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Geologic columns for the ICDP-USGS Eyreville A and C cores, Chesapeake Bay impact structure: Postimpact sediments, 444 to 0 m depth

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ABSTRACT

A 443.9-m-thick, virtually undisturbed section of postimpact deposits in the Chesapeake Bay impact structure was recovered in the Eyreville A and C cores, Northampton County, Virginia, within the "moat" of the structure's central crater. Recovered sediments are mainly fine-grained marine siliciclastics, with the exception of Pleistocene sand, clay, and gravel. The lowest postimpact unit is the upper Eocene Chickahominy Formation (443.9–350.1 m). At 93.8 m, this is the maximum thickness yet recovered for deposits that represent the return to "normal marine" sedimentation. The Drummonds Corner beds (informal) and the Old Church Formation are

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thin Oligocene units present between 350.1 and 344.7 m. Above the Oligocene, there is a more typical Virginia coastal plain succession. The Calvert Formation (344.7–225.4 m) includes a thin lower Miocene part overlain by a much thicker middle Miocene part. From 225.4 to 206.0 m, sediments of the middle Miocene Choptank Formation, rarely reported in the Virginia coastal plain, are present. The thick upper Miocene St. Marys and Eastover Formations (206.0–57.8 m) appear to represent a more complete succession than in the type localities. Correlation with the nearby Kiptopeke core indicates that two Pliocene units are present: Yorktown (57.8–32.2 m) and Chowan River Formations (32.2–18.3 m). Sediments at the top of the section represent an upper Pleistocene channel-fill and are assigned to the Butlers Bluff and Occohannock Members of the Nassawadox Formation (18.3–0.6 m).

INTRODUCTION

In 2005–2006, a project of the International Continental Scientific Drilling Program (ICDP) and the U.S. Geological Survey (USGS) drilled the Eyreville core holes to a total depth of 1766 m into the deepest part or "moat" of the Chesapeake Bay impact structure (Gohn et al., 2006, 2008). The structure is completely buried beneath postimpact sediments in southeastern Virginia, USA (Fig. 1). The impact occurred ca. 35.5 Ma (during the late Eocene) and produced a complex crater that is 85 to 90 km wide. Earlier investigations pertaining to the structure and stratigraphy are reviewed in Powars and Bruce (1999), Powars (2000), Poag et al. (2004), and Horton et al. (2005). Previously drilled core holes in the structure provide additional information for comparison.

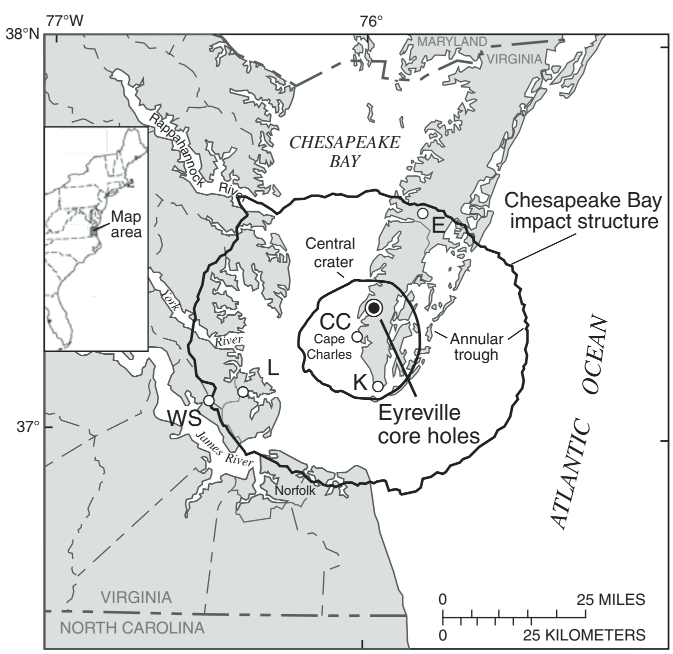

Figure 1. Regional map showing the location of the Chesapeake Bay impact structure, features of the structure, the location of the Eyreville core holes, and the locations of other test holes in southeastern Virginia (modified from Powars et al., this volume). WS—Watkins School, L—USGS-NASA Langley, K—Kiptopeke, E—Exmore, CC—Cape Charles.

This chapter describes the sediments of late Eocene to Pleistocene age (443.9 m to land surface) at the Eyreville site that overlie material that was generated or redistributed by the impact. We document the general lithologic characteristics, contacts, and stratigraphic thicknesses of each formation, member, or informal lithostratigraphic unit recognized at the site, and we provide a summary of age and environmental information. The appendices include moderately detailed lithologic descriptions of the cores from the postimpact sediments. Other chapters in this volume discuss the strontium-isotope chronology, paleontology, and sequence stratigraphic interpretations (Browning et al., this volume) and the postimpact history of the structure (Kulpecz et al., this volume).

Coring and Logging History

The drill site is on Eyreville Farm, owned by the Buyrn family, 7 km north of the town of Cape Charles, Northampton County, Virginia. Postimpact sediments were recovered from two core holes, Eyreville A and Eyreville C. Work began at the Eyreville site in July 2005 with the drilling of a water-supply well (USGS 63G69) and the installation of steel casing to a depth of 125.58 m in the Eyreville A hole. The hole was then sealed with cement until 15 September, when the rig operated by Major Drilling America, Inc., began the coring operation, drilling through the cement and recovering material below 126.89 m. Coring in the postimpact part of the section continued until 20 September, when the underlying impact-generated sediments were encountered at 443.90 m. The following year, from 29 April to 4 May 2006, the USGS returned to the site and cored Eyreville C from land surface to a final depth of 139.57 m. Eyreville C is 6.0 m north of the wellhead for Eyreville A (Fig. 2).

Cores recovered from the postimpact part of Eyreville A are 85 mm in diameter (PQ). Cores from Eyreville C are 63.5 mm in diameter (HQ). The precise global positioning system (GPS) location for Eyreville A is lat 37°19′17.30301″N, long 75°58′30.64427″W; for Eyreville C, it is lat 37°19′17.48782″N, long 75°58′30.70924″W (WGS84 datum). Elevation is ~2.4 m.

A full suite of geophysical logs was run on the water supply well and on Eyreville C. Only gamma logs and temperature logs were run on Eyreville A because the PQ rods were used as casing.

Physical properties of selected core segments (including a small number of postimpact segments) are detailed in Pierce and Murray (this volume).

METHODS

All core material was boxed at the drill site according to a policy developed by the principal investigators prior to core retrieval. The key aspects of this policy were that onsite depths were recorded in feet, and the depth of the top of the run was used to label the boxes for the top of the recovered core from that run. If the amount of core recovered from a run exceeded the depth drilled, all values in excess of the drilled depth were recorded in quotation marks. In rare instances, excess core was assigned onsite to depth values corresponding to the previous run and boxed accordingly. All drilling runs that included excess core were evaluated by the USGS scientific staff in Reston in order to determine the most reasonable explanation for the overage and to assign revised depth values. Excess core was inferred to be the result of recovery from a lost interval in a higher run, or from core expansion, or both. By convention, an entire coring run was treated as an entity. In addition to the depth of the start of the run as recorded on the core box, each coring run was assigned two computational values: one reflecting the difference between the top of the run as recorded onsite and the top of the run as determined by the staff (push-up), and a second reflecting a multiplication factor (<1) necessary to fit the amount of boxed core into the known cored interval (scale factor). All recorded depths in feet were adjusted by computer programs to reflect the individual computational values and, within the same computer programs, were converted to metric values. In Eyreville A, one interval (572.1–734.46 ft) was determined to be 1.5 m too shallow as recorded onsite due to drillers' miscount of the drilling rods.

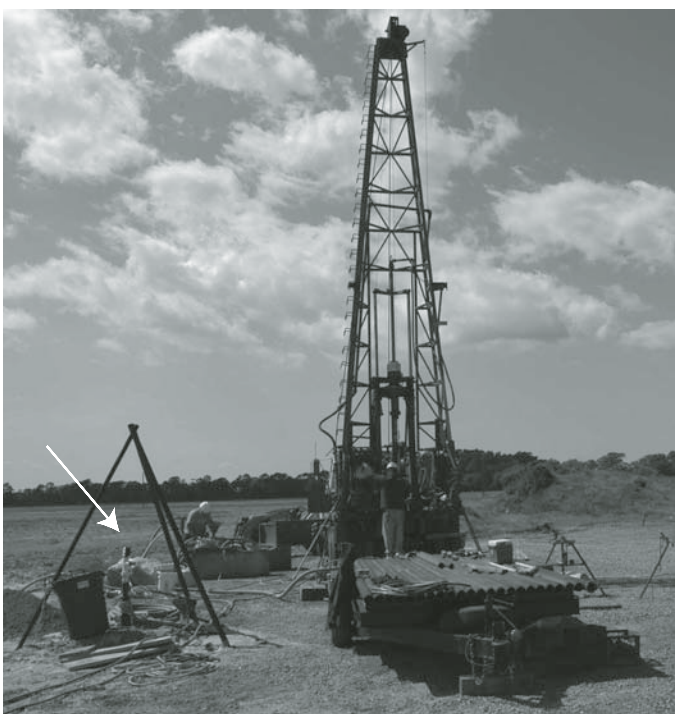

Figure 2. U.S. Geological Survey drill rig onsite for Eyreville C, 29 April 2006. Capped wellhead for Eyreville A is below the tripod to the left (arrow). Drill rods on the trailer are 20 ft long (6 m).

The policy for the Eyreville cores is that the value in feet as boxed (ft*) is the primary record for each lithologic description or sample location. The computationally adjusted value in meters (rmcd; revised meters composite depth) is used for the best estimate of the true depth of the description or sample. The computation for each run is a simple linear equation. For many of the runs, in which the push-up value is zero and the scaling factor is one, the computationally adjusted value is the value that would be obtained by a simple foot-to-meter conversion (1 ft = 0.3048 m, exactly). For other runs, the computationally adjusted value is significantly different.

For the descriptions that follow, contacts are measured down from the labels on the boxes or trays to the nearest 0.1 ft or, rarely, the nearest 0.05 ft and then adjusted computationally to be given in meters. For angled or irregular contacts, the shallowest depth is given.

Core descriptions (Appendices 1 and 2) are based on a combination of descriptions written by onsite geologists, evaluation of core photographs, and examination and reevaluation of core material by the authors. Onsite descriptions used both Munsell® Soil Color Chart (gley 1, gley 2) and the Geological Society of America Rock Color Chart. Color was observed in either natural sunlight or artificial light depending on the time of day or night. Eyreville A was cored on a 24 h schedule. Eyreville C was cored only during daylight hours.

Core photographs were taken onsite with a Nikon D100 digital camera in natural sunlight as soon as possible after the core was retrieved and while the core was still wet. Subsequent photographs were taken in either natural sunlight or fluorescent indoor light.

Paleomagnetic studies were carried out in the Laboratory of Solid Earth Geophysics, Department of Physics, University of Helsinki, Finland. The stepwise alternating field (AF; up to 160 mT) demagnetization was performed in 2.5–10 mT steps, using the 2G Model 755 Superconducting Rock Magnetometer in combination with the Applied Physics Model 2G600 AF-demagnetizer in order to identify magnetization components of core samples.

Annotated core-box photographs and full details of the drilling history and the algorithms used to compute rmcd values are given in Durand et al. (this volume).

LITHOSTRATIGRAPHIC UNITS OF THE GEOLOGIC COLUMNS

The postimpact section in the Eyreville cores (Figs. 3 and 4) consists of marine to marginal marine, siliciclastic sediments, commonly with biogenic components (shells and microfossils). From the

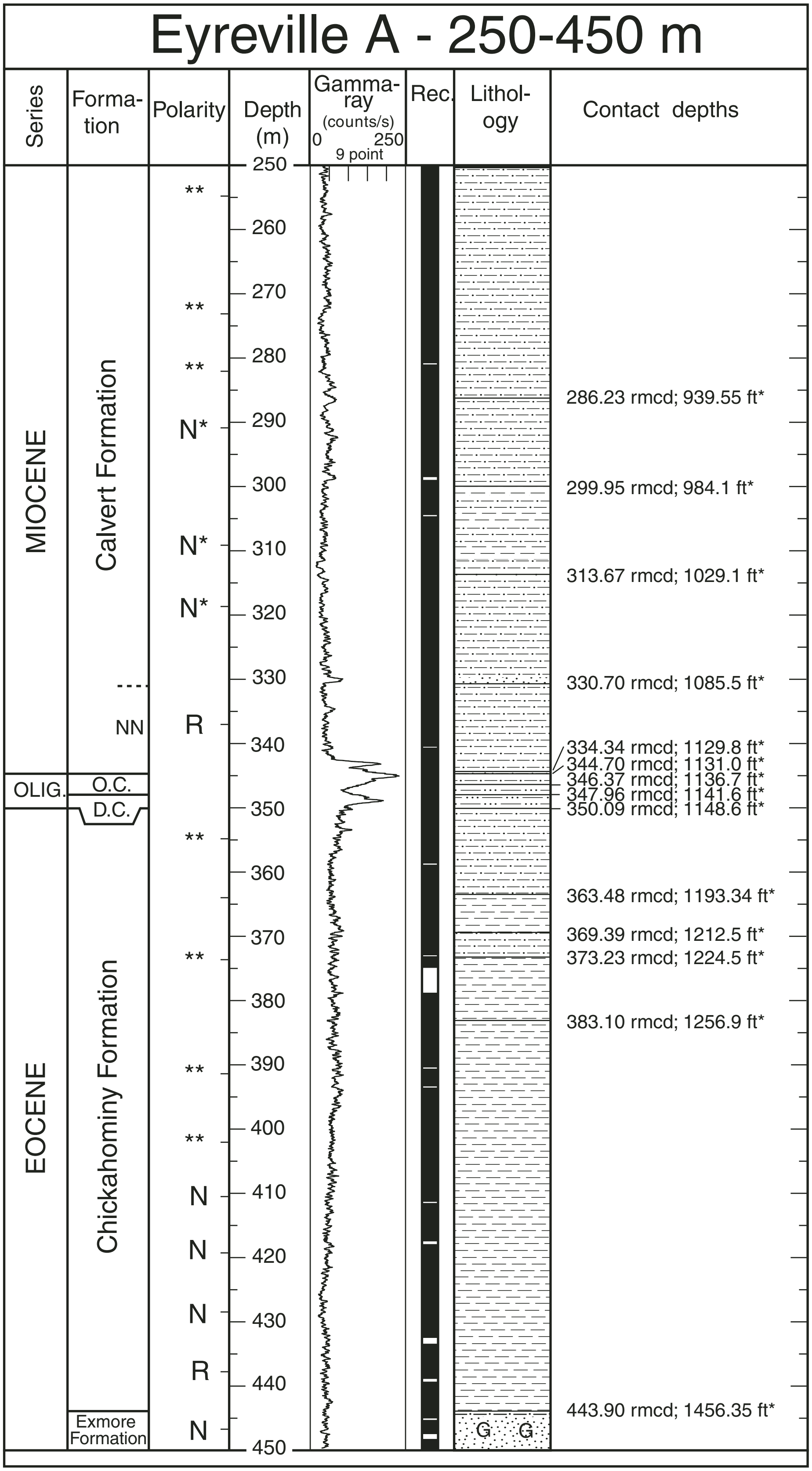

Figure 3 (*continued on following page*). Geologic column of post-impact chronostratigraphic and lithostratigraphic units in Eyreville A showing the magnetic polarity, gamma-ray log, core recovery, generalized lithology, and depths to stratigraphic contacts. Gamma-ray curve is nine-point moving average. Rec.—core recovery (black, recovered; white, no recovery), D.C.—Drummonds Corner beds (informal), O.C.—Old Church Formation, NN—Newport News beds, an informal member of the Calvert Formation.

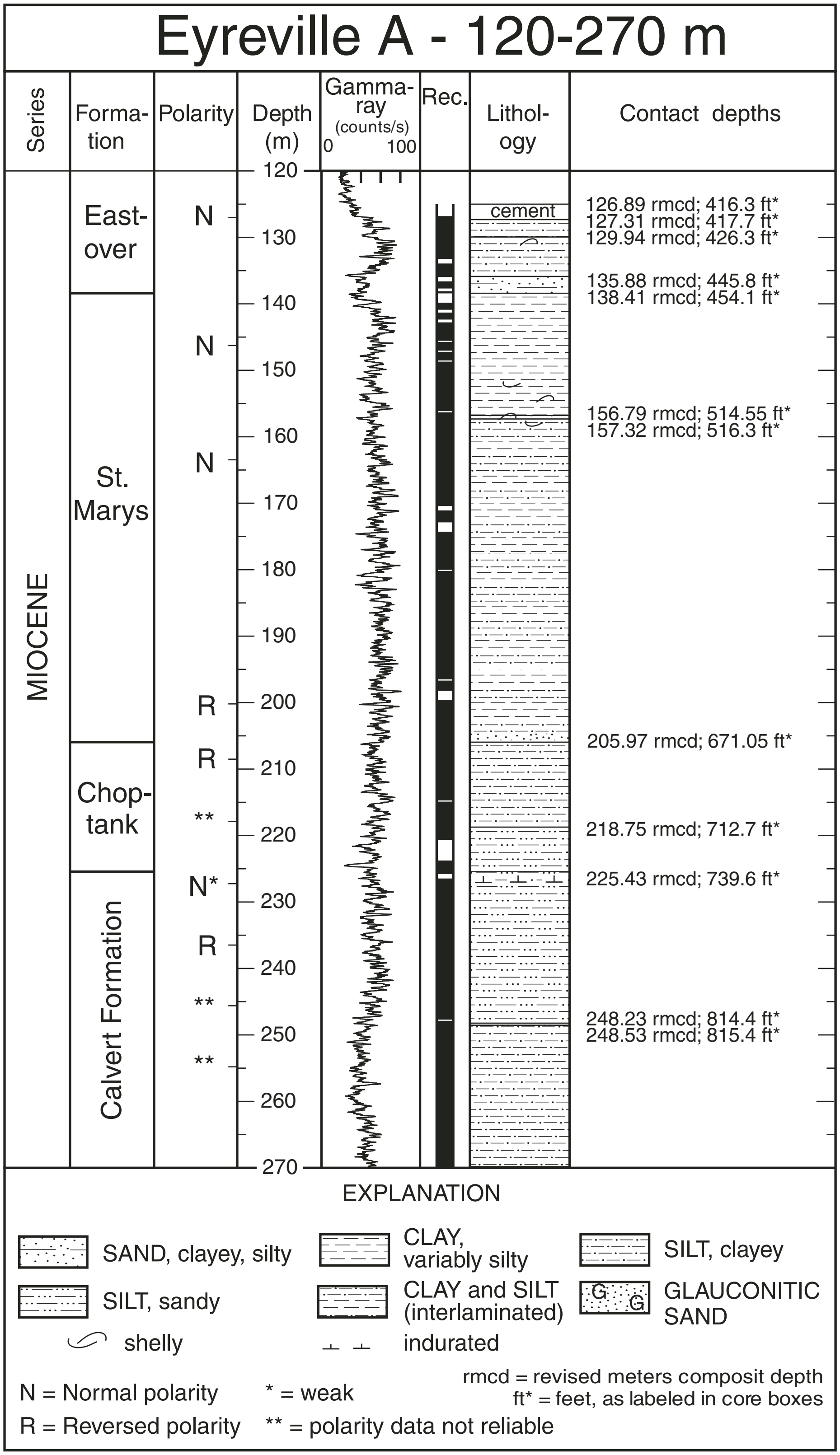

Figure 3 (*continued*).

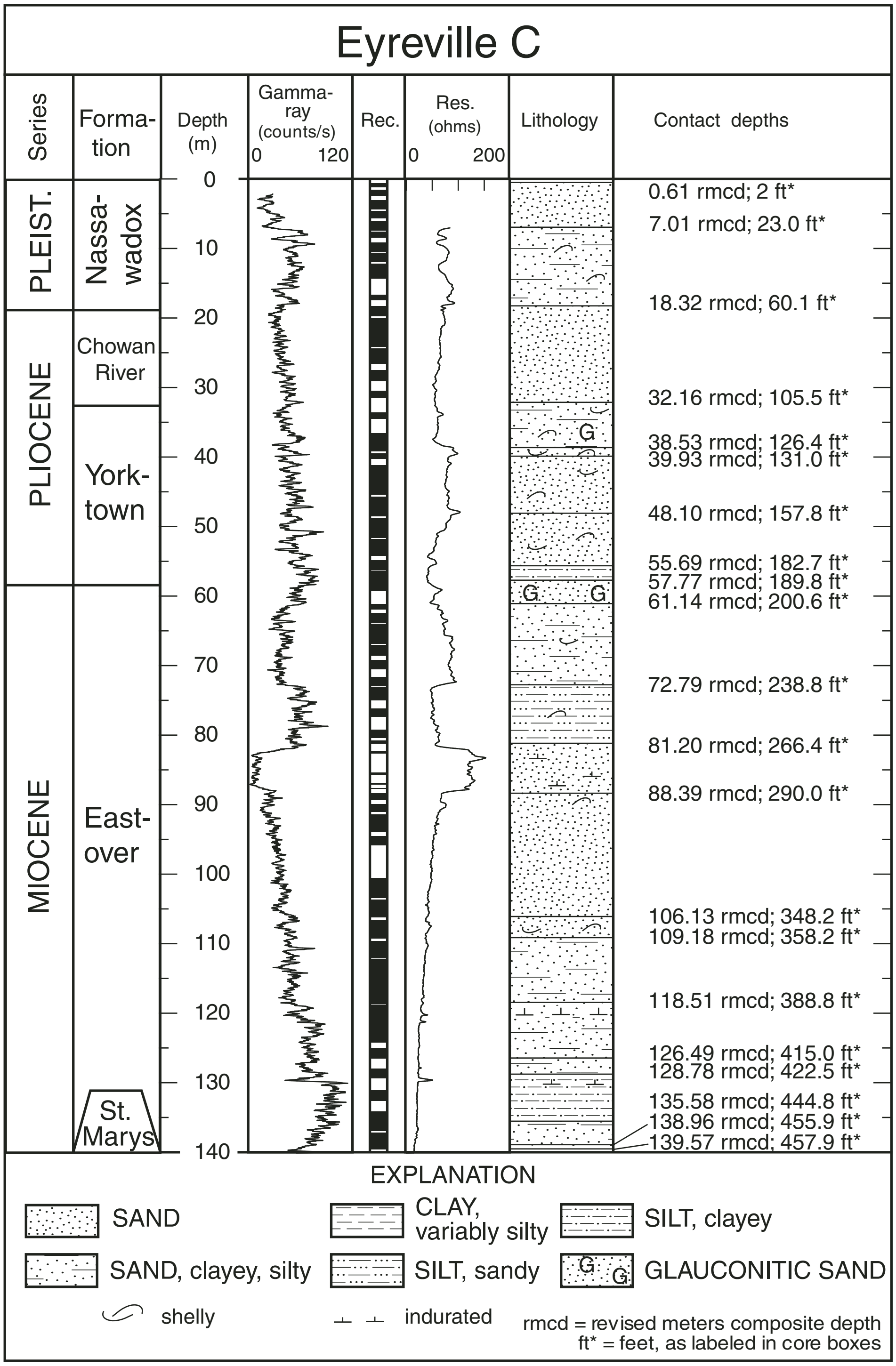

Figure 4. Geologic column of chronostratigraphic and lithostratigraphic units in Eyreville C showing selected geophysical logs, core recovery, generalized lithology, and depths to stratigraphic contacts. Gamma-ray curve is nine-point moving average. Rec.—core recovery (black, recovered; white, no recovery), Res.—single-point resistance.

base of the postimpact section at 443.90 m to 90.31 m, the sediments are overwhelmingly clays, silts, and very fine to fine sands. Above that, coarser material is present and locally abundant. In the Virginia coastal plain, upper Eocene and Oligocene sediments are known mostly from subsurface studies (Powars et al., 1992; Powars and Bruce, 1999). In ascending order, the Eocene and Oligocene lithostratigraphic units at Eyreville are the Chickahominy Formation, the informal Drummonds Corner beds, and the Old Church Formation. In contrast, the Miocene, Pliocene, and Pleistocene lithostratigraphic units are well known from outcrop studies in Virginia and Maryland, and most have been studied for over a century. In ascending order, these units are the Calvert, Choptank, St. Marys, Eastover, Yorktown, Chowan River, and Nassawadox Formations. Formational assignments are based on lithologic similarity and relative stratigraphic position in comparison with type localities. Most contacts between lithostratigraphic units are difficult to place because of extensive bioturbation. By convention, we place each contact at the highest position of the underlying lithology that can reasonably be inferred to be in place and intact.

Chickahominy Formation, Upper Eocene (443.90–350.09 m)

The Chickahominy Formation was named by Cushman and Cederstrom (1945) for clays and silts containing sand-sized, late Eocene foraminifera. The unit, then and now, is known only from the subsurface. The Chickahominy Formation is recognized in Eyreville A where its lower contact (Fig. 5A) with the upper laminated part of the Exmore Formation at 443.90 m is sharp and nearly horizontal. Above the contact, the Chickahominy is a tight clay with few features other than bioturbation (Fig. 5B). The upper contact with the overlying Drummonds Corner beds at 350.09 m is sharp and irregularly burrowed, where phosphatic glauconitic sand overlies the foraminifera-rich, silty clay of the Chickahominy (Figs. 6A and 6B).

The Chickahominy Formation in Eyreville A consists of tight clay that is silty and slightly sandy. The sand-sized portion consists of common to abundant foraminifera, very fine quartz, shell fragments (bivalves, scaphopods, solitary coral), ostracodes, fish skeletal debris, glauconite, and traces of pyrite and mica. Pyrite also occurs in local concretions. The unit is homogeneous to laminated to burrow-mottled; clay-lined and clay-filled burrows are locally present (Fig. 5B) and may have elliptical cross sections due to compaction. A sharp, burrowed contact occurs at 383.10 m, and a more subtle burrowed contact occurs at 369.39 m. Subtle lithologic contrasts mostly reflect variations in the proportions of silt versus clay, with more silt than clay from ~425.04–424.34 m, 373.23–369.36 m, and 363.48–350.09 m.

The Chickahominy Formation in Eyreville A is 93.81 m thick, the maximum reported from any core to date. Paleomagnetic data in the upper part of the unit show weak magnetization values (see also Elbra et al., this volume). In the lower part, these data suggest the presence of a thin but unsampled normal interval (because samples from the underlying Exmore Formation show normal polarity), overlain by a thin reversed interval, and a much thicker normal interval. The microfossils present (Schulte et al., this volume; Browning et al., this volume) constrain the interpretations of this lower part to either C16n.2n-C16n.1r-C16n.1n or C16n.1n-C15r-C15n. Either interpretation requires that the rate of sediment accumulation within the Chickahominy Formation must have undergone marked changes.

Browning et al. (this volume) report that Eyreville samples from the Chickahominy Formation yield planktonic foraminifera diagnostic of upper Eocene zones E15 and E16 and estimate the age of the unit as 35.4–33.8 Ma. The Chickahominy Formation in Eyreville A appears to have been deposited in a restricted offshore environment at deep outer neritic to upper bathyal depths (200 m best estimate, Browning et al., this volume; 300 m best estimate, Poag, this volume).

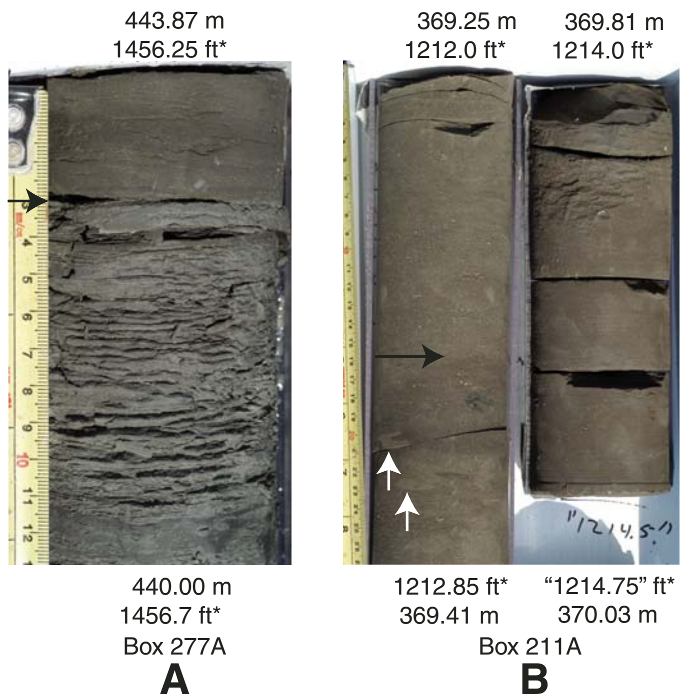

Figure 5. Onsite photographs of the Chickahominy Formation in Eyreville A. (A) Lower contact, black arrow marks contact at 443.90 m (1456.35 ft*) between the stratified upper part of the Exmore Formation and the tight clay of the Chickahominy Formation. Centimeters and millimeters are shown on left. (B) Typical lithology of the Chickahominy Formation and subtle contact within it at 369.39 m (1212.5 ft*). Above the contact, silty clay includes shell fragments and abundant sand-sized foraminifera (visible white specks). Below the contact, burrows (white arrows) from above are conspicuous. Close-up of upper part of two trays. Centimeters and millimeters are shown on left.

Drummonds Corner Beds, Lower and/or Upper Oligocene (350.09–347.96 m)

The name Drummonds Corner beds (informal) was introduced by Powars et al. (2005) for the muddy quartz-glauconite sand that overlies and fills burrows in the top of the Chickahominy Formation in the USGS-NASA Langley core. The unit (Fig. 6) is 2.13 m thick in Eyreville A, from 350.09 to 347.96 m. The lower contact with the underlying Chickahominy Formation is heavily burrowed, and burrows extend down at least 1.3 m into the Chickahominy Formation. The contact is placed at the highest intact clayey silt of the Chickahominy Formation (Figs. 6A and 6B). The upper contact with the overlying Old Church Formation is also heavily burrowed (see Figs. 6D and 6E).

In Eyreville A, the Drummonds Corner beds consist of a basal sand that grades rapidly upward into a sandy, clayey, heavily burrowed silt. The sand is very fine to fine and predominately glauconite in the lower part and quartz in the upper part. Visible foraminifera and shell fragments may be concentrated in burrows (Fig. 6C). An interval from 349.39 to 349.73 m is semi-indurated.

The grain size and composition of the Drummonds Corner beds are markedly different from those of the underlying Chickahominy Formation. These beds appear as an easily recognized spike (deviation to the right) on the gamma log (Fig. 3) and as a prominent reflector on seismic profiles (Catchings et al., 2008; Powars et al., this volume). The gamma-log signature suggests that phosphate is also present, especially near the base of the Drummonds Corner beds.

As was the case in the USGS-NASA Langley core (Powars et al., 2005), the lowest Oligocene unit known in the subsurface of the Virginia coastal plain, the informal Delmarva beds (Powars and Bruce, 1999), is not recognized in Eyreville A.

The Drummonds Corner beds are Oligocene. In Eyreville A, calcareous nannofossils place the Drummonds Corner beds at

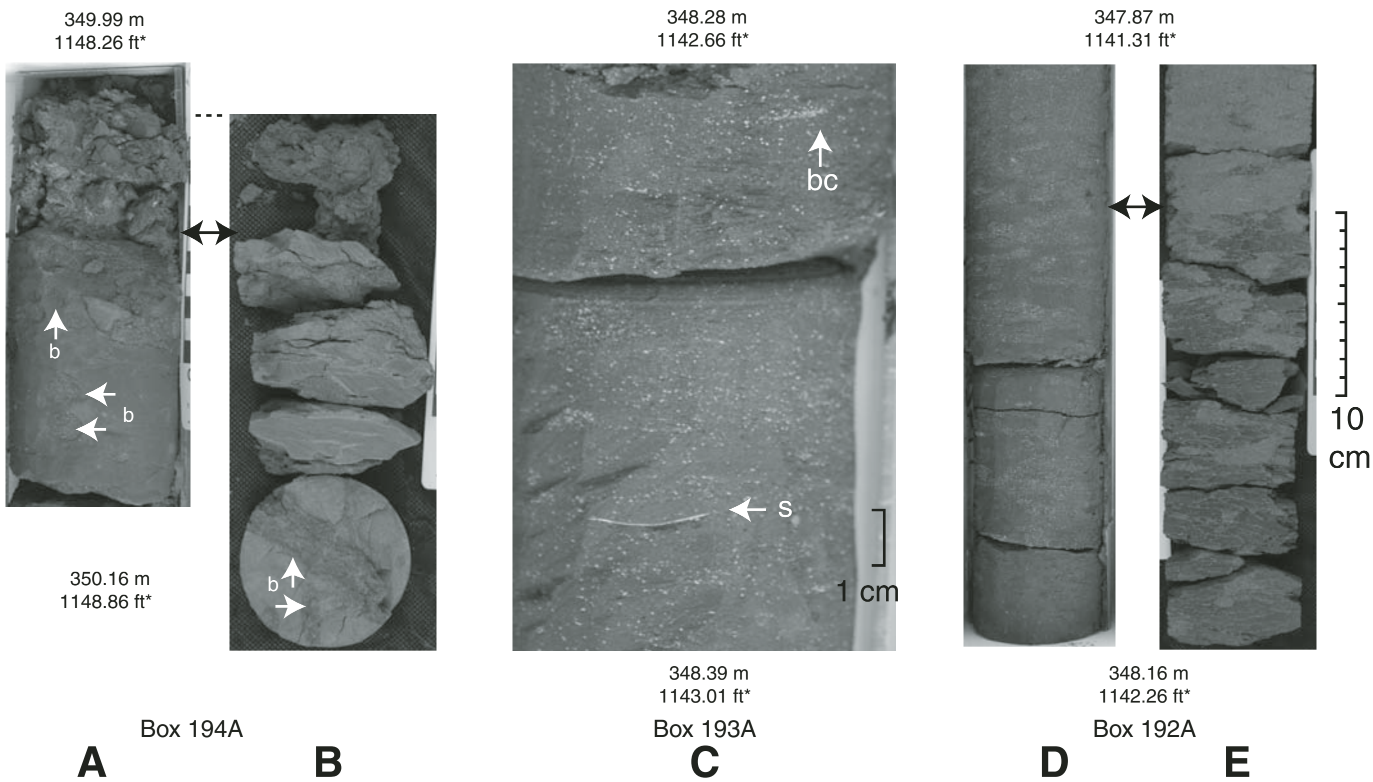

Figure 6. Photographs of Chickahominy Formation, Drummonds Corner beds, and Old Church Formation in Eyreville A. (A) Onsite photograph showing the sharp burrowed contact between the Chickahominy Formation and the Drummonds Corner beds at 350.09 m (1148.6 ft*). Above the contact, glauconitic, phosphatic quartz sand of the Drummonds Corner beds overlies and fills burrows in the tight massive silty clay of the Chickahominy Formation. Below the contact, burrows (white arrows labeled b) are conspicuous down more than a meter. (B) Split, dry core of the same interval showing the contrasting lithologies. At the bottom, there is a bedding-layer view of additional branches of burrows (white arrows labeled b). (C) Onsite photograph showing detail of foraminifera-rich, slightly shelly (s), silty clay of the upper part of Drummonds Corner beds. Note foraminifera and other biogenic clasts (white specks) are both scattered and concentrated into small patches, likely in burrows (bc). (D) Onsite core photograph showing the burrowed contact (arrows) at 347.96 m (1141.6 ft*) between foraminifera-rich, glauconitic quartz sand of the Old Church Formation and the underlying darker silty clay of the Drummonds Corner beds. (E) Split, dry core clearly shows the contact and numerous irregular, small, lighter-colored, silt-filled cracks or burrows in the tight clay of the uppermost Drummonds Corner beds. Scale to the right is 10 cm.

349.71 m in zone NP 24. A higher sample at 348.7 m is placed in zones NP24–NN1 undifferentiated (Schulte et al., this volume). Although the boundary between lower (Rupelian Stage) and upper (Chattian Stage) Oligocene has not been formalized by international agreement, it will likely be placed somewhere with NP24 (Coccioni et al., 2008). A single Sr age of 27.7 Ma (Browning et al., this volume) places the Drummonds Corner beds at Eyreville within the lower part of the upper Oligocene. Powars et al. (2005) and Edwards et al. (2005) considered these beds to be lower Oligocene in the USGS-NASA Langley core. The Drummonds Corner beds were deposited in an offshore marine environment (Browning et al., this volume).

Old Church Formation, Lower and/or Upper Oligocene (347.96–344.70 m)

The Old Church Formation was named by Ward (1985) for a thin (<1 m thick) unit cropping out in the Virginia coastal plain that consists of poorly sorted, shelly, clayey sand separated above and below by unconformities. Prior to Ward's publication, the occurrence of Oligocene sediments had not been documented either in outcrops or in the subsurface in Virginia. In Eyreville A, the Old Church Formation (Figs. 6D, 6E, and 7B) is 3.26 m thick and is recognized from 347.96 to 344.70 m. At its lower contact with the underlying Drummonds Corner beds at 347.96 m, the Old Church Formation is a foraminifera-rich, glauconitic sand that prominently fills burrows into darker, finer-grained clayey silt (Figs. 6D and 6E). The upper contact with the overlying Newport News beds of the Calvert Formation at 344.34 m is heavily burrowed, and the contact is placed at the highest intact fine-grained clayey silt (Fig. 7B). The Old Church Formation in Eyreville A includes a burrowed contact at 346.37 m that separates glauconite-rich sand above from finer-grained clayey silt below.

Overall, the Old Church Formation in Eyreville A consists of glauconitic sand and sandy silt with clay laminae. Foraminifera and shell fragments are visible and concentrated in the sandier intervals and in burrows. The Old Church was deposited in an offshore marine environment (Browning et al., this volume).

Age assignment of the Old Church Formation at Eyreville is complicated by the fact that the boundary between lower (Rupelian Stage) and upper (Chattian Stage) Oligocene has not yet been formalized by international agreement. According to recent

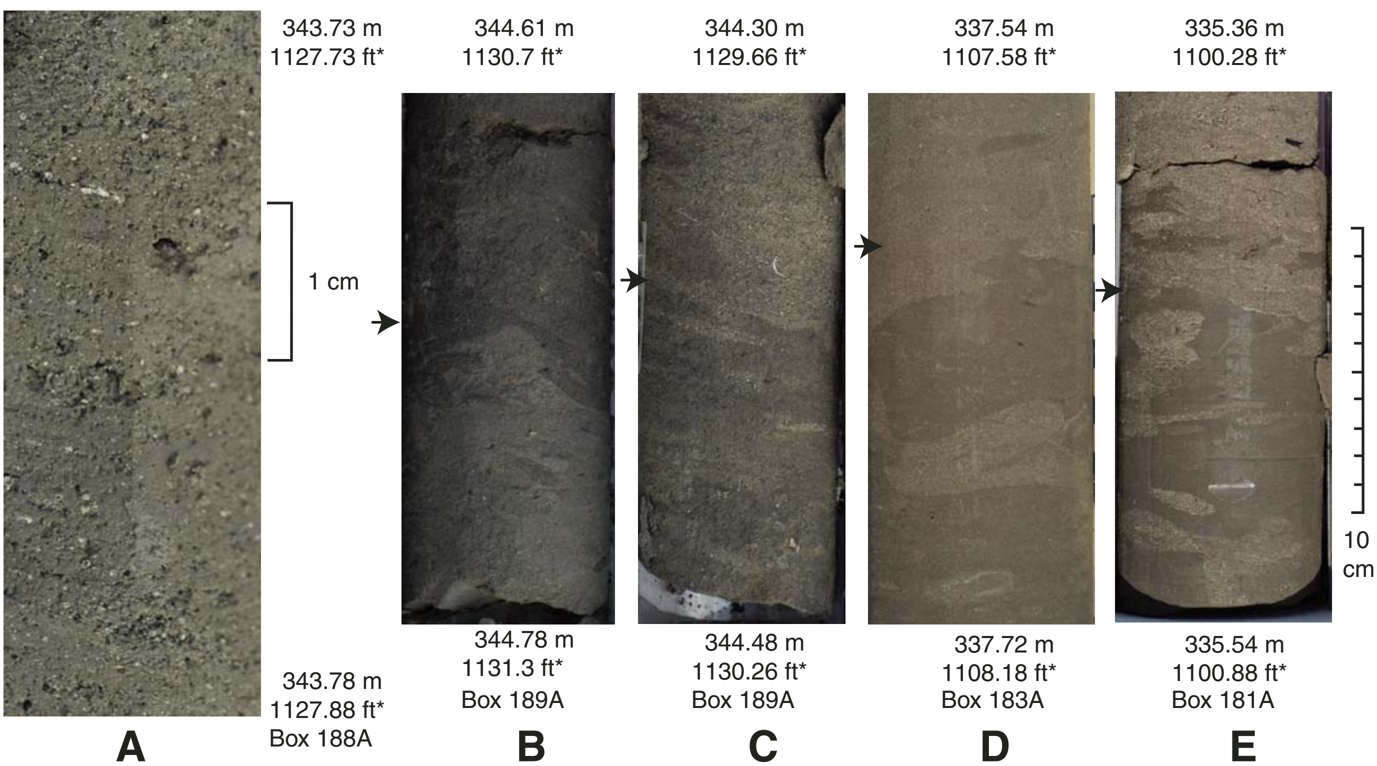

Figure 7. Onsite photographs of the Old Church Formation and Newport News beds of the Calvert Formation. (A) Detail of foraminifera-rich, diatom-rich sandy silt of the Newport News beds. (B) Irregular contact at 344.70 m (1131.0 ft*) between the Old Church Formation (below) and the Newport News beds (above). The contact (arrow) separates lighter-colored clayey silt (the top of a fining-upward sequence) from darker, fine-grained glauconitic quartz sand (the base of another fining-upward sequence). (C) Sharp burrowed contact (arrow) within the Newport News beds at 344.34 m (1129.8 ft*). Above the contact, lighter-colored, foraminifera-rich, glauconitic sand fills burrows in darker clayey silt. (D–E) Additional burrowed contacts (arrows) within the Newport News beds.

compilations (Luterbacher et al., 2004), the Old Church in Eyreville A is probably wholly upper Oligocene; however, it could include both lower and upper Oligocene when a formal boundary is established (Coccioni et al., 2008). Strontium-isotope analyses (Browning et al., this volume) yield ages that range from 24.4 to 27.2 Ma. These ages are slightly younger than ages reported by Weems et al. (2006) for the Old Church Formation in Virginia. Calcareous nannofossils from the Old Church Formation in Eyreville A place it in zones NP24–NN1 undifferentiated.

Calvert Formation, Lower and Middle Miocene (344.70–225.43 m)

Both the Calvert Formation and the overlying Choptank Formation were named by Shattuck (1902, 1904) for olive-colored, generally fine-grained, diatomaceous sediments that crop out on the east and west sides of the Chesapeake Bay. Originally, the two formations were recognized by their molluscan faunas. Gernant (1970) repositioned the boundary between the two formations downward and named the Calvert Beach Member as the lower part of his redefined Choptank Formation. Ward (1984, 1985) further redefined the Calvert and Choptank Formations by raising their mutual boundary, placing the Calvert Beach Member of Gernant (1970) in the Calvert Formation. Here, we recognize the Calvert Formation in the sense of Ward (1984, 1985) (Figs. 7 and 8). Rader and Evans (1993) noted that the Calvert Formation in Virginia typically consists of 2–7 fining-upward sequences.

Powars and Bruce (1999) recognized the Newport News unit (informal) as a distinctive lower part of the Calvert Formation in and around the Chesapeake Bay impact crater. On the western edge, this unit consists of a sandy, shelly facies with distinctive geophysical signatures (high resistivity, high gamma). Within the crater, Powars and Bruce (1999) noted that sediments in the equivalent stratigraphic position are finer grained. The informal usage reflects the uncertainties in biostratigraphic and strontium-isotopic correlations of these lower beds to the formal Popes Creek Sand and Fairhaven Members of the Calvert Formation. Powars et al. (2005) called these sediments the Newport News

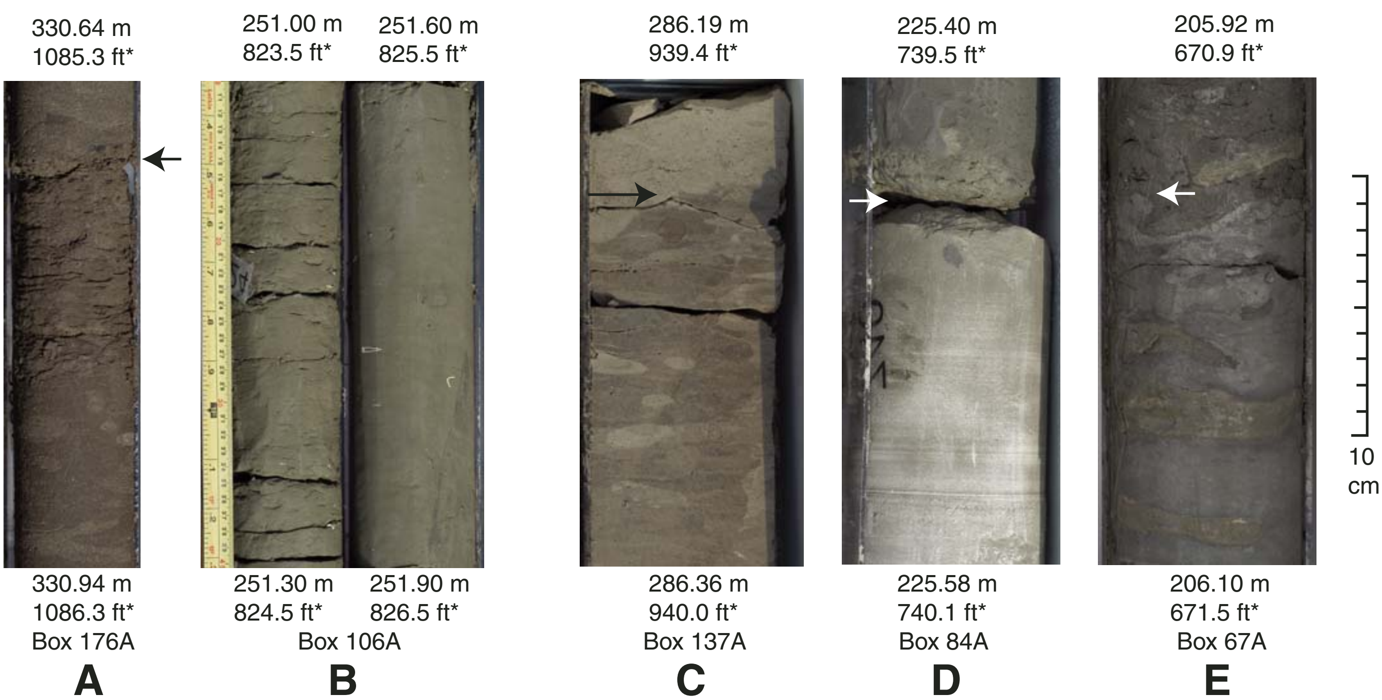

Figure 8. Photographs of the Calvert, Choptank, and St. Marys Formations. (A) Onsite box photograph of the contact (black arrow) at the top of the Newport News beds at 330.70 m (1085.5 ft*). The precise location of the contact was determined by sectioning the core and searching for the highest material from the underlying darker silty clay. (B) Onsite box detail of the Calvert Formation, undifferentiated. Left tray shows faintly laminated silts and clays; right tray shows massive appearance typical of the Calvert strata. Note burrows and the rare shell fragments (?flattened). (C) Contact (black arrow) within the undifferentiated Calvert Formation at 286.23 m (939.55 ft*). Cut, dry core showing flattened burrows. Faint dot marks location of acid test. (D) Onsite box detail showing the finer-grained, clayey silt to siltstone (calcareous-cemented) top of the Calvert Formation, undifferentiated, and its sharp, irregularly burrowed contact (white arrow) at 225.43 m (739.6 ft*) with the overlying silty, slightly glauconitic, microfossil-rich (foraminifera and diatoms), very fine to fine quartz sand of the basal Choptank Formation. (E) Onsite box detail of the sharp burrowed contact (white arrow) at 205.97 m (671.05 ft*) between the olive-gray, slightly shelly and glauconitic, clayey silt with scattered very fine to very coarse phosphate and quartz grains of the basal St. Marys Formation (above) and the gray clayey silt of the uppermost Choptank Formation (below).

beds of the Calvert Formation, and this usage is followed here. In Eyreville A, we do not differentiate the Calvert Formation above the Newport News beds into lithostratigraphically defined members or their biostratigraphic correlatives, although additional study is clearly warranted.

The Newport News beds of the Calvert Formation in Eyreville A (Fig. 7) are recognized from 344.70 m to 330.70 m and are 14.00 m thick. The upper part of the Calvert Formation is recognized from 330.70 to 225.43 m and is 105.27 m thick. The contact between the Newport News beds and the underlying Old Church Formation is irregular and burrowed (Fig. 7B). The lowest 0.2 m of the Newport News beds is a glauconitic-phosphatic sand that extends into the underlying Old Church Formation in conspicuous burrows and produces a prominent deflection to the right on the gamma log (Figs. 3 and 7B). In Eyreville A, as in other cores in the crater (Powars and Bruce, 1999), the Newport News beds display additional burrowed contacts (Figs. 7C–7E). Their upper boundary is placed at a sharp, highly burrowed contact (Fig. 8A). The Newport News beds are predominantly clayey silt in alternating light, foraminifera-rich (Fig. 7A) and dark, foraminifera-poor layers that are heavily bioturbated (Figs. 7B–7E).

The thick, undifferentiated, upper part of the Calvert Formation consists of clayey silt that is locally sandy (Fig. 8B). Foraminifera and diatoms are consistent and conspicuous components. In a few intervals in the upper part of the formation, it is slightly (<25%) sandy, predominantly very fine quartz sand with around 1% very fine glauconite (Browning et al., this volume). Complex burrows (some flattened) and irregularly burrowed surfaces (Fig. 8C) predominate; laminated zones are scattered throughout the unit. The upper contact (Fig. 8D) is marked by the top of a carbonate-cemented siltstone at 225.43 m.

The paleomagnetic data of the Calvert Formation at Eyreville (Fig. 3) reveal a reversed polarity zone in the lower part of the section and another near the top. Normal polarity intervals are weakly magnetized.

Planktonic foraminifera, dinoflagellates, and strontium-isotopes allow the Calvert Formation to be recognized as lower and middle Miocene in Eyreville A. The Newport News beds are assignable to the upper part of the lower Miocene, between 20 and 17 Ma (Browning et al., this volume). The remainder of the Calvert Formation is placed in the lower part of the middle Miocene, between ca. 16 and 13 Ma (Browning et al., this volume). The Calvert Formation in Eyreville A was deposited in offshore marine environments. Benthic foraminifera suggest overall shallowing in an outer neritic (to possibly middle neritic) environment, with water depths as deep as 200 m in the Newport News beds to ~70–100 m in the upper part of the Calvert Formation (Browning et al., this volume).

Choptank Formation, Middle Miocene (225.43–205.97 m)

The Choptank Formation was named and described by Shattuck (1902, 1904). Its type section is in Talbot County on Maryland's Eastern Shore. We follow the usage of Ward (1984, 1985), who redefined the Choptank by raising its base to exclude the Calvert Beach Member (of Gernant, 1970), which he then placed in the Calvert Formation. In its type area, the Choptank Formation consists of intervals of muddy, shelly, fine sands and muddy, nonshelly, very fine sands, silts, and clays.

The lower contact of the Choptank Formation is placed at 225.43 m in Eyreville A (Fig. 8D) where silty, slightly glauconitic, microfossil-rich, very fine to fine quartz sand of the basal Choptank overlies the carbonate-cemented siltstone at the top of the Calvert Formation. The upper contact of the Choptank was recovered in Eyreville A at 205.97 m, where burrows of the coarser basal St. Marys extend 0.3 m into the underlying silt of the uppermost Choptank Formation (Fig. 8E).

The Choptank Formation in Eyreville A is locally sandier and apparently slightly younger than the Calvert Formation below it (Browning et al., this volume). Above the indurated zone at 225.43 m that marks the top of the Calvert, the overlying Choptank (Fig. 8D) is a sandy silt with a basal lag of scattered quartz and phosphate. Sand content decreases upward, and a sharp, irregular contact marks the base of a locally laminated clayey silt. The Choptank contains visible foraminifera and diatoms and is heavily bioturbated. The Choptank Formation in Eyreville A is 19.46 m thick. We did not attempt to differentiate the formal members of the Choptank Formation, although the relatively fine-grained St. Leonard Member (very fine sand to silt, not shelly) may be represented in Eyreville A.

The upper part of the Choptank Formation and the lower part of the St. Marys Formation at Eyreville show reversed polarity (Fig. 3).

The Choptank Formation at Eyreville is middle Miocene. Strontium and dinoflagellate data (DN6) suggest an age of ca. 13 Ma (Browning et al., this volume). This age control suggests that the Choptank Formation in the Eyreville A core is correlative to parts of the Choptank Formation in Virginia and Maryland (de Verteuil and Norris, 1996) and is approximately the same age as only the upper part of strata referred to as the Choptank in Delaware (see Browning et al., this volume). The Choptank Formation in Eyreville A represents deposition in an offshore, middle neritic environment at ~75–100 m water depth, possibly shallowing to less than 50 m at the top (Browning et al., this volume).

St. Marys Formation, Upper Miocene (205.97 to ~139 m)

The St. Marys Formation in Maryland was named by Shattuck (1902) who recognized it by its molluscan faunas. Clark (1903) described it as fossiliferous sandy clay.

The St. Marys Formation is 67.54 m thick in Eyreville A (Figs. 8 and 9). Its lower contact at 205.97 m was recovered in Eyreville A, where burrows filled with the coarser basal St. Marys extend 0.3 m down into the silt of the uppermost Choptank Formation (Fig. 8E). Like the Choptank Formation, the St. Marys shows fairly uniform, moderately high natural gamma values at Eyreville, and the boundary between these formations is difficult to pick on the gamma-ray log.

The upper contact of the St. Marys Formation is present in both Eyreville A and C. In Eyreville A, the contact is placed at 138.41 m where the somewhat shelly, clayey sand of the Eastover Formation overlies the slightly sandy, silty clay of the St. Marys (Fig. 9D). The contact is readily visible when the core is dry and appears to be horizontal. Poor recovery in the core run, however, makes the exact location of the contact and its geometry uncertain. In Eyreville C, the contact is at 138.96 m where the shelly, silty sand of the Eastover overlies the clayey silt of the St. Marys (Fig. 9E). Shell concentrations, presumably in burrows, extend 0.3 m downward. The placement of the St. Marys–Eastover contact is straightforward in onshore sections where the sand overlies silt or clay. In the Eyreville cores, the sand of the typical Eastover overlies a clayey silt, which overlies a thin sand, which overlies a clayey silt. For consistency and ease of correlation, we place the contact at the base of the thin sand. This thin sand is readily apparent on the gamma log as a deflection to the left.

In the Eyreville cores, the St. Marys Formation varies from a silty clay to a clayey silt. Sand-sized particles are locally present and include very fine quartz, minor glauconite and phosphate, and foraminifera. Shell fragments and a few articulated shells are generally sparse, but locally concentrated in horizontal layers (Figs. 9A–9C). The formation appears massive, but it may show bioturbation or may be faintly laminated with an alternation of slightly lighter and darker layers. At its base, the St. Marys Formation is a silt with coarser sand and multiple generations of burrows (Fig. 8E).

A dinocyst zone assignment (DN9) and a planktonic foraminiferal occurrence in the lower part of the formation, along with broadly interpreted strontium isotope data, place the St. Marys

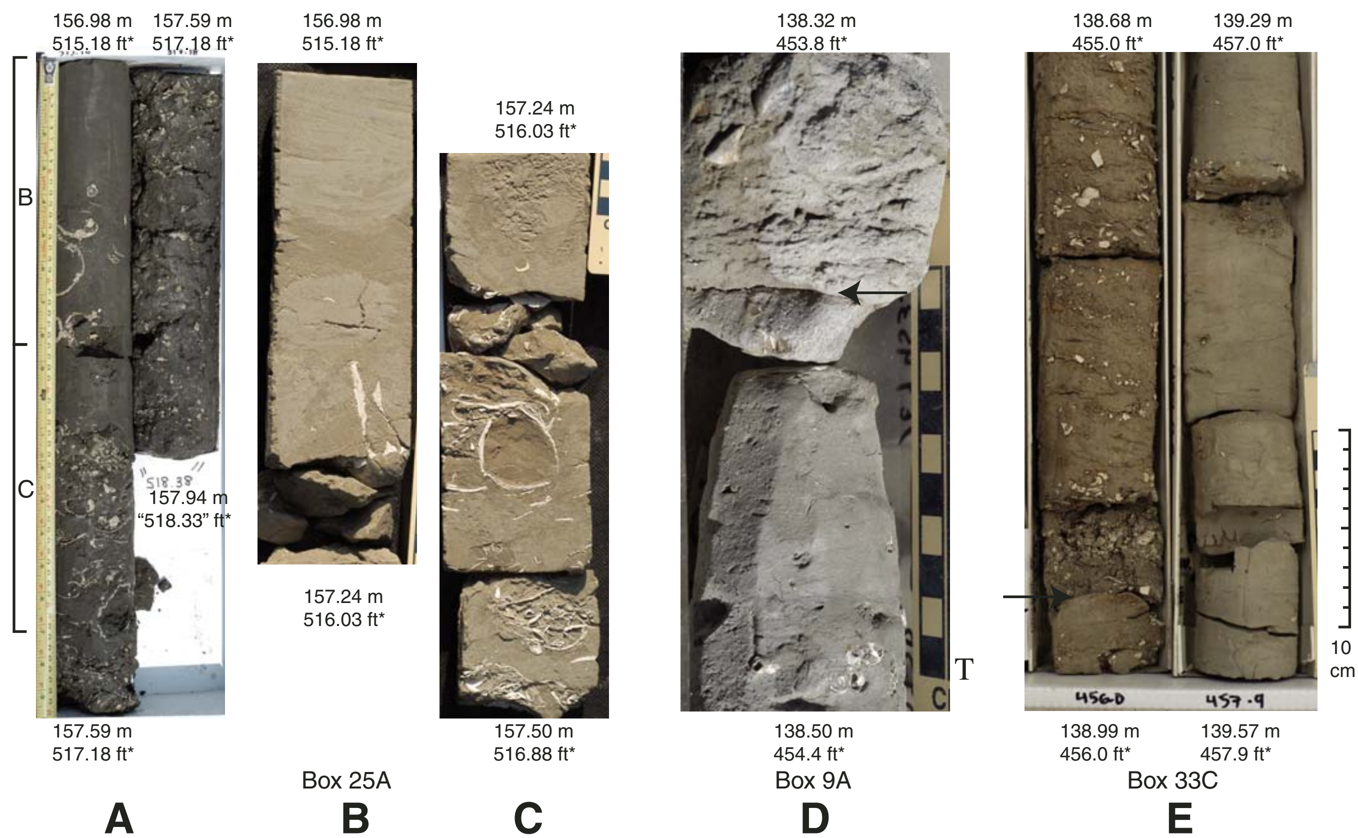

Figure 9. Photographs of the St. Marys and Eastover Formations. (A) Onsite box photograph showing the typical lithologies within the St. Marys Formation: a clayey silt (top) and a more shelly, sandy clayey silt. Left side shows the locations of detailed photographs. (B) Cut, dry core, detail of clayey silt. (C) Cut dry core, detail of shelly, sandy silt. (D) Sharp contact (black arrow) between muddy sand of the basal Eastover Formation and silty clay of the uppermost St. Marys Formation in Eyreville A at 138.41 m (454.1 ft*), dry core. Note the chambers of the *Turritella* (T) in the St. Marys strata. (E) The same contact (black arrow) in Eyreville C at 138.96 m (455.9 ft*), dry core. This photograph also illustrates the typical sandy Eastover lithology above the contact in the left tray in contrast to the clayey lithology of the St. Marys unit in the right tray.

Formation in the upper Miocene at Eyreville, in a range no older than 8.3 Ma and no younger than around 7.0 Ma (Browning et al., this volume). The age of the St. Marys Formation at Eyreville is generally consistent with those reported from other cores and outcrops from the Chesapeake Bay region (de Verteuil and Norris, 1996; Powars and Bruce, 1999; Edwards et al., 2005). However, similar fine-grained strata in southern Delaware (Bethany Beach) assigned to the St. Marys Formation are slightly older, between 11.0 and 9.5 Ma (Browning et al., this volume).

The St. Marys Formation is an offshore deposit in the Eyreville cores. Benthic foraminiferal data indicate that water depths shallowed upward from middle neritic (50–80 m) at the base to inner neritic (around 25 m) near the top (Browning et al., this volume).

Eastover Formation, Upper Miocene (~139–57.77 m)

The Eastover Formation was named by Ward and Blackwelder (1980). It is 81.19 m (266.4 ft) thick in Eyreville C, from 138.96 to 57.77 m. Only its lower part was recovered in Eyreville A. The sandiness of this and the overlying units was the principal reason for the decision to ream and case through them prior to drilling Eyreville A and to return later to core and log Eyreville C separately.

The lower contact with the underlying St. Marys Formation is placed at 138.41 m in Eyreville A (Fig. 9D) and at 138.96 m in Eyreville C (Fig. 9E). In both cores, silty sand overlies slightly sandy, finer-grained sediment that consists of roughly equal amounts of silt and clay. The upper contact with the overlying Yorktown Formation is placed at 57.77 m in Eyreville C, where the glauconitic sands of the upper part of the Eastover Formation are overlain by a laminated silt at the base of the Yorktown Formation (Figs. 10B and 10C).

In the Eyreville cores, the Eastover Formation is a very fine to fine quartz sand, typically shelly. Cemented zones are locally present (Fig. 10A). Ward and Blackwelder (1980) divided the formation into a lower Claremont Manor Member and an upper

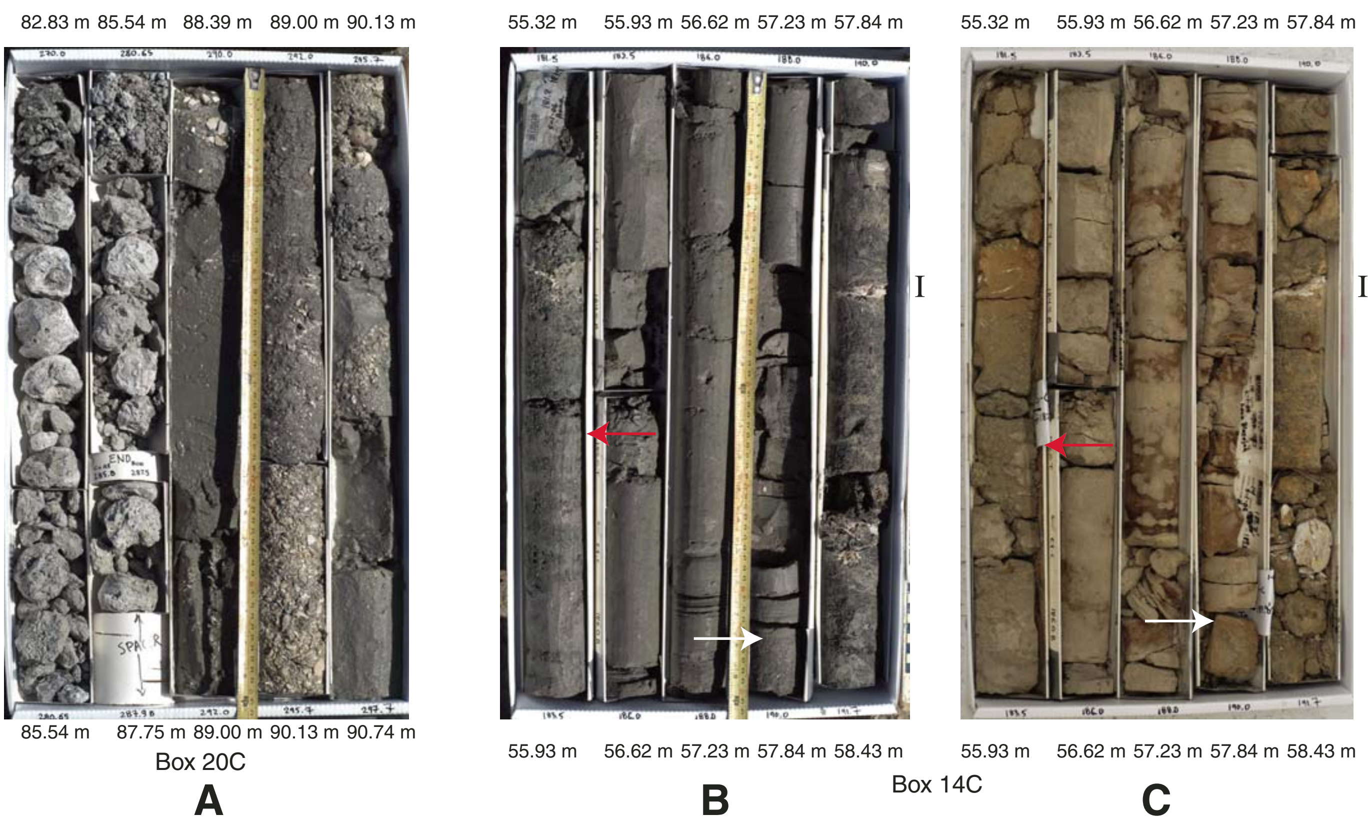

Figure 10. Eyreville C, box photographs of the Eastover and Yorktown Formations. (A) Representative lithologies in the Eastover: shelly, silty sands in the two right trays; well-sorted, water-bearing sands in the middle tray; carbonate-cemented sandstone in the two left trays. (B) Onsite photograph showing, in ascending order: the glauconitic sand of the upper part of the Eastover Formation (containing *Isognomon* [I], an index fossil for the Eastover and lower units); clayey silt of the lowermost 2.16 m (7.1 ft*) of the Yorktown Formation; and shelly, muddy glauconitic sands higher in the Yorktown Formation. Contacts are at 57.77 m (189.8 ft*, white arrow) and 55.69 m (182.7 ft*, red arrow). (C) Same box, photographed 20 months later. Note that the lower silt of the Yorktown dries to a grayish brown, is laminated to locally cross-stratified, and contains visible organic matter (arrows as in B).

Cobham Bay Member. The interval from 138.96 m to 128.78 m compares well with their description of the Claremont Manor Member as a clayey sand that fines upward (Fig. 9E). Above this fine-grained lower part, the Eastover Formation in Eyreville C is much thicker than the type section of the Cobham Bay Member along the James River. In the core, this part of the Eastover Formation is mostly a sand to shelly sand, glauconitic at the top (Figs. 10B and 10C). A zone of alternating carbonate-cemented sandstone and loose sand (Fig. 10A) was poorly recovered from 88.39 to 81.20 m. A finer-grained interval is present from 81.20 to 72.79 m. The Cobham Bay Member was described by Ward and Blackwelder (1980) as a well-sorted shelly sand with some clay present where structural or depositional barriers were located. Powars and Bruce (1999) noted that cores in southeastern Virginia included thick upper sections of the Eastover Formation that did not correspond precisely to the named members, which were based on outcrops. Here, as in Powars and Bruce (1999) and Powars et al. (2005), we note that the Eastover has a more clay-rich lower part and an upper, shelly part with a characteristically high resistance signature (Fig. 4).

The Eastover Formation is considered to be upper Miocene at Eyreville on the basis of numerous strontium isotope determinations and one dinoflagellate determination (DN9 near the base; Browning et al., this volume). This placement is consistent with other age determinations for the Eastover Formation in the region on the basis of dinoflagellates (DN9–10), calcareous nannofossils (NN11), and strontium isotopes (Powars et al., 2005; Powars and Bruce, 1999). The lithologies in the Eyreville cores indicate that the Eastover Formation was deposited in offshore, lower shoreface, and upper shoreface environments (Browning et al., this volume).

Yorktown Formation, Lower and Upper Pliocene (57.77–32.16 m)

The Yorktown Formation was originally named by Clark and Miller (1906). It was redefined to exclude much of its original lower part and subdivided into formal members by Ward and Blackwelder (1980). Three of their members, in ascending order, the Sunken Meadows Member, the Rushmere Member, and the Morgarts Beach Member (also spelled Mogarts Beach), are tentatively recognized here. The lower contact of the Yorktown Formation with the underlying Eastover Formation at 57.77 m is atypical because a 2.08-m-thick, faintly laminated, burrowed silt is present above, and fills burrows in, the glauconitic sand of the Eastover (Figs. 10B and 10C), as opposed to the typical shelly-sand on shelly-sand contact (Ward and Blackwelder, 1980; Powars and Bruce, 1999). The upper contact with the Chowan River Formation was not recovered, and a prominent deflection in the gamma-ray log at 32.16 m is used to place the contact.

The Yorktown Formation is 25.74 m thick in Eyreville C, where it is predominantly very fine to medium sand, locally glauconitic, with shell-rich intervals (Fig. 11A) above the basal laminated silt (Figs. 10B and 10C). The lower part, from 57.77 to 48.10 m, is placed in the Sunken Meadows Member due to its lithologic similarity with the type section. The middle of the Yorktown Formation in Eyreville C is a shell-rich sand tentatively placed in the Rushmere Member (48.10–38.53 m). The sand of the Yorktown becomes more clayey in its upper part and shells are mostly fragments. This interval (38.53–32.03 m) is tentatively placed in the Morgarts Beach Member.

The age of the Yorktown was considered to be both early and late Pliocene by Dowsett and Wiggs (1992, 4.0–3.0 Ma) and Krantz (1991, 4.8–3.0 Ma). In the Kiptopeke core (Powars and Bruce, 1999), planktonic foraminiferal zonal assignments (N18 for the Sunken Meadow Member and N19–20 for the Morgarts Beach Member) suggest that the Yorktown could include both upper Miocene and Pliocene. In the age model for the Yorktown Formation in Eyreville C (Browning et al., this volume), the unit is divided into an early Pliocene and a late Pliocene sequence; however, Sr-isotopic resolution for this interval is limited by the low rates of global change in the Pliocene and the scatter in the data. The depositional environment for most of the Yorktown Formation is interpreted as lower shoreface; the laminated silt at the base is interpreted as estuarine.

Chowan River Formation, Upper Pliocene (32.16–18.32 m)

The Chowan River Formation was separated from the underlying Yorktown Formation by Blackwelder (1981), who reported that it represented an unconformity-bounded unit deposited during the late Pliocene. The unit was recognized and dated in the Kiptopeke core (Powars and Bruce, 1999). A similar gamma-log pattern was used to recognize the Chowan River Formation in Eyreville C from 32.16 to 18.32 m depth.

The lower contact of the Chowan River Formation and the underlying Yorktown Formation was not recovered in Eyreville C (Fig. 11B). The upper contact with the Nassawadox Formation is placed at the base of the pebbles and cobbles that represent the lowest Nassawadox. In Eyreville C, the Chowan River Formation is well-sorted, silty quartz sand that coarsens upsection. Sand-sized shell fragments are scattered throughout, and fine laminations and local cross-beds are apparent (Fig. 11C).

The Chowan River Formation is dated as late Pliocene using Sr-isotope stratigraphy (Browning et al., this volume), in close agreement with previous assignments (Krantz, 1991; Dowsett and Wiggs, 1992). The silty, burrowed character of these shelly sands suggests deposition in a lower shoreface environment.

Nassawadox Formation, Upper Pleistocene (18.32–0.61 m)

Sediments recovered from 18.32 to 0.61 m are placed in the Nassawadox Formation of Mixon (1985). The lower contact with the underlying Chowan River Formation is poorly recovered, but it is placed at the lowest gravel near the top of a coring run

(Figs. 12A and 12B). Where complete, the Nassawadox Formation consists of a lower Stumptown Member that fills the Eastville paleochannel and the more widely distributed middle Butlers Bluff Member and upper Occohannock Member (Mixon, 1985; Colman and Halka, 1989; Parsons et al., 2003). Only the Butlers Bluff (18.32–7.01 m) and Occohannock Members (7.01–0.61 m) are identified in Eyreville C.

The Butlers Bluff Member of the Nassawadox Formation is fine to medium sand with scattered shells and shell fragments. A layer of gravel forms its base (Figs. 12A and 12B). Near the top, two intervals (0.4 m and 1.7 m thick) are mostly clay. This member is abruptly overlain (Figs. 12C and 12D) by the relatively clean sands of the Occohannock Member. These sands are oxidized in their upper part and include thin intervals (<1 cm) of weathered clays.

The Nassawadox Formation is upper Pleistocene. Strontium dates from the Butlers Bluff Member in Eyreville C (Browning et al., this volume) suggest it correlates with marine isotope chron 11 (420–360 ka). The formation is interpreted as nearshore and lagoonal deposits (Browning et al., this volume).

DISCUSSION

The Eyreville A and C cores were drilled with the goal of recovering thick stratigraphic sections in the "moat" of the Chesapeake Bay impact structure. From 444 m to land surface, the cores represent an overwhelming success. The recovered stratigraphic succession does not represent simple passive-margin deposition because structural adjustments, such as differential compaction and faulting, continue to the present day (Johnson et al., 1998; Powars and Bruce, 1999; Poag et al., 2004; Kulpecz, this volume). Details of the sequence stratigraphy and chronostratigraphy of these sediments are given in Browning et al. (this volume).

The upper Eocene Chickahominy Formation is thicker in the Eyreville cores than in any other section cored to date. Lying immediately above the impact-generated deposits, it represents an initial episode of rapid deposition in a deep-water setting. In contrast, the two Oligocene units present, the Drummonds Corner beds and the Old Church Formation, are thinner in the impact crater "moat" of Eyreville than in

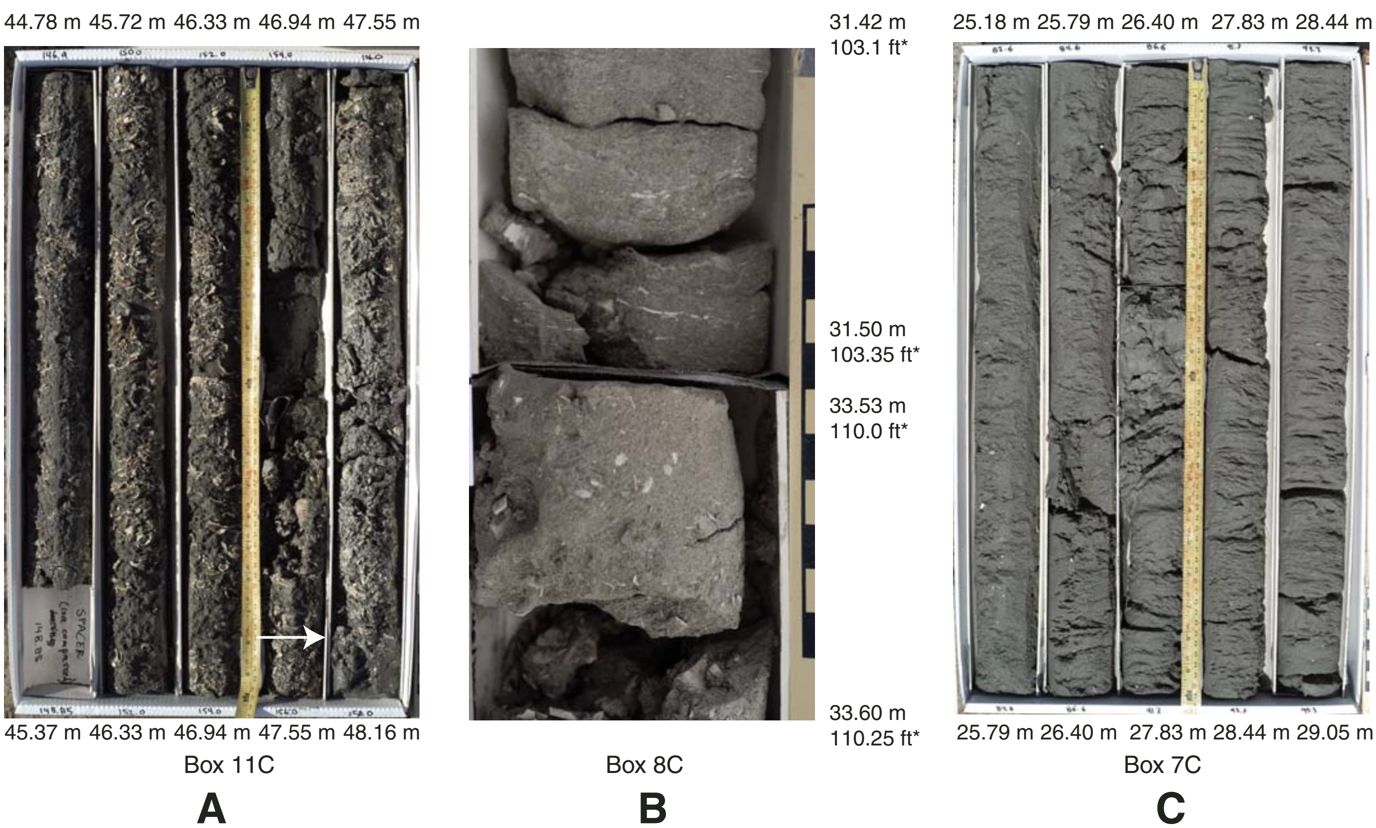

Figure 11. Photographs of Yorktown and Chowan River Formations in Eyreville C. (A) Onsite box photograph of typical very shelly sand of the lower Yorktown Formation. Arrow marks indistinct ?Sunken Meadows Member–?Rushmere Member boundary at 48.10 m (157.8 ft*). (B) Dry core detail photograph of the interval across the Yorktown–Chowan River contact (not recovered) at the run break between recovered silty, clayey sand of the Yorktown (below) and silty, but not clayey, sand of the Chowan River Formation (above). (C) Onsite box photograph of typical stratified sand of the Chowan River Formation. White specks are small shell fragments.

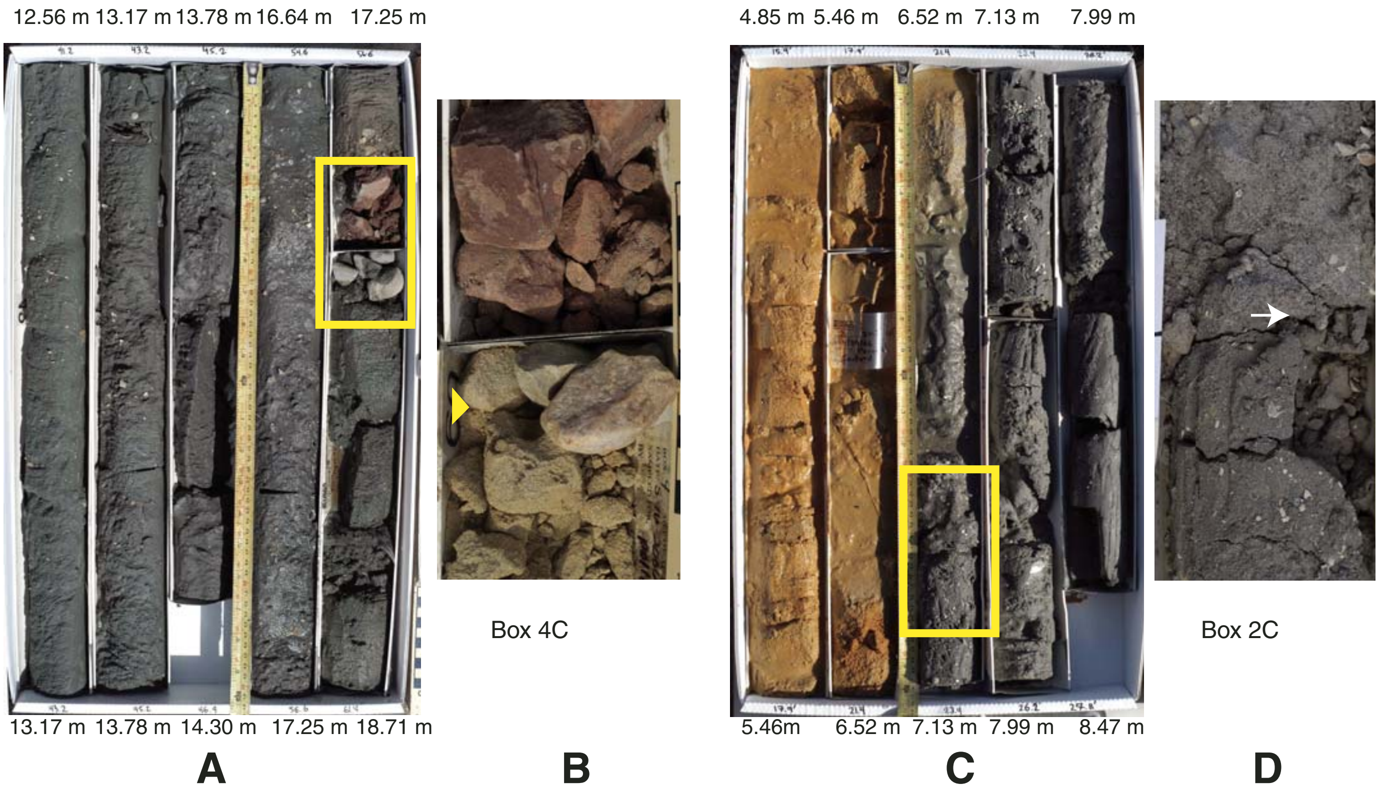

Figure 12. Photographs of Chowan River and Nassawadox Formations in Eyreville C. (A) Onsite box photograph showing a sharp contact at 18.32 m (60.1 ft*) at the base of the cobbles that mark the unconformity between the Butlers Bluff Member of the Nassawadox Formation (upper Pleistocene) and the Chowan River (upper Pliocene) strata. Yellow rectangle shows interval of detail. (B) Photograph of the dry core interval and contact (yellow arrow). Note that the gray sands of the uppermost Chowan River strata have turned yellowish (compare with A), revealing a probable high sulfide content. (C) Onsite box photograph of the Nassawadox Formation showing the contact at 7.01 m (23.0 ft*) between the wet sands (mostly oxidized except the bottom 0.3 m) of the Occohannock Member and the finer-grained, clayey, silty, shelly sands of the Butlers Bluff Member. Yellow rectangle shows interval of detail. (D) Detail of the contact (white arrow) in the dried core.

some onshore cores (e.g., USGS-NASA Langley, Powars et al., 2005; see also Powars and Bruce, 1999). Because the Oligocene units are also thin (11.6 m) over the structure's central peak at Cape Charles (Gohn et al., 2007), the central crater may have been starved of sedimentation during Oligocene time and/or subject to submarine scour subsequently. Additionally, structural complications and differential compaction produced a highly irregular surface for initial deposition of these thin units. Early Miocene deposition is also poorly represented.

The thick record of middle Miocene deposition in Eyreville indicates a second episode of rapid sediment accumulation. The St. Marys and Eastover Formations show a third episode of rapid sediment accumulation during late Miocene time. Episodes of channel-filling are represented by the Pliocene Yorktown and Chowan River Formations and by the Pleistocene Nassawadox Formation (Powers et al., this volume). The locations of these channels may be related to low elevation due to continued compaction and/or other features of crater geometry. Details of the complex history of deposition are given in Kulpecz et al. (this volume).

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APPENDIX 1. LITHIC SUMMARY OF EYREVILLE A

Grain size abbreviations for sand: vf—very fine, f—fine, m—medium, c—coarse, vc—very coarse.

Depth to base rmcd (ft*)	Thickness (m)	Lithology
126.89 m (416.3)	——————Beginning of boxed recovery (Box 1A)——————	
		CEMENT from drilling and casing in July 2005
127.31 m (417.7)	——————Beginning of suspect core——————	
		SILT, clayey, shelly
129.94 m (426.3)	——————Beginning of good core—————— *Eastover Formation*	
	5.94	SILT, clayey, slightly sandy (vf quartz), slightly micaceous, sparse shell fragments, local whole shells (*Mercenaria*, *Turritella*), heavily burrowed, some sand-filled; dark greenish gray (5GY 4/1).
135.88 m (445.8)	——————Contact (Box 8A) not recovered——————	
	2.53	SAND, very clayey, very silty, slightly micaceous, vf quartz, <1% glauconite (vf), heavily burrowed with abundant sand-filled burrows and clay-lined burrows, sparse shells (bivalves, turritellids); dark greenish gray (5GY 4/1).
138.41 m (454.1)	*Base of Eastover Formation* ——————Contact (Box 9A) sharp—————— *Top of St. Marys Formation*	
	18.38	CLAY, silty, locally slightly sandy (vf quartz), carbonate-cemented siltstone at 140.76–140.94 m (461.8–462.4 ft*), massive, heavily bioturbated, locally with faint wavy bedding, local concentrations of shells in horizontal layers and in burrows, e.g., turritellids, at 148.38–148.41 m (486.8–486.9 ft*), 149.47–149.50 m (490.4–490.5 ft*), bivalves at 151.27–151.30 m (496.4–496.5 ft*), 151.36–151.39 m (496.7–496.8 ft*), 151.45–151.48 m (497.0–497.1 ft*), 153.61–153.64 m (504.0–504.1 ft*), 154.38–154.44 m (506.6–506.8 ft*); dark greenish gray (10GY 4/1) and very dark greenish gray (5GY 3/1).
156.79 m (514.55)	——————Contact (Box 24A) sharp, irregular, difficult to see——————	
	0.53	SILT, clayey, sandy, with sand-filled burrows (quartz, glauconite, phosphate), inclined bedding visible at 157.02–157.08 m (515.3–515.5 ft*); sandier (vf) and burrowed with sparse whole bivalves and gastropods at 157.08–157.32 m (515.5–516.3 ft*); very dark greenish gray (5GY 3/1).
157.32 m (516.3)	——————Contact (Box 25A) sharp, irregular——————	
	48.63	CLAY and SILT, slightly sandy (vf); sandier and with more abundant shells (punky, some articulated bivalves) at 157.32–157.96 m (516.3–“518.38” ft*); faintly laminated with alternation of siltier and clay-rich intervals or color-mottled with bioturbation of siltier and clay-rich intervals; locally visible foraminifera, locally visible shells; at 204.52 m (666 [uncorrected] ft*) grades from a silty clay to a silt over 0.46 m (1.5 ft) with abundant sand-filled burrows and has conspicuous sand (vf-m, rare c-vc) below 205.68 m (669.8 ft*) with up to 5% vf-c phosphate grains and chips (soft? glauconite or heavy mineral?), rare teeth and bone fragments, small shells and fragments, scattered echinoid spines, foraminifera, and rare pyritized diatoms, heavily burrowed (multiple generations, back-filled, clay-filled); very dark greenish gray (5GY 3/1, 10Y 3/1, 10GY 3/1) and dark greenish gray (5GY 4/1, 10Y 4/1).
205.97 m (671.05)	*Base of St. Marys Formation* ——————Contact (Box 67A) sharp, burrowed down up to 0.9 ft—————— *Top of Choptank Formation*	

	12.80	SILT, clayey, locally sandy (vf quartz), 1%–2% black grains (phosphate or heavy mineral), trace to 2% mica, bioturbated, locally faintly laminated to wavy bedding, occasional to rare fossils: foraminifera, diatoms (some pyritized), echinoid spines, fish scales; sandier and more glauconite at 218.72 m (712.6 [uncorrected] ft*); dark greenish gray (10Y 4/1).
218.75 m (712.7)	——Contact (Box 78A) sharp, irregular, burrowed——	
	6.68	SILT, sandy, (vf-f quartz), sand increasing downward to 25%; bioturbated and color-mottled throughout; visible fossils: foraminifera, diatoms (some pyritized), echinoid spines; burrowed interval and possible burrowed contact at 223.33 m (732.7 ft*); dark greenish gray (10Y 4/1).
225.43 m (739.6)	*Base of Choptank Formation* ——Contact (Box 84A) sharp, irregular, burrowed—— *Top of Calvert Formation, undifferentiated upper part*	
	22.80	SILTSTONE, calcareous-cemented, slightly sandy (vf quartz); at 225.75 m (740.66 ft*) becomes a SILT, sandy (vf quartz), clayey, calcareous, heavily bioturbated and color-mottled; locally laminated; visible foraminifera, diatoms (including pyritized, more abundant downward), rare shell fragments, echinoid spines, fish scales; dark greenish gray (5GY 4/1, 10Y 4/1).
248.23 m (814.4)	——Contact (Box 103A) sharp, angular——	
	0.30	SILT, sandy (up to 25%, vf-m quartz, 1%–2% vf-f phosphate), slightly micaceous, faintly laminated to heavily burrowed, sand and foraminifera concentrated in burrows; visible foraminifera and diatoms; dark greenish gray (5GY 4/1).
248.53 m (815.4)	——Contact (Box 104A) sharp, irregular——	
	37.70	SILT, clayey, locally sandy (vf quartz), slightly micaceous, heavily bioturbated and color-mottled, sand and foraminifera concentrated in burrows; locally laminated (mm-scale); visible foraminifera and diatoms, scattered bivalves at 252.35–252.94 m (828–830 ft*) and below 278.28 m (913 ft*); scattered phosphate (vf-pebbles) at 261.59–262.72 m (858.5–862.4 ft*) and (vf-c) in sand-filled burrows at 276.02–276.26 m (905.7–906.5 ft*); dark greenish gray (5GY 4/1), dark gray (5Y 4/1), greenish gray (5GY 5/1).
286.23 m (939.55)	——Contact (Box 137A) sharp, burrowed down to 0.15 ft——	
	13.72	SILT, clayey, minor sand (vf quartz, vf glauconite), visible foraminifera and diatoms; faintly laminated to locally intensely burrowed (e.g., 286.19–286.97 m [939.4–941.5 ft*], 293.15–293.41 m [961.8–962.7 ft*], 293.98–294.18 m [964.6–965.3 ft*]); at 295.28 m (969.0 ft*) becomes darker and faintly laminated; at 298.93 m (980.74 ft*) sand-sized foraminifera become conspicuous and lighter sandy zones (1% green and black glauconite, vf-m quartz) show complex burrows into darker, finer-grained remnants of underlying material; greenish gray (5GY 5/1), very dark grayish brown (2.5Y 3/2).
299.95 m (984.1)	——Contact (Box 149A) sharp, irregular (0.3 ft relief), burrowed——	
	13.72	SILT, clayey and CLAY, silty; faintly laminated to locally intensely burrowed (e.g., 303.86–304.22 m [996.9–998.1 ft*], 307.79–308.05 m [“1010.3”–1010.7 ft*]), visible foraminifera, visible diatoms; at 311.63 m (1022.4 ft*) becomes foraminiferal sand (foraminifera are poorly preserved, locally with vf quartz) interbedded with clayey silt layers; lighter and conspicuously laminated below 312.48 m (1025.2 ft*); dark olive gray (5Y 3/2).
313.67 m (1029.1)	——Contact (Box 161A) sharp, irregular, difficult to see——	
	17.03	SILT, clayey, locally slightly sandy (vf), massive and bioturbated to locally faintly laminated; visible foraminifera (locally abundant), visible diatoms, scattered shell fragments; phosphatic and sandy at base with very fine pebbles and elongated (up to 3 mm) phosphatic bone and/or tooth fragments; very dark grayish brown (2.5 Y 3/2), olive gray (5Y 4/2), dark olive gray (5Y 3/2).

330.70 m (1085.5)[1]
Calvert Formation, undifferentiated upper part
——————Contact (Box 176A) sharp, irregular, highly burrowe ——————
Calvert Formation, Newport News beds

13.64 SILT, clayey, foraminifera-rich, alternating intervals that are lighter and have more abundant foraminifera (sand-sized) and darker and more clayey, separated by burrowed surfaces (e.g., 333.30 m [1093.7 ft*], 335.42 m [1100.5 ft*], 337.60 m [1107.8 ft*]); bioturbated throughout, locally with a variety of crosscutting burrows, rarely laminated (wavy), glauconitic (vf-f, 1%) at base of sandy intervals; at 1129.2–1129.8 ft* becomes a foraminifera-rich GLAUCONITIC SAND, quartz (vf-vc), glauconite (silt-c), phosphate (including shark teeth and bone fragments), shell fragments; additional fossils include foraminifera, diatoms, echinoid spines, fish scales; dark gray (5Y 4/1), dark olive brown (2.5Y 3/3), and dark olive gray (5Y 3/2).

344.34 m (1129.8)
——————Contact (Box 189A) sharp, irregular——————

0.35 SILT, clayey, glauconitic (vf-m), heavily burrowed, subhorizontal layers possibly compressed burrows (foraminifera-rich quartz sand) that include much material from overlying unit, foraminifera in clay and more abundant in burrows, grades downward at ~344.49 m (1130.3 ft*) into GLAUCONITIC SAND (vf-f, up to 30%, concentrated in burrows), clayey, silty, visible foraminifera; rare shell fragments, shark teeth, bone fragments; very dark greenish gray (5Y 3/1).

344.70 m (1131.0)
Base of Calvert Formation, Newport News beds
——————Contact (Box 189A) sharp, irregular——————
Top of Old Church Formation

1.67 SILT, very clayey, minor glauconite (silt-vf), visible foraminifera, especially in burrows, bioturbated clay (darker) with wavy silt lenses (lighter); near base is PHOSPHATIC, GLAUCONITIC SAND (silt-c), clayey, silty; very dark greenish gray (5Y 3/1), black (5Y 2.5/1).

346.37 m (1136.7)
——————Contact (Box 191A) sharp, irregular——————

1.59 SILT, sandy, with clay laminae, foraminifera-rich, glauconitic (vf-f), quartz (vf-f), heavily bioturbated (concentrating foraminifera); from 347.14 m (1138.9 ft*) to 347.96 m (1141.6 ft*) is GLAUCONITIC SAND (30%–40% foraminifera, 30%–40% f-m glauconite, vf quartz), heavily bioturbated; shark tooth at 347.62 m (1140.5 ft*); black (5Y 2.5/1).

347.96 m (1141.6)
Base of Old Church Formation
——————Contact (Box 192A) sharp, burrowed——————
Top of Drummonds Corner beds

2.13 SILT, sandy (vf-f glauconite), clayey, complexly burrowed and more clay-rich near top; heavily burrowed throughout, visible foraminifera concentrated in burrows, scattered bivalve shells and fragments, glauconite concentrated in burrows, conspicuous quartz component to sand at 348.72–348.81 m (1144.1–1144.4 ft*), semi-indurated at 349.48–349.73 m (1146.6–1147.4 ft*); very dark greenish gray (5GY 3/1).

350.09 m (1148.6)
Base of Drummonds Corner beds
——————Contact (Box 194A) sharp, irregular, burrows down 4.2 ft——————
Top of Chickahominy Formation

13.39 SILT, clayey, foraminifera-rich, glauconite 2%–3%, more in burrows, slightly micaceous, scattered pyrite; massive and burrow-mottled, with conspicuous clay-lined and clay-filled burrows, locally laminated; common foraminifera that may be concentrated locally in horizontal layers or in burrows, scattered shell fragments; very dark gray (2.5Y 3/1), very dark grayish brown (2.5Y 3/2).

363.48 m (1193.34)
——————Contact (Box 205A) gradational——————

[1]An inconsistency was found in the location of one sample (R6467 V, 1080.5–1080.7 ft) as recorded on site and the core segments as boxed for run 84 in Eyreville A (boxes 175–177; 1078.88–1088.88 ft*). Descriptions here are based on the core as boxed. Future workers should be aware of the possibility of irregularities in these three boxes.

	5.91	CLAY, silty, 1% sand (vf, quartz), trace pyrite, visible foraminifera, scattered shell fragments (bivalves), alternating laminated (1 mm silt) and massive (bioturbated) zones; very dark greenish gray (5GY 3/1).
369.39 m (1212.5)	——————Contact (Box 211A) subtle, burrowed——————	
	3.84	SILT, very clayey, shellier than above, abundant foraminifera; massive with foraminifera-filled and pyrite-filled burrows to locally laminated (3 mm); very dark greenish gray (5GY 3/1).
373.23 m (1224.5)	——————Contact (Box 214A) gradational——————	
	9.87	CLAY, silty, slightly sandy (vf-f glauconite), common foraminifera, slightly micaceous, rare pyrite (including nodules), massive to laminated (siltier) to burrow-mottled, fossils include foraminifera, shell fragments, ostracodes, solitary coral?; olive gray (5Y 4/2), very dark gray (5Y 3/1), and dark olive gray (5Y 3/2).
383.10 m (1256.9)	——————Contact (Box 223A) sharp, burrowed——————	
	60.80	CLAY, tight, slightly silty, locally sandy (foraminifera, shell fragments, vf glauconite, ± quartz), slightly micaceous, rare pyrite; faintly laminated and burrow-mottled to locally massive; lined burrows (glauconite and/or chlorite, may be compressed); fossils include foraminifera, shell fragments, ostracodes, sponge spicules, fish scales, scaphopod; silt layer at 424.34–425.04 m (1392.2–1394.6 ft*); dark olive gray (5Y 3/2), very dark gray (2.5Y 3/1), and dark gray (5Y 4/1).
443.90 m (1456.35)	*Base of Chickahominy Formation* ——————Contact (Box 277A) sharp, horizontal, color and bedding change—————— *Top of Exmore Formation*	

APPENDIX 2. LITHIC SUMMARY OF EYREVILLE C

Grain size abbreviations for sand: vf—very fine, f—fine, m—medium, c—coarse, vc—very coarse.

Depth to base rmcd (ft*)	Thickness (m)	Lithology
0.61 m (2.0)	——————Beginning of core—————— *Nassawadox Formation, Occohannock Member*	
	0.64	SAND, variably silty, f-m, quartz, 1%–2% opaques, trace mica, local clay zones 0.5–5 mm laminae, mostly massive and thixotrophic, rarely cross-bedded, shell fragments and ?phosphate in lower ft; yellowish brown (10YR 5/6) to brownish yellow (10YR 6/6), gray (N 5/) at base.
7.01 m (23.0)	*Nassawadox Formation, Occohannock Member* ——————Contact (Box 2C) sharp—————— *Nassawadox Formation, Butlers Bluff Member*	
	11.31	SAND, locally a shelly, sandy clay at 7.01–7.38 m (23.0–24.2 ft*) and 8.23–9.91 m (27.0–32.5 ft*), f-m quartz, trace mica, up to 5% opaques, scattered shells and shell fragments, mostly massive and bioturbated, local horizontal concentrations of shells, visible foraminifera, bivalves, gastropods, echinoid spines; at base, there is a zone of pebbles and a large sandstone cobble broken by drilling; dark greenish gray (10GY 3/1, 5G 4/1).
18.32 m (60.1)	*Base of Nassawadox Formation, Butlers Bluff Member* ——————Contact (Box 4C) poorly recovered—————— *Top of Chowan River Formation*	
	13.84	SAND, m at top, vf-f downward, silty (but not clayey), well-sorted, quartz with up to 10% sand-sized (and larger) shell fragments, 2%–3% opaques that may include glauconite and phosphate, trace mica; massive with visible burrowing, including clay-lined burrows, thin bedded to locally cross-bedded; very dark grayish green (5G 3/2), very dark greenish gray (5G 3/1), and grayish green (5G 4/2).

32.16 m (105.5)

Base of Chowan River Formation
——————Contact (Box 8C) not recovered (natural-gamma log used)——————
Top of Yorktown Formation (probably Morgarts Beach Member)

6.37 SAND, silty, clayey, vf-m quartz (primarily angular), locally abundant shell, mostly as fragments; glauconite present and up to 10%–15% near base, indistinctly laminated with laminae cut by burrows; dark greenish gray (5GY 4/1).

38.53 m (126.4)

(probably Morgarts Beach Member)
——————Contact (Box 9C) sharp, angular——————
(?Rushmere Member)

1.40 SHELLY SAND, silty, clayey, vf-m quartz, many shell fragments, glauconite up to 5%; massive but with faint horizontal alignment of shells; shells are chalkier near base, dominantly bivalves including pectenids; grayish green (5G 4/2).

39.93 m (131.0)

——————Contact (Box 9C) sharp——————

8.17 SAND, silty, f-m quartz, glauconite 3%–5%, scattered shells; silt increases and sand coarsens downward to vf-vc sand with concentrated shells at 45.99–46.94 m (150.9–154.0 ft*) and 47.24–48.10 m (155.0–157.8 ft*); phosphatized shells and quartz pebbles at base, shells include *Cardium*, *Pecten*, barnacles; massive but with faint horizontal alignment of shells to faintly laminated but cut by burrows; dark greenish gray (5G 4/1), grayish green (5G 4/2), and very dark greenish gray (5G 3/1).
Megafossils identified onsite by L.W. Ward include *Chesapecten jeffersonius* at 47.55 m (156 ft*).

48.10 m (157.8)

(?Rushmere Member)
——————Contact (Box 11C) sharp——————
(?Sunken Meadow Member)

7.59 SAND, slightly silty, f-m quartz, m-c glauconite, scattered shells and zone of concentrated shells at 48.98–49.35 m (160.7–161.9 ft*), visible foraminifera throughout; glauconite/phosphate 3%–5%, up to 40% in basal burrows; massive but with faint horizontal alignment of shells to faintly laminated but cut by burrows; large barnacle at 50.54 m (165.8 ft*); at ~50.60 m (166.0 ft*), silt increases downward and glauconite/phosphate blebs are visible; silty clay at 53.89–53.98 m (176.8–177.1 ft*); phosphatic (to pebble size) and numerous clay clasts at base; scattered punky shells greenish gray (5GY 4/1 and 10GY 5/1), very dark grayish green (5G 2.5/1 and 5G 2.5/2).

55.69 m (182.7)

——————Contact (Box 14C) sharp, irregular, burrowed over 1.0 ft——————

2.08 SILT, clayey, faintly laminated and locally cross-laminated, much infilling of overlying sand in burrows, rare shell fragments, visible organics; grayish green (5GY 4/2).

57.77 m (189.8)

Base of Yorktown Formation (?Sunken Meadow Member)
——————Contact (Box 11C) sharp——————
Top of Eastover Formation, not differentiated

3.37 GLAUCONITIC SAND with lighter clay burrows, quartz increases downsection; shelly at 58.03 m (190.4 ft*) (*Isognomon*), 58.28 m (191.2 ft*), and 58.49–61.14 m (191.9–200.6 ft*); dark greenish gray (5BG 4/1) and light brownish gray (10YR 6/2).

61.14 m (200.6)

——————Contact (Box 15C) sharp, irregular, burrowed——————

11.65 SAND, silty, vf-m quartz, 3%–5% glauconite, abundant shell fragments (pectenids, oysters), trace opaques; less abundant shell fragments 68.28–70.53 m (224.0–231.4 ft*); chalkier shells, more massive (heavily burrowed) and more silt and phosphate at base; dark greenish gray (5GY 4/1).

72.79 m (238.8)

—————— Contact (Box 18C) gradational ——————

8.41 SILT, sandy, slightly clayey, 3%–5% glauconite, slightly shelly with large *Isognomon*, concentration of shell fragments at 77.33–78.58 m (253.7–257.8 ft*), heavily bioturbated with 3 mm silt-filled burrows, increase in fine sand near base; greenish gray (5GY 5/1) and dark greenish gray (5GY 4/1).

81.20 m
(266.4) ——————Contact (Box 19C) sharp——————

7.19 SANDSTONE (recovered) and SAND (not recovered), quartz sand (f-m) and shell fragments firmly cemented by carbonate, locally moldic, 2%–3% glauconite or other opaques, shells mostly bivalves (pectenids, oysters); greenish gray (5GY 6/1) to light bluish gray (10B 7/1); drillers note that indurated zones alternate with very soft zones.

88.39 m
(290.0) ——————Contact (Box 20C) sharp, noted by drillers——————

17.74 SAND, vf-f at top, coarsening to m-vc by 90.31 m (296.3 ft*), silty zone of angular shell fragments and whole bivalves and gastropods 89.92–90.25 m (295.0–296.1 ft*), vf-f clean quartz sand with very rare shell fragments to 93.94 m (308.2 ft*), silt increases below 94.49 m (310.0 ft*), clay layers begin at 95.74 m (314.1 ft*), sandier and increasing shell material and burrowing (some clay-lined) below 100.58 m (330.0 ft*), more glauconitic (5%–10%) at 104.42–105.37 m (342.6–345.7 ft*); overall 1%–3% glauconite, 1%–2% other opaques, common foraminifera and echinoid spines; dark greenish gray (5GY 4/1, 10Y 4/1, 10GY 4/1).
Megafossils identified onsite by L.W. Ward include *Oliva* at 89.92 m (295 ft*). (Suggestive of Cobham Bay Member of Eastover Formation.)

106.13 m
(348.2) ——————Contact (Box 24C) sharp, irregular——————

3.05 SHELLY SAND, silty, clayey, vf-f quartz, 5%–10% glauconite, shells are all broken, some dark-coated, mostly bivalves, some gastropods and barnacles; massive to wavy laminations downward, shells decreasing in abundance in lower 0.43 m (1.4 ft); very dark greenish gray (5GY 3/1).

109.18 m
(358.2) ——————Contact (Box 25C) sharp, irregular——————

9.33 SAND, silty, slightly clayey, vf-f quartz, 1%–3% glauconite, shell fragments present but in variable concentrations (more abundant at 116.80–118.51 m [383.2–388.8 ft*]), wavy laminations reflecting variable brown clay content and abundant burrows (some clay-lined) prominent between 110.19 and 113.48 m (361.5–372.3 ft*), burrowing less conspicuous below; dark greenish gray (5GY 4/1, 10Y 4/1, 10GY 4/1).

118.51 m
(388.8) ——————Contact (Box 28C) sharp, irregular, burrowed——————

7.98 SAND and SILT, clayey, interlaminated; from 119.60 to 119.73 m (392.4–392.8 ft*) and 120.61–120.72 m (395.7–397.3 ft*) is carbonate-cemented, shelly, vf SANDSTONE (moldic); trace glauconite, locally with whole or fragmented shells, wavy laminations reflecting variable clay content, heavily burrowed; sulfur present on dried core in vf sand zones; sand/silt is dark greenish gray (10GY 4/1) to very dark greenish gray (10GY 3/1); sandstone is light gray (N 7/).
Megafossils identified onsite by L.W. Ward include small *Nucula* at 123.15 m (404.05 ft*), *Turritella plebeia* at 125.36 m (411.3 ft*).

126.49 m
(415.0) ——————Contact (Box 30C) sharp, irregular, burrowed——————

2.29 SAND, clayey, silty, vf quartz; from 126.49 to 126.58 m (415.0–415.3 ft*) and 128.11–128.17 m (420.3–420.5 ft*) is carbonate-cemented, shelly, vf SANDSTONE; locally with scattered whole or fragmented shells, wavy to hackly laminations reflecting variable clay content, heavily burrowed; sand is very dark greenish gray (5GY 3/1); sandstone is dark greenish gray (5GY 4/1).
Megafossils identified onsite by L.W. Ward include *Chesapecten* and *Ostrea geraldjohnsoni* at 126.52 m (415.1 ft*).

128.78 m *Eastover Formation, not differentiated*
(422.5) ——————Contact (Box 31C) sharp, irregular——————
Eastover Formation, Claremont Manor Member

6.80 SILT, clayey, slightly sandy (vf quartz); upper part from 128.78 to 129.24 m (422.5–424.0 ft*) is carbonate-cemented SILTSTONE (moldic); incipient pyrite nodules; wavy laminations reflecting variable clay content, heavily burrowed including silt-filled and clay-lined burrows, sparse bivalves occur mostly

as fragments; very dark greenish gray (5GY 3/1), dark greenish gray (5GY 4/1); siltstone is light gray (N 7/) and light brownish gray (5YR 6/1).
Megafossils identified onsite by L.W. Ward include *Mercenaria* at 132.59 m (435.0 ft*).

135.58 m
(444.8) ——————Contact (Box 32C) difficult to pick——————

3.38 SAND, very silty, clayey, vf quartz, slightly glauconitic, locally abundant gastropods (turritellids), scattered bivalve fragments, benthic foraminifera, pyritized diatoms; wavy laminations reflect variable clay content, heavily burrowed; dark greenish gray (10Y 4/1, 5GY 4/1).

138.96 m *Base of Eastover Formation, Claremont Manor Member*
(455.9) ——————Contact (Box 33C) difficult to pick, probably irregular——————
Top of St. Marys Formation

0.61 SILT, clayey, sand-sized foraminifera, rare shells in sandy burrows, local clay laminae, irregularly bioturbated; dark greenish gray (5GY 4/1); clay is dark gray (N 4/).

139.57 m
(457.9) END OF EYREVILLE C

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