each facies in a core from given levels in the Fort Mott borehole. (Continued on next page.)

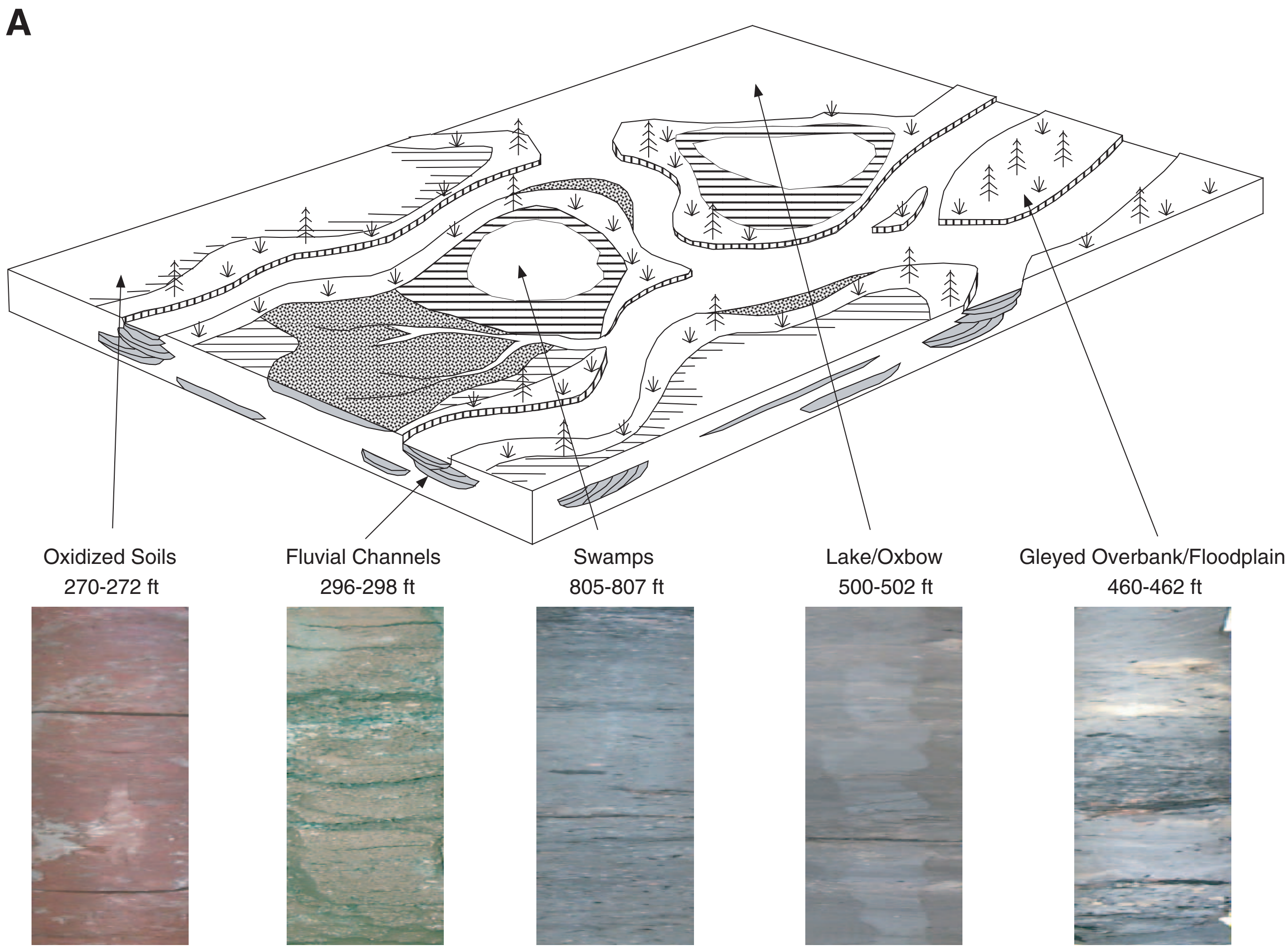


Figure F3 (continued). B. Facies model for delta plain sedimentation from the Potomac Formation (modified from Reading, 1986). Photographs are examples of each facies in a core from given levels in the Fort Mott borehole.

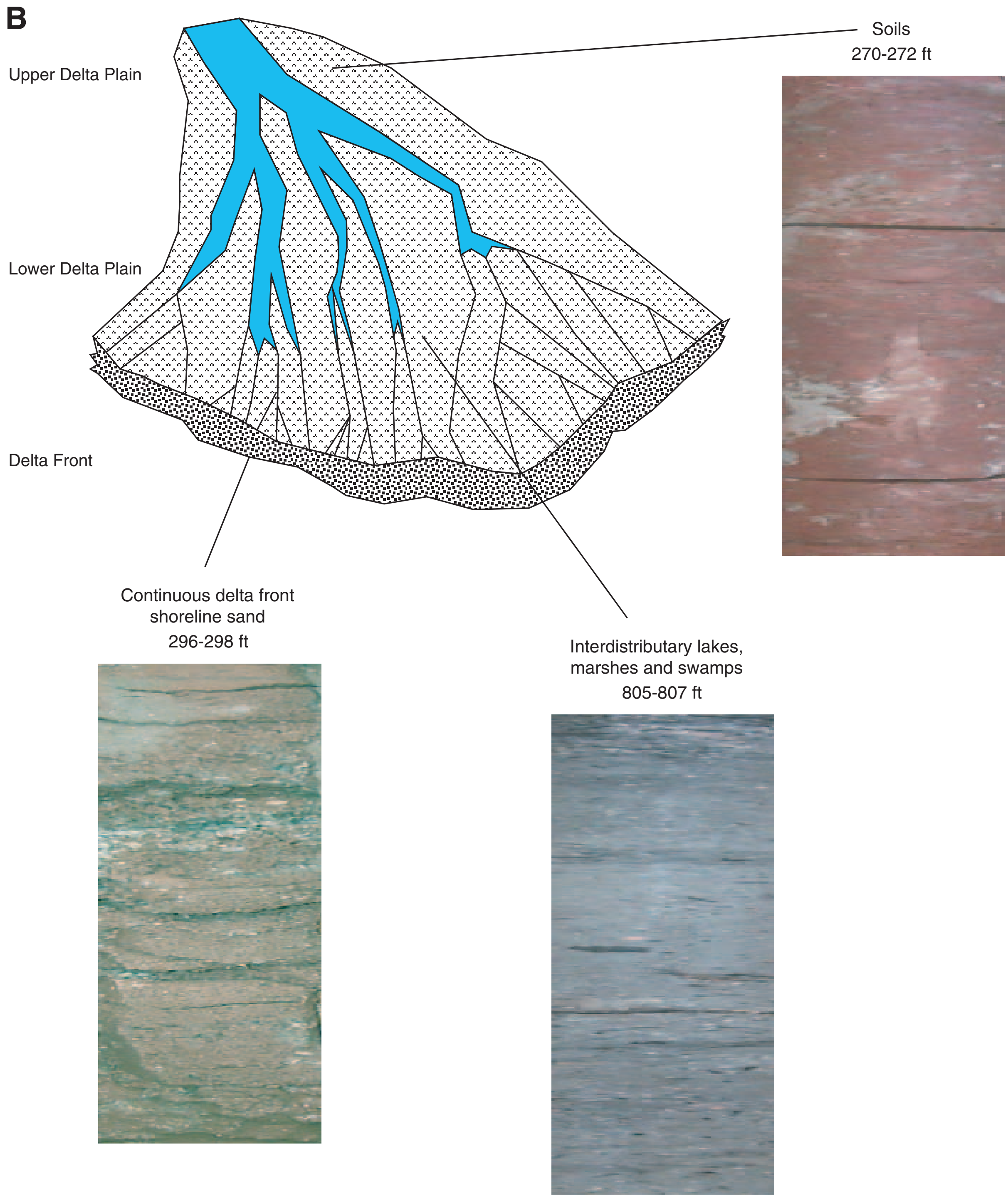


Figure F4. Summary stratigraphic section for Cape May Formation (Quaternary), Marshalltown? Formation (?Upper Cretaceous), Englishtown Formation (Upper Cretaceous), Woodbury Formation (Upper Cretaceous), Merchantville Formation (Upper Cretaceous), Cheesequake Formation (Upper Cretaceous), and Magothy Formation (Upper Cretaceous) from the Fort Mott borehole. This, and subsequent similar figures, summarize core recovery, lithology, gamma ray log signature, age, and environment.

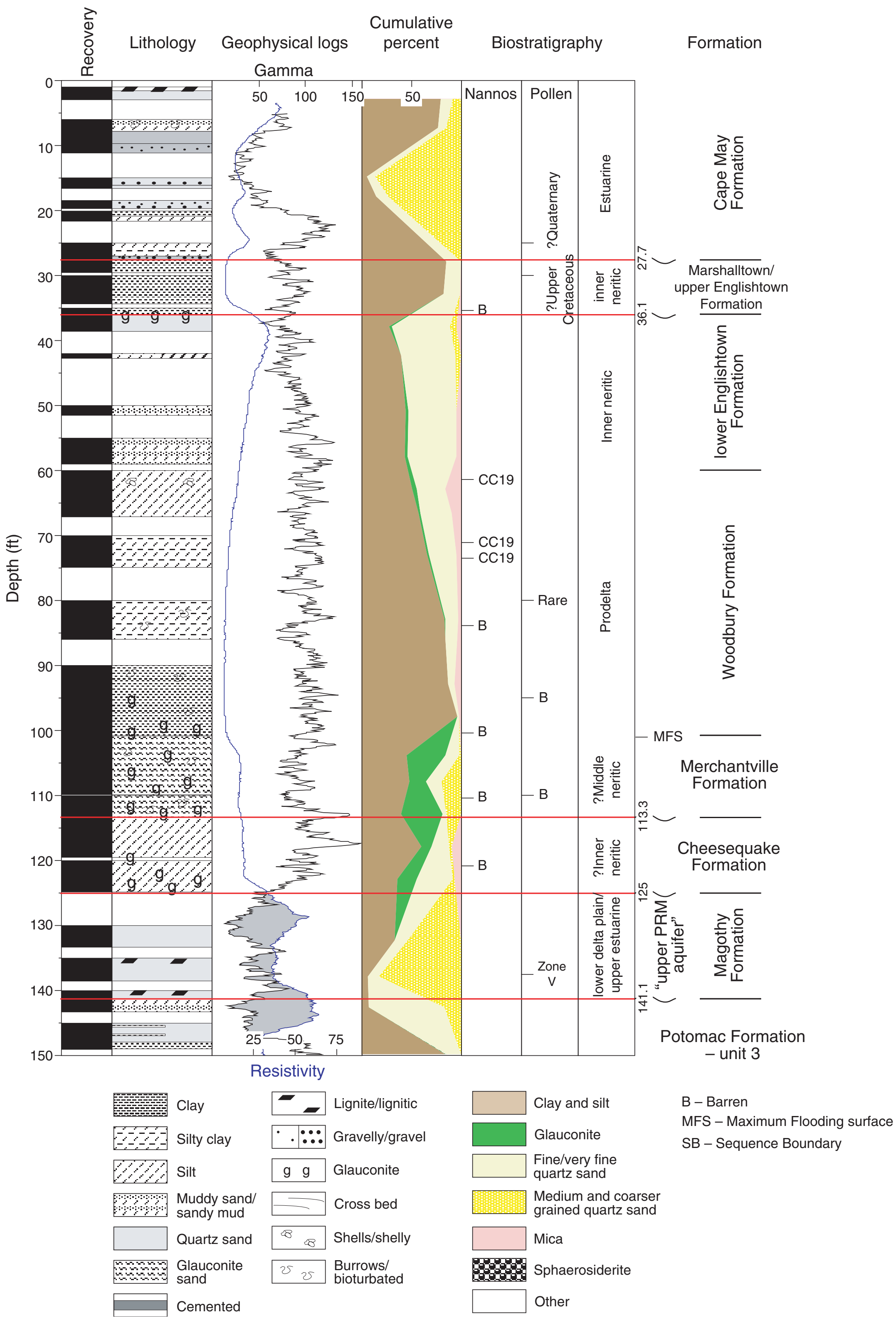


Figure F5. Summary stratigraphic section for Potomac Unit 3 (Cenomanian) from the Fort Mott borehole.

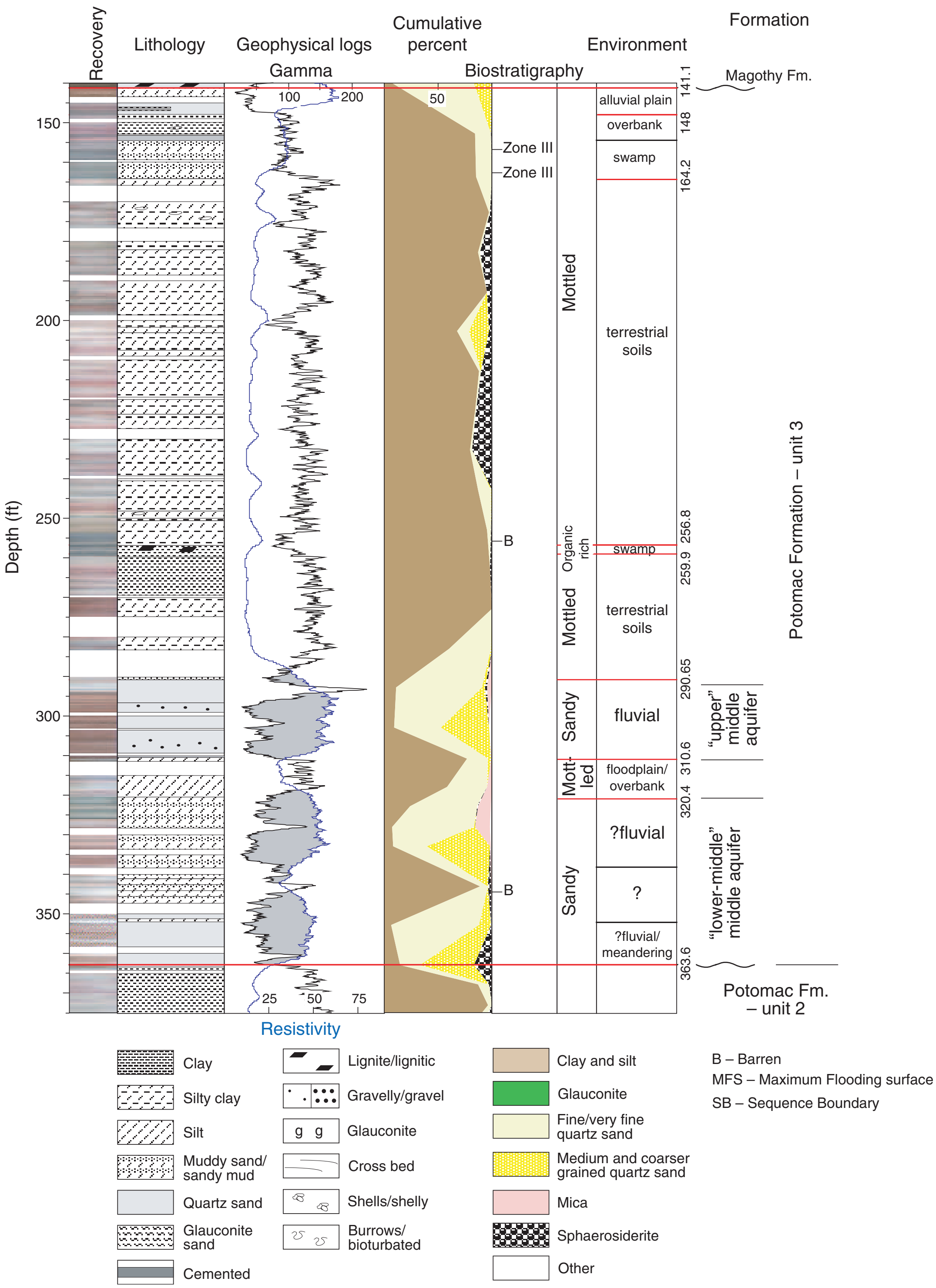


Figure F6. Summary stratigraphic section for Potomac Unit 2 partim (Albian), from the Fort Mott borehole.

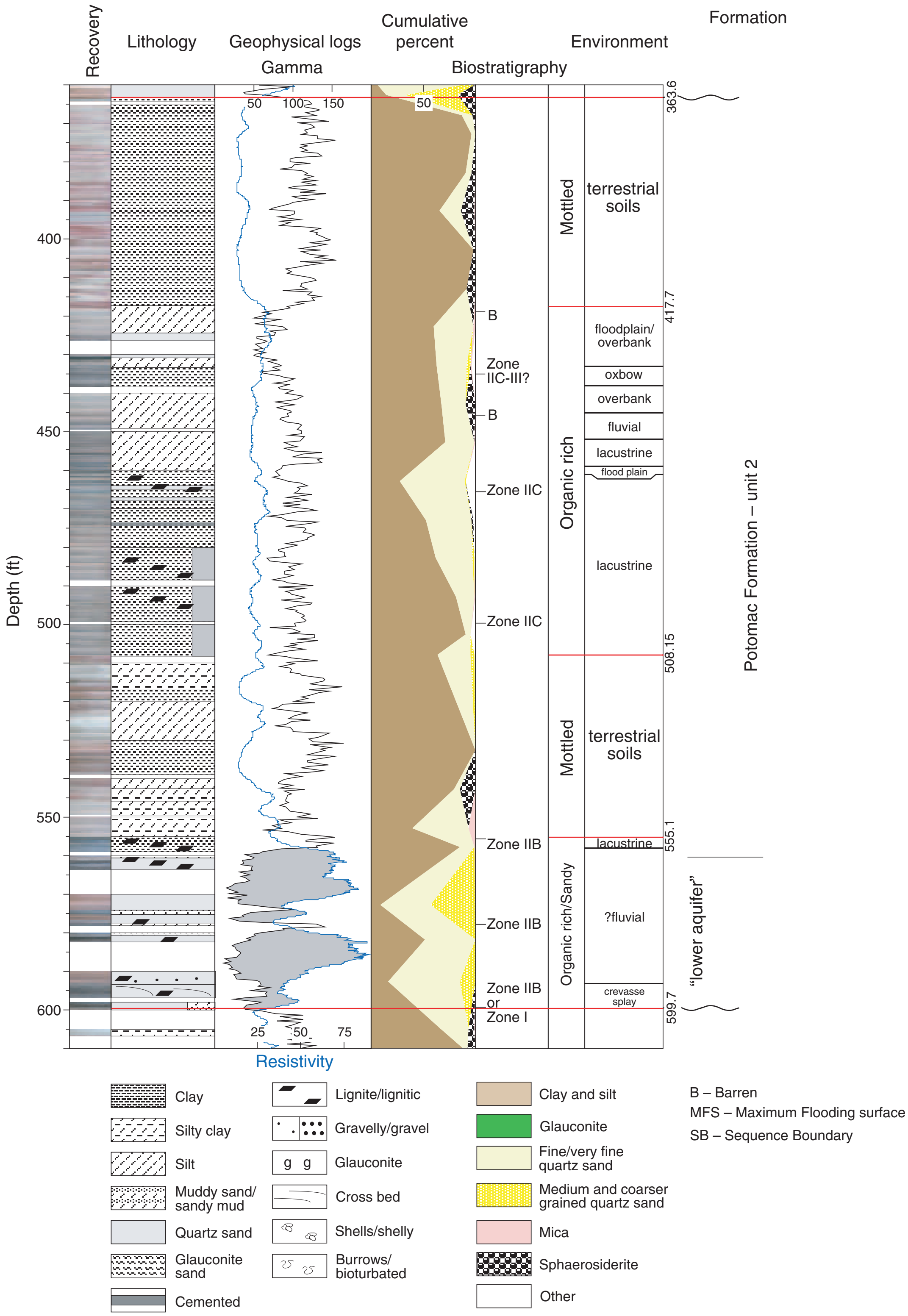


Figure F7. Summary stratigraphic section for Potomac Unit 2 partim (Albian) and Potomac Unit 1 (Aptian) from the Fort Mott borehole. T.D. = total depth.

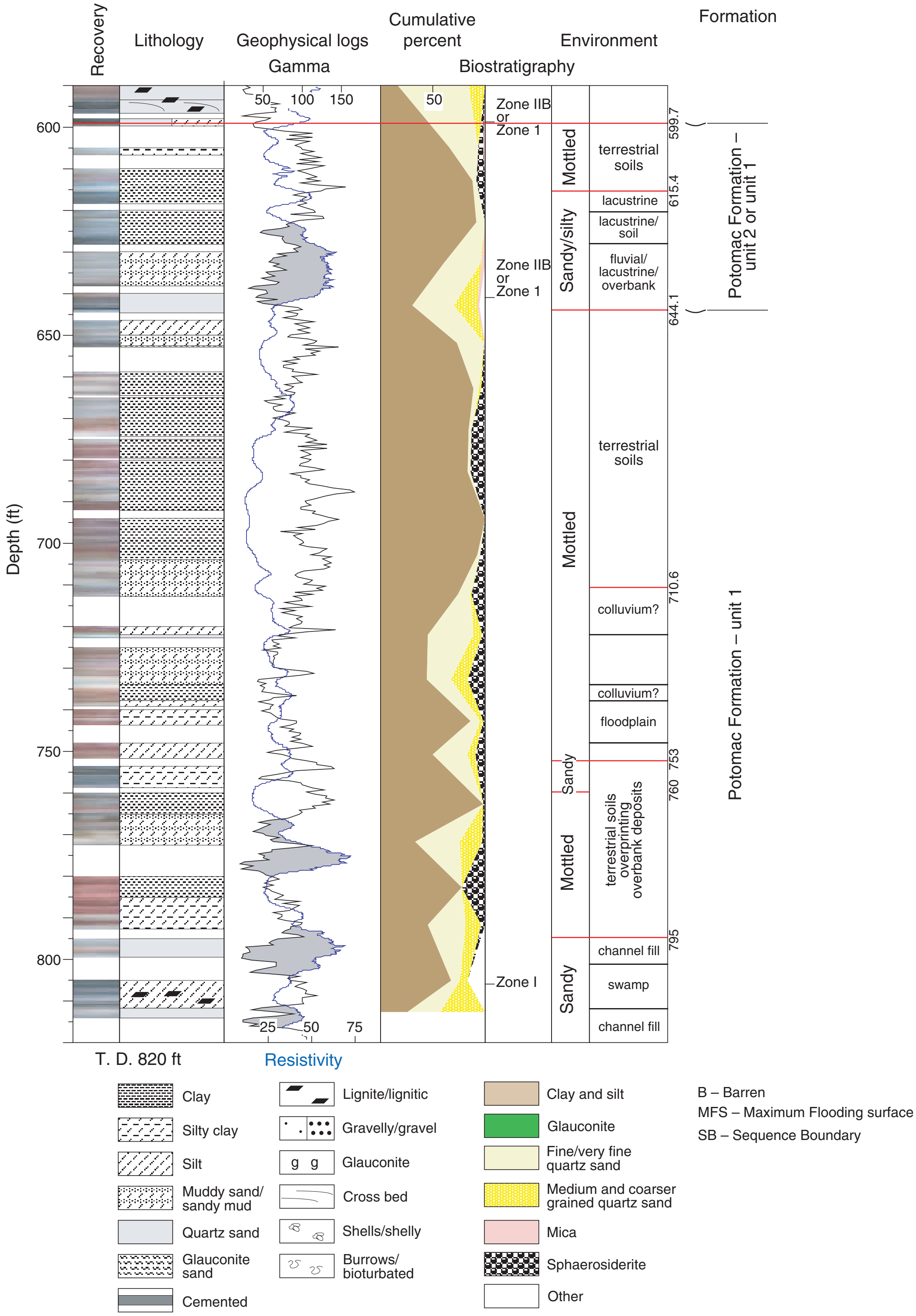


Table T1. Core descriptions, Fort Mott borehole, Leg 174AX. (Continued on next page.)

Run	Date (Oct 2001)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Primary lithology	Formation
1	3	1–6	5.0	2.00	40	Silty sand	Cape May
2	3	6–9.5	3.5	4.20	120	Sandy clay	Cape May
3	3	9.5–15	5.5	1.60	29	Sandy clay	Cape May
4	3	15–18.5	3.5	1.60	46	Gravely sand	Cape May
5	3	18.5–20	1.5	1.10	73	Gravely sand	Cape May
6	3	20–25	5.0	1.60	32	Clay	Cape May
7	3	25–30	5.0	4.70	94	Sand on top; 27.7 ft contact; clay below	Cape May/?upper Englishtown
8	3	30–35	5.0	4.20	84	Clay	?upper Englishtown Fm
9	3	35–40	5.0	3.70	74	Clay on top; 36.0 ft contact; sand below	?upper Englishtown/lower Englishtown
10	4	40–45.5	5.0	2.80	56	Slurry in top 2.1 ft; clay with drilling mud	lower Englishtown
11	4	45.5–50	5.0	0.00	0	?	lower Englishtown
12	4	50–55	5.0	1.40	28	Laminated silt	lower Englishtown
13	4	55–60	5.0	4.00	80	Laminated silt	lower Englishtown
14	4	60–63.6	3.6	3.60	100	Laminated silt	Woodbury
15	5	63.6–70	6.4	3.45	54	Silt and laminated silt	Woodbury
16	5	70–80	10.0	4.80	48	Silt and laminated silt	Woodbury
17	5	80–90	10.0	6.00	60	Silt and laminated silt	Woodbury
18	5	90–95	5.0	5.10	102	Laminated clay	Woodbury
19	5	95–100	5.0	5.20	104	Clay/silt with glauconite at base	Woodbury
20	5	100–110	10.0	9.90	99	Glauconitic sandy clay and silt	Woodbury/Merchantville
21	5	110–120	10.0	9.50	95	Glauconitic clayey sand; 113.3 ft contact; silt below	Merchantville/Cheesequake
22	5	120–130	10.0	4.80	48	Sandy silt with chert nodule at bottom	Cheesequake
23	5	130–135	5.0	3.30	66	Sand	Magothy
24	5	135–140	5.0	3.40	68	Sand	Magothy
25	6	140–145	5.0	3.30	66	Sand with interlaminated silty clay; 141.1 ft contact; sand below	Magothy
26	6	145–150	5.0	4.00	80	Interbedded clay and fine sand with sphaerosiderite nodules	Potomac
27	6	150–160	10.0	9.30	93	Clay with sphaerosiderite; sand to silty sand; silt	Potomac
28	6	160–170	10.0	5.80	58	Silt; very fine silty sand; silty clay	Potomac
29	6	170–180	10.0	6.60	66	Clay, silty with clayey silt laminae	Potomac
30	6	180–190	10.0	8.40	84	Silty clay, finely banded; sphaerosiderite	Potomac
31	6	190–200	10.0	8.50	85	Silty clay; mottled/laminated	Potomac
32	7	200–210	10.0	9.00	90	Clay, silty, very fine sand; mottled/laminated	Potomac
33	7	210–220	10.0	9.70	97	Clay, silty, mottled/laminated; some sphaerosiderite	Potomac
34	7	220–230	10.0	7.30	73	Clay, mottled/laminated; root zones	Potomac
35	7	230–240	10.0	9.30	93	Silt, mottled, common sphaerosiderite	Potomac
36	7	240–245	5.0	5.00	100	Clay; 241 ft faint contact; slightly clayey silt below	Potomac
37	8	245–250	5.0	5.20	104	Mottled clay	Potomac
38	8	250–260	10.0	10.30	103	Mottled clay and silty clay; sand	Potomac
39	8	260–270	10.0	9.65	97	Mottled clay	Potomac
40	8	270–280	10.0	4.80	48	Mottled clay	Potomac
41	8	280–290	10.0	3.10	31	Mottled clay	Potomac
42	9	290–290.4	0.4	0.40	100	Micaceous silt	Potomac
43	9	290.4–300	9.6	8.50	89	Sand, some gravel	Potomac
44	9	300–303.5	3.5	3.20	91	Sand and gravel	Potomac
45	9	303.5–310	6.5	6.00	92	Coarse sand	Potomac
46	9	310–315	5.0	1.35	27	Coarse sand and mottled clay	Potomac
47	10	315–320	5.0	5.25	105	Mottled clay	Potomac
48	10	320–330	10.0	8.35	84	Medium to fine sand	Potomac
49	10	330–335	5.0	3.75	75	Medium to fine sand	Potomac
50	10	335–340	5.0	3.15	63	Medium to fine sand	Potomac
51	10	340–350	10.0	7.10	71	Interbedded clay and fine sand	Potomac
52	10	350–360	10.0	8.65	87	Interbedded clay and fine sand	Potomac
53	10	360–365	5.0	4.25	85	Interbedded clay and fine sand	Potomac
54	11	365–370	5.0	5.00	100	Mottled clay	Potomac
55	11	370–380	10.0	10.00	100	Mottled clay	Potomac
56	11	380–390	10.0	10.00	100	Mottled clay	Potomac
57	11	390–400	10.0	10.00	100	Mottled clay	Potomac
58	11	400–410	10.0	10.00	100	Mottled clay	Potomac
59	12	410–420	10.0	10.00	100	Mottled clay and silty clay	Potomac
60	12	420–430	10.0	6.30	63	Silty sand and clayey sand	Potomac
61	12	430–440	10.0	7.90	79	Silty sand and clayey sand	Potomac
62	12	440–450	10.0	9.40	94	Silty sand and clayey sand	Potomac
63	12	450–460	10.0	10.10	101	Slightly silty clay	Potomac
64	12	460–470	10.0	10.20	102	Slightly silty clay	Potomac
65	12	470–475	5.0	5.30	106	Slightly silty clay; sandstone interbed	Potomac

Table T1 (continued).

Run	Date (Oct 2001)	Cored interval (ft)	Run length (ft)	Recovery (ft)	Recovery (%)	Primary lithology	Formation
66	13	475–480	5.0	5.40	108	Silty clay, mottled/laminated	Potomac
67	13	480–490	10.0	8.65	87	Silty clay with interlaminated very fine to fine sand	Potomac
68	13	490–500	10.0	9.30	93	Silty clay with interlaminated very fine to fine sand	Potomac
69	13	500–510	10.0	8.55	86	Silty clay with interlaminated very fine to fine sand; 508.15 ft contact; silty clay below	Potomac
70	13	510–520	10.0	10.35	104	Clayey silt; 517 ft contact; slightly silty clay	Potomac
71	13	520–530	10.0	9.90	99	Slightly clayey silt	Potomac
72	15	530–540	10.0	9.00	90	Mottled clay	Potomac
73	15	540–550	10.0	9.40	94	Mottled clay/gray silt	Potomac
74	15	550–560	10.0	9.30	93	Mottled clay/gray silt	Potomac
75	15	560–570	10.0	3.70	37	Sand and lignite	Potomac
76	15	570–580	10.0	8.00	80	Sand, lignite, clay	Potomac
77	15	580–590	10.0	2.30	23	Silty clay; lignitic very fine sand	Potomac
78	16	590–598	8.0	6.80	85	Lignitic medium sand; very coarse sand; very fine sand	Potomac
79	16	598–605	7.0	1.90	27	Lignitic sand and interbedded clay	Potomac
80	16	605–610	5.0	1.80	36	Gray silt	Potomac
81	16	610–620	10.0	8.40	84	Mottled clay with sand at bottom	Potomac
82	16	620–630	10.0	8.10	81	Clay over interbedded silt/sand	Potomac
83	17	630–640	10.0	8.20	82	Silty sand	Potomac
84	17	640–646.5	6.5	4.70	72	Silty sand	Potomac
85	17	646.5–651	4.5	6.00	133	Silty clay	Potomac
86	17	651–660	9.0	1.85	34	Silty sand, silty clay (2 runs, 86 and 86A)	Potomac
86A	17	651–661	9.0	1.20	34	Silty sand, silty clay (2 runs, 86 and 86A)	Potomac
87	18	660–665	5.0	4.55	91	Mottled clay	Potomac
88	18	665–675	10.0	9.70	97	Mottled clay	Potomac
89	18	675–680	5.0	4.70	94	Mottled clay	Potomac
90	18	680–690	10.0	10.00	100	Mottled clay	Potomac
91	19	690–694	4.0	2.15	54	Mottled clay	Potomac
92	19	694–700	6.0	6.10	102	Mottled clay	Potomac
93	19	700–710	10.0	10.25	103	Mottled clay over light gray clayey silt	Potomac
94	20	710–720	10.0	2.90	29	Mottled clayey silt	Potomac
95	20	720–725	5.0	2.80	56	Clayey silt	Potomac
96	20	725–730	5.0	5.50	110	Hard mottled silty sand	Potomac
97	20	730–740	10.0	9.20	92	Hard mottled silty sand and soft clay/sand	Potomac
98	22	740–748	8.0	3.90	49	Mottled silt	Potomac
99	22	748–753.5	5.5	4.80	87	Laminated clay and silt	Potomac
100	22	753.5–760	6.5	5.15	79	Silt, clay, sand	Potomac
101	22	760–765	5.0	5.00	100	Silty clay	Potomac
102	22	765–775	10.0	7.50	75	Mottled clay and silt	Potomac
103	23	775–780	5.0	0.00	0	?	Potomac
104	23	780–785	5.0	5.10	102	Mottled clay	Potomac
105	23	785–795	10.0	7.70	77	Mottled clay	Potomac
106	23	795–805	10.0	4.50	45	Very fine sand and silt	Potomac
107	23	805–810	5.0	5.20	104	Lignitic silt and clay	Potomac
108	23	810–820	10.0	4.00	40	Silt over clayey sand	Potomac
Fort Mott coring totals:			820	638.85	77.9		

Table T2. Pollen occurrences in the Fort Mott borehole, Leg 174AX. (See table note. Continued on next two pages.)

Sample depth (ft)	Sample depth (m)	Stage	Zone	Stratigraphic correlation	Paleoecology	Palynological recovery	Diagnostic palynomorphs, pollen, and spores	Biozone/stage	Discussion
137.5	41.9	Late Turonian	V	Magothy Formation–South Amboy Fire Clay Member	Nonmarine	Good	*Complexipollis exigua* Christopher	V	Diagnostic angiosperms make up a small part of the total microflora. The palynological assemblage is dominated by spores of the Sphagnaceae, Pinaceae and Bryophyta. Advanced Normapolles of the Magothy are absent. Typical Normapolles of the South Amboy Fire Clay are represented by such forms as *Complexipollis* sp. C and *Complexipollis exigua* and *Porocolpopollenites* sp.
							Complexipollis sp. C Doyle and Robbins, 1975	IV-V	
							Complexipollis sp. v Christopher	V	
							Nyssapollenites spp. Wolf & Pakiser	V	
							Porocolpopollenites sp. Doyle and Robbins, 1975	V	
							Tricolporopollenites sp. C Doyle and Robbins, 1975	V	
157.0	47.9	Early Cenomanian	III	Uppermost Patapsco: Elkneck Beds of Maryland	Nonmarine	Very good	*Granulatisporites dailyi*	Zone IIC and III	The most common angiosperms in this sample are the pollen of *Tricolporoidites* sp. A Doyle and Robbins, 1975, which is restricted to Zone III. *Tricolporopollenites* sp. B is also restricted to Zone III. Many of the spores found in this sample are typically found throughout the Potomac Group.
							Rugubivesiculites reductus	II-Maestrichtian	
							Rugubivesiculites rugosus	IIC-III	
							Taurocusporites spackmani Brenner, 1962	IIB2-III	
							Tricolporopollenites sp. B Doyle and Robbins, 1975	III	
							Tricolporoidites subtilliz	IIC-III	
							Tricolporoidites sp. A Doyle and Robbins,1975	IIC-III (Rare in II)	
162.8	49.6	Early Cenomanian	III	Uppermost Patapsco: Elkneck Beds of Maryland	Nonmarine	Very good	*Ajatipollis* sp. A Doyle and Robbins, 1975	IIB-III, most common in III	The most common angiosperm in this sample is the pollen of *Tricolporoidites* B Doyle and Robbins, 1975, which is restricted to Zone III. *Tricolporopollenites* sp. A is also more common in Zone III.
							Clavatipollenites hughesi	I-III	
							Granulatisprites dailyi	Common in Zones IIC & III	
							Tricolporopollenites sp. B Doyle and Robbins, 1975	III	
							Tricolporoidites sp. B Doyle and Robbins, 1975	III	
435.4	132.7	Late Albian	IIC-?III	Upper Patapsco		Very poor	*Araucariacites australis*	More abundant in II & IIC	There are no stratigraphically restricted palynomorphs in this poorly preserved sample. There is a lot of fusain and degraded vitrain present. This is common in terrains that have undergone forest fires. Usually only the most resistant spores survive.
							Cicatricosisporites hallei	I-III	
							Gleicheniidites circinidites	I-III	
							Granulatisporites dailyi	I-III (Common to IIC)	
							Taurocusporites reduncus	II-III	
465.3	141.8	Late Albian	IIC	Upper Patapsco	Nonmarine	Very good	*Araucariacites australis* (very abundant)	II-Cenozoic	The abundance of small, prolate tricolporates and the common appearance of *Tricolporpollenites distinctus* and *Tricolporopollenites triangulus*, together with the absence of any oblate tricolporates that are commonly found in Zone III, clearly place this sample in Zone IIC.
							Pinuspollenites spp. (very abundant)	Broad range	
							Tricporpollenites distinctus	IIC-III	
							Tricolporopollenites triangulus	Rare in Upper IIB, first occurs/ common in IIC/III	
							Tricolpopollenites minutus Brenner	II-III	
							Tricolpopollenites micromunis	II-III	

Table T2 (continued).

Sample depth (ft)	Sample depth (m)	Stage	Zone	Stratigraphic correlation	Paleoecology	Palynological recovery	Diagnostic palynomorphs, pollen, and spores	Biozone/stage	Discussion
500.0	152.4	Albian	IIC	Upper Patapsco	Nonmarine	Fair	*Araucariacites australis*	Very abundant from II-Cenozoic	The assemblage is characterized by an abundance of *Araucariacites australis* and *Pinuspollenites* spp. as in the sample above at 465.3 ft.
							Brenneropollis peroreticulatus	I-III	
							Pinuspollenites spp. (very abundant)	Broad range	
							Tricolpites albiensis	IIC-III	
							Tricolporoidites sp. A Doyle and Robbins, 1975	IIC-III	
							Tricolporoidites subtilis	IIC-III	
556.2	169.5	Albian	IIB	Upper Patapsco	Nonmarine	Poor	*Araucariacites australis* (very abundant)	II-Cenozoic	
							Appendicisporites segmentus	II	
							Cicatricosisporites hallei (abundant)	I-II	
							Cicatricosisporites patapscoensis	IIB	
							Cicatricosisporites potomacensis	I-II	
577.2	175.9	Albian	IIB	Upper Patapsco	Nonmarine	Poor	*Araucariacites australis* (abundant)	Common from II-Cenozoic	The appearance of *C. patapscoensis* at 557.2 and 556.2 ft indicates a Zone II date for both these samples.
							Cicatricosisporites hallei (abundant)	I-II	
							Eucommiidites troedssoni	I-II	
							Classopollis torosus	I-IV	
							Cicatricosisporites patapscoensis	IIB	
							Clavatipollenites hughesi	I-III	
599.3	182.7	Aptian	I	Patuxent-Arundel	Nonmarine	Fair	*Classopollis torosus*	More common in Zone I	In samples 599.3, 641.05, and 806 ft the organic residue shows a marked increase in vitrain and fusain particles. There are no tricolpate or tricolporate pollen, or any pteridophyte spores that are typical of Zone II of the Patapsco Formation. There is also an increase in the pollen of Classopollis, Eucommiidites, Cicatricosisporites and smooth triangular trilete spores of the *Cyatheaceae*. This type of assemblage is characteristic of the Patuxent-Arundel Sequence in Maryland.
							Clavatipollenites hughesi	More common in Zone I	
							Very small *Cicatricosisporites* spp.		
							Cicatricosisporites aralica	More common in Zone I	
							Cicatricosisporites australensis	More common in Zone I	
							Deltoidospora hallii (Cyatheaceae)	More common in Zone I	
							Pilosisporites trichopapillosus	Zone I-II	
641.1	195.4	Aptian	I	Patuxent-Arundel	Nonmarine	Fair to poor	*Classopollis torosus*	More common in Zone I	See Discussion for sample 599.3 ft.
							Clavatipollenites hughesi	More common in Zone I	
							Alisporites bilateralis	I-II	
							Cicatricosisporites spp.	I-II	
							Cingulatisporites eukirchensoides	I-II	
							Cicatricosisporites australensis	More common in Zone I	
							Cicatricosisporites dorogensis	Restricted to Zone I	
							Deltoidospora hallii (Cyatheaceae)	More common in Zone I	

Table T2 (continued).

Sample depth (ft)	Sample depth (m)	Stage	Zone	Stratigraphic correlation	Paleoecology	Palynological recovery	Diagnostic palynomorphs, pollen, and spores	Biozone/stage	Discussion
							Classopollis torosus	More common in Zone I	
							Pilosisporites trichopapillosus	I-II	
806.0	245.7	Aptian	I	Patuxent-Arundel	Nonmarine	Very poor	*Cicatricosisporites* spp.	I-II	See Discussion for sample 599.3 ft.
							Cicatricosisporites australensis	More common in Zone I	
							Classopollis torosus	More common in Zone I	
							Deltoidospora hallii (Cyatheaceae)	More common in Zone I	
							Trilobosporites crassus	I-II	

Note: Data in this table determined by G. Brenner.

Table T3. Data used to construct the cumulative percent plots on Figures F4–F7. (**See table notes.** Continued on next page.)

Sample depth (ft)	Clay/silt (%)	Glauconite (%)*	Fine quartz (%)	Medium/coarser quartz sand (%)	Sphaerosiderite (%)*	Mica (%)*	Other (%)*
3.0	79.43	0	13	8	0	0	0
7.5	76.79	0	9	14	0	0	0
15.0	5.15	0	9	86	0	0	0
18.0	14.69	0	13	73	0	0	0
28.0	85.28	0	15	0	0	0	0
33.0	82.00	0	17	0	0	1	0
38.0	27.66	3	58	7	0	4	0
42.4	39.56	0	55	6	0	0	0
51.0	44.54	3	48	0	0	4	0
58.0	43.95	3	49	0	0	4	0
63.0	50.78	5	28	0	0	16	0
66.7	57.38	2	31	0	0	9	0
73.0	65.73	2	28	0	0	5	0
83.0	83.21	1	13	0	0	3	0
86.0	84.60	0	11	0	0	4	0
93.0	87.35	0	6	0	0	7	0
98.0	96.32	0	2	0	0	2	0
104.0	45.34	39	13	2	0	0	0
108.0	48.06	17	16	19	0	0	0
113.0	39.83	41	4	15	0	0	0
118.0	60.49	10	17	3	0	9	0
123.0	36.17	19	36	2	0	6	0
132.5	33.01	0	13	54	0	0	0
138.0	6.03	0	11	83	0	0	0
142.7	7.02	0	76	17	0	0	0
153.0	84.14	0	15	0	1	0	0
164.0	85.02	0	14	0	0	0	0
173.0	96.59	0	2	0	2	0	0
183.0	86.82	0	2	0	11	0	0
193.0	95.22	0	0	0	5	0	0
203.0	67.34	0	11	19	3	0	0
213.0	87.76	0	2	0	11	0	0
223.0	84.22	0	0	0	15	0	0
233.0	79.12	0	2	0	19	0	0
243.0	86.47	0	13	0	0	0	0
253.0	94.92	0	4	0	1	0	0
263.0	97.65	0	0	0	2	0	0
273.0	99.63	0	0	0	0	0	0
283.0	59.81	0	40	0	0	0	0
293.0	10.58	0	80	3	2	4	0
303.0	9.41	0	43	44	0	0	3
311.0	76.68	0	19	3	0	1	0
318.0	58.06	0	37	0	0	5	0
323.0	23.90	0	62	1	1	12	1
328.0	7.14	0	76	1	0	14	2
333.0	8.11	0	31	59	0	1	1
343.0	88.56	0	8	0	2	1	0
353.0	6.42	0	81	12	0	0	1
363.0	14.40	0	19	49	17	0	0
368.0	86.89	0	10	0	2	1	0
373.0	95.74	0	4	0	0	0	0
383.0	90.68	0	6	0	3	0	0
393.0	65.08	0	20	0	13	1	0
403.0	97.97	0	0	0	2	0	0
413.0	90.95	0	1	0	8	0	0
423.0	60.03	0	37	1	0	2	0
433.0	62.45	0	29	3	0	2	4
443.0	67.46	0	23	0	10	0	0
453.0	70.76	0	28	0	0	1	0
463.0	27.14	0	63	1	0	0	10
473.0	53.01	0	43	0	2	0	2
483.0	62.16	0	35	1	0	1	1
493.0	81.07	0	18	0	0	0	0
503.0	90.25	0	5	0	0	0	5
508.0	63.90	0	32	3	0	0	1
533.0	99.53	0	0	0	0	0	0
543.0	79.45	0	6	0	14	1	0

Table T3 (continued).

Sample depth (ft)	Clay/silt (%)	Glauconite (%)*	Fine quartz (%)	Medium/coarser quartz sand (%)	Sphaerosiderite (%)*	Mica (%)*	Other (%)*
553.0	40.05	0	54	0	0	6	0
558.0	85.28	0	13	0	0	1	0
573.0	8.60	0	49	42	0	0	0
582.0	51.98	0	48	0	0	0	0
593.0	16.58	0	68	15	0	0	0
605.0	65.80	0	27	0	5	1	0
613.0	87.52	0	5	0	8	0	0
623.0	91.74	0	8	0	0	0	0
633.0	60.11	0	36	0	0	4	0
643.0	30.95	0	39	22	0	2	6
652.0	73.07	0	26	0	0	1	0
663.0	88.98	0	6	1	4	0	0
673.0	84.59	0	3	0	12	0	0
683.0	83.65	0	3	0	14	0	0
694.5	99.84	0	0	0	0	0	0
703.0	92.43	0	3	0	4	0	0
712.5	74.07	0	12	1	13	0	0
722.2	45.20	0	44	8	3	0	0
733.0	44.58	0	23	16	17	0	0
743.0	85.93	0	9	3	2	0	0
751.0	49.66	0	33	8	9	0	0
763.0	97.88	0	0	0	2	0	0
772.0	33.08	0	42	21	3	0	0
783.0	77.67	0	0	0	22	0	0
792.0	44.94	0	36	15	4	0	0
805.5	67.15	0	9	7	0	0	16
813.0	25.94	0	31	43	0	0	0

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

CHAPTER NOTE*

N1. Browning, J.V., Miller, K.G., McLaughlin, P.P., Sugarman, P.J., Kominz, M.A., Monteverde, D., Feigenson, M.D., and Hernández, J.C., submitted, Miocene sequences and facies, Bethany Beach, Delaware: effects of eustasy, tectonics, and sediment supply. *Geol. Soc. Am. Bull.*

*Dates reflect file corrections or revisions.