Preliminary Physical Stratigraphy, Biostratigraphy, and Geophysical Data of the USGS South Dover Bridge Core, Talbot County, Maryland

By Wilma B. Alemán González, David S. Powars, Ellen L. Seefelt, Lucy E. Edwards, Jean M. Self-Trail, Colleen T. Durand, Arthur P. Schultz, and Peter P. McLaughlin

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Cover. U.S. Geological Survey geologist and outer barrel of drill stem.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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By Wilma B. Alemán González,[1] David S. Powars,[1] Ellen L. Seefelt,[1] Lucy E. Edwards,[1] Jean M. Self-Trail,[1] Colleen T. Durand,[1] Arthur P. Schultz,[1] and Peter P. McLaughlin[2]

Introduction

The South Dover Bridge (SDB) corehole was drilled in October 2007 in Talbot County, Maryland (fig. 1). The main purpose for drilling this corehole was to characterize the Upper Cretaceous and Paleogene lithostratigraphy and biostratigraphy of the aquifers and confining units of this region. The data obtained from this core also will be used as a guide to geologic mapping and to help interpret well data from the eastern part of the Washington East 1:100,000-scale map near the town of Easton, Md. Core drilling was conducted to a depth of 700 feet (ft). The Cretaceous section was not penetrated due to technical problems during drilling. This project was funded by the U.S. Geological Survey's (USGS) Eastern Geology and Paleoclimate Science Center (EGPSC) as part of the Geology of the Atlantic Watersheds Project; this project was carried out in cooperation with the Maryland Geological Survey (MGS) through partnerships with the Aquifer Characterization Program of the USGS's Maryland-Delaware-District of Columbia Water Science Center and the National Cooperative Geologic Mapping Program.

The SDB corehole was drilled by the USGS drilling crew in the northeastern corner of the Trappe 7.5-minute quadrangle (fig. 2), near the type locality of the Boston Cliffs member of the Choptank Formation. Geophysical logs (gamma ray, single point resistance, and 16-inch and 64-inch normal resistivity) were run to a depth of 527.5 ft; the total depth of 700.0 ft could not be reached because of the collapse of the lower part of the hole. Of the 700.0 ft drilled, 531.8 ft of core were recovered, representing a 76 percent core recovery. The elevation of the top of the corehole is approximately 12 ft above mean sea level; its coordinates are lat 38°44′49.34″N. and long 76°00′25.09″W. (38.74704N., 76.00697W. in decimal degrees) (fig. 2).

A groundwater monitoring well was not installed at this site. The South Dover Bridge corehole was the first corehole that will be used to better understand the geology and hydrology of the Maryland Eastern Shore. (fig. 1).

Physical Stratigraphy and Lithology

The South Dover Bridge (SDB) corehole penetrated 700.0 ft of upper Paleocene to Pleistocene sediments. Nine formations are recognized in the corehole. From oldest to youngest, they are the Aquia Formation, Marlboro Clay, Nanjemoy Formation, Shark River Formation

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equivalent unit, Piney Point Formation, Drummonds Corner beds, Calvert Formation, Choptank Formation, and Kent Island Formation. Calcareous nannofossil and palynological data, together with detailed onsite field descriptions of the core, were used to assign ages to these formations (fig. 3; appendixes A, B, C, and E). The geologic time scale of Gradstein and others (2004) is used in this report. Box numbers in the unit descriptions below correspond to appendixes A and D.

Aquia Formation

In the SDB corehole, 30.7 ft of the upper part of the Aquia Formation was penetrated from 700.0 to 669.3 ft depth (box 73). The base of the Aquia was not reached; therefore, its total thickness is uncertain. The recovered upper part of the Aquia consists of very fine to fine, glauconitic quartz sand with variable amounts of scattered medium to very coarse sand grains and granules, shell and small wood fragments, and other organic material. The strata vary from massive to faintly bedded with variable amounts of burrowing, sparse to common foraminifera, and common to abundant, very fine to fine mica. The contact between the Aquia Formation and the overlying Marlboro Clay is at 669.3 ft. The contact is sharp with burrows as deep as 0.5 ft and is marked by olive-gray, glauconitic (very fine silt, 1 to 4 percent), silty clay above greenish-black, variably clayey and silty, very fine to fine, glauconitic (35–50 percent) quartz sand with a few scattered medium grains and very fine to medium-sized mica flakes. The age of the Aquia Formation is late Paleocene based on the presence of calcareous nannofossil representing Zone NP9a (Self-Trail, 2011) and dinoflagellates indicative of the *Muratodinium fimbriatum* Zone.

Marlboro Clay

The Marlboro Clay is 51.3 ft thick and is located between 669.3 and 618.0 ft depth (box 67). The unit consists primarily of silty clay with laminations and wisps of quartz silt and very fine to fine sandy quartz silt. It contains minor amounts of mica and glauconite (<1 percent) which slightly increase in abundance (<1–4 percent) in the basal 0.1 ft of the unit. A few wood bits and thin, small shells and molds are present from 631.0 to 630.5 ft. Burrows are common to abundant and vary in size and shape. From 669.0 to 665.8 ft, the Marlboro Clay is pale red. Above 665.8 ft the color is olive gray (5*Y* 4/1). The contact between the Marlboro Clay and the overlying Nanjemoy Formation is sharp and highly burrowed. The contact represents an unconformity because the lowest dinoflagellate zone that is normally found in the Nanjemoy across the region is missing. The upper contact of the Marlboro Clay is placed at 618.0 ft, which is the location of a small in situ remnant of grayish-olive-green, silty clay, which contrasts strongly with the basal Nanjemoy sediments. The basal Nanjemoy consists of greenish-black, very fine to medium, glauconitic quartz sand that contains a few shell fragments and coarser grains, including a few very fine phosphate pebbles and round pyrite nodules (<1 millimeter (mm)). The age of the Marlboro Clay is early Eocene based on the presence of calcareous nannofossils indicative of the upper part of Zone NP9a and the lower part of Zone NP10 (Self-Trail, 2011) and dinoflagellates representative of the *Muratodinium fimbriatum* Zone.

Nanjemoy Formation

The Nanjemoy Formation is 61.2 ft thick and is located between 618.0 and 556.8 ft depth (box 59). The Nanjemoy sediments vary from (1) clayey and silty, glauconitic quartz sand to (2) sandy, clayey silt to (3) sandy, silty clay. The unit contains a wide variety of common to scattered burrows and foraminifera and variable minor amounts of mica, pyrite, and small shell fragments. The unit contains six lithic packages, informally referred to as units A through F, which are bounded by sharp, mostly burrowed contacts ranging in thickness from 4.3 ft to 16.8 ft.

The basal unit A (618.0–613.7 ft depth) consists of 4.3 ft of very fine to medium glauconite (50–80 percent) sand with abundant burrows, scattered quartz grains, and shell fragments and molds that increase in abundance downward to the contact with the Marlboro Clay. The basal 0.3 ft of the unit also contains a few very fine phosphate pebbles and large burrows that penetrate downward at least 1.5 ft into the upper part of the Marlboro Clay, leaving only small remnants of in situ Marlboro Clay in the core in its upper 0.6 ft. The upper contact with overlying unit B is marked by a sharp contact at 613.7 ft between greenish-black, clayey and silty, glauconitic sand below and dark-greenish-gray, silty, slightly glauconitic, sandy clay above. This contact is interpreted to be a diastem within which lies the boundary between calcareous nannofossil Zones NP10 and NP11 (Self-Trail, 2011).

Unit B is 5.2 ft thick (613.7–608.5 ft depth) and consists of a fining-upward sequence. The basal 2.2 ft consists of silty very fine to medium glauconitic (<5–10 percent) and quartzose (5–10 percent) sand floating in a clay matrix. The upper 3.0 ft of the unit consists of foraminiferal, silty, and sandy clay. The unit ranges from massive to faintly laminated and variably burrowed (but less burrowed than unit A below) and includes quartz- and (or) glauconite-sand-filled and clay-filled burrows with foraminifera concentrated in some. The contact with overlying unit C was not recovered in the core; in the absence of the geophysical log, the lost base of the unit is arbitrarily placed at 608.5 ft.

Unit C is 11.1 ft thick (608.5–597.4 ft depth) and consists of a fining-upward sequence of grayish-olive, micaceous, silty, very fine to fine, glauconitic quartz sand that grades upward into a slightly clayey, very fine, glauconitic, sandy silt (silt is composed of glauconite and quartz) with scattered foraminifera. The section includes a few glauconitic and calcareous (foraminiferal), very fine sand layers and is faintly laminated with only a few tan, clay-filled and glauconite-filled burrows. The upper 3.6 ft contains scattered small shell fragments. The contact between units C and B is interpreted as the contact between calcareous nannofossil Zones NP11 and NP12. The upper contact with unit D is sharp and burrowed with silty and clayey, quartzose (10–20 percent) glauconite (40–50 percent) sand burrowed down into slightly clayey, glauconitic (10 percent) silt.

Unit D is 16.8 ft thick (597.4–580.6 ft depth) and consists of grayish-olive, highly to slightly burrowed, slightly clayey, very silty, variably glauconitic (very fine to medium, 5–20 percent) quartz (very fine, 30–40 percent) sand. The upper 5.4 ft is homogeneous with only a few scattered burrows and minor glauconite (5 percent) and mica (1–2 percent). The middle of the unit (589.2–586.5 ft depth) is highly burrowed with a few scattered, small shell fragments. Burrows range from clay filled (some tan) to sand filled; some contain up to 40 percent glauconite. Indurated, glauconitic burrows filled with abundant foraminifera and some shells are present between 587.6 and 587.3 ft depth.

Unit E is 9.8 ft thick (580.6–570.8 ft depth) and subtly, but sharply, overlies unit D. The burrowed contact is marked by a color change from dark-grayish-olive, laminated silty clay to clayey, silty sand above to unit D’s light-grayish-olive, slightly clayey, silty sand below. The basal 0.6 ft of unit E consists of laminated (<1.1 centimeter (cm) thick) silty clay to clayey and silty, very fine quartz sand. The remainder of the unit coarsens upward and gradually changes around the middle of the unit from a finer grained, glauconitic (very fine to fine, 10 percent), quartzose (very fine to fine, 30–40 percent), very clayey silt with foraminifera (20 percent) to a very clayey, silty, glauconitic (very fine to medium, 40 percent), quartz (very fine to fine, 20 percent) sand that has variable amounts of foraminifera (10 percent). The unit is variably burrowed and has a minor amount of mica and one small lignite fragment at 578.5 ft depth. The contact between units D and E is interpreted as contact between calcareous nannofossil Zones NP 12 and NP13.

The uppermost unit in the Nanjemoy Formation, unit F, is 14.0 ft thick (570.8–556.8 ft depth) and sharply overlies unit E. At the contact, coarser clayey, quartzose (very fine, 1–5 percent), glauconite (very fine to coarse, 35–50 percent) sand with 15 percent foraminifera is burrowed down into finer clayey, silty, quartzose (very fine to fine, 20 percent) glauconite (very fine to medium, 40 percent) sand with 10 percent foraminifera. Unit F fines upward from a basal clayey, very fine to coarse, foraminiferal, quartzose glauconite sand to a very fine to coarse glauconite sand with a clayey matrix. Burrows are sparse near the base but become more abundant above 567.5 ft and are lined with clay and filled with clay and sand. From 566.1 to 566.7 ft depth, one long, vertical burrow is present that is >2 cm wide and 16 cm long. The Nanjemoy is overlain by a unit that is laterally equivalent to the Shark River Formation. The contact is subtle but sharp with a slightly burrowed, glauconitic (very fine to medium, quartzose, 10 percent), silty clay above and a highly burrowed, glauconitic (very fine to coarse, quartzose, 40 percent), silty clay below. The age of the Nanjemoy is early Eocene based on the presence of calcareous nannofossils representing Zones NP10 (lower part), NP11, NP12, and NP13 (Self-Trail, 2011); and the dinoflagellates *Muratodinium fimbriatum, "Wetzzeliella" hampdenensis, Dracodinium varielongitudum,* and *Diphyes ficusoides.*

Shark River Equivalent

Between 556.8 and 503.4 ft depth (box 53), there is a 53.4-ft-thick package of sediments that has not been encountered in Maryland before. The lower part appears to be the equivalent of the Shark River Formation of southern New Jersey based on calcareous nannofossil data (Bybell and Self-Trail, 1995). The upper part of the strata in the South Dover Bridge core correlates with the Piney Point Formation in the Solomons Island corehole, which was drilled in Calvert County, Md. (Gibson and Bybell, 1994). The name "Shark River equivalent" was used by Gibson and Bybell (1994) for the sediments below the Piney Point in that report and its usage is extended to this location. The Shark River equivalent contains six lithic packages (informally named units A through F) that range in thickness from 4.7 to 18.4 ft and are bounded by sharp and (in some cases) burrowed contacts. The contact with the underlying Nanjemoy is subtle and is marked by a slightly glauconitic (10 percent), sandy, silty clay that is burrowed down into a very fine to coarse, glauconitic (40 percent), sandy, silty clay. All of the sand in the Shark River equivalent is predominately fine to medium and rich in glauconite, quartz, and forminifera. The units are burrowed throughout.

The basal unit A is 4.7 ft thick (556.8–552.1 ft depth) and contains two lithic subunits. The lower subunit, A1, is 2.5 ft thick and consists of light-olive-gray, slightly burrowed, glauconitic (very fine to medium, 10 percent), foraminiferal (30–40 percent), sandy clay. Subunit A1 is separated from the overlying subunit, A2, by a sharp, burrowed contact at 554.3 ft. The contact is marked by greenish-black, highly burrowed, glauconitic (very fine to medium, 30–35 percent), foraminiferal (15–20 percent), sandy clay that sharply overlies and is burrowed down into unit A1. Subunit A2 is 2.2 ft thick and contains more abundant burrows that are filled with sand and clay.

Unit B is 10 ft thick (552.1–542.1 ft depth) and consists of a fining-upward sequence of clayey, fine to medium, glauconite (80–90 percent) sand containing quartz (very fine to fine, 10 percent) and foraminifera (5–10 percent) that gradually grades up into a clayey, very fine to fine glauconite (70 percent) sand containing minor quartz and foraminifera (5–10 percent) and increasing numbers of sand- and clay-filled burrows toward the top. Some bedding is preserved at 545.5 to 545.7 ft and at 544.9 to 545.2 ft. The contact with unit C is sharp with less burrowed, slightly more glauconitic, sandy clay overlying the highly burrowed, clayey, glauconitic sand of the upper part of unit B.

Unit C is 6.5 ft thick (542.1–535.6 ft depth) and consists of glauconitic (very fine to medium, 20–25 percent), foraminiferal (15–20 percent) sand in a clay (60 percent) matrix. There are sparse, coarse quartz grains, a few small shell fragments, and abundant burrows except in the lowest 0.7 ft. The unit has backfilled, sand- and clay-filled, and clay-lined burrows. The contact between units C and D is arbitrarily placed at the base of a lost interval (534.8–535.6 ft) that separates clayey, coarser, glauconite-rich sand above from the sandy clay of unit C.

Unit D is 5.2 ft thick (535.6–530.4 ft depth) and consists of a fining-upward sequence of burrowed, foraminiferal (5–10 percent), clayey (25 percent), glauconite (fine to medium, 60–75 percent) sand in the lower part grading upward to a less burrowed, more clayey (5 percent), finer-grained (very fine to fine, rarely medium), and less glauconitic (25 percent) sand. Burrows can be filled with sand or lined with clay. One shell fragment is present at 534.1 ft depth. The contact between unit D and overlying unit E is at 530.4 ft depth and is marked by quartz granules floating in a clay matrix at the base of unit E.

Unit E is 18.4 ft thick (530.4–512.0 ft depth) and is a coarsening-upward sequence. The lower 10 ft is very fine to fine glauconitic (25–35 percent) and foraminiferal (10–15 percent) sand with interbedded silt to clay (50–65 percent) layers containing sparse quartz (coarse to granule) and common, brown-stained shells and shell fragments. These sediments are overlain by a partly indurated interval (519.0–515.1 ft depth) that is lithologically similar to the sediments below, except that the glauconite is fine to medium grained. This indurated interval grades upward into a less clayey (25 percent), quartzose (1 percent), fine to medium glauconite (74 percent) sand. This unit is burrowed throughout with some indurated burrows. The contact between unit E and unit F is marked by a 1.5-cm-thick, glauconitic, indurated layer at the base of unit F that has scattered quartz pebbles (up to 1.5 cm).

Unit F is the uppermost unit of the Shark River equivalent and is 8.6 ft thick (512.0–503.4 ft depth). Above a very clayey basal 2-ft section is a fining-upward sequence that changes upward from a clayey, foraminiferal (10 percent), fine to medium glauconite (80 percent) sand with scattered granules of quartz (1–4 percent) and lignitic material (1–4 percent) into a clayey sand that is finer grained with sparse, coarse quartz grains, less glauconite (50 percent), and foraminifera that are concentrated (15–20 percent) in clay-rich zones and burrows. The upper part has scattered shell fragments. The entire unit has sand-filled and clay-lined burrows. The contact between the Shark River equivalent and the overlying Piney Point Formation is sharp at 503.4 ft depth and marked by clayey, foraminiferal (10 percent), fine to medium glauconite (50–60 percent) sand with scattered quartz granules and lignitic fragments that overlies and is burrowed down into the sandy clay at the top of unit F. The age of the Shark River equivalent is early middle Eocene based on the presence of calcareous nannofossils indicative of nannofossil Zones NP14 and NP15b and the presence of the dinoflagellate *Diphyes ficusoides*.

Piney Point Formation

The Piney Point Formation is a 183.4-ft-thick sediment package located between 503.4 and 320.0 ft depth (box 32). This formation consists of silty clay at the base which grades upward to interbedded silty clay, sandy clay, clay, and sandy silt between 465.0 ft and 431.7 ft. This mix of lithologies coarsens upward to a shelly silt and finally to a sand. The basal silty clay is tight and dry with minor amounts of very fine to medium, subrounded to subangular sand (less than 5 percent). The sand in the top section of this formation ranges from fine to very coarse, subrounded to subangular, and poorly sorted. The sand in the Piney Point Formation is mostly composed of glauconite, quartz, and shell fragments (which increase in abundance in the sandier section toward the top). The Piney Point is intensely bioturbated throughout. The contact with the overlying Drummonds Corner beds is sharp and unconformable, changing from sand with scattered indurated rip-up clasts in the Piney Point below to very clayey and sandy silt with some scattered phosphate grains in the Drummonds Corner beds. At the contact, the color changes upward from dark greenish gray (5*GY* 4/1) to olive gray (5*Y* 4/1) in the Piney Point Formation to brownish black (5*YR* 2/1) in the overlying Drummonds Corner beds. The Piney Point falls within calcareous nannofossil Zone NP16 and contains the dinoflagellate *Pentadinium goniferum*. The age of this formation is late middle Eocene.

Drummonds Corner Beds

The informally named Drummonds Corner beds constitute a 9.4-ft-thick package of sediment located between 320.0 and 310.6 ft depth (*box 32*). This unit is composed of sandy, very clayey silt with minor amounts of glauconite, shell fragments, and foraminifera. The quartz sand in this section is very fine to coarse, poorly sorted, and subrounded to angular with a few chlorite-stained quartz grains. The contact between the Drummonds Corner beds and the overlying Calvert Formation is sharp, unconformable, irregular, and heavily burrowed, changing upward from a sandy, very clayey silt in the Drummonds Corner beds below to a very silty and clayey sand, with phosphate grains in the overlying Calvert Formation. At the contact, the color changes from brownish black (5*YR* 2/1) in the Drummonds Corner beds below to olive gray (5*Y* 4/1) with black specks to light olive gray (5*Y* 6/1) in the Calvert Formation above. These sediments were not examined for calcareous nannofossil content; however, dinoflagellates suggest a possible Oligocene age.

Calvert Formation

The Calvert Formation is 251.7 ft thick and is located between 310.6 and 58.9 ft depth (box 6). This formation contains 12 fining-upward sequences that range in thickness from 4.8 to 38.0 ft and is overlain by one 14.3-ft-thick, coarsening-upward sequence at the top of the unit (73.2–58.9 ft depth). One 7.8 ft section (187.0–179.2 ft depth) is either a thirteenth fining-upward sequence that had its upper finer part truncated by the overlying sequence, or else represents a coarsening-upward trend at the top of the seventh fining-upward sequence. The Calvert Formation generally consists of very fine to medium quartz sand, silt, and clay with variable amounts of coarse to granule-sized quartz grains and shells and shell fragments that are locally concentrated into shell hashes. Locally, a few layers are indurated with calcium carbonate. Some of the 12 fining-upward sequences contain lag deposits at their basal contacts; these lag deposits (1) consist of poorly sorted, variably clayey and silty, very fine to coarse quartz sand with scattered, very coarse grains; (2) typically contain shells and shell fragments;

and (3) may have granules and fine pebbles of phosphate and quartz, some very fine to very coarse glauconite, and (in one instance) a shark's tooth. The basal contact of the Calvert Formation is sharp and heavily burrowed. The Calvert overlies a poorly recovered, clayey, sandy silt layer that is undated, but contains dinoflagellates that suggest a possible Oligocene age and equivalence to the Drummonds Corner beds. The overlying shelly, phosphatic quartz sand with sand-sized shell fragments fines upward over about 2 ft to clayey, sandy silt. The upper contact with the overlying Choptank Formation is located within a shell hash interval and is marked by a change from calcitic shells below to aragonitic shells above. This upper contact is sharp, irregular, and burrowed; the clayey silt of the uppermost Calvert is overlain by fine sand of the basal Choptank, which contains phosphate and macrofossils.

The lower 96.5 ft of the Calvert contains common to abundant visible diatoms and constitutes five fining-upward sequences. Their thicknesses and depth intervals in ascending order are as follows:

- Unit A—13.4 ft thick (310.7–297.3 ft depth);
- Unit B—17.5 ft thick (297.3–279.8 ft depth)
- Unit C—4.8 ft thick (279.8–275.0 ft depth)
- Unit D—36.2 ft thick (275.0–238.8 ft depth)
- Unit E—25.3 ft thick (238.8–213.5 ft depth).

The upper part of the Calvert consists of seven fining-upward sequences. Their thicknesses and depth intervals in ascending order are as follows:

- Unit F—26.5 ft thick (213.5–187.0 ft depth)
- Unit G—6.3 ft thick (179.2–172.9 ft depth) or 14.1 ft (187.0–172.9 ft depth) if a finer grained, 7.9-ft thick sand above unit F (from 187.0 to 179.2 depth) is included
- Unit H—11.9 ft thick (172.9–161.0 ft depth)
- Unit I—10.1 ft thick (161.0–150.9 ft depth)
- Unit J—11.4 ft thick (150.9–139.5 ft depth)
- Unit K—28.2 ft thick (139.5–111.3 ft depth)
- Unit L—38.1 ft thick (111.3–73.2 ft depth).

The one coarsening-upward sequence at the top (unit M on figure 3) is 14.3 ft thick and is located between 73.2 and 58.9 ft depth.

Throughout the section, the Calvert Formation consists of fine-grained, diatomaceous sand, silt, and clay. The sand is mostly very fine to fine quartz, but includes diatoms, shell fragments, foraminifers, and fish scales. Locally, glauconite and phosphate are present in amounts between 5 and 10 percent. Above each burrowed contact, the sand is coarser and shell material is more conspicuous. The sand is typically either silty and clayey or well sorted and alternating with clayey silt laminae. The silt is variably clayey with scattered sand grains. The clay is silty and sandy except where it is interlaminated with sand. The lower part of the Calvert (below 231.4 ft depth) is predominately silt; diatoms are conspicuous with a hand lens and shell fragments are locally present but not common except in the upper few feet. From 231.4 to 213.5 ft depth, the Calvert consists of silt to clay. Above 213.5 ft depth, the Calvert is predominantly very fine sand and shell fragments and shells are more consistently present. An indurated, shelly sand between 179.2 and 177.0 ft depth forms a prominent marker bed within the Calvert.

The age of the Calvert is early and middle Miocene based on calcareous nannofossil assemblages that are indicative of nannofossil Zones NN1, NN2–3, NN4, and NN6–7 from the basal fining upward sequence A up to 104.8 ft within the lower part of fining upward sequence L. Dinoflagellate assemblages in the Calvert are indicative of dinoflagellate Zones DN2a, DN2b, DN2c, DN3, DN4, and DN5. The sample locations in the core and their distributions relative to the members, the fining-upward sequences, and the coarsening-upward sequences of the Calvert are shown in figure 3. Details of the fossil assemblages are given below.

The indurated, shelly sand between 179.2 and 177.0 ft depth can be used to divide the Calvert Formation into upper and lower parts. The lower part yielded early Miocene dinocysts and calcareous nannofossils. The upper part yielded dinocysts of Zones DN4 and DN5 and calcareous nannofossils of Zones NN4 and NN5. The zones of the upper part all fall within the lower part of the middle Miocene, except for the base of Zone DN4 which does not coincide exactly with the base of the middle Miocene. The correlation chart of de Verteuil and Norris (1996) indicates that the bottom of DN4 includes the uppermost 300,000 years of early Miocene time.

The lowest five dinocyst samples from the Calvert Formation in the South Dover Bridge core (310.1–278.5 ft depth) are placed in Zone DN2 of de Verteuil and Norris (1996) and specifically in subzone DN2a of de Verteuil (1997). They are above the highest occurrence of species of *Chiropteridium* and below the lowest occurrence of *Exochosphaeridium insigne*. Important species present include *Cerebrocysta satchelliae*, *Hystrichosphaeropsis obscurum*, *Sumatradinium soucouyantiae*, and *Pentadinium* sp. I of Edwards (1986). The lower sample is more diverse and includes *Cousteaudinium aubryae* de Verteuil and Norris 1996, *Membranilarnacia*? *picena*, and *Stoverocysta conerae*. Zone DN2a is early Miocene, Aquitanian to Burdigalian. The dinocyst assemblage (presence of *S. soucouyantiae* and absence of *Chiropteridium* spp.) suggests a slightly younger age than most correlation charts show for Zone NN1.

Four dinocyst samples from 272.2 to 237.5 ft depth are placed in Zone DN2 and specifically subZone DN2b. This subZone is delimited by the lowest occurrence of *Exochosphaeridium insigne* and the highest occurrence of *Cordosphaeridium cantharellus*. The occurrence of *C. cantharellus* is inconsistent within this interval and is found in sandier samples. Thus, the highest occurrence of *C. cantharellus* may not be of chronostratigraphic significance. The highest occurrences of *E. insigne*, *Pentadinium* sp. I of Edwards (1986), *Cribroperidinium tenuitabulatum*, and *C. cantharellus* are all found in the sample at 237.5 ft depth.

Four dinocyst samples in the Calvert Formation (219.2–180.7 ft depth) are placed in Zone DN3. This zone is an absence zone as its base is placed above the highest occurrence of *E. insigne* and its top is placed below the lowest occurrence of *Labyrinthodinium truncatum*. In the South Dover Bridge core, as in cores studied by de Verteuil and Norris (1996), *L. truncatum* subsp. *modicum* has a lower occurrence than *L. truncatum* subsp. *truncatum*. *Apteodinium spiridoides*, *C. aubryae*, *Pyxidiniopsis fairhavenensis* are present in most samples.

Nine dinocysts samples in the upper part of the Calvert Formation are placed in Zones DN4 and DN5. They are above the defining event for the base of Zone DN4 (lowest occurrence of *Labyrinthodinium truncatum*) and below the defining event for the top of Zone DN5 (highest occurrence of *Cleistosphaeridium placacanthum*). These samples are difficult to place biostratigraphically within these two zones. The highest occurrence of *Distatodinium paradoxum* (which elsewhere marks the boundary between Zones DN4 and DN5) is too low in the South Dover Bridge core and not of stratigraphic value. The top of Zone DN4 can be approximated by the highest occurrence of *C. aubryae*, and so its presence up to 123 ft depth in the core places the lower four samples within the chronozone of DN4. The lower six samples contain *L. truncatum modicum*; *L. truncatum truncatum* is absent. The lowest occurrence of *L. truncatum modicum* is calibrated by de Verteuil and Norris (1996) to be near, but slightly below, the boundary between the lower and middle Miocene. Notable dinocysts reported within Zone DN5 by de Verteuil and Norris (1996) include the highest occurrence of *A. tectatum* at 85.5 ft depth, the lowest occurrence of *Habibacysta tectata* at 74.1 ft depth (a tentatively identified specimen was found in the sample at 85.4 ft depth), and a single occurrence of *Unipontidinum aquaeductum* at 74.1 ft depth. The presence of *U. aquaeductum* in this sample may suggest a more offshore component at this locality.

Of the eight calcareous nannofossil samples from the lower part of the Calvert Formation in the South Dover Bridge core, six are placed in the lower Miocene Zone NN2. The lowest and the highest samples are problematic. Based on the presence of *Helicosphaera recta* (highest occurrence in Zone NN1), the lowest nannofossil sample could be older than the higher samples. Alternately, because the sample contains specimens known to be reworked (*Dictyococcites bisectus*), it does not have to be older because reworking could also explain the presence of *H. recta.* The next six samples are clearly within Zone NN2 because they contain frequent *Helicosphaera ampliaperta* (lowest occurrence at the base of Zone NN2) in the absence of *Sphenolithus belemnos*, whose lowest occurrence marks the bottom of Zone NN3. *Discoaster deflandrei* (acme near the top of Zone NN2) is present in a few samples. The highest sample (184.0 ft depth) contains so few specimens that the absence of *S. belemnos* is not definitive.

Either the lowest calcareous nannofossil sample is higher than the upper boundary of Zone NN1, or the range of the dinoflagellate *S. soucouyiantae* relative to the boundary between Zones NN1 and NN2 is not as shown on figure 3 of de Verteuil and Norris (1996).

Six nannofossil samples from the upper part of the Calvert Formation in the South Dover Bridge core are placed in Zone NN4, two are placed in Zone NN5, and one (uppermost, at 73.8 ft depth) is not diagnostic. The placement of samples in Zone NN4 is based on (1) the frequent occurrence of *Sphenolithus heteromorphus*, which has its lowest occurrence at the base of Zone NN4 (Perch-Nielsen, 1985); (2) co-occurrence with *Helicosphaera ampliaperta* (highest occurrence at the top of Zone NN4); and (3) the absence of *Sphenolithus belemnos*, with which *S. heteromorphus* overlaps at the very top of Zone NN3. The placement of samples in Zone NN5 placement is based on the absence of *Helicosphaera ampliaperta* (highest occurrence at the top of Zone NN4 at 104.8 ft depth). Within the middle Miocene at the stratotype section for the base of the Serravallain Stage, two nannofossil occurrences (the lowest occurrence of *Helicosphaera walbersdorfensis* and the highest occurrence of *S. heteromorphus*) bracket the boundary, which is presently calibrated to 13.82 million years ago (mega-annum, or Ma). These occurrences were found at 94.6 and 84.3 ft depth in the South Dover Bridge core. Thus, the lower part of Zone NN5 may be missing within the unconformity at 98.3 ft depth.

Choptank Formation

The middle Miocene Choptank Formation in the South Dover Bridge core is 41.3 ft thick and is located between 58.9 to 17.6 ft depth (box 6). The Choptank consists of a fining-upward section of fine sand, silt, and clay with locally abundant shell material. The lower contact with the underlying Calvert Formation is located within a shell-hash interval and is marked by a change from calcitic shells below to aragonitic shells above. This contact is sharp, irregular, and burrowed with phosphate and macrofossils (bivalves, shark tooth) in fine sand overlying the clayey silt of the Calvert. The upper contact is sharp and irregular where the sandy quartz gravel of the late Pleistocene Kent Island Formation overlies the silty clay of the Choptank.

The lower part of the Choptank, which was poorly recovered in the South Dover Bridge core, consists mostly of very shelly, fine to medium sand. The carbonate content approaches 50 percent. Pebbles are present near the base. An indurated interval was recovered from 58.9 to 57.6 ft depth. Above this interval, the sand has a conspicuous clay to silt matrix. The sediment fines to a silt at above about 50 ft depth and to a silty clay with minor amounts of very fine to medium quartz sand above about 47 ft depth.

Concentrations of whole bivalve shells and shell fragments (all producing high percentages of calcium carbonate) are present up to 42.7 ft depth. A distinct color change occurs at 41.4 ft, above which variably silty clay alternates in gray and pale-red layers and contains small amounts of shell fragments that yield carbonate percentages between 1 and 6 percent. Concretions are present between 33.0 and 30.0 ft depth. A burrowed surface was noted at 26.7 ft depth.

Five samples from the Choptank Formation in the South Dover Bridge core contain middle Miocene dinocysts. The lower two samples are placed in Zone DN5 (upper part, above the lowest occurrence of *H. tectata*) because they contain *C. placacanthum* (its highest occurrence defines the top of Zone DN5). The upper three samples are placed in Zone DN6. This zone is an absence zone as its base is placed at the highest occurrence of *C. placacanthum* and its top is placed at the lowest occurrence of *Cannosphaeropsis passio*. All samples contain *H. tectata*, *Hystrichosphaeropsis obscura*, *L. truncatum truncatum*, *Palaeocystodinium golzowense*, members of the *Pentadinium granulatum/sabulum* species complex, *Sumatradinium druggii*, and *Sumatradinium soucouyantiae*. De Verteuil and Norris (1996, p. 13) noted that the combination of either *L. truncatum* or *H. tectata* with any of *S. druggii*, *S. soucouyantiae*, or *P. golzowense* in the absence of *C. placacanthum* and *C. passio* characterizes this zone.

Four samples from the Choptank Formation in the South Dover Bridge core contain nondiagnostic calcareous nannofossils. A sixth (uppermost) sample was barren. Most of the species present are long ranging; a few range from Miocene to Pliocene. *Helicosphaera walbersdorfensis*, present in the sample at 43.0 ft, has a shorter range within the Miocene and may prove to be biostratigraphically useful. The top 9.0 ft of the Choptank may be a separate unit, but further work is needed in order to determine this.

Kent Island Formation

The Kent Island Formation is a 12.6-ft-thick sediment package occurring from 17.6 ft to 5.0 ft depth (box 1). The formation is composed of fine to very coarse sand; granules and pebbles become abundant towards the base of this formation. The sand alternates between fine, well-sorted layers and coarse, poorly sorted layers. This formation varies in color from pale yellowish brown (10YR 6/2) and dark yellowish orange (10YR 6/6) to grayish orange (10YR 7/4). No calcareous nannofossils are present in this formation and no dinoflagellate samples were taken.

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Appendix A. South Dover Bridge Lithologic Log

Appendix A contains a detailed description of the lithological units encountered in the South Dover Bridge corehole. Click here to access appendix A.

Appendix B. South Dover Bridge Core-Run Log

Log shows date, run number, time of day when inner barrel surfaced, run depth, amount of core drilled, and amount of core recovered. Click here to access appendix B.

Appendix C. South Dover Bridge Core Sampling Log

Log shows date sample was taken, sample depth, sample type, the individual who took the sample, the scientist for whom the sample was taken, and the purpose of the sample. Some samples were taken at the drill site, others were taken once the core was removed to a core repository. Click here to access appendix C.

Appendix D. Photographs of Boxed Core From the South Dover Bridge Corehole

Box numbers are referred to in the report text. Click on the box number below to access a photograph of the boxed core.

Box 1	Box 21	Box 41	Box 61
Box 2	Box 22	Box 42	Box 62
Box 3	Box 23	Box 43	Box 63
Box 4	Box 24	Box 44	Box 64
Box 5	Box 25	Box 45	Box 65
Box 6	Box 26	Box 46	Box 66
Box 7	Box 27	Box 47	Box 67
Box 8	Box 28	Box 48	Box 68
Box 9	Box 29	Box 49	Box 69
Box 10	Box 30	Box 50	Box 70
Box 11	Box 31	Box 51	Box 71
Box 12	Box 32	Box 52	Box 72
Box 13	Box 33	Box 53	Box 73
Box 14	Box 34	Box 54	Box 74
Box 15	Box 35	Box 55	Box 75
Box 16	Box 36	Box 56	Box 76
Box 17	Box 37	Box 57	Box 77
Box 18	Box 38	Box 58	
Box 19	Box 39	Box 59	
Box 20	Box 40	Box 60	

Appendix E. Calcareous Nannofossil Occurrences in the South Dover Bridge Corehole for the Late Paleocene to Middle Miocene

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Appendix E consists of two charts that document the calcareous nannofossil occurrences in the core, by formation. Click on the appropriate appendix letter below to access a chart.

Appendix E1. Calcareous Nannofossil Occurrences in the South Dover Bridge Corehole for the Early Miocene to Middle Miocene

Appendix E2. Calcareous Nannofossil Occurrences in the South Dover Bridge Corehole for the Late Paleocene to Middle Eocene