Stratigraphy and Characteristic Mollusks of the Pamunkey Group (Lower Tertiary) and the Old Church Formation of the Chesapeake Group—Virginia Coastal Plain

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CONTENTS

ILLUSTRATIONS

[Plates follow References cited]

STRATIGRAPHY AND CHARACTERISTIC MOLLUSKS OF THE PAMUNKEY GROUP (LOWER TERTIARY) AND THE OLD CHURCH FORMATION OF THE CHESAPEAKE GROUP— VIRGINIA COASTAL PLAIN

By LAUCK W. WARD

ABSTRACT

Along the Pamunkey River and its tributaries can be found a very complete, well-preserved, Tertiary stratigraphic record that reflects the sea-level changes as well as the local tectonic history of the central Virginia Coastal Plain. Using this record, I have described the lower Tertiary units and proposed a sequential model for their occurrence. Sediments examined in this study range in age from early Paleocene to latest Oligocene or earliest Miocene. Upper Tertiary units are described where they occur in the same sections with the lower Tertiary beds. The Brightseat Formation (lower Paleocene), Aquia Formation (upper Paleocene), Marlboro Clay (upper Paleocene), Nanjemoy Formation (lower Eocene), Piney Point Formation (middle Eocene) and Old Church Formation (new unit, upper Oligocene and lower Miocene) were studied. The definitions of the Piscataway and Paspotansa Members of the Aquia are amended, and a lectostratotype (principal reference section) is designated for those units as well as the Aquia on the Potomac River just below the mouth of Aquia Creek. A lectostratotype section is also designated for the Nanjemoy and its two members, the Potapaco and the Woodstock. That section is on the Potomac above Popes Creek. Beds assigned to the Piney Point and Old Church Formations, previously known only in the subsurface, crop out extensively on the Pamunkey River. A hypostratotype (reference section) is selected for the Piney Point Formation on the Pamunkey River at Horseshoe. The Old Church Formation (named herein) is included in the Chesapeake Group. Areal extent of the stratigraphic units was determined by correlation of outcropping beds on the Pamunkey, Patuxent, Potomac, Rappahannock, Mattaponi, Chickahominy, and James Rivers supplemented by well data. Comparisons of the onlap histories of the Salisbury, Albemarle, and Charleston Embayments indicate a number of simultaneous transgressive events implying global sea-level rises. More restricted transgressions appear to be the result of local downwarping.

INTRODUCTION

The stratigraphy of the central Virginia Coastal Plain, and specifically of the Pamunkey River area, has been the subject of attention since the early 19th century. The earliest work was accomplished by W.B. Rogers in the 1830's, 1840's, and 1850's (for a complete account of this work see W.B. Rogers, 1884, and J.K. Roberts, 1942). Most later work consisted of paleontological descriptions (see, for example, Bagg, 1895, 1896; Conrad, 1843, 1847; Cope, 1896; Van Winkle, 1919, 1921; Van Winkle and Harris, 1919; Clark, 1896b; Clark and Martin, 1901). Intensive stratigraphic work began with Darton (1891), who used the Pamunkey River exposures as typical of those glauconitic units that he termed the Pamunkey Formation. The Pamunkey Formation was later mapped by Darton (1894, 1896). Work by Clark (1896a,b) and Clark and Martin (1901) refined and modified the concept of the Pamunkey Formation and raised the unit to group status, while dividing it into formations and members. Darton (1911, 1948, 1951) accepted this stratigraphic revision and extensively mapped the formations included in the Pamunkey Group. Clark and Miller (1912) extended their stratigraphic work into the Virginia Coastal Plain, giving sections and faunal lists from outcrops on all the important rivers. The Pamunkey River received only a small share of attention in this work in spite of its numerous exposures. Paleontological interest in beds exposed along the Pamunkey was revived as a result of a Cornell University collecting venture in 1897 (Van Winkle and Harris, 1919). Van Winkle (1919) described numerous new taxa on that expedition to the lower and middle Eocene exposures in the vicinity of New Castle, Hanover County, Va. Since that time, no further work has been published on the paleontology of that area. Later stratigraphic work, however, included that of Gildersleeve (1942), Cederstrom (1957), and Ward and Blackwelder (1980). None of this work has presented a comprehensive picture of the stratigraphic framework as shown by beds exposed along the Pamunkey River.

It is the purpose of this paper to synthesize the stratigraphic framework, describe the depositional patterns, and correlate the various units recognized on the Pamunkey with those on the James, Chickahominy, Mattaponi, Rappahannock, Potomac, and Patuxent Rivers. The excellent and frequent exposures encountered on the Pamunkey lend themselves particularly well to the recognition of the natural stratigraphic sequence. The excellence of the exposures and the fact that the entire sequence is exposed over a relatively short distance make it a fine "teaching" section. Well-exposed units, exhibiting both upper and lower contacts, help one to interpret the physical evidence of depositional breaks, while the various well-preserved fossil groups enable the paleontologist to maintain excellent chronostratigraphic control. The result is an extensive record of sea-level fluctuations and paleogeography from the Paleocene through the late Pliocene. Only the lower Tertiary units are described in detail in this work (fig. 1).

Two of the factors that, perhaps, stymied earlier research on the Pamunkey River section were the failure to recognize critical formational contacts and the apparently unfossiliferous nature of many of the exposures. When closely examined, the contacts between units are seen to be clearly defined but often intensely burrowed. Sampling errors are common when collecting near contacts because of the deep burrowing (as deep as 9 feet (2.7 m)) and reworking of microfossils. Further, in spite of the good preservation of the calcareous fossil groups at many exposures, in several of the units those taxa are poorly preserved. Pollen and dinoflagellates were used to help correlate these beds.

This combination of lithostratigraphic and biostratigraphic techniques has facilitated the recognition of a complex onlap-offlap (transgressive-regressive) history in the central Virginia Coastal Plain. Such a detailed record, together with similar information from adjoining basins, makes possible the reconstruction of global sea-level fluctuations independent of local tectonic imprint. Immediately apparent, when comparing the sea-level curves of the mid-Atlantic region and the Gulf area, are the very different tectonic and sedimentary histories of the two basins. The Gulf Coastal Plain was the site of accumulation of thick sequences of alluvial and deltaic sediments; tongues of marine sediment mark intermittent sea-level rises. The Atlantic basins (Salisbury, Albemarle, and Charleston Embayments) (see fig. 2), however, were characterized by relatively thin deposits, principally marine, with only remnants of nearshore facies. It is clear that large volumes of sediment were not being transported to the Atlantic Coastal Plain during the Tertiary. Marine deposition was of longer duration than that in the Gulf area, with fewer breaks, but the shallow basins accumulated relatively thin deposits. This pattern is well developed in the central Virginia Coastal Plain where intermittent deposition of thin marine to marginal-marine beds combined to record a relatively complete tectonic and depositional history of the area.

ACKNOWLEDGMENTS

A comprehensive chronostratigraphic framework for the beds exposed in the Virginia and Maryland Coastal Plains could not have been accomplished without the help of several micropaleontologists at the U.S. Geological Survey (USGS), Reston, Va. These were: J.E. Hazel (ostracodes), R.Z. Poore (planktic foraminifers), L.E. Edwards (dinoflagellates), N.O. Frederiksen (pollen), L.M. Bybell (calcareous nannofossils), and J.A. DiMarzio (calcareous nannofossils). Also helpful was P.J. Huddlestun (planktic foraminifers) of the Georgia Geologic Survey. Suggestions on stratigraphy were provided by R.B. Mixon (USGS, Reston), P.M. Brown (North Carolina Geological Survey), C.F. Koch, D.A. Darby, and R.S. Spencer (Old Dominion University, Norfolk, Va.), and G.H. Johnson (College of William and Mary, Williamsburg, Va.). Many of the subsurface data have been adapted from Brown, Miller, and Swain (1972). The following persons aided in the field work: Thor Hansen (University of Texas, Austin), B.W. Blackwelder (Tenneco, Houston, Tex.), G.B. Lawrence (Richmond, Va.), C.M. Crampsey (USGS, Reston), E.G. Shaw (USGS, Reston), E.E. Compton (USGS, Reston), G.L. Strickland (George Washington University, Washington, D.C.), and C.C. Morrell (Old Dominion University, Norfolk, Va.).

STRATIGRAPHY

PAMUNKEY GROUP

Most of the beds now assigned to the Pamunkey Group were originally placed in the Pamunkey Formation by Darton (1891) and were considered to be of Eocene age. Describing its areal extent in some detail, Darton (1891) referred to the work of Rogers (see Rogers, 1884) and considered the exposures along the Pamunkey River, as described by Rogers, to be the typical section. (See fig. 3 for a composite section of the beds exposed along the Pamunkey River.) More detailed lithic and faunal work on the Pamunkey Formation by Clark (1896a,b) resulted in its division, on biostratigraphic grounds, into the "Aquia Creek stage" and the "Woodstock stage." Further, the beds exposed along the Potomac River from near Aquia Creek to Popes Creek were separated into 17 "clearly defined lithological zones" (Clark, 1896b, p. 39). Clark and Martin (1901)

FIGURE 1.—Correlation chart showing Tertiary units in the Coastal Plain from New Jersey to Alabama.

SERIES		STAGE		NEW JERSEY	DELAWARE	MARYLAND	VIRGINIA	NORTH CAROLINA	SOUTH CAROLINA	GEORGIA	ALABAMA
		AQUITANIAN		Old Church (?) Formation	Old Church (?) Formation	Old Church (?) Formation	Old Church (?) Formation	Belgrade Formation; Pollocksville Mbr; Haywood Landing M	Edisto Formation	Tampa Formation	
OLIGOCENE	UPPER	CHATTIAN	CHICKASAWHAN					River Bend Formation	Cooper Group: Ashley Formation	Suwannee Limestone	Chickasawhay Limestone
OLIGOCENE	LOWER	RUPELIAN	VICKSBURGIAN							Glendon Limestone; Marianna Formation	Byram Formation; Marianna Formation; Red Bluff Formation
EOCENE	UPPER	PRIABONIAN	JACKSONIAN			Chickahominy Formation (?)	Chickahominy Formation		Cooper Group: Parkers Ferry Fm.; Harleyville Fm.	Tobacco Road Sand; Dry Branch Formation; Tivola Limestone	Ocala Limestone
EOCENE	MIDDLE	BARTONIAN	CLAIBORNIAN					Castle Hayne Formation: Spring Garden Member	Santee Limestone: Cross Member	Gosport Sand	Gosport Sand
EOCENE	MIDDLE	LUTETIAN	CLAIBORNIAN	Piney Point Formation	Piney Point Formation	Piney Point Formation	Piney Point Formation	Castle Hayne Formation: Comfort Member; New Hanover Member	Santee Limestone: Moultrie Member	Lisbon Formation; Tallahatta Formation	Lisbon Formation; Tallahatta Formation
EOCENE	LOWER	YPRESIAN	SABINIAN	Shark River Formation; Manasquan Formation		Nanjemoy Formation: Woodstock Member; Potapaco Member	Nanjemoy Formation: Woodstock Member; Potapaco Member		Fishburne Formation	Hatchetigbee Formation	Hatchetigbee Formation
PALEOCENE	UPPER	THANETIAN	SABINIAN / MIDWAYAN	Vincentown Formation	Vincentown Formation	Marlboro Clay; Aquia Formation: Paspotansa Mbr; Piscataway Member	Marlboro Clay; Aquia Formation: Paspotansa Mbr; Piscataway Member	Beaufort Formation	Black Mingo Formation	Tuscahoma Formation; Nanafalia Formation; Porters Creek Clay	Tuscahoma Formation; Nanafalia Formation; Naheola Formation; Porters Creek Clay
PALEOCENE	LOWER	DANIAN	MIDWAYAN	Hornerstown Sand	Hornerstown Sand	Brightseat Formation	Brightseat Formation	Beaufort Formation: Jericho Run Member	Black Mingo Formation	Clayton Formation	Clayton Formation

[1]For use of the name in Maryland see Brown and others, 1972.

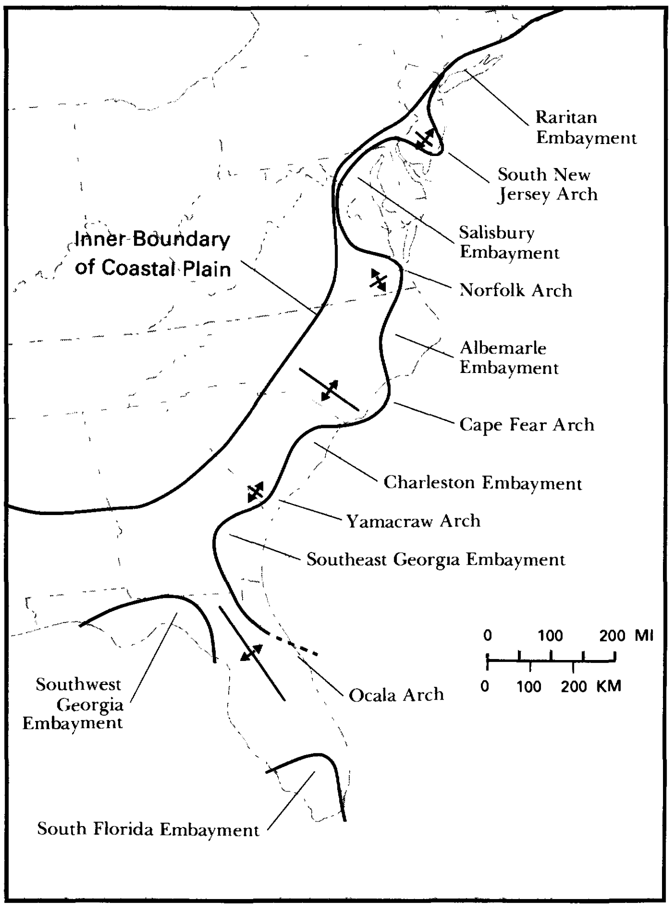

FIGURE 2.—Major Tertiary structural features of the Atlantic Coastal Plain from New York to Florida. Heavy lines to east mark edges of depositional basins.

raised the Pamunkey Formation to group status, divided it into two formations (or "stages"), the Aquia and Nanjemoy, and further subdivided each of these into two members ("substages"). The Aquia consisted of (in ascending order) the Piscataway and Paspotansa Members, and the Nanjemoy consisted of the Potapaco and Woodstock Members. In the 1901 report, Clark and Martin used the terms "formation" and "stage" and "member" and "substage" interchangeably, and there is evidence of confusion of rock-stratigraphic and biostratigraphic terms. It is clear, however, that the Aquia and Nanjemoy Formations and their members were described on their lithic characteristics in a series of 17 beds ("zones"). Lists of fossils were made from each bed. Clark and Miller (1912) expanded on their work southward into Virginia but at that time used only the terms "formation" and "member", deleting "stage" and "substage".

Clark and Martin (1901, p. 65) and Clark and Miller (1906, p. 17; 1912, p. 115) briefly mentioned a pink clay unit that occurs at the base of the Potapaco Member. This bed was informally referred to as the Marlboro clay. The term "Marlboro clay" continued in the literature informally until Darton (1948) raised the unit to member rank. Glaser (1971) described the unit in considerable detail and proposed its elevation to formational status.

Further subdivision of the Pamunkey Group came when Bennett and Collins (1952) recognized the Brightseat Formation as lithologically and faunally distinct from the Aquia Formation. The Brightseat consists of micaceous, silty, very fine sand that was included in "zone" 1 by Clark and Martin (1901, p. 60). Later, Cederstrom (1957) introduced another and more confusing stratigraphic unit, the Mattaponi Formation, to include beds that he considered to be Paleocene in age. Observing that the first 28 feet (8.5 m) below the Marlboro Clay in a corehole at Colonial Beach, Va., contained Eocene foraminifers, he assigned that interval to the Aquia Formation. In the underlying 149 feet (45.4 m), Cederstrom recognized the presence of Paleocene foraminifers. Since the Aquia was thought to be Eocene, Cederstrom suggested that the term "Mattaponi Formation" be used for these Paleocene beds and the underlying 280 feet (85.3 m) of sands and clays (probably part of the Potomac Group). Because the concept of the Mattaponi was based on an age determination and because the beds included in that formation all had previously been assigned to lithic units, I recommend that the term be discarded.

The Piney Point Formation, a lithologically distinct unit, was defined on the basis of subsurface data and was named from a well in St. Marys County, Md. (Otton, 1955). The formation's distribution and lithology were discussed by Otton (1955), but its assignment to the upper Eocene was based on analyses by Shifflett (1948) of foraminifers from two Eastern Shore counties, far from the type area. Later work on ostracodes from the type well (Brown and others, 1972) showed the Piney Point to be middle Eocene in age. Beds of the same age and similar lithology crop out on the Pamunkey River in the type area of the Pamunkey Group. On this basis, the Piney Point is included as a formation within that group.

The youngest unit, the Chickahominy Formation, was recognized in the subsurface of Virginia by Cushman and Cederstrom (1945). This formation was recognized on the basis of the presence of upper Eocene foraminifers. The lithic description they provided indicated little difference between this unit and the underlying glauconitic Pamunkey beds. The Chickahominy is not known to crop out along the Pamunkey River or elsewhere on the Coastal Plain and is not treated in this report. Its

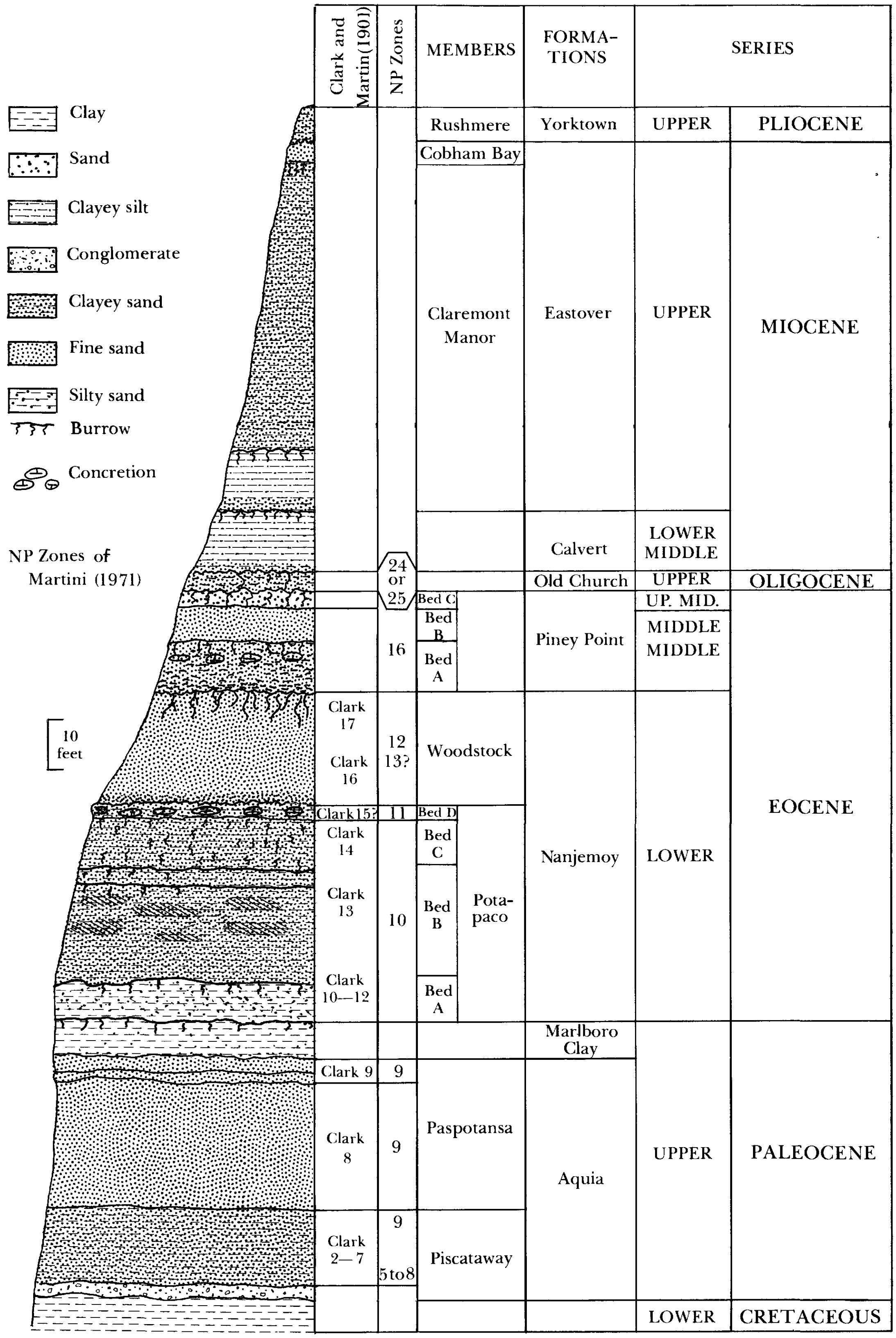

FIGURE 3.—Composite stratigraphic section showing the relationship of Tertiary units found along the Pamunkey River in Caroline, Hanover, King William, and New Kent Counties, Va. Thicknesses indicated are the average maximum thicknesses for units cropping out on the Pamunkey River.

lithology suggests that it should probably be included in the Pamunkey Group even though it was not included in the original description.

To summarize, formations included in the Pamunkey Group in this report are as follows:

Chickahominy Formation	upper Eocene
Piney Point Formation	middle Eocene
Nanjemoy Formation	
Woodstock Member	lower Eocene
Potapaco Member	lower Eocene
Marlboro Clay	upper Paleocene
Aquia Formation	
Paspotansa Member	upper Paleocene
Piscataway Member	upper Paleocene
Brightseat Formation	lower Paleocene

BRIGHTSEAT FORMATION

The Brightseat Formation, named by Bennett and Collins (1952), consists of olive-black (5 Y 2/1) (Goddard and others, 1948), micaceous, clayey, and silty sands. The Brightseat does not crop out on the Pamunkey River, but fieldwork during this study revealed that it crops out as far south as the Rappahannock River in Virginia. In its type area, 1 mile (1.6 km) west-southwest of Brightseat, Prince Georges County, Md., mollusks are abundant, but only the calcitic forms are well preserved. Away from the type area, the macrofossils are leached, leaving only molds and casts. In the Prince Georges County area, the Brightseat unconformably overlies marine deposits of the Severn Formation (Upper Cretaceous). To the south, on the Potomac and Rappahannock Rivers, it overlies fluvial deposits of the Potomac Group (Lower Cretaceous). Beds now placed in the Brightseat were originally assigned, with some reservations, to "zone" 1 of the Aquia Formation (Clark and Martin, 1901). Bennett and Collins (1952) pointed out the disconformity between the Brightseat and the Aquia, and this relationship was later substantiated by the work of Hazel (1969). (The opinion of Nogan (1964) and Drobnyk (1965) that this contact was gradational was discussed by Hazel in his paper and was shown to be the product of sampling near a burrowed contact between the formations.) Hazel (1969) recognized the presence of the Brightseat Formation in Stafford County, Va., near the mouth of Aquia Creek, on the basis of its lithology and stratigraphic position. On the right bank of Aquia Creek (Locality 1; locality descriptions given in section entitled "Localities and measured sections"; see fig. 4 for locality map), the Brightseat unconformably overlies the Patapsco Formation of the Potomac Group (fig. 5). The Brightseat is, in turn, unconformably overlain by the Aquia Formation at that locality. A similar sequence may be seen on the Rappahannock River, just below Fredericksburg (Locality 2) (see fig. 5*B*). Macrofossils there are leached and are present only as rare molds and casts, but the micaceous, silty sand, devoid of glauconite, distinguishes the unit. The Brightseat is not known in outcrop or the subsurface to the south of the Rappahannock River exposures but may be present in the Oak Grove core drilled in Westmoreland County, Va., and reported on by Reinhardt and others (1980), Gibson and others (1980), and Estabrook and Reinhardt (1980). A series of sandy clays between approximately 410 feet (125 m) and 435 feet (138 m) below ground level was lacking in calcareous fossils but has been determined to be lower Paleocene and equivalent to the Brightseat Formation on the basis of dinoflagellates (oral commun., 1984, by L.E. Edwards, interpretation of dinoflagellate data in Gibson and others, 1980). The areal extent of the depositional basin of the Brightseat is shown on figure 6.

Hazel (1968, 1969) studied the ostracodes of the Brightseat in its type area, found the unit to be the equivalent of the upper Clayton Formation in Alabama, and placed it in the *Globoconusa daubjergensis*–*Globorotalia trinidadensis* zone on the basis of its planktic foraminifers. Further, he showed the Brightseat to be early Paleocene in age and placed it in the upper part of the lower Danian Stage. The foraminifers listed by Brown and others (1977, p. 13) suggest the equivalency of the Brightseat to the Jericho Run Member of the Beaufort Formation.

Dinoflagellates were found at the type Brightseat, at the mouth of Aquia Creek (Locality 1), and on the Rappahannock River below Fredericksburg (Locality 2). These floral assemblages appear to be equivalent in age (L.E. Edwards, oral commun., 1984). Dinoflagellate data from the Oak Grove core suggest the presence of Brightseat in that well (L.E. Edwards, oral commun., 1984). According to L.M. Bybell (oral commun., 1984), calcareous nannofossils present in the Brightseat indicate its placement in nannoplankton zone NP 3 (of Martini, 1971).

AQUIA FORMATION

The term "Aquia", for a stratigraphic unit, was first introduced by Clark (1896a,b); he gave the name "Aquia Creek Stage" to beds that crop out in the vicinity of Aquia Creek, Stafford County, Va. The concept of the unit was soon revised, and it was renamed the Aquia Formation by Clark and Martin (1901). Two members, the Piscataway and Paspotansa, were recognized by the authors. Clark and Martin (1901) expanded the work on the Aquia farther southward into Virginia but recognized its members only in their sections along the Potomac River. Bennett and Collins (1952) restricted

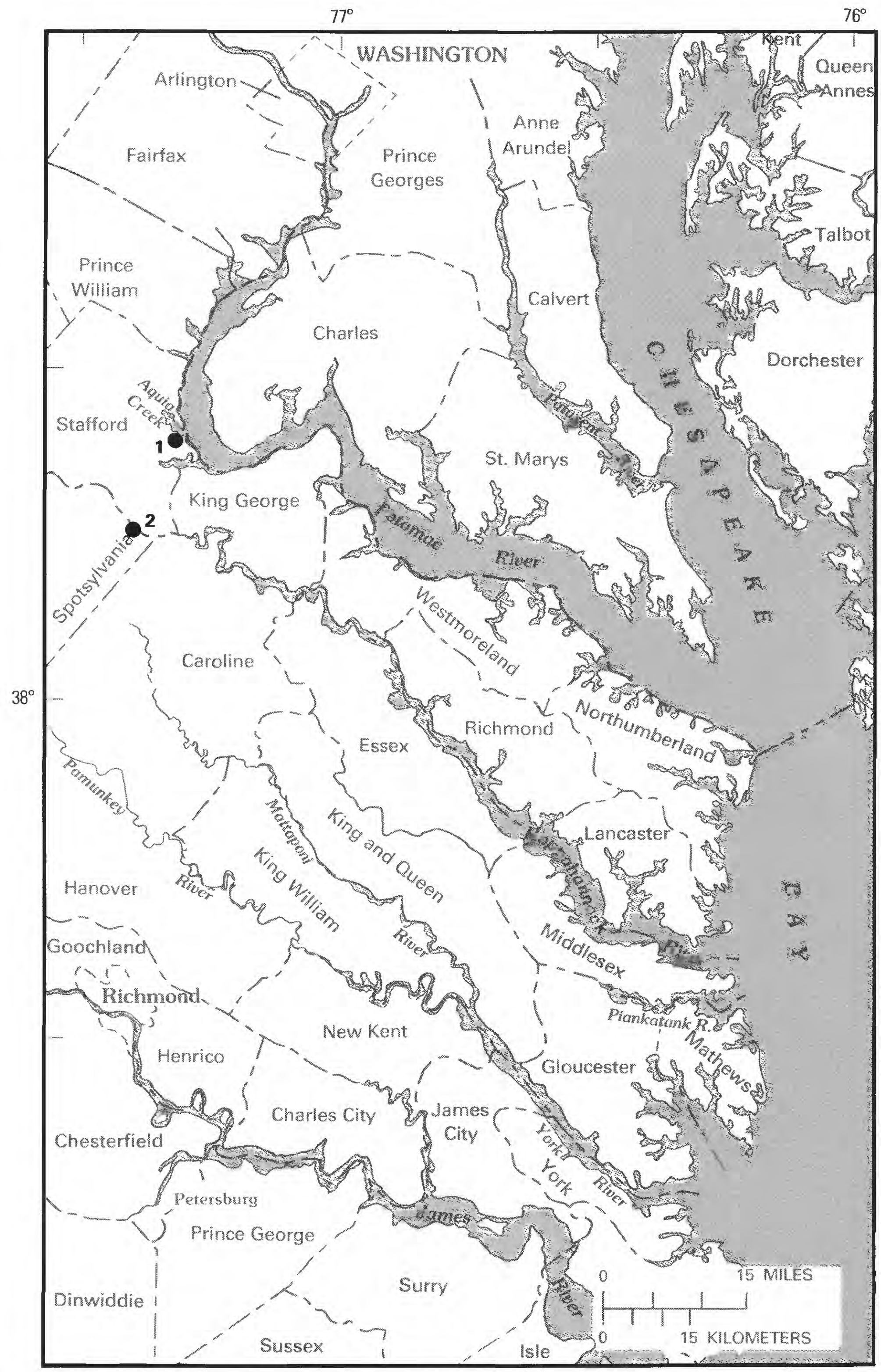

FIGURE 4.—Map showing localities where the Brightseat Formation is exposed. Numbers refer to localities mentioned in the text.

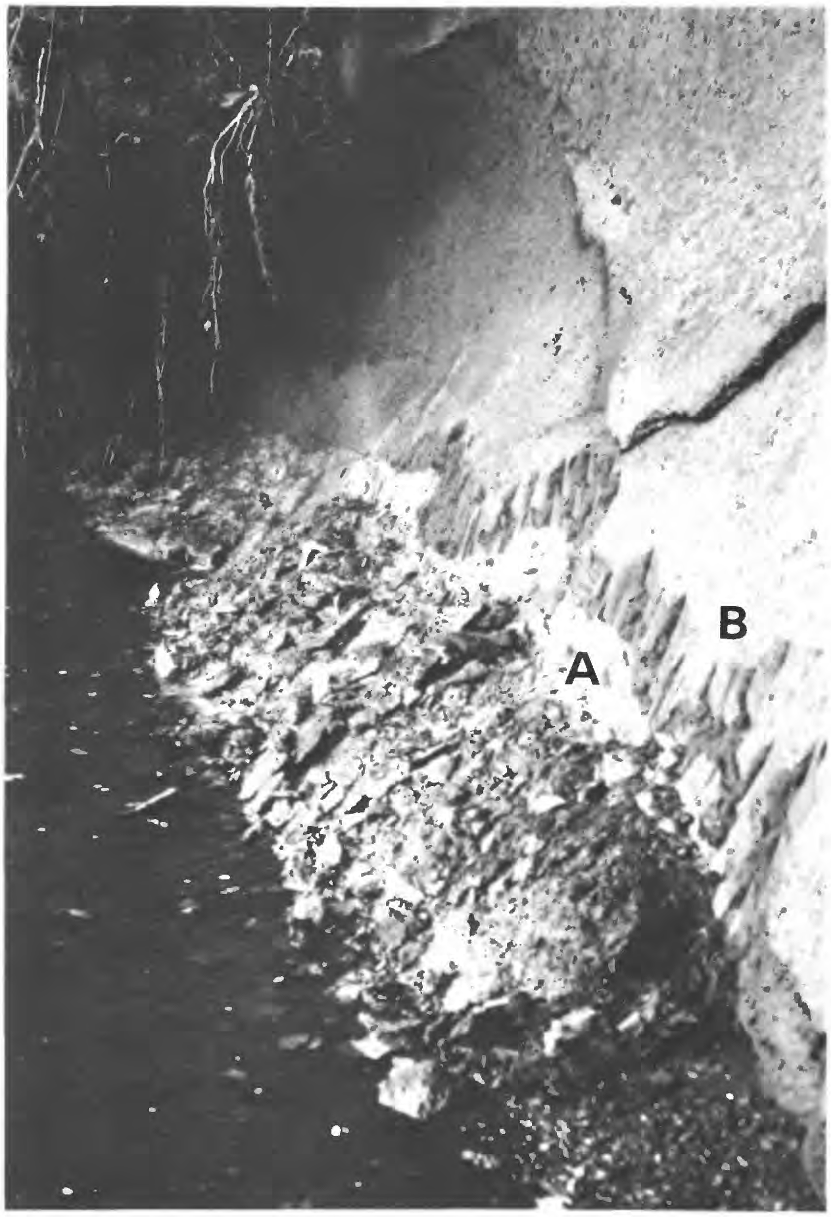

FIGURE 5*A*.—Aquia Creek, above Thorney Point, Stafford County, Va. (Locality 1), showing contact between the Lower Cretaceous (A) and the Brightseat Formation (B). Section cleaned off by pick is approximately 5.0 feet (1.52 m) in length.

Clark and Martin's (1901) earlier definition of the Aquia by designating beds that Clark had placed in zone 1 the Brightseat Formation. It is the Aquia Formation, in this presently restricted sense, that unconformably overlies the Brightseat Formation, in the northeastern area of the Aquia's range, and Lower Cretaceous deposits, south of the Rappahannock River.

The Aquia consists of clayey, silty, very shelly, glauconitic sand; it crops out in a continuous arc from the upper Chesapeake Bay to the area around Hopewell on the James River, Va. Both members of the Aquia may be recognized along the Potomac, Rappahannock, Mattaponi, Pamunkey, and James Rivers. (See fig. 7 for the basinal outline of the Aquia sea.) Macrofossils locally are well preserved but more commonly are leached, making recovery difficult. Microfossil groups consist of ostracodes, foraminifers, pollen, dinoflagellates, and calcareous nannofossils. Macrofossil and microfossil work has indicated that the Aquia Formation is upper Paleocene (Gibson and others, 1980). L. M. Bybell (oral commun., 1984), on the basis of calcareous nannofossils, placed the Aquia Formation in zones NP 5–9. The Aquia

FIGURE 5*B*.—Rappahannock River, 1.85 miles (2.98 km) east of Greenfield, Spotsylvania County, Va. (Locality 2), showing contact between the Lower Cretaceous (A) and the Brightseat Formation (B).

Formation is further characterized here by the description of its members.

PISCATAWAY MEMBER (REVISED)

The Piscataway Member of the Aquia Formation was named by Clark and Martin (1901) from exposures along Piscataway Creek, Prince Georges County, Md. It included seven "zones", which were traceable along the Potomac River in the type area of the Aquia. "Zone" 1 of Clark and Martin (1901) has since been recognized as a distinct unit by Bennett and Collins (1952) and termed the Brightseat Formation. The present study of the lectostratotype section (principal reference section) of the Aquia Formation, the Piscataway Member, and the Paspotansa Member (herein designated Locality 3 of this report; see fig. 8) has revealed that the most significant lithic change in the formation, from a poorly sorted, clayey sand to a very well sorted, micaceous, silty, fine sand, takes place between "zones" 5 and 6 of Clark and Martin (1901). It is recommended, therefore, that the boundary between the two members be placed between those "zones" and that the base of the Paspotansa be extended downward to include Clark and Martin's (1901) zones 6 and 7. Evidence from calcareous nannofossils (L.M. Bybell, oral commun., 1984) and dinoflagellates (L.E. Edwards, oral commun., 1984) indicates a biostratigraphic break between "zones" 5 and 6, which is further substantiated by mollusk data. The remaining beds assigned to the Piscataway Member consist of clayey, silty, poorly sorted, glauconitic sands, which contain large numbers of macrofossils, principally mollusks (see fig. 9). The mollusks are concentrated in beds of varying thicknesses and are cemented at several intervals into locally traceable indurated ledges. Large bivalves, including *Cucullaea, Ostrea, Dosiniopsis*, and *Crassatellites* (see pl. 1), are the most conspicuous taxa. The quartz sand incorporated into the Piscataway is usually poorly sorted, angular, and clear. Glauconite is extremely abundant, ranging from sand-size pellets to coatings on and in molluscan fossils. The sand, glauconite, and mollusks are interspersed in a clayey, silty matrix producing a very tough, olive-gray (5 Y 4/1), calcareous marl. Glauconite percentages range from a low of 20 percent in far updip localities to 70 percent or more in the seaward parts of the basin.

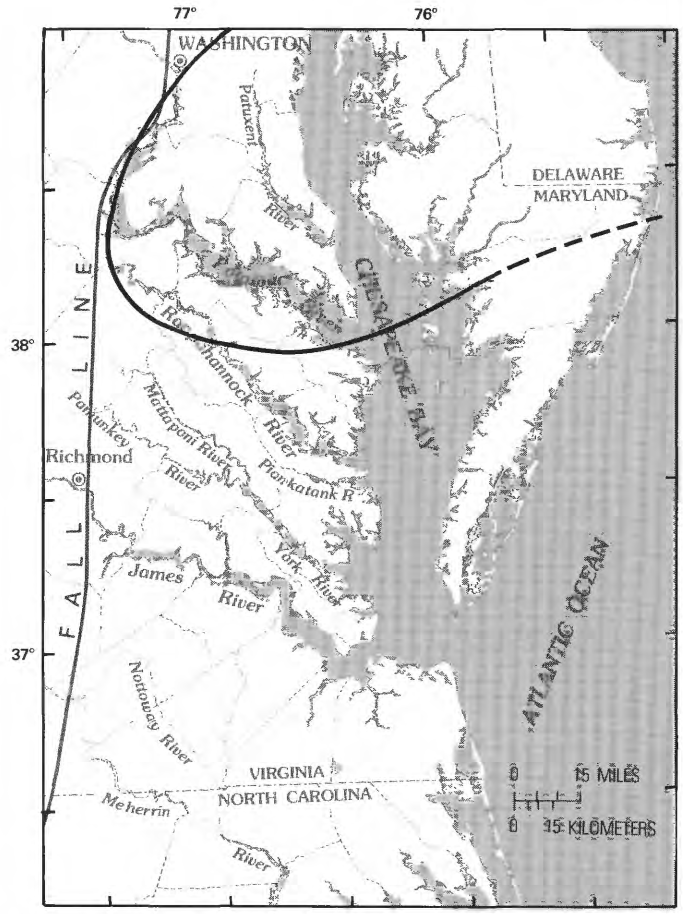

FIGURE 6.—Map showing the areal extent of the middle early Paleocene depositional basin of the Brightseat Formation in the Salisbury Embayment. Dashed line indicates area where boundary data are lacking. Map is based on outcrop and core data used in this report as well as on subsurface data from Brown and others (1972).

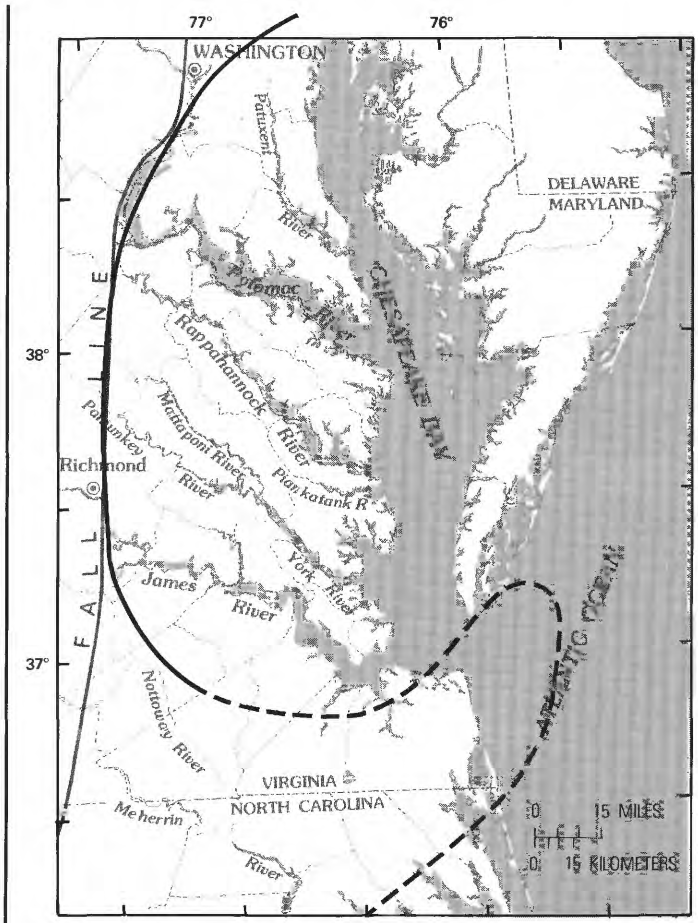

FIGURE 7.—Map showing the areal extent of the late Paleocene depositional basin of the Aquia Formation in the Salisbury Embayment. Dashed line indicates area where boundary data are lacking. Map is based on outcrop and core data used in this report as well as on subsurface data from Brown and others (1972).

The Piscataway Member unconformably overlies the Brightseat in Prince Georges County, Md., and at Aquia Creek, Va. (see Hazel, 1969; Bennett and Collins, 1952). At Aquia Creek (Locality 1), a transgressing Aquia sea angularly beveled off the underlying Brightseat beds, resulting in a pronounced unconformity (see fig. 10). The micaceous, silty sand of the Brightseat contrasts sharply with the overlying, poorly sorted, glauconitic sand of the Piscataway Member. The Piscataway Member may be seen along the Potomac River in continuous exposures from Aquia Creek to Potomac Creek. This is the best series of outcrops of Piscataway in either Maryland or Virginia; as much as 20 feet (6.0 m) of extremely fossiliferous, olive-gray (5 Y 6/1), glauconitic sand is exposed. Aragonitic forms of mollusks are soft but obtainable, and calcitic forms are well preserved but often incorporated into indurated masses or thin beds. The fine, silty, glauconitic sand of the Paspotansa apparently disconformably overlies the Piscataway. The contact between the Brightseat and the Aquia has not been observed along the Rappahannock River in Virginia but is presumed to be similar to those contact exposures to the north. The Brightseat crops out on the Rappahannock below Fredericksburg, 1.85 miles (2.98 km) east of Greenfield, Spotsylvania County (Locality 2, fig. 5*B*), and the Piscataway is first seen on that river 0.15 mile (0.24 km) below the mouth of Snow Creek, Caroline County (Locality 4). The contact between the two units may be presumed to descend to water level (sea level) somewhere between the two localities. No outcrops of the Piscataway are known along the Mattaponi River, but a core taken by R.B. Mixon (USGS, Reston) at Blantons Pond, 0.65 mile (1.05 km) southwest of the Rte. 207 bridge over the Mattaponi River (Locality 5), showed sediments assigned to the Piscataway directly overlying Lower Cretaceous clays.

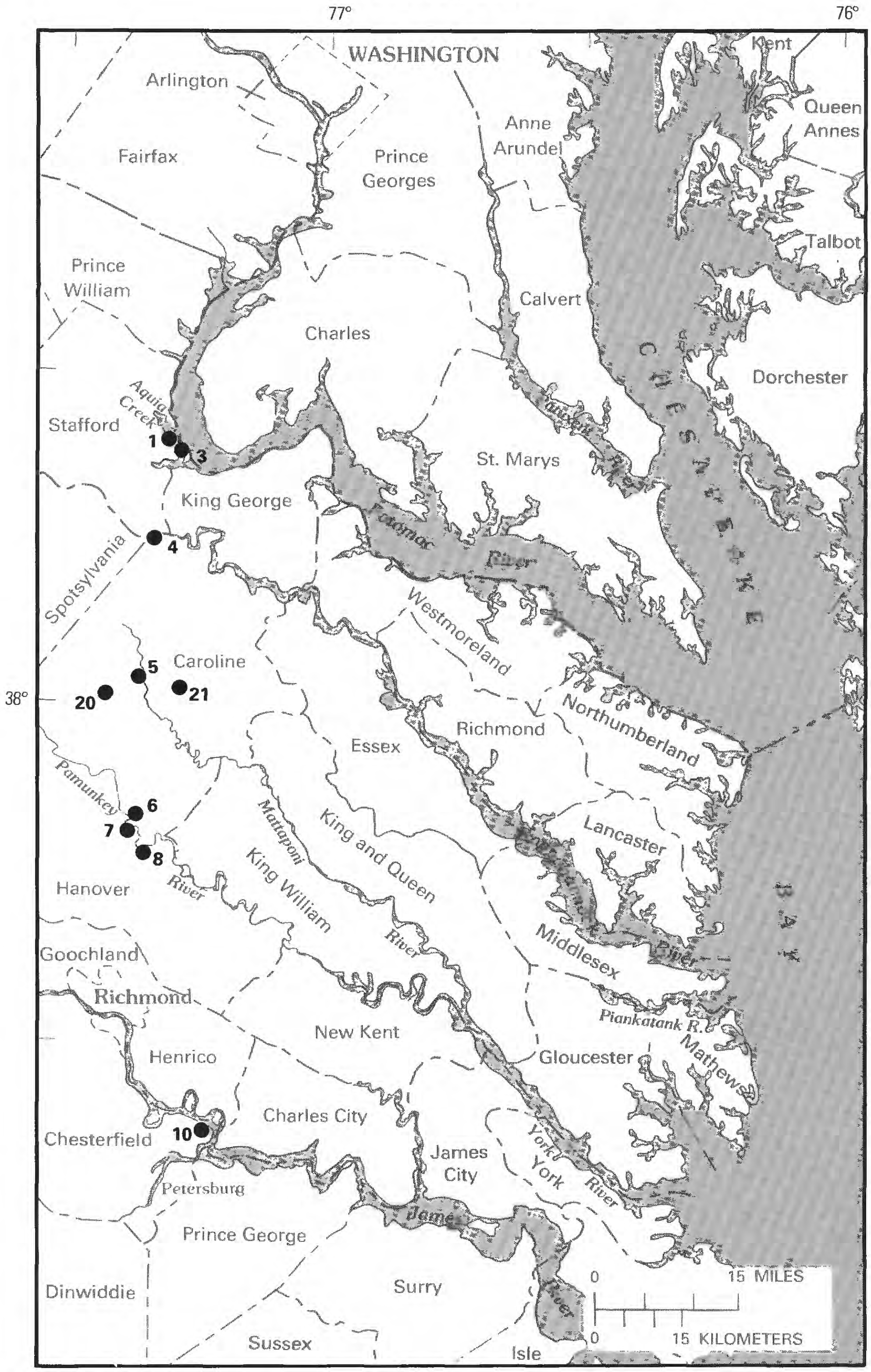

FIGURE 8.—Map showing localities where the Piscataway Member (revised) of the Aquia Formation is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

FIGURE 9.—Locality 8 on the Pamunkey River, 0.5 mile (0.8 km) east of Wickham Crossing, Hanover County, Va. Note the large number of mollusks, which typify the Piscataway Member of the Aquia Formation. The pick handle is 25 inches (63.5 cm) long.

The Piscataway Member first appears on the Pamunkey River about 0.65 mile (1.05 km) below the confluence of the North and South Anna Rivers (Locality 6). There it overlies a greenish-blue clay belonging to the Lower Cretaceous. The contact between the two units is especially conspicuous and is marked by 1.5 feet (0.5 m) of cobble- to boulder-sized clasts along the base of the Aquia. The Piscataway is extremely weathered there, and only calcitic mollusks are preserved. The Pamunkey River continues southward, and 0.8 miles (1.3 km) downriver from Locality 6, on the right bank, a similar section is exposed (Locality 7). There the Piscataway is relatively fresh and contains a large and varied assemblage of preserved mollusks. In spite of the apparent excellent preservation in the field, the mollusks become crumbly when dried. The calcitic forms, however, are well preserved, as is the microfauna.

The farthest downdip outcrop of the Piscataway Member on the Pamunkey is just downstream from Wickham Crossing on the right bank (Locality 8, fig. 11). At this locality 13.5 feet (4.1 m) of fresh, olive-gray (5 Y 4/1), very fossiliferous, clayey sand is exposed and

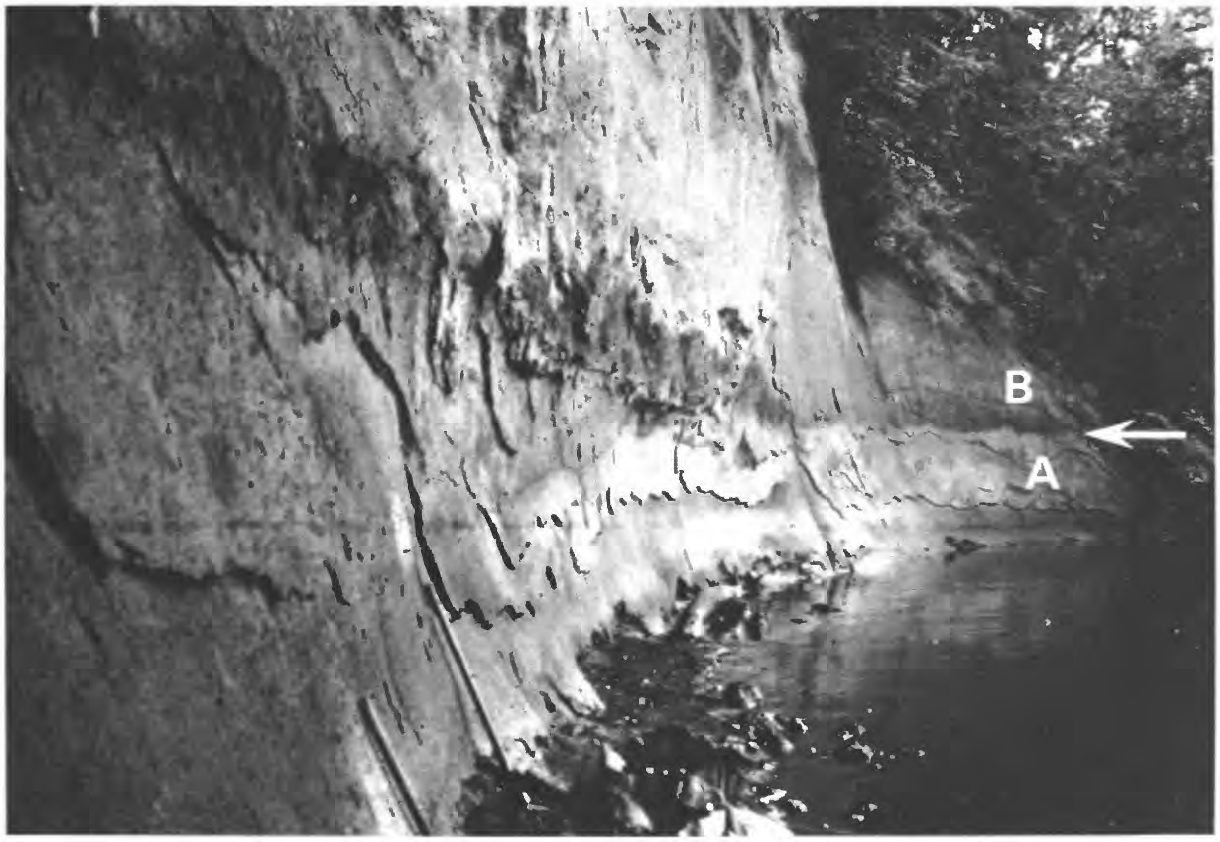

FIGURE 10.—Aquia Creek (looking upstream), above Thorney Point, Stafford County, Va. (Locality 1) showing the contact (arrow) between the Brightseat (A) and the Aquia (B) Formations. Nearer the photographer the Brightseat is capped by an indurated bed. Upstream that bed has been beveled off by the transgressing Aquia sea.

is underlain by a blue-green clay (presumed to be Lower Cretaceous). The Piscataway is overlain by the olive-black (5 Y 2/1), very well sorted, silty, very fine, glauconitic sand of the Paspotansa Member of the Aquia. The contact between the two Aquia units at this locality seems to be undulant and exhibits as much as one foot of relief. The top of the Piscataway descends below stream level, and 30 feet (9.1 m) of Paspotansa is exposed in a large bluff (Locality 9) 1.1 miles (1.8 km) (straightline) downstream from Locality 8. The Aquia is not known along the Chickahominy River but was reported by Darton (1911) from Shockoe, Gillis, and Almond Creeks in Richmond. Strata older than the Miocene have been covered by buildings and sewers, but detailed descriptions by Darton (1911) and Rogers (1861) make certain the presence of both the Piscataway and Paspotansa Members of the Aquia Formation in Richmond. Reported thicknesses range from 15 to 25 feet (4.6 to 7.6 m). The only exposure of Piscataway beds along the James River found in this study is 1.0 mile (1.6 km) above the Turkey Island Cutoff on the right bank (Locality 10, fig. 12). There, 2.0 feet (0.6 m) of dark-olive-gray (5 Y 4/1), poorly sorted, glauconitic sand overlies a basal gravel and cobble conglomerate. Molluscan fossils are poorly preserved but include aragonitic forms (*Crassatellites, Turritella*) as well as calcitic forms (*Ostrea*). Downriver from this locality the top of the Piscataway dips below river level (sea level), and the Paspotansa is the only member of the Aquia Formation exposed.

Calcareous macrofossils in the Piscataway Member are generally poorly preserved and often soft and friable. Slow and careful extraction methods, however, make it possible to recognize a number of molluscan taxa. Calcitic mollusks are generally well preserved, and some localities exhibit moderately well preserved aragonitic forms. At the lectostratotype locality of the Aquia Formation on the Potomac River below Aquia Creek (Locality 3), mollusks are present in large numbers but are relatively poorly preserved. Preservation is somewhat better along the Rappahannock River below Fredericksburg (Locality 4) but is probably best in that section of the Pamunkey River above the U.S. Rte. 301 bridge (Localities 7, 8). In all these exposures, molluscan diversity is relatively low, and a small group of taxa forms a relatively large percentage of the

FIGURE 11.—Locality 8 on the Pamunkey River, 0.5 mile (0.8 km) east of Wickham Crossing, Hanover County, Va., showing the Piscataway Member of the Aquia Formation. Cobbles occur along the Lower Cretaceous contact near the bottom of the photograph. The Paspotansa Member occurs near the head level of the person at upper right.

fauna. Some of these common taxa include the following (see pl. 1):

Cucullaea gigantea Conrad, 1830 (fig. 7)
Ostrea alepidota Dall, 1898 (figs. 1, 2, 4, 5)
Crassatellites capricranium (Rogers, 1839) (fig. 9)
Lucina aquiana Clark, 1895
Dosiniopsis lenticularis (Rogers, 1839) (fig. 10)
Pitar pyga Conrad, 1845 (fig. 8)
Corbula aldrichi Meyer, 1885
Turritella mortoni Conrad, 1830 (fig. 6)
Turritella humerosa Conrad, 1835 (fig. 3)

Clark (1896b) and Clark and Martin (1901) listed many additional species of mollusks found in the Piscataway Member. However, lack of abundance or poor preservation, or both conditions, cause these taxa to constitute only a small percentage of the total Piscataway assemblage. The relative lack of diversity and the absence of known warm-water mollusks suggest temperate conditions. Distribution of sediments indicates a basin bordered to the south by the Norfolk Arch and to the west by the Piedmont (Brown and others, 1972). Access to the paleo-Atlantic was to the northeast through Maryland, Delaware, and New Jersey. This northeastward alignment, with the Norfolk Arch acting as a barrier between the Piscataway sea and the Beaufort sea in the Albemarle Embayment to the south (see fig. 2), probably affected current circulation patterns creating more temperate conditions.

The molluscan taxa found in the Piscataway Member indicate a late Paleocene age. A more specific age is difficult to determine on the basis of mollusks, but in Gulf Coast stratigraphic terms the unit is clearly a pre-Tuscahoma, post-Porters Creek equivalent. On the basis of ostracodes and planktic foraminifers, Hazel (1969) placed the Piscataway in the *Globorotalia pseudomenardii* Subzone of the *Globorotalia velascoensis* Zone and in the upper Landenian Stage. Hazel (oral commun., 1982) believes the Piscataway to be the equivalent of the Coal Bluff Member of the Naheola Formation and the lower Nanafalia Formation. Foraminifers listed by Brown and others (1977, p. 13) indicate an equivalency of the upper beds of the Beaufort Formation in North Carolina to the Piscataway. These glauconitic sands, which overlie the Jericho Run Member of the Beaufort, were assigned to the basal part of the *Globorotalia pseudomenardii* Zone (P4) of Berggren (1972).

FIGURE 12.—Locality 10 on the James River, 1.0 mile (1.6 km) above the mouth of the Turkey Island Cutoff, Chesterfield County, Va., showing the basal portion of the Piscataway Member of the Aquia Formation. The pick handle is approximately 36 inches (91.5 cm) long.

PASPOTANSA MEMBER (REVISED)

The Paspotansa Member of the Aquia Formation, described by Clark and Martin (1901), received its name from Passapatanzy Creek, a tributary of the Potomac River in Stafford County, Va. As originally defined, the Paspotansa included zones 8 and 9 of Clark and Martin (1901). However, as previously discussed, it is here recommended that "zones" 6 and 7 also be included in the Paspotansa. "Zone" 6 is an olive-black (5 Y 2/1), very fine, micaceous, glauconitic sand containing large numbers of *Turritella mortoni*. "Zones" 7 and 8 consist of olive-black (5 Y 2/1), fine, glauconitic sand containing scattered, thin *Turritella* beds. "Zone" 9 is an olive-black (5 Y 2/1), fine, glauconitic sand containing large numbers of closely packed *Turritellas* in beds of varying thickness (see figs. 13, 14). The thickness of the units, as well as their fossil content, varies from locality to locality, but several characteristics are internally consistent. The Paspotansa consists of fine to very fine, silty, well-sorted, micaceous, glauconitic and quartzose sand, which appears as massive or very thick beds. This texture is strikingly different from the underlying poorly sorted, clayey, shelly, glauconitic and quartzose sands of the Piscataway Member. Further, the Paspotansa is usually overlain by a gray (N 7, when fresh), tough clay termed the Marlboro Clay (see fig. 15). This bed, when present, makes the recognition of the upper boundary of the Paspotansa relatively easy. Where the Marlboro is absent, the well-sorted, fine sands of the Paspotansa may be distinguished from the overlying clayey, highly bioturbated, poorly sorted glauconitic sands of the Potapaco Member of the Nanjemoy Formation. As in all the formations in the Pamunkey Group, the glauconite content of the Paspotansa varies with proximity to the paleoshoreline. Percentages are much lower near the perimeter of the basin and in some areas are as low as 20 percent. Seaward, in an eastward direction, the glauconite content may reach 90 percent. The nature of the shell deposits within the Paspotansa further serves to distinguish that unit from the underlying Piscataway and overlying Nanjemoy. Massive glauconitic sands, containing many large *Turritella* in thin beds or lenses, characterize the Paspotansa, in striking contrast to the very shelly, silty sands of the Piscataway, which are usually dominated by closely

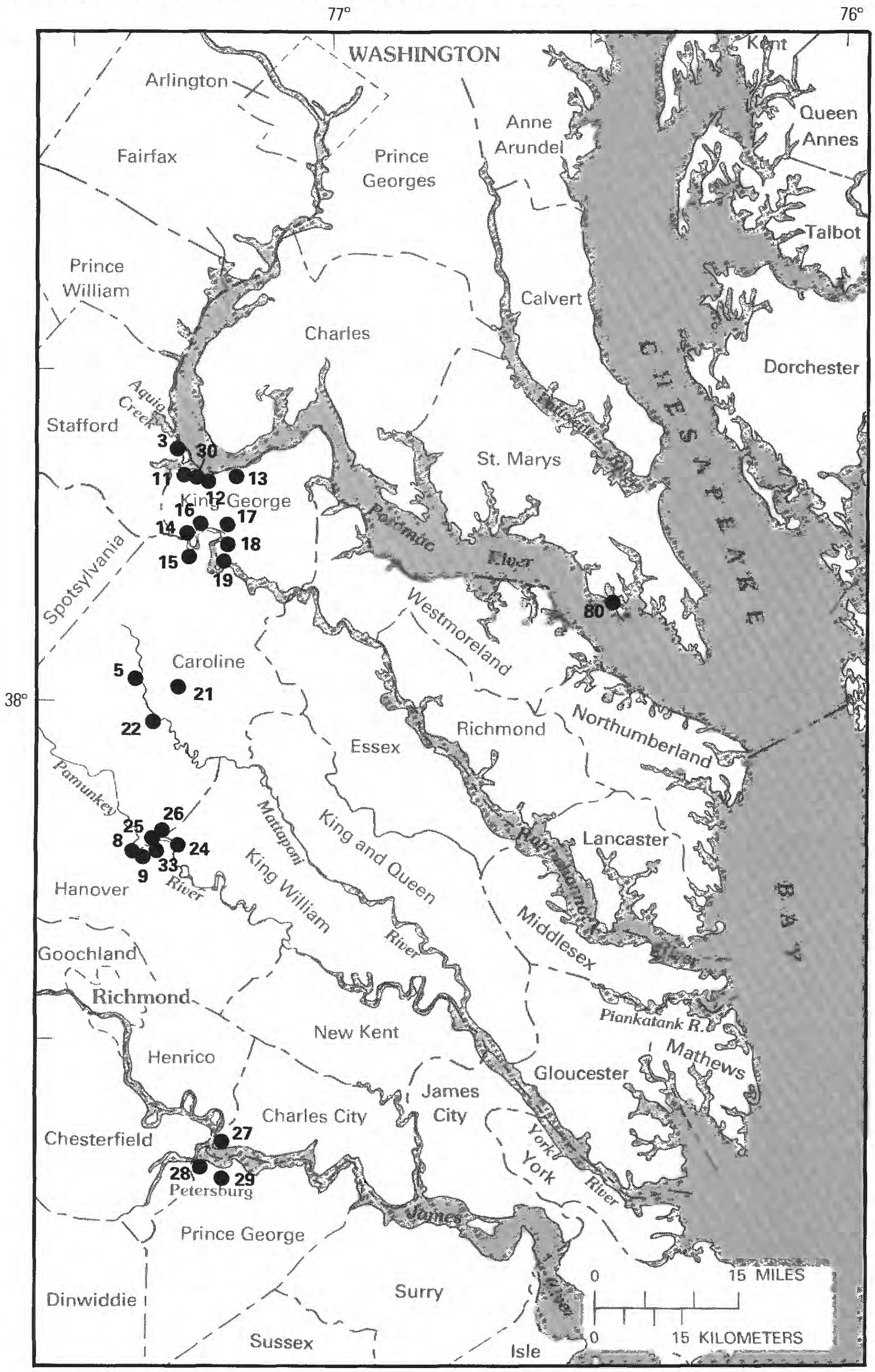

FIGURE 13.—Map showing localities where the Paspotansa Member (revised) of the Aquia Formation is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

packed, medium-sized to large bivalves. Also notable is the massive nature of the Paspotansa, often exposed in the high vertical walls of bluffs along the Potomac, Rappahannock, and Pamunkey Rivers. Where very fresh the unit is dark olive black (5 Y 2/1). Where partially weathered it is grayish orange (10 YR 7/4), and where very weathered it appears yellowish orange (10 YR 7/6) owing to the oxidation of iron in the glauconite.

The Paspotansa apparently disconformably overlies the Piscataway, but the contact is commonly obscured. Clark and Martin (1901) described the contact between "zones" 6 and 7 along the bluffs below Aquia Creek, but, as previously discussed, the most notable lithic change occurs at the contact between their zones 5 and 6. On the Rappahannock and Mattaponi Rivers, the contact between the two members is obscured by slumping and poor outcrops. On the Pamunkey River, however, the contact between the two members is sharp and undulating. No phosphate accumulations or burrows are present, indicating, at most, only a brief period of nondeposition. The contact is not exposed on the Chickahominy and James Rivers, but the distinct textural makeup of the Piscataway and Paspotansa, as well as their unique macrofaunal assemblages, enable the field geologist to differentiate them readily.

The Paspotansa is overlain over much of its areal extent by the Marlboro Clay. The contact between the two units is abrupt, and there is little or no mixing of their sediments. Some burrows extend down into the underlying Paspotansa and are filled with Marlboro sediment, a tough, light-gray (N 7) clay (pink 10 R 7/4, when weathered) with small admixtures of sand and gravel. In some areas where the Marlboro Clay is absent, beds of the Nanjemoy Formation (Potapaco Member) directly overlie the Paspotansa.

The Paspotansa sea, like that of the preceding Piscataway, was embayed from the northeast; the still-positive Norfolk Arch separated the basin from the Paleocene embayment in North Carolina.

The Paspotansa Member crops out in a broad arc from the Eastern Shore of Maryland to the James River in Virginia (see figs. 7, 13). Clark and Martin (1901, p. 73) described the Paspotansa from the Chester River in Kent County, Md., and their descriptions of the sections on the Severn and South Rivers in Anne Arundel County, Md., indicate the presence of the unit there. Additional sections are given for the Upper Marlboro area of Prince Georges County, Md., where the Paspotansa includes a heavy concentration of bryozoans. The most extensive outcrops of the member extend along the Virginia shore of the Potomac River from the mouth of Aquia Creek to near Fairview Beach. Between Potomac Creek and Aquia Creek (Locality 3), 61.5 feet (18.8 m) of the Paspotansa crops out in steep, almost vertical bluffs, which have been weathered to a reddish-orange color (fig. 16). This section is here designated the principal reference section (lectostratotype locality) of the Paspotansa. Several distinct shell beds are present, as well as several ledges of somewhat discontinuous boulder-sized concretions. Other shells, principally large, current-oriented *Turritella mortoni*, are concentrated in lens-shaped masses. Below the mouth of Potomac Creek (Locality 11), the Paspotansa descends to near water level, is considerably fresher, and consists of olive-black (5 Y 2/1), glauconitic, shelly sand. Mollusks are abundant and well preserved; *Turritella mortoni, Ostrea sinuosa, Crassatellites alaeformis,* and *Cucullaea gigantea* are the dominant taxa (see pl. 2). The last unweathered outcrop of the Paspotansa on the Potomac occurs just below the mouth of Passapatanzy Creek (Locality 12). The next exposure of Paleogene beds is at a bluff 1.75 miles (2.8 km) below the large wharf at Fairview Beach where the Aquia, Marlboro, and Nanjemoy crop out (Locality 13, fig. 15).

On the Rappahannock River, the Paspotansa makes its first appearance 1.0 mile (1.6 km) upriver from the mouth of Ware Creek on the left bank, King George County, Va. (Locality 14). There 10.0 feet (3.0 m) of glauconitic, micaceous, shelly sand is exposed, 7.0 feet (2.1 m) of which is fresh. Mollusks are present and preserved; *Turritella mortoni* is abundant, and *Ostrea sinuosa* is common. Downriver of this locality the Paspotansa crops out intermittently near water level. At the large bluff on the right bank of the Rappahannock 0.4 mile (0.6 km) below the mouth of Ware Creek (Locality 15), 4 feet (1.2 m) is exposed, but slumping obscures its contact with the overlying units. Small exposures of the Paspotansa are present above and below the mouth of Lambs Creek on the left bank (Localities 16, 17), above Hopyard Landing (Locality 18), and below Jones Top Creek (Locality 19).

Outcrops of the Paspotansa are relatively scarce in the Mattaponi River valley, a condition due principally to the low stream gradient. In Caroline County, Va., several boreholes drilled by R.B. Mixon (USGS) (some with the help of the author) have penetrated sediments assignable to that unit. A core taken at Blantons Pond south of Bowling Green (Locality 5) contained 58 feet (17.7 m) of Aquia, the upper two-thirds of which is considered to be Paspotansa. Farther to the west, 1.0 mile (1.6 km) northwest of Wrights Corner, where Rte. 634 crosses Hobby Swamp (Locality 20), a core to basement revealed 27.0 feet (8.2 m) of Aquia directly overlying Piedmont rocks. The Aquia, in turn, was directly overlain by the Calvert, the Nanjemoy having apparently been beveled off. Another core, taken at Smoots Pond on the Camp A.P. Hill Military Base (Locality 21),

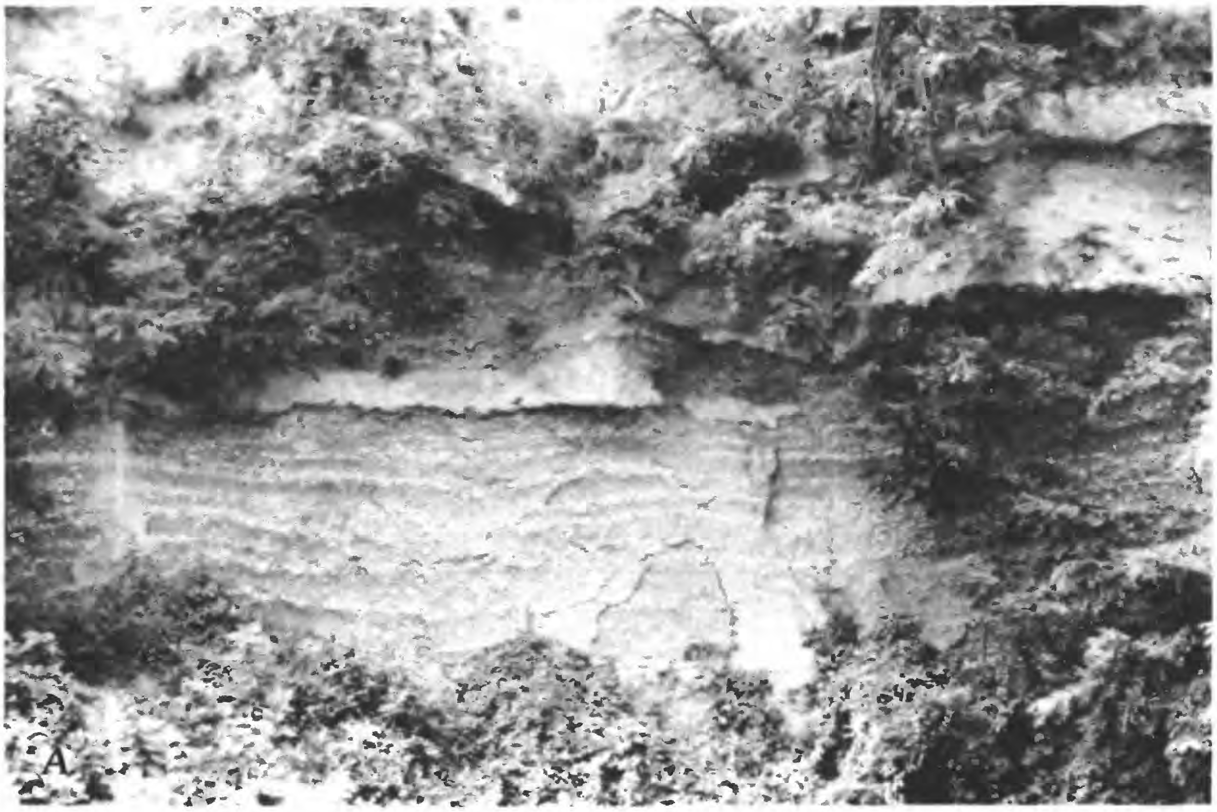

FIGURE 14.—Paspotansa Member of the Aquia Formation as exposed along the Potomac River near Potomac Creek. *A*, Bull Bluff, right bank of the Potomac River at the mouth of Potomac Creek, King George County, Va. (Locality 11). Exposed are numerous thin beds made up almost entirely of large *Turritella*. This taxon is also abundant in the indurated blocks in the upper half of the photograph. *B*, Potomac River, 0.1 mile (0.16 km) below the mouth of Passapatanzy Creek, King George County, Va. (Locality 12). Large indurated blocks, like those seen in figure 14*A*, litter the shore here and contain large numbers of silicified *Turritella*. The pick handle is 25 inches (63.5 cm) long.

contained 57 feet (17.4 m) of Aquia, at least half of which is Paspotansa. The only known outcrops of the Aquia on the Mattaponi River occur between the Richmond, Fredericksburg, and Potomac Railroad bridge and the Rte. 301 bridge. Exposed are beds assignable to the Paspotansa Member. Clark and Miller (1912) and Gildersleeve (1942) reported Aquia beds in the vicinity of the railroad bridge. This locality was not accessible during this study, but the description and faunal lists of those authors suggest that the exposed beds are Paspotansa. Clark and Miller (1912) and Gildersleeve (1942) both described a section on the Mattaponi River, just upstream from the Rte. 301 bridge. This locality (Locality 22) is still accessible; the exposure consists of 3 to 6 feet (0.9 to 1.8 m) of fine, silty, glauconitic sand containing numerous poorly preserved *Turritella mortoni*. The lithology and faunal assemblage are typical of the Paspotansa Member. At the next bridge downstream (Rte. 654), in a small ravine, basal Potapaco (Nanjemoy Formation) is exposed (Locality 23).

The Paspotansa Member is better exposed along the Pamunkey River: outcrops occur from below Wickham Crossing (Locality 8) to 0.65 mile (1.05 km) below Sturgeon Hole (Locality 24). Most of the calcareous material has been leached from the upriver exposures, but molluscan molds and casts are common. The Paspotansa makes its farthest updip appearance 0.5 mile (0.8 km) east of Wickham Crossing (Locality 8) (fig. 11) where it overlies the Piscataway Member. The olive-black (5 Y 2/1), very fine, silty, micaceous, relatively unfossiliferous, very well sorted glauconitic sands of the Paspotansa may be readily distinguished from the poorly sorted, clayey, very fossiliferous, glauconitic sands of the Piscataway. Downstream, 1.6 miles (2.6 km) east of Wickham Crossing (Locality 9), 30 feet (9.1 m) of Paspotansa are exposed. There, molds of *Turritella mortoni* are scattered throughout the unit but are concentrated in thin beds in the upper 10 feet (3.0 m). Unweathered Paspotansa, containing preserved mollusks, crops out 0.25 mile (0.40 km) below the Rte. 301 bridge (Littlepage Bridge) (Locality 25), at Sturgeon Hole (Locality 26), and 0.65 mile (1.05 km) below Sturgeon Hole (Locality 24). At Locality 24 the Paspotansa is unconformably overlain by the Marlboro Clay.

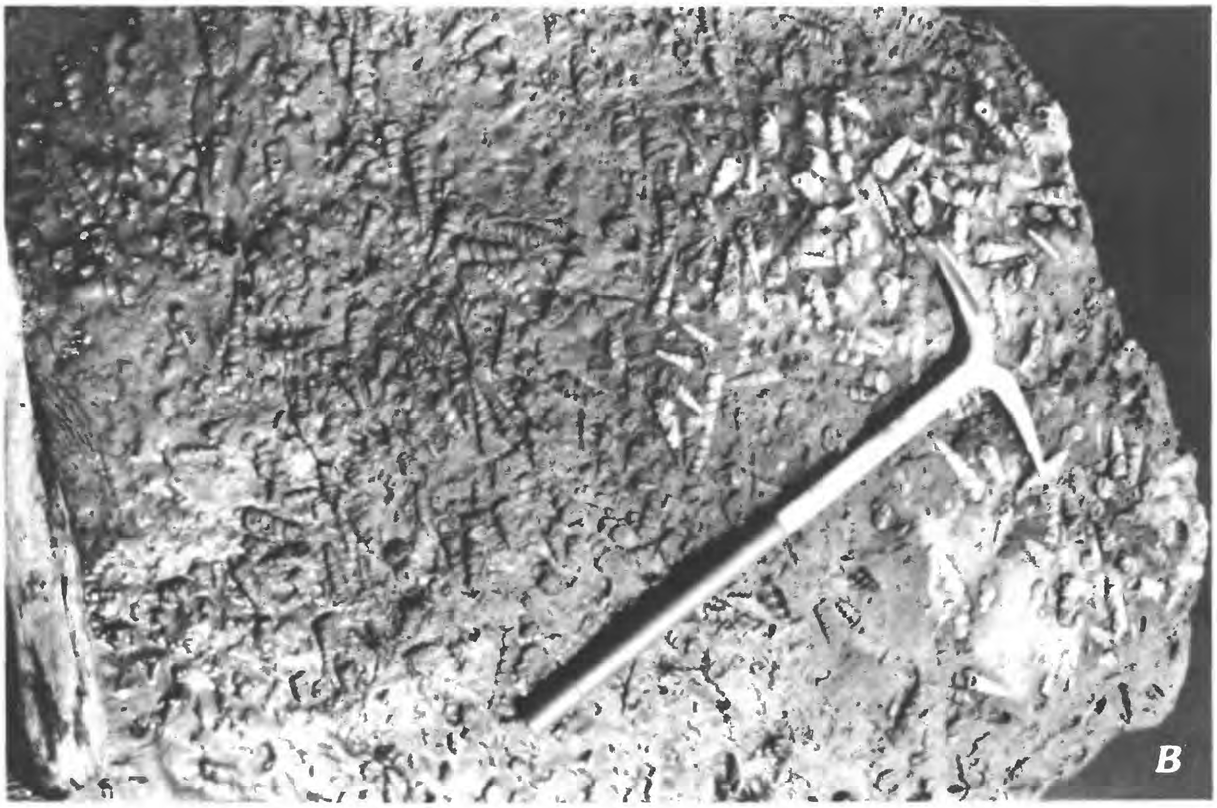

FIGURE 14.—Continued.

As previously mentioned, the description by Rogers (1861) and Darton (1911) of the glauconitic sand occurring in Richmond indicates the presence of the Paspotansa there, but these exposures have since been covered. Along the James River, however, the Paspotansa crops out along the left bank 1.1 miles (1.8 km) above Shirley Plantation (Locality 27). Another, smaller exposure may be seen at City Point, near the mouth of the Appomattox River in Hopewell (Locality 28). The farthest downriver exposure of the Paspotansa on the James occurs on the right bank just below the mouth of Bailey Creek (Locality 29), where this unit is overlain by as much as 10 feet (3.0 m) of Marlboro Clay. *Turritella mortoni* and *Ostrea sinuosa* are both common in the Paspotansa at that outcrop, and it is probably the topotype locality for the latter taxon (Rogers and Rogers, 1835).

The Paspotansa contains large numbers of macrofossils, principally mollusks (fig. 17). The shells are often concentrated in thin or lens-shaped beds. At many localities where the outcrop has dried out, the mollusks are very soft or entirely dissolved, and only molds or casts remain. Localities with the best fossil preservation include those on the Potomac River below Aquia Creek (Locality 3) and below Potomac Creek near Belvedere Beach (Localities 12, 30). Preservation is good at some localities along the Rappahannock River (Localities 14, 15), but it is poor on the Mattaponi River above the Rte. 301 bridge (Locality 22) and below the mouth of Baileys Creek on the James River (Locality 29). Preservation of macrofossils at the Pamunkey River localities is poor above the Rte. 301 bridge and consists mainly of molds and casts. Molds of large taxa such as *Turritella mortoni, Ostrea sinuosa,* and *Crassatellites alaeformis* are easily recognized even when preservation is poor. At the localities below the Rte. 301 bridge (Localities 24, 25, 26), preservation is fair to good. Although many species of mollusks were listed by Clark (1896b) and Clark and Martin (1901) as occurring in the Paspotansa Member, the most common taxa are the following (see pl. 2):

Cucullaea gigantea Conrad, 1830 (fig. 1)
Pycnodonte sp. (fig. 2)
Ostrea sinuosa Rogers and Rogers, 1837 (fig. 4, 8)
Crassatellites alaeformis Conrad, 1830 (fig. 7)
Venericardia regia Conrad, 1865 (fig. 5)
Pitar pyga Conrad, 1845 (fig. 9)
Turritella humerosa Conrad, 1835 (fig. 10)
Turritella mortoni Conrad, 1830 (fig. 3, 6)
Lunatia marylandica Conrad, 1865

Generally poor preservation of mollusks may account for the apparent low diversity. Some localities, such as

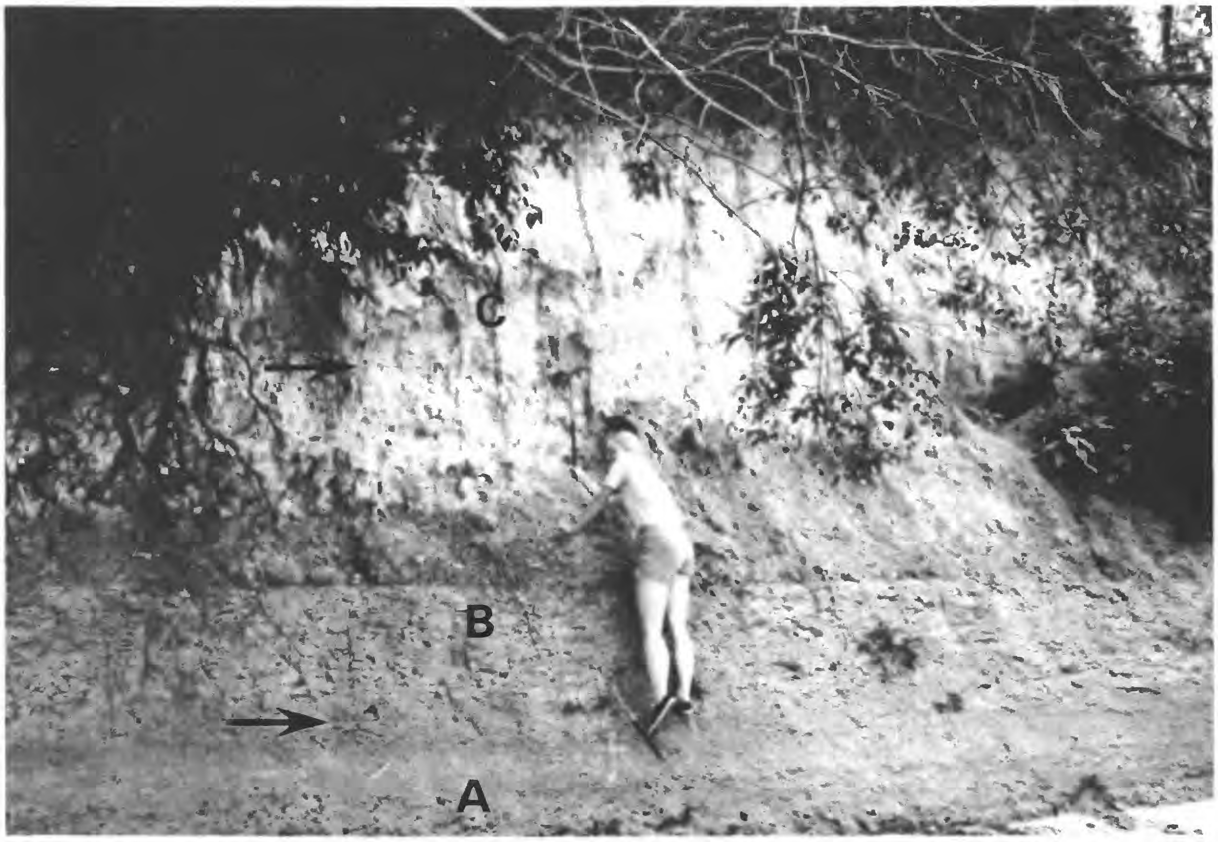

FIGURE 15.—Potomac River, 1.75 miles (2.8 km) below the large wharf at Fairview Beach, King George County, Va. (Locality 13). Lower arrow and Lynn Strickland's foot are on the contact between the Paspotansa Member of the Aquia Formation (A) and the Marlboro Clay (B); upper arrow and her pick point are at the contact between the Marlboro Clay (B) and the Nanjemoy Formation (Potapaco Member) (C).

the small bluff on the Potomac River just below the mouth of Passapatanzy Creek (Locality 12), where the sediment is fresh, contain a number of well-preserved, small mollusks, but they make up a small percentage of the total assemblage. Paspotansa molluscan faunas are dominated principally by the large gastropod *Turritella mortoni*. Forms closely related or identical to that taxon have been found in upper Paleocene deposits in South Carolina at Wilsons Landing on the Santee River. *Turritella praecincta* occurs with *T. mortoni* at Wilsons Landing and has been reported from the Tuscahoma Formation of Georgia by Gibson (1980). Both forms occur in Alabama and range from the Nanafalia Formation to the Bells Landing Marl Member of the Tuscahoma Formation. *T. humerosa*, another common taxon in the Paspotansa, is also found in the Nanafalia and Tuscahoma Formations. *Ostrea sinuosa*, a less abundant but very conspicuous form, is also commonly found in upper Paleocene beds in South Carolina, Georgia, and Alabama.

Gibson and others (1980) identified the Paspotansa Member in a core taken in Westmoreland County, Va., and placed the entire member in calcareous nannoplankton zone NP 9. L.M. Bybell (oral commun., 1984) concurs with this assignment.

MARLBORO CLAY

Clark and Martin (1901, p. 65) first applied the term "Marlboro clay" to sediments included in "zone" 10 of Clark (1896b, p. 42). The name was derived from exposures of that unit near Upper Marlboro, Prince Georges County, Md. Clark and Martin (1901) considered this unit to be the basal unit of the Potapaco Member of the Nanjemoy Formation. Clark and Miller (1906) briefly described the outcrop area of the "Marlboro clay" across Maryland and Virginia and included it in the basal bed of the Nanjemoy Formation. Clark and Miller (1912) again included the pink clay in the basal bed of the Nanjemoy. However, at only one locality, below Hopewell on the James River (Clark and Miller, 1912, p. 115), did those authors give a specific section where this unit crops out. Darton (1948), in a

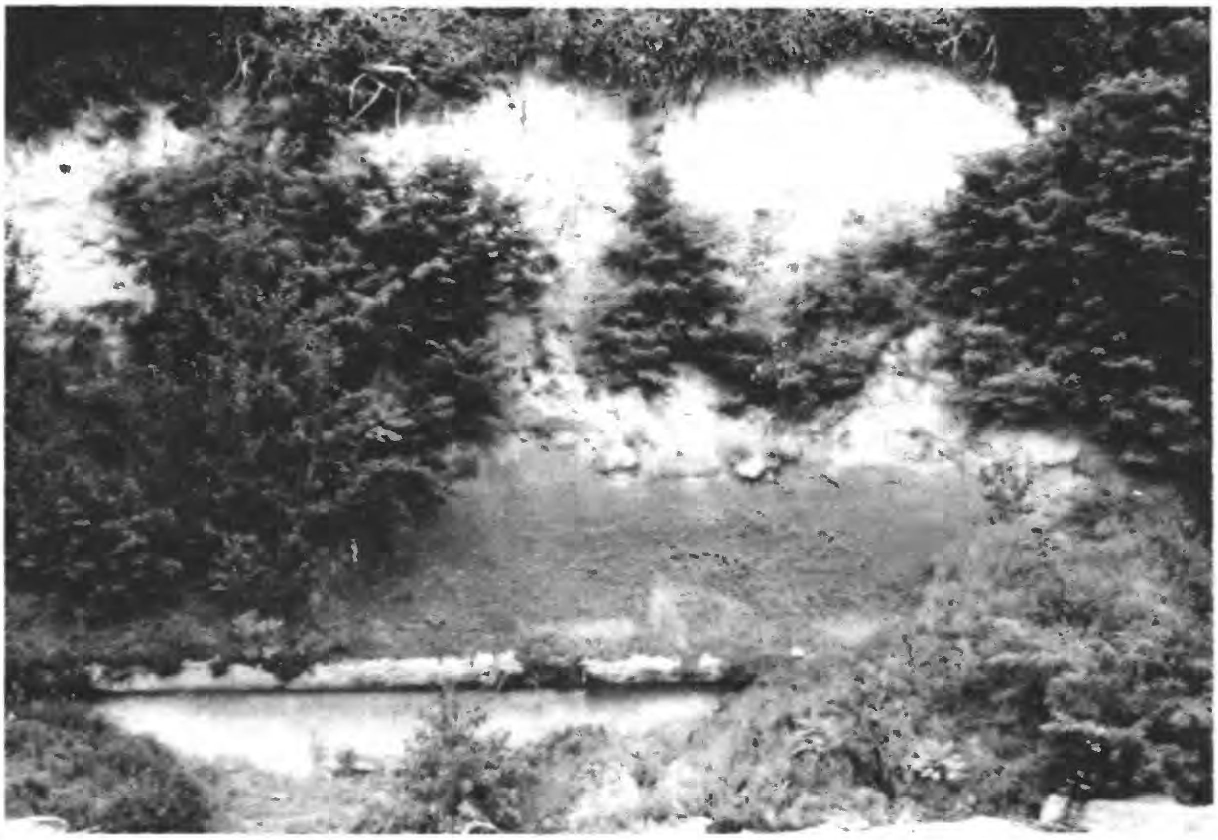

FIGURE 16.—Potomac River, 1.5 miles (2.4 km) below the mouth of Aquia Creek, Stafford County, Va. (Locality 3). Principal reference section and lectostratotype locality of the Aquia Formation and its Piscataway and Paspotansa Members. The Piscataway Member (as herein amended) includes the beds from beach level up to and including the prominent indurated ledge. For scale, the top of the indurated ledge is approximately 14.0 feet (4.3 m) above water level. The Paspotansa occupies the remainder of the exposure.

short note, described the areal extent of the Marlboro Clay and referred to that unit as the basal member of the Nanjemoy Formation. This had the effect of formalizing the name. A more detailed study, including a detailed geologic map by Darton (1951), continued the placement of the Marlboro as the basal bed of the Nanjemoy. Well studies in Virginia by Cederstrom (1957) showed the persistence and mappability of the unit in the subsurface in that area. Glaser (1971), however, was the first to formally propose the elevation of the Marlboro Clay to formational rank. This restricted the original concept of the Nanjemoy Formation and, more specifically, of the Potapaco Member. This treatment of the Marlboro as a separate formation was continued by Reinhardt and others (1980). Glaser (1971, p. 14), in a rather complete description of the unit, characterized it as "a silvery-gray to pale-red plastic clay interbedded with much subordinate yellowish-gray to reddish silt." Observing the silty, somewhat ripple-marked texture of the Marlboro and the restricted fauna from the unit reported by Nogan (1964), Glaser (1971) concluded that the evidence suggests very shallow, possibly tidal-flat, depositional conditions. Glaser pointed out that both the lower and upper contacts of the Marlboro were sharp and nongradational and probably represented at least a brief hiatus between the underlying and overlying units. A more recent study by Reinhardt and others (1980) on a core in Westmoreland County, Va., conluded that the Aquia-Marlboro contact was somewhat gradational whereas the upper Marlboro-Nanjemoy contact was sharp and was marked by burrows into the underlying Marlboro. In the present study, Marlboro outcrop and well information is scanty (fig. 18). Where the unit was observed, both the upper and lower contacts were abrupt and burrowed, which indicates periods of nondeposition or unconformities.

The areal distribution of the Marlboro was mapped by Darton (1951) and was schematically shown by Glaser (1971), but no detailed study of the formation has been made in much of the Virginia Coastal Plain (see fig. 19). Outcrops of the Marlboro examined in this study have been limited to the Potomac, Mattaponi,

FIGURE 17.—Pamunkey River at Sturgeon Hole, 0.75 mile (1.21 km) below the Rte. 301 bridge (Littlepage Bridge), Caroline County, Va. (Locality 26). Numerous thin bands of *Turritella* are present, as is common in the upper part of the Paspotansa Member of the Aquia Formation.

Pamunkey, and James Rivers. Several additional data points were observed in cores taken by R.B. Mixon (while assisted by me) in Caroline County, Va. Preliminary results indicate a spotty, though widespread, occurrence of the unit. In some places the Nanjemoy directly overlies the Aquia. In others, the Marlboro separates the two. Depositional trends indicated by these presences or absences of the Marlboro are not yet clear but may reflect thinning or erosion across an intermittently structurally active area. Thinning of this type has been described by Mixon and Newell (1977) where it has affected the Aquia Formation in the Fredericksburg area of northern Virginia. Further drilling may make clear any such depositional or erosional trends. Knowledge of the presence of the Paspotansa Member of the Aquia and the overlying Potapaco Member of the Nanjemoy may help bracket the area in which the Marlboro is present, even without the benefit of exposures. Along the Potomac River, very thin discontinuous remnants of the Marlboro Clay are present at the lectostratotype section of the Aquia (Locality 3) and Bull Bluff (Locality 11). On the right bank of the Potomac River 1.75 miles (2.5 km) below Fairview Beach (Locality 13, fig. 15), the Marlboro may be seen to overlie several feet of weathered Paspotansa and is in turn overlain by the Potapaco Member of the Nanjemoy Formation. Darton's (1951) map of northern Virginia and part of southern Maryland indicates that the Marlboro is present in that area. On the Rappahannock River, the last exposure of Aquia occurs below Hopyard Landing (Locality 18), and the Nanjemoy crops out at water level a short distance downriver (Locality 31). The bluffs between the two localities are slumped and covered by vegetation, but it may be inferred that the Marlboro dips to water level (sea level) somewhere in that interval. Darton (1951) mapped the Marlboro in that area. Outcrop and well data concerning the distribution of the Marlboro Clay south of the Rappahannock River are scarce. Clark and Miller (1912) listed only the outcrop on the right bank of the James River below the mouth of Baileys Creek (Locality 29) as exposing the Marlboro, while Gildersleeve (1942, p. 15) mentioned that he nowhere observed the unit in his study area. Subsurface work by Cederstrom (1945, 1957) indicated the presence of the Marlboro in many water wells in southeastern Virginia, although the clay

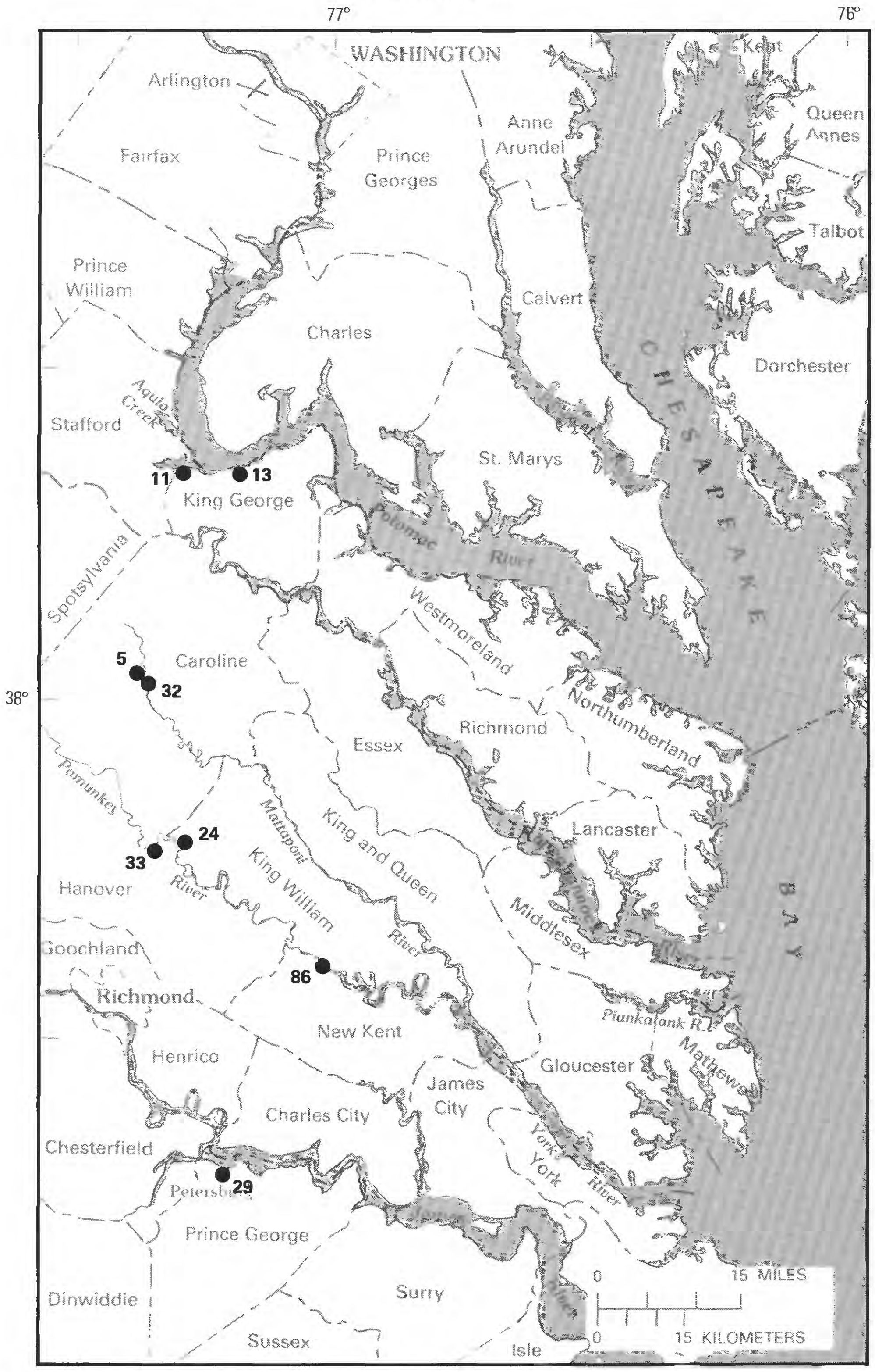

FIGURE 18.—Map showing localities where the Marlboro Clay is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

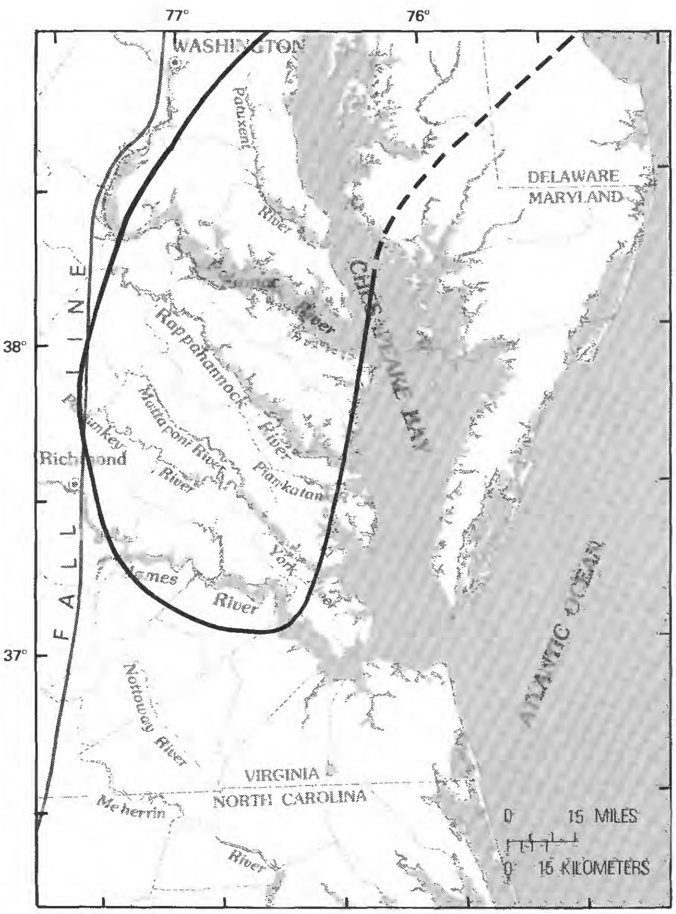

FIGURE 19.—Map showing the areal extent of the late Paleocene depositional basin of the Marlboro Clay in the Salisbury Embayment. Dashed line indicates area where boundary data are lacking. Map is based on outcrop and core data used in this report as well as on subsurface data from Brown and others (1972).

unit was never identified as such. The Marlboro Clay crops out on the right bank of the Mattaponi River, just below the Rte. 207 bridge in Caroline County (Locality 32, fig. 20). There the unit consists of light-gray (N 7) clay containing scattered sand and pebbles. Burrows extend down into the Marlboro from the glauconitic, sandy Potapaco Member of the Nanjemoy Formation and are filled with sediment from that unit, in sharp contrast to the gray clay below. The contact with the underlying Aquia is not exposed there, but the two units are present in a core to the west at Blantons Pond (Locality 5). In that core 7.0 feet (2.1 m) of Marlboro Clay are present in the subsurface. The lower contact with the Aquia and the upper contact with the Nanjemoy are sharp and suggest at least brief diastems. To the east, at Smoots Pond, in Camp A.P. Hill in Caroline County (Locality 21), a core revealed the absence of the Marlboro, and the Paspotansa was directly overlain by the Potapaco. This contact is not as obvious, but the fine, well-sorted, glauconitic sands of the Paspotansa may be distinguished from the clayey, poorly sorted sands of the Potapaco.

On the Pamunkey River, the Marlboro Clay was observed at only two localities. At a large bluff 0.95 mile (1.53 km) above the Rte. 301 bridge over the Pamunkey (Locality 33), 1.5 feet (0.4 m) of weathered gray clay belonging to the Marlboro overlies at least 10.0 feet (6.1 m) of fine, micaceous, glauconitic sand of the Paspotansa. The Marlboro is in turn overlain by a weathered, poorly sorted, brown, micaceous, clayey sand, which contains a dinoflagellate flora found at other localities in the lowermost bed (Bed A) of the Potapaco Member of the Nanjemoy Formation. Both the upper and lower contacts are sharp and are marked by burrows. The Marlboro contains small amounts of sand, probably as a result of burrowing from above. The other exposure of the Marlboro on the Pamunkey River occurs 0.65 mile (1.05 km) below Sturgeon Hole (Locality 24, fig. 21). There the Marlboro unconformably overlies the Paspotansa and is unconformably overlain by the Nanjemoy (Bed A of the Potapaco Member). Downriver of this section, it may be inferred by the last outcrop of the Aquia and Marlboro and downdip exposures of the lower Nanjemoy that the Marlboro approaches river level approximately 2 miles (3.2 km) east of the Littlepage Bridge (Rte. 301). A water well described by Cederstrom (1957, p. 87) northeast of Mechanicsville, Hanover County, contained 10.0 feet (3.0 m) of pink mud at the base of the Nanjemoy, which was probably the Marlboro. It occurred at the interval between 5 and 15 feet (1.5 and 4.6 m) below sea level. Records of wells closer to the Pamunkey are absent. However, the distinctive nature of the Marlboro Clay makes it easily recognizable in many of the wells described by Cederstrom (1957) in Hanover, King William, and New Kent Counties.

The sole known occurrence of the Marlboro Clay on the James River was first reported by Clark and Miller (1912, p. 115) (Locality 29). At that locality the unit is still exposed; it overlies 17.5 feet (5.3 m) of somewhat weathered, fine, glauconitic sand of the Paspotansa that contains *Turritella mortoni*. The Marlboro consists of light-gray to pink clay and contains a few molds of small indeterminate gastropods, the only known fossil occurrence in the Marlboro. The Marlboro Clay's lower contact with the Aquia is sharp and bioturbated; its upper contact is obscured by slumped sediments from beds of the Eastover and Yorktown Formations.

Because of the lack of calcareous fossils, the age of the Marlboro Clay has been based principally on the fact that it occurs between the Aquia and Nanjemoy Formations. This effectively brackets its age but does not afford primary evidence. A detailed study of a core from

FIGURE 20.—Mattaponi River, just below the Rte. 207 bridge, Caroline County, Va. (Locality 32). Pick is at the contact of the Marlboro Clay and the Nanjemoy Formation. The Nanjemoy unit is Bed A of the Potapaco Member.

Oak Grove, Westmoreland County, Va., by Gibson and others (1980) and Frederiksen (1979) afforded the best paleontologic evidence of its age. The consensus of pollen and dinoflagellate data suggested a very late Paleocene or a very early Eocene age assignment. Mixing of the two floral assemblages may have been accomplished through reworking and bioturbation, or the unit may indeed straddle the Paleocene-Eocene boundary. N.O. Frederiksen (oral commun., 1984) found Eocene pollen only in the upper part of the Marlboro, where it may have been reworked downward by burrowing organisms. The Marlboro will be treated by the author in this work as an upper Paleocene unit until primary evidence suggests a younger age assignment. Nogan (1964) reported the presence of arenaceous foraminifers in the lower part of the Marlboro and suggested this as evidence of brackish-water conditions. Dinoflagellate assemblages are relatively low in diversity and contain several brackish-water forms, which suggest a shallow, estuarine environment (Gibson and others, 1980, p. 24).

NANJEMOY FORMATION

Beds now included in the Nanjemoy Formation were first studied in detail by Clark (1896b), who divided them, along with those now included in the Aquia Formation, into "zones." Those "zones" above the Aquia Creek Stage of Clark (1896b) were numbered 10 through 17. "Zone" 17 was defined as the Woodstock Stage. Clark and Martin (1901) revised this terminology and placed their zones 10 through 17 in the "Nanjemoy Formation or Stage." The Nanjemoy was divided into the "Potapaco member or substage," including "zones" 10 through 15, and the "Woodstock member or substage," including "zones" 16 through 17. In this same publication Clark and Martin (1901, p. 65) introduced the term "Marlboro clay," informally, for part of their zone 10. In a brief, preliminary report on the stratigraphy of the Virginia Coastal Plain, Clark and Miller (1906) dropped the stage and substage terminology and referred only to the Aquia and Nanjemoy Formations. Clark and Miller (1912) continued this usage and retained both in formational status. Again, the "Marlboro clay" was briefly mentioned (Clark and Miller, 1912, p. 103) but was specifically reported from only one locality (Clark and Miller, 1912, p. 115). The zonation of beds and their breakdown into members was retained only for those well-studied exposures along the Potomac River. South of the Potomac only assignment to formation was attempted.

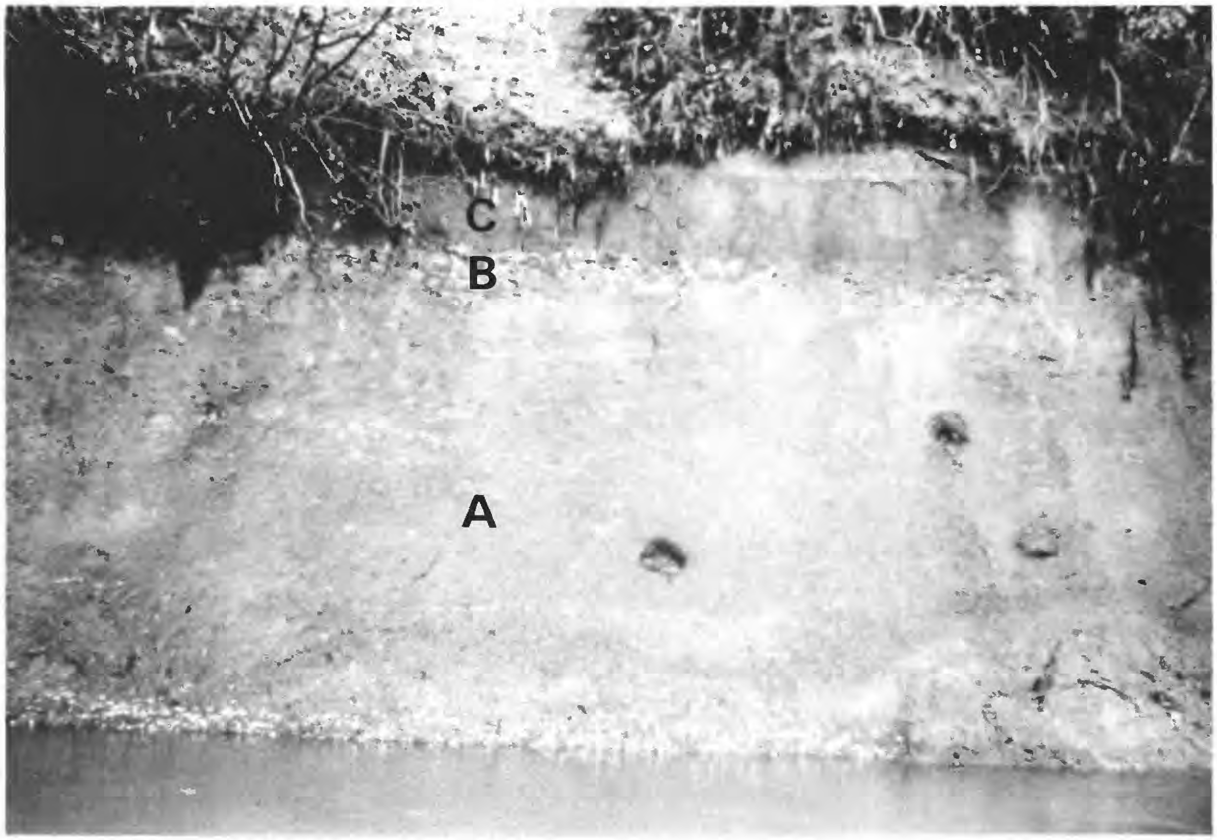

FIGURE 21.—Pamunkey River, 0.65 mile (1.05 km) below Sturgeon Hole, Caroline County, Va. (Locality 24). Exposed is the Paspotansa Member of the Aquia Formation (A), the Marlboro Clay (B), and the Potapaco Member (Bed A) of the Nanjemoy Formation (C).

The term "Marlboro Clay" was finally formalized by Darton (1948), but he retained the unit as a basal member of the Nanjemoy. This removed the Marlboro ("zone" 10, in part, of Clark) from beds previously included in the Potapaco Member. The Marlboro was retained as a member of the Nanjemoy until Glaser (1971) elevated it to formational rank. This, in effect, restricted the original concept of the Nanjemoy, and only part of "zone" 10 and "zones" 11–17 remained in that formation. Younger beds, not included in the original description or sections of the Nanjemoy, were later lumped under the term "Nanjemoy Formation" by Clark and Miller (1912). Included were beds of middle Eocene and late Oligocene or early Miocene age along the Pamunkey and James Rivers. Later, work by Gildersleeve (1942) continued this practice. Otton (1955) described "a light gray to yellowish glauconitic sand and interbedded rock" in a well near Piney Point in St. Marys County, Md. He termed this unit the Piney Point Formation and believed it to be of late Eocene age, on the basis of foraminifers found in wells on the Eastern Shore of Maryland. Later, work by Brown and others (1972) established the age of the Piney Point as middle Eocene (Claibornian). Because of their age equivalency and because of their similar lithic composition and texture, I believe that the middle Eocene beds along the Pamunkey and James Rivers should be included in the Piney Point. The beds there represent the only known outcrops of that unit. Along the Pamunkey, the Piney Point is overlain by a grayish-olive (10 Y 4/2), sandy unit herein named the Old Church Formation (late Oligocene and early Miocene). Sharp contacts mark the unconformity. The Old Church is devoid of glauconite except small amounts reworked from the Piney Point. Because beds included in the Piney Point and Old Church were not included in the original description of the Nanjemoy, are not present at the "type area" of the Nanjemoy, and are lithologically distinct from the unit, it seems appropriate to treat them as separate units of formational status. This effectively restricts the Nanjemoy to those beds originally included in the Potapaco and Woodstock Members, less the Marlboro Clay. For the distribution of sediments assigned to the Nanjemoy, see figure 22.

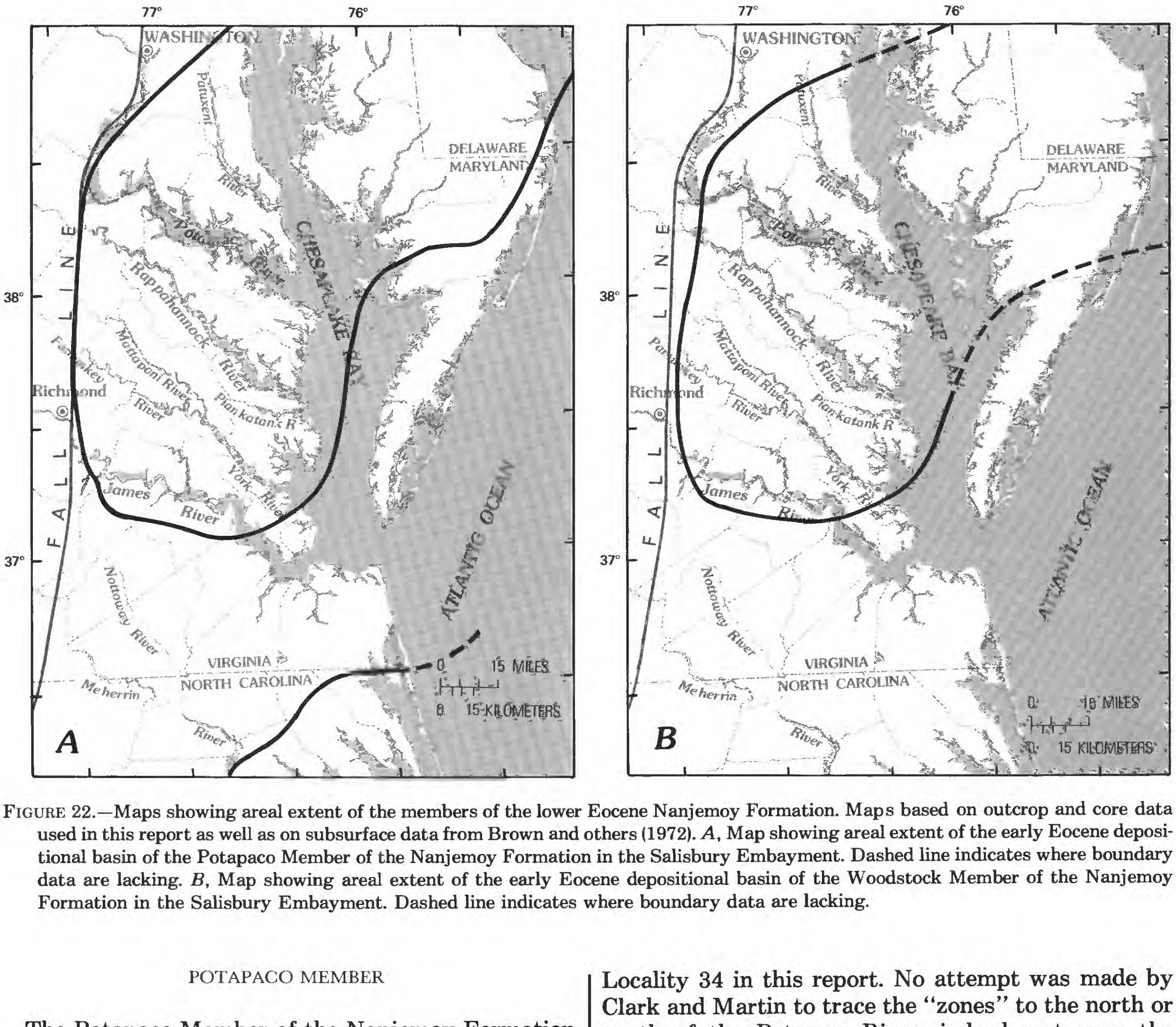

FIGURE 22.—Maps showing areal extent of the members of the lower Eocene Nanjemoy Formation. Maps based on outcrop and core data used in this report as well as on subsurface data from Brown and others (1972). *A*, Map showing areal extent of the early Eocene depositional basin of the Potapaco Member of the Nanjemoy Formation in the Salisbury Embayment. Dashed line indicates where boundary data are lacking. *B*, Map showing areal extent of the early Eocene depositional basin of the Woodstock Member of the Nanjemoy Formation in the Salisbury Embayment. Dashed line indicates where boundary data are lacking.

POTAPACO MEMBER

The Potapaco Member of the Nanjemoy Formation was described by Clark and Martin (1901, p. 65) and received its name from "the word Potapaco found on the (Captn. John) Smith and others early maps***." The Potapaco included Clark and Martin's (1901) "zones" 10–15. Part of their "zone" 10 included the Marlboro Clay. This unit was later termed the Marlboro Clay Member (Darton, 1948) and eventually was elevated to formational rank by Glaser (1971). Clark (1896b), Clark and Martin (1901), and Clark and Miller (1912) described the beds ("zones") found in the Potapaco at sections above Popes Creek on the left bank of the Potomac River, Charles County, Md. The section described by Clark and Martin (1901, p. 70, Section VIII) is herein designated the principal reference section (lectostratotype) of the Nanjemoy Formation and the Potapaco Member. The exposure is just downstream of Locality 34 in this report. No attempt was made by Clark and Martin to trace the "zones" to the north or south of the Potomac River; indeed, not even the members were recognized away from the Potomac sections. Recent work, principally on the Pamunkey River, but with supplemental sections on the James, Mattaponi, Rappahannock, and Patuxent Rivers (see fig. 23), has enabled me to identify a consistent and readily recognizable stratigraphic sequence of beds in the Potapaco. Vague descriptions of the "zones" by Clark (1896b) has made the correlation of his beds with the present scheme, in many cases, a matter of guesswork. For that reason, the following terminology is used for the series of four beds that have been recognized in the Potapaco (lettered from bottom to top):

Bed D—concretion-bed Potapaco,
Bed C—burrowed Potapaco,
Bed B—bedded Potapaco,
Bed A—nonbedded Potapaco.

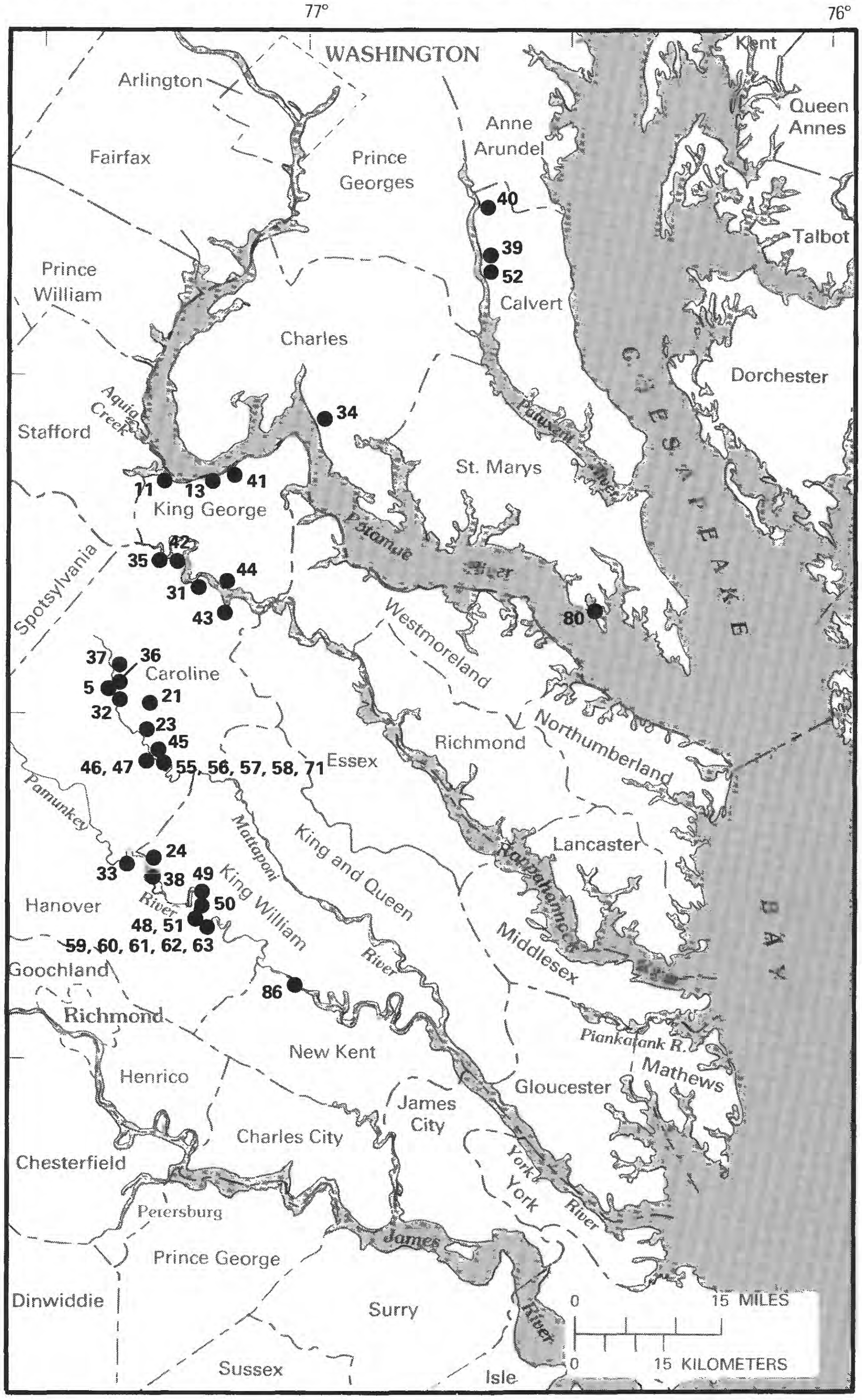

FIGURE 23.—Map showing localities where the Potapaco Member of the Nanjemoy Formation is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

The most striking characteristic of the Potapaco Member is its clayey texture. In all four beds, the dominant lithology is a gray to pink clay, studded with varying amounts of fine-sand-sized grains of glauconite. This characteristic texture serves to distinguish the Potapaco from the silty, fine, glauconitic sand of the overlying Woodstock Member and from the underlying silty, fine, glauconitic sand of the Paspotansa Member of the Aquia Formation (when the Marlboro Clay is not present). The clayey nature of the Potapaco was first described by Clark (1896b), Clark and Martin (1901), and Clark and Miller (1912). Later work by Glaser (1971) and Reinhardt and others (1980) alluded to the very clayey texture of the lower Nanjemoy.

Another distinguishing characteristic of the Potapaco is the relative lack of diversity in the molluscan assemblages. A single, small bivalve, *Venericardia potapacoensis* Clark and Martin, 1901, dominates, occurring in relatively thin, very crowded beds. This faunal assemblage enables the ready distinction of the Potapaco from the *Turritella*-packed sands of the underlying Paspotansa Member of the Aquia Formation. Faunally, the overlying Woodstock Member may be distinguished by the relative increase in molluscan diversity and the occurrence of common to abundant large bivalves, *Venericardia ascia* Rogers and Rogers, 1839. Mollusks in the Woodstock are scattered throughout the unit and only locally are concentrated in thin bands as in the Potapaco.

Of the four beds recognized in the Potapaco, Beds B and C seem to grade into each other with no discernible, continuous, or mappable contacts. It is believed, therefore, that they represent nearly continuous deposition with, perhaps, several marine pulses involving a deepening or shallowing of the sea, which caused the lithic or environmental changes. Beds A and D, however, seem to represent separate marine pulses and have sharp contacts marking their lower and upper boundaries. In spite of the physical evidence for a stratigraphic break between Beds C and D and between Bed D and the Woodstock Member, the floras and faunas present in the units indicate, at the most, breaks of only short duration and the deposition of both the Potapaco and Woodstock during the early Eocene.

Bed A—Nonbedded Potapaco

Bed A is found on the Pamunkey, Potomac, Rappahannock, and Mattaponi Rivers. It consists of a clayey, silty, fine sand containing scattered, small mollusks including *Venericardia potapacoensis* Clark and Martin, 1901. Glauconite occurs in relatively small amounts in the sand-sized fraction in updip areas, but glauconite percentages increase in a seaward direction. Small phosphate pebbles are common. The bed is estimated to be 15 to 20 feet (4.6 to 6.1 m) thick and in most instances unconformably overlies the Marlboro Clay. Bed A is distinguishable from Bed B because of its darker color, lack of bedding, and less clayey texture. Calcareous fossils are generally leached, leaving only molds and casts; however, preserved mollusks are present opposite Goat Island, on the right bank of the Rappahannock River 2.5 miles (4.0 km) above Port Royal, Caroline County, Va. (Locality 31), where Bed A descends to sea level. The unit also occurs high in the bluff just below the mouth of Ware Creek on the right bank of the Rappahannock in Caroline County (Locality 35). The unit is present on the right bank of the Potomac River 1.0 mile (1.6 km) below Fairview Beach in King George County, Va. (Locality 13). On the Mattaponi River, it can be seen overlying the Marlboro Clay just below the Rte. 207 bridge on the right bank in Caroline County (Locality 32, fig. 20). The contact with the Marlboro is abrupt; burrows deep into the Marlboro contain Potapaco sediments. Medium to coarse sand is concentrated in the lower part of Bed A, and phosphate and quartz pebbles are common. An apparent reverse dip (trending north) brings the Marlboro below water level upriver of the Rte. 207 bridge and causes higher beds in the Potapaco to descend to water level with increasing distance above Locality 32. At a point where the R.F.& P. Railroad track passes near the left bank of the Mattaponi 1.5 miles (2.4 km) above the Rte. 207 bridge (Locality 36), some 4.0 feet (1.2 m) of Bed A are exposed. Bed A descends to water level 2.4 miles (3.9 km) above the Rte. 207 bridge (Locality 37), indicating a continuing reverse dip. The Marlboro-Nanjemoy contact occurs at approximately 79 feet (24.1 m) above sea level just below the Rte. 207 bridge (Locality 32). In a small roadcut 0.9 mile (2.3 km) south of this locality on Rte. 676, the Nanjemoy-Calvert contact is exposed at approximately 90 feet (27.4 m). The relatively thin beds of the Nanjemoy in this area (11 feet (3.3 m)) indicate beveling of the Nanjemoy by a transgressing Calvert sea during the middle Miocene. The result is a thinning of Nanjemoy over an apparent high area and a thickening of that unit to the north and south on the flanks of that structure. An additional possible exposure of Bed A was found to the southeast, just below the Rte. 654 bridge on the left bank of the Mattaponi River in Caroline County (Locality 23), where it is overlain by bedded glauconitic sands of Bed B. The farthest updip exposure of Bed A on the Pamunkey River is at a large bluff, 1.0 miles (1.6 km) above the Rte. 301 bridge (Locality 33). There the unit consists of a weathered, brownish-gray (5 YR 4/1), micaceous, clayey sand. At Locality 24 on the Pamunkey (fig. 21), Bed A unconformably overlies the Marlboro Clay, which, at that locality, is only 6.0 to 8.0 inches (15.2 to 20.3 cm) thick. The upper surface of the Marlboro is intensely burrowed, and the burrows are filled with sediment from Bed A. Downstream, 0.65 mile (1.04 km) above Normans Bridge (Rte. 614), at a sharp bend (Locality 38, fig. 24), 4.0 feet (1.2 m) of Bed A are overlain, at least disconformably, by 6.0 feet (1.8 m) of Bed B. The contact is sharp and marked by the burrowed upper surface of Bed A as well as a concentration of pebbles. There is also an abrupt color change from the olive-black (5 Y 2/1) of Bed A to olive-gray (5 Y 4/1) of Bed B. No exposures are known on the James River, but, if present, Bed A should be near sea level at the Rte. 156 bridge over the James in Prince George County, Va.

The lithic and faunal makeup of Bed A suggests an initial marine pulse and basal trangression following the quiet, protected embayment represented by the Marlboro Clay. Physical and paleontologic evidence indicates that little time is represented by the break between the Marlboro and Bed A of the Potapaco. Low molluscan diversity and small glauconite percentages reflect less than normally saline conditions during the deposition of Bed A. In spite of this reduced salinity, renewed marine influence is apparent. Dinoflagellate assemblages are marked by reduced diversity, the flora being dominated by a single taxon, indicating brackish or restricted marine conditions (L.E. Edwards, oral commun., 1984). Mollusks, in general, are poorly preserved but where present are low in diversity. The following mollusks were present above Port Royal on the Rappahannock (Locality 31). One of these taxa is illustrated on plate 3.

Venericardia potapacoensis Clark and Martin, 1901
Macrocallista sp.
Corbula sp.
Lucina sp. (fig. 10)
Lucina sp.
Cadulus sp.

Such a list indicates a somewhat restricted, shallow-shelf environment but is of little help in determining an age for the unit other than a regional, relative stratigraphic placement. Calcareous nannoplankton, found in the Oak Grove core in Westmoreland County (Gibson and others, 1980) from the interval just above the Marlboro Clay, probably come from Bed A and indicate the placement of that bed in calcareous nannoplankton zone NP 10. This zonation indicates an early Eocene age assignment. Assemblages of pollen, dinoflagellates, foraminifers, and ostracodes tend to substantiate this placement. Dinoflagellates found in Bed A at two localities above the Rte. 207 bridge in Caroline County (Localities 36, 37) indicate an early Eocene age (L.E. Edwards, oral commun., 1984); on the basis of the dinoflagellate data, Edwards believes that Bed A is correlative with the Bashi Member of the Hatchetigbee Formation (as used by MacNeil, 1946) as exposed at its type section as Bashi Creek in Alabama. Further, the small assemblage and the dominance of a single taxon point toward a restricted marine environment.

Bed B—Bedded Potapaco

Bed B, the most striking unit in the Potapaco, is easily recognized by its bedded appearance. This effect is created by the accumulation of a small bivalve, *Venericardia potapacoensis* Clark and Martin, 1901, in vast numbers along numerous, discontinuous, thin bedding planes (figs. 24, 25). Bed B varies in thickness from locality to locality. Its exact thickness in surface exposures is difficult to determine because of poor outcrops. It can be estimated to range from only a few feet (about 1 m) to more than 15 feet (4.6 m). The sediment in Bed B is olive-gray (5 Y 4/1), very clayey, glauconitic sand to sandy clay. The clay, when fresh, appears grayish-orange-pink (5 YR 7/2) and contains varying amounts of fine to medium glauconite and quartz sand. Glauconite content ranges from less than 10 percent in the westernmost exposures to more than 75 percent with increasing distance from the paleoshoreline. Bedded concretions ranging up to boulder size are common in Bed B. These concretions, although sometimes regionally traceable, are not sufficiently stratigraphically continuous to be used as marker beds. It is believed that Bed B is equivalent to parts of "zones" 13 and 14 of Clark (1896b) and Clark and Martin (1901). "Zone" 13 matches the description well, and "zone" 14 seems to correspond to parts of Bed B where the calcareous fossils have been leached out, leaving bands of molds. Often these surfaces are encrusted with gypsum crystals. The physical appearance of Bed B, especially the bedding, is so obvious that it may be identified easily in some section descriptions in the older literature. Descriptions by Clark (1896b), Clark and Martin (1901), and Clark and Miller (1912) indicate the presence of Bed B at many localities in Maryland and Virginia. Among the more notable of their localities are the bluff at Potomac Creek, Virginia (Bull Bluff on the Passapatanzy 7.5-min quadrangle map; Locality 11 of this report); 3 miles (4.8 km) below Potomac Creek, Va.; 3 miles (4.8 km) above Popes Creek, Md.; and near Thrift in Prince Georges County, Md. These section descriptions reflect the homogeneous nature of the unit over a wide geographic area. Limited, poor exposures on the Patuxent River in Maryland make it difficult to observe the unit there, but the appearance of Bed C of the Potapaco Member plus the presence of the Woodstock Member 0.85 mile (1.37 km) below Nottingham on the left bank

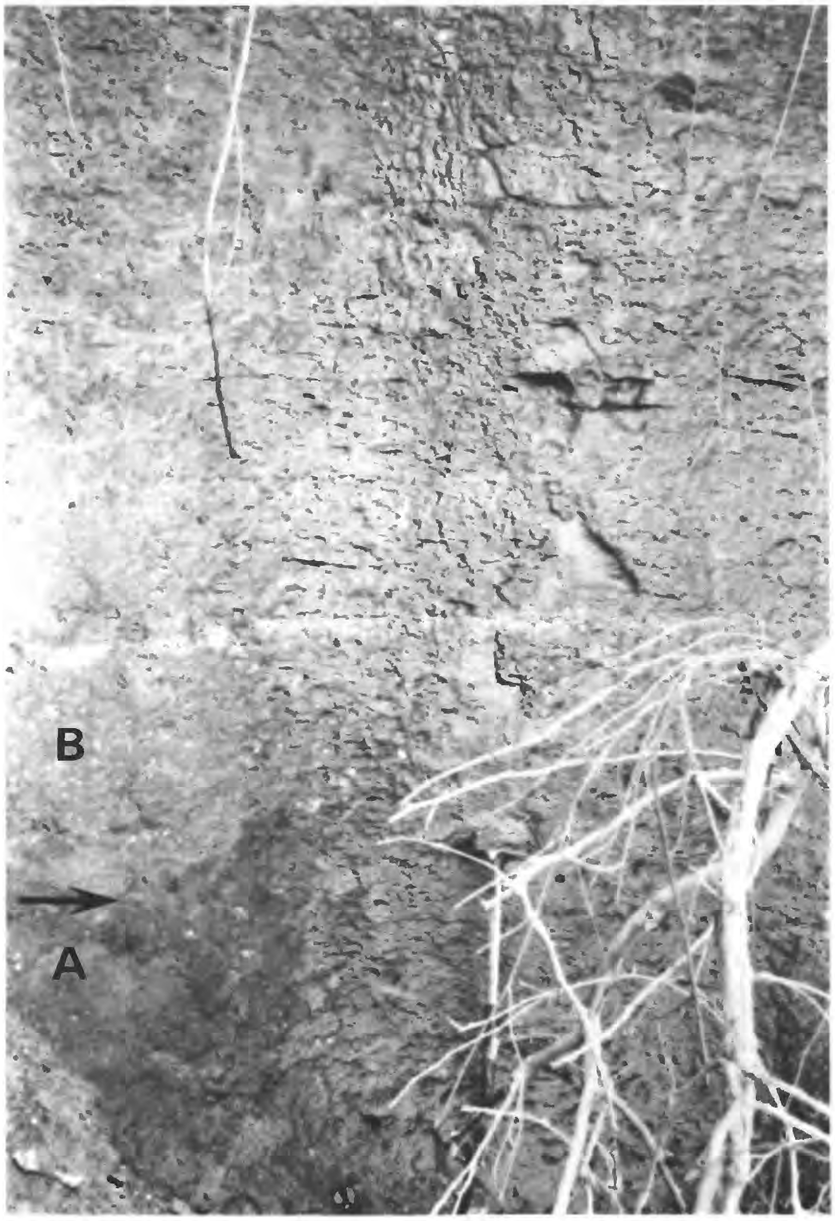

FIGURE 24.—Pamunkey River, 0.65 mile (1.04 km) above Normans Bridge (Rte. 614), King William County, Va. (Locality 38). Bed A (nonbedded) of the Potapaco Member of the Nanjemoy Formation is overlain by Bed B (bedded) of the Potapaco. The contact between the beds (arrow) is clearly exposed.

(Locality 39) indicate that Bed B should be near water level (sea level) in the vicinity of Lyons Creek Wharf, Calvert County (Locality 40).

The unit is present at Bull Bluff on the Potomac River (Locality 11), as previously stated, but is high in the section (62.5 feet, 19.0 m) and badly weathered. The same bed dips to water level 2.7 miles (4.3 km) below the big pier at Fairview Beach in King George County, Va. (Locality 41). The next occurrence downriver of Bed B of the Potapaco is 2.5 miles (4.0 km) above Popes Creek on the left bank, Charles County, Md. (Locality 34, fig. 26), where it exhibits the typical thin beds of *Venericardia potapacoensis* Clark and Martin, 1901, and contains irregularly bedded, boulder-sized concretions. Sediments herein assigned to Bed B were found in the Oak Grove core by Reinhardt and others (1980). In that report the interval at 276.9 feet (84.4 m) was figured (fig. 8, p. 7) and clearly shows the crowding of the bivalve *Venericardia potapacoensis* Clark and Martin, 1901.

FIGURE 25.—Mattaponi River, 1.0 mile (1.6 km) east of Reedy Mill, Caroline County, Va. (Locality 45). Poorly preserved, disarticulated valves of *Venericardia potapacoensis* Clark and Martin are crowded along thin, locally continuous beds, as is typical of Bed B of the Potapaco Member of the Nanjemoy Formation.

On the Rappahannock River, Bed B is first exposed in a high bluff on the right bank just below the mouth of Ware Creek in Caroline County (Locality 35). There it may be seen to overlie bed A at approximately 22.0 feet (6.7 m) above river level (sea level). It is seen again 0.9 mile (1.4 km) downstream on the right bank at approximately 20.0 feet (6.0 m) above water level (Locality 42), and it dips to water level on the right bank opposite Goat Island (Locality 31). Downriver, exposures are scattered and poor, but a small stream cut on Mill Creek just below the now-drained Millers Pond (Locality 43) exposes as much as 8.0 feet (2.4 m) of Bed B. A short distance downstream on the left bank of the Rappahannock, just above the mouth of Gingoteague Creek (Locality 44), Bed C crops out at water level, suggesting that Bed B has dipped below sea level.

On the Mattaponi River, the lower portion of Bed B is exposed in a small gully adjacent to the Rte. 654 bridge (Locality 23). Downriver, Bed B is exposed intermittently from 1 mile (1.6 km) (straightline) above Reedy Mill, Caroline County, to 0.6 mile (1.0 km) east of Reedy Millpond on the right bank. Best exposures, with preserved mollusks, are below Reedy Mill (Localities 45, 46, 47). There they show the typical, thinly bedded nature of Bed B with many *Venericardia potapacoensis* Clark and Martin, 1901, crowded along thin bedding planes (fig. 24). At Locality 46, beds with a pronounced reverse dip (approximately 4°) are exposed; the *Venericardia* bed dips upstream or northwest. These exposures occur at approximately 40 to 45 feet above sea level. Where Bed B reaches sea level in the Mattaponi River area can only be estimated until drilling establishes the location. The bed may be estimated to dip below sea level in the area of the Rte. 628 bridge over the Mattaponi in King William and King and Queen Counties, Va.

The next extensive outcrop area of Bed B to the south is along the Pamunkey River from 0.65 mile (1.04 km) above Normans Bridge (Locality 38, fig. 24) to 0.8 mile (1.3 km) south of Hanovertown (Locality 48). At Locality 49, above Dabneys Millpond, Bed B is exposed between 5 and 10 feet (1.5 and 3.0 m) above water level (which here is approximately 5 feet (1.5 m) above sea level). Just below the boat landing at Dabneys Millpond (Locality 50, fig. 27), a good section is exposed in a high bluff that includes Beds B and C of the Potapaco, as

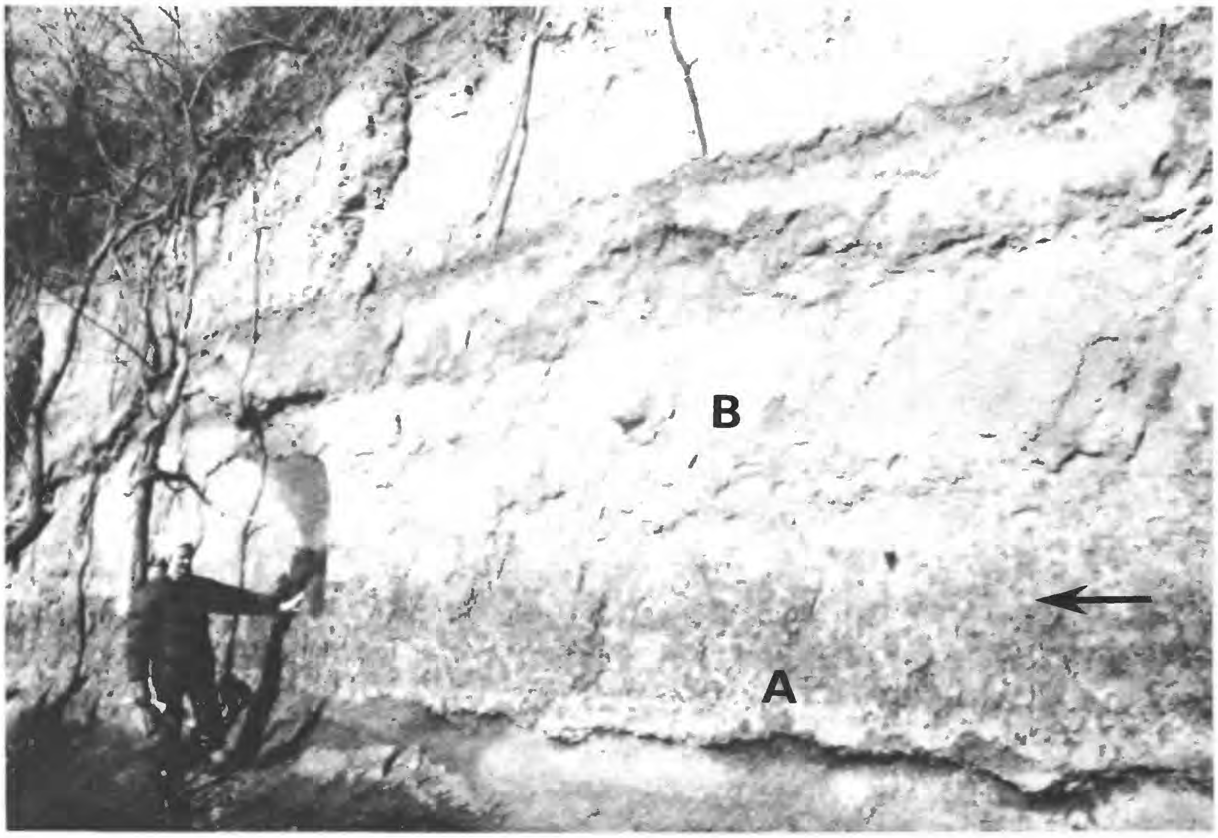

FIGURE 26.—Potomac River, 2.5 miles (4.0 km) upstream from Popes Creek, Charles County, Md. (Locality 34). E.G. Shaw (USGS, Reston, Va.) has her hand on a contact marking a diastem within Bed B of the Potapaco Member of the Nanjemoy Formation. The lower bed (A) of the Potapaco has a burrowed upper surface. The burrows are filled with sediment from B.

well as the Woodstock Member. Bed B crops out in the river bed where, at low water, thousands of *Venericardia potapacoensis* Clark and Martin, 1901, may be seen. Bed B also crops out to a height of 4 feet (1.2 m) depending on the water level, and contains abundant, poorly preserved *Venericardia* and common *Cubitostrea.* It is overlain by Bed C; the contact between the two is apparently gradational with no abrupt lithic change. Downriver, and along strike, at Hanovertown (Locality 51), small outcrops expose Bed B to a height of 8.0 feet (2.4 m) (approximately 11 feet (3.4 m) above sea level). At a sharp bend 0.8 mile (1.3 km) south of Hanovertown, Hanover County, on the right bank of the Pamunkey (Locality 48), Bed B crops out to a height of 5.0 feet (1.5 m) at low water. Sediments exposed at low water contain moderately well preserved mollusks at approximately 5 feet (1.5 m) above sea level. To the east and downriver of this point, the burrowed, glauconitic clays of Bed C crop out, Bed B apparently having dipped below river level.

Bed B probably is present, but has not been seen, along the James River. Outcrop patterns of the Aquia, Marlboro, Nanjemoy, and Piney Point Formations suggest that Bed B probably crops out near water level (sea level) just below the Rte. 156 bridge over the James in Prince George County, Va.

Sedimentological and faunal characteristics of Bed B indicate deposition in a shallow, somewhat restricted embayment. Glauconite grains, which appear to be concentrated in burrows, are common. The burrows and the concentrations of abraded bivalves along bedding planes suggest shallow depths, probably not below wave base. Glauconite-coated, worn, disarticulated valves of *Venericardia* indicate at least periods of slow sediment accumulation. Bivalves may be concentrated along those winnowed zones because of favorable bottom conditions or storms. Elsewhere in the section, where soft clays inhabited by burrowing organisms predominated, the bottom may not have been suitable for the settlement of bivalve larvae. The molluscan assemblage of Bed B is dominated (as much as 95 percent) by *Venericardia potapacoensis* Clark and Martin, 1901. This small bivalve has a striking, forward umbonal inclination, which makes it easy to separate from even young individuals of *Venericardia ascia* Rogers and Rogers, 1839, found in the Woodstock Member.

FIGURE 27.—Pamunkey River, just below the boat landing at Dabneys Millpond, King William County, Va. (Locality 50). P.F. Huddlestun (Georgia Geologic Survey, Atlanta, Ga.) is standing on Bed B of the Potapaco Member of the Nanjemoy Formation. Bed C of the Potapaco extends from approximately shoulder height up into the vegetation. The Woodstock Member of the Nanjemoy Formation is visible in the upper left clearing.

Gardner and Bowles (1939) pointed out the affinities of *V. potapacoensis* with *V. clavidens* Grzybowski, 1899, from Peru and with *V. diga* Gardner and Bowles, 1939, from Mexico. Both of these forms occur in the lower Eocene, but no analogue is known in the Gulf States. Another common, though never abundant, taxon is an unnamed species of *Cubitostrea* (pl. 3, figs. 1-6), which also occurs in the Woodstock Member. Toulmin (1977, pl. 35, figs. 1, 3) figured a specimen from the lower Tallahatta along the Chattahoochee River in Alabama that appears to be similar to, if not identical with, this species. A figure of a young *Ostrea brevifronta* Dockery, 1980, found in the Bashi Formation (lower Eocene) in Mississippi (Dockery, 1980, pl. 4, fig. 4) appears very similar to the form from the Potapaco. Harris (1897, pl. 6, fig. 2) figured a specimen from Hatchetigbee Bluff on the Tombigbee River in Alabama that closely resembles the Maryland and Virginia forms. Beds at Hatchetigbee Bluff from which the specimens were collected are considered to be lower Eocene. A collection from Tunnell Springs, Monroe County, Ala., in a railroad cut, contains specimens of *Cubitostrea* that appear to be the same species. The thin marine bed exposed there is, stratigraphically, somewhat higher in the Hatchetigbee Formation than the Bashi but is still considered to be lower Eocene. Other mollusks present in Bed B occur in small numbers and are of little stratigraphic value. These include the following genera (see pl. 3):

- *Vokesula* sp. (figs. 9, 11)
- *Lucina* sp. (fig. 10)
- *Nucula* sp.
- *Nuculana parva* (Rogers, 1837) (fig. 8)
- *Macrocallista* sp.
- *Cadulus* sp. (fig. 12)

Calcareous nannofossils are poorly preserved in many parts of the basin, but the core at Oak Grove, Westmoreland County, Va., contained an assemblage in the Potapaco indicative of NP 10 and NP 11 (Gibson and others, 1980). L.M. Bybell (oral commun., 1984) believes that this part of the Potapaco contains nannofossils assignable to NP 11. Detailed work on dinoflagellates by L.E. Edwards (USGS) has enabled her to correlate those assemblages with the calcareous nannofossil zonation. In this way, the wide areas lacking calcareous forms can be safely zoned. Such an area is the updip region of Virginia where nannofossils are scarce or leached out. Along the Pamunkey River, samples from Bed B have been found to contain a dinoflagellate flora correlative to what has been called NP 10 or 11.

Bed C—Burrowed Potapaco

Above the thin-bedded clayey sand of Bed B is a series of sandy clays to clayey sands, which is easily recognized by its intensely burrowed appearance. Bedding, if it was ever present, has been obscured by bioturbation except along a few very thin planes. Along those surfaces sedimentation appears to have been interrupted; they are marked by at least regional diastems, a concentration of glauconitic sand, and glauconite-filled burrows extending down into the underlying sediment. These stratigraphic breaks, if that is what they represent, have not been traced over a wide area and may be only local, possibly current-scoured surfaces. The dominant lithic characteristic of Bed C is its very clayey texture, with interspersed grains of fine- to medium-sand-sized glauconite in a grayish-orange-pink (5 YR 7/2) clay matrix. In some areas, the concentration of glauconite is such that the lithology is best described as a clayey sand. This very clayey, glauconitic texture is typical of the entire Potapaco Member, but the intensely burrowed nature of the unit is unique to Bed C. The macrofossils in Bed C are principally small or broken, poorly preserved mollusks that are concentrated in burrows and make up a small percentage of the bed. Thicknesses of as much as 20 feet (6.1 m) of Bed C have been observed in outcrop. The bed overlies Bed B with no distinct contact between the two, suggesting a gradation from one environmental regime to another. In most of its outcrop area, Bed C is overlain by the Woodstock Member of the Nanjemoy Formation. On the Pamunkey River, at least, Bed C is overlain by a thin bed, 1.5 to 3.0 feet (0.5 to 0.9 m) thick, of clayey, glauconitic sand marked by a series of boulder-sized indurated blocks. The contact between Bed C and the younger unit, Bed D, is abrupt and is marked by a sharp but burrowed contact indicating a probable diastem. Elsewhere, where Bed D is missing, the Bed C–Woodstock boundary is disconformable and is marked by an abrupt change in lithology, a lag deposit of phosphate, bone, pebbles, and wood in the lower Woodstock, and burrows containing Woodstock sediment several feet into the underlying Bed C. The olive-black (5 Y 2/1), very fine, well-sorted, micaceous, glauconitic sand of the Woodstock is easily distinguishable from the very clayey, burrowed sands of Bed C. This contact has been observed on the Patuxent, Potomac, Mattaponi, and Pamunkey Rivers.

Bed C is present on the Patuxent River from 0.3 to 0.8 mile (0.5 to 1.4 km) above Jones Point, Calvert County, Md. (Localities 52, 39). There it is disconformably overlain by the Woodstock. The Potapaco-Woodstock contact is sharp and burrowed and is marked by a line of pebbles as well as by the textural changes previously mentioned. At both localities (52 and 39), 15.0 feet (4.5 m) of Bed C is exposed near water level (sea level); it consists of a very burrowed, olive-gray (5 Y 4/1) (grayish-yellow, 5 Y 8/4, where weathered), clayey, glauconitic sand. Weathering of the burrows has brought out their detail; they appear to have been built by *Callianassa*, a burrowing, shrimp-like arthropod. Above Popes Creek on the left bank of the Potomac River, Charles County, Md., the area in which Bed C probably descends to water level is slumped and obscured, causing weathering of the cliff face. However, in 1969 an unusual combination of wind and tide swept much of the normal beach sand away and revealed an intensely burrowed unit at beach level and below. The burrows were apparently made by the burrowing shrimp *Callianassa* and were visible for several miles above Popes Creek. They were best developed 0.4 mile (0.6 km) above the mouth of Popes Creek (Locality 53). These beds are now covered by slump and beach sand in that area. Below Popes Creek, the Woodstock Member descends to beach level, indicating that the contact between Bed C and the Woodstock probably reaches water level (sea level) very near Popes Creek.

On the Rappahannock River, Bed C is visible only on the left bank 0.4 mile (0.6 km) above the mouth of Gingoteague Creek (Locality 44). There some 10.0 feet (3.0 m) of the unit is exposed at beach level (sea level). At the next exposure downstream, just above Greenlaw Wharf on the left bank (Locality 54), the Woodstock crops out, Bed C presumably having dipped below sea level.

Outcrops of Bed C on the Mattaponi River are known at numerous small exposures below Reedy Mill. There Bed C is overlain by the Woodstock Member (Localities 55, 56, 57, 58) (see fig. 28). Bed C is better exposed at places along the Pamunkey River where some 15 feet (4.6 m) crops out and its upper and lower contacts may be seen. At the large bluff just below the boat landing at Dabneys Millpond (Locality 50, fig. 27), Bed C is exposed from 4 feet (1.2 m) above water level (approximately 13 feet (2.7 m) above sea level) to approximately 14.0 feet (4.2 m) above water level (23 feet (7.0 m) above sea level). It consists of a very bioturbated, clayey, somewhat weathered, olive-gray (5 Y 4/1) and grayish-yellow (5 Y 8/4) glauconitic sand. At least three "contacts" may be seen within the unit. These appear to represent only pauses in deposition or current winnowing, because identical lithologies occur above and below. Medium-sized glauconitic sand is concentrated above the contact and fills burrows into the underlying

FIGURE 28.—Mattaponi River, 0.8 mile (1.28 km) southeast of Reedy Mill, Caroline County, Va. (Locality 58). D.R. Womer (USGS, Reston, Va.) has his pick on the contact between the Potapaco Member (below) and the Woodstock Member of the Nanjemoy Formation.

sediment. Small shell fragments are present but are poorly preserved. The low bluffs between Dabneys Millpond and 0.7 mile (1.1 km) south of Hanovertown (Locality 48) expose only small sections of Bed B. Poor exposures of Bed C are present along the stretch of the Pamunkey 0.55 mile (0.89 km) downriver of the sharp bend below Hanovertown to a point 1.45 miles (2.33 km) southeast of Hanovertown (Localities 59, 60). Bed C is best seen in a series of excellent, though low, outcrops beginning 0.4 mile (0.6 km) below the mouth of Totopotomoy Creek and continuing to the sharp bend to the east, 0.2 mile (0.3 km) downstream. Below this point the Woodstock Member descends to river level (approximately 2.5 feet (0.8 m) above sea level). The outcrop nearest the bend, and another about 0.1 mile (0.2 km) above the bend, expose Bed C to a height of 5.0 feet (1.5 m) (Localities 61, 62). It consists of glauconitic, burrowed, olive-gray (5 Y 4/1) clay. Bed C is overlain, at these two outcrops and the following one upstream (Locality 63), by Bed D, a thin bed, 1.5 to 2.0 feet (0.5 to 0.6 m) thick, of clayey, very glauconitic sand that has only been seen in this area. Bed D is, in turn, overlain by the Woodstock Member. The contact between Bed C and the overlying Bed D is sharp and marked by a lag deposit of phosphate pebbles, burrows into the top of Bed C, and a coarser texture in the basal part of Bed D. Higher concentrations of glauconite in Bed D make the unit easily distinguishable from the more clayey, burrowed Bed C below. The contact between the two units appears to represent a hiatus of longer duration than the breaks observed within Bed C. A reverse dip (upriver, to the northwest) brings the top of Bed C to within 2.5 feet (0.8 m) above water level (which here is sea level) at Locality 63. Downriver of this area, Bed C is believed to have dipped below water level. The unit is not exposed on the James River, but if present it would approach water level (sea level) in the vicinity of Indian Point, on the right bank, below the Rte. 156 bridge, King George County.

Biostratigraphic information afforded by mollusks is meager in Bed C. Apparently bottom conditions were unsuitable for settlement by most taxa. The extreme bioturbation seen in Bed C certainly played a part in the absence of adult or large mollusks. Probably the very clayey aspect of Bed C was also a limiting factor. The result is a nondiverse assemblage (where preserved) consisting of a few *Corbula, Lucina,* and *Cadulus* that offer little evidence of age. The lithic combination of clays mixed with sand-sized glauconite and quartz, together with the intricate burrow systems, indicate a shallow (above wave base), restricted embayment, perhaps protected by offshore bars, which served to trap the finer sediment. The presence of *Callianassa* indicates high-energy conditions, possibly accomplished by current or tidal scour, and at least near normal salinities. Dinoflagellate assemblages indicate near-shore or high-energy conditions and an abundant source of nutrients (L.E. Edwards, oral commun., 1984). On the basis of the dinoflagellate flora, Bed C may be correlated with calcareous nannoplankton zone NP 10 or 11. Samples examined for nannoplankton by J.A. DiMarzio (oral commun., 1984) were barren in the Pamunkey River area.

BED D—CONCRETION-BED POTAPACO

As previously mentioned, Bed D crops out along the Pamunkey River only from Locality 63 to Locality 61, below the mouth of Totopotomoy Creek. Upriver, at Dabneys Millpond (Locality 50), Bed D is not present, possibly having been beveled off by the transgressing Woodstock sea. There the Woodstock directly overlies Bed C. Bed D, in its small outcrop area, consists of 1.5 to 2.0 feet (0.5 to 0.6 m) of clayey, very glauconitic sand and is marked above and below by sharp contacts. Both contacts are marked by abrupt changes in lithology and color and contain concentrations of phosphate pebbles, quartz, and wood. Burrows at both contacts extend down into the underlying beds. The high glauconite content of Bed D makes it easily differentiated from the lighter colored clays of Bed C and the less glauconitic silty sand of the basal portion of the Woodstock Member (see fig. 29). At Localities 61 and 62 the lower contact of Bed D is at approximately 5 feet (1.5 m) above water level (7.5 feet (2.3 m) above sea level). The bed is marked by a line of cobble- to boulder-sized concretions in the middle of the unit. Further upstream (Locality 63), as previously mentioned, a reverse dip brings the top of Bed D to within 4.5 feet (1.4 m) above river level (5.0 feet (2.1 m) above sea level).

Mollusks in Bed D, in the small area they could be studied, are very poorly preserved, small, and fragmentary. Recognizable forms included *Corbula, Lucina, Venericardia,* and *Cadulus.* Adequate molluscan evidence on the environment is lacking, but the assemblage, together with the more massively bedded, more evenly textured, very glauconitic lithology of the unit, indicates near normally saline, open, shallow-shelf conditions. Dinoflagellates obtained from Bed D indicate near-shore or marginal-marine conditions much like those of Bed C (L.E. Edwards, oral commun., 1984). The similarity of floras in the two beds may be the result of reworking into the very thin Bed D. However, the dinoflagellate assemblage indicates an equivalency with calcareous nannoplankton zones NP 10 and 11. NP 11 was recognized in the Oak Grove core in Westmoreland County (Gibson and others, 1980), where it may represent the same beds recognized on the Pamunkey River as Bed D.

WOODSTOCK MEMBER

The Woodstock Member of the Nanjemoy was first proposed by Clark and Martin (1901, p. 66) for beds of glauconitic sand exposed near Woodstock, "an old estate situated a short distance above Mathias Point," King George County, Va. The term "Woodstock" had previously been used by Clark (1895, 1896b) to describe the Woodstock Stage, a unit defined principally on its fauna. Clark and Martin (1901) described the member as consisting of their two lithic "zones" 16 and 17. The bluff described by Clark (1896b, p. 40, pl. IV, Section III) and Clark and Martin (1901, p. 70, Section IX) exhibits both the Potapaco and Woodstock Members and is therefore designated herein the lectostratotype section for the Woodstock. It is just downstream from Locality 67 of this report. (See fig. 30 for locality map.)

The Woodstock Member of the Nanjemoy consists of olive-black (5 Y 2/1), very fine, well-sorted, silty, glauconitic sands. The glauconite content increases markedly from a low of 10–15 percent in its most inland outcrops to 70–80 percent in its most seaward exposures. Carbonaceous material in the form of logs, branches, and nuts is abundant. The Woodstock unconformably overlies the Potapaco Member and is unconformably overlain either by the Piney Point Formation, where present, or by younger beds, depending on the area. The lower contact with the Potapaco is a constant and easily recognized feature that may be seen from the Patuxent River to the Pamunkey River. Biostratigraphically there is a significant faunal and floral change at this boundary, though it marks only a relatively brief hiatus. The Woodstock may be distinguished from the underlying Potapaco by its fine-textured, micaceous, massive appearance, in contrast to the very clayey, poorly sorted, bioturbated texture of the underlying Potapaco.

Molluscan assemblages in the Woodstock are diverse and abundant and are scattered throughout the fine matrix. Large valves of *Venericardia ascia* Rogers and Rogers, 1839, are concentrated along bedding planes in some areas but are easily distinguished from the much smaller *Venericardia potapacoensis* found in the

FIGURE 29.—Pamunkey River, 0.58 mile (0.93 km) below the mouth of Totopotomoy Creek, Hanover County, Va. (Locality 61). Beds C (below lower arrow) and D (between arrows) of the Potapaco Member of the Nanjemoy Formation are exposed. Bed D is unconformably overlain by the Woodstock Member (above upper arrow).

Potapaco Member. The overlying Piney Point Formation is coarser textured, clayey, and poorly sorted. Both units contain a large number of mollusks, but they have no species in common. In some areas along the Pamunkey River, mollusks from the Woodstock have been reworked upward into the base of the Piney Point. This is clearly illustrated at Locality 64, where the Piney Point transgression beveled across a bed of articulated *Venericardia ascia* in living position. Specimens of this taxon were reworked upward, the valves still adhering, and showing almost no abrasion, by as much as 1 foot (0.3 m) into the overlying Piney Point. Their origin is easily determined, however, by the presence of distinctive, olive-black (5 Y 2/1), micaceous, silty, very fine sand of the Woodstock within the double valves.

Outside of the Pamunkey River and James River areas, the Woodstock is directly overlain by beds younger than the Piney Point. On the Patuxent River above Jones Point, Calvert County, Md. (Locality 52), the Woodstock is directly overlain by a basal sandstone included in the Calvert Formation. This sandstone is "zone" 2 of Shattuck (1904) and is early Miocene in age. At the old Kaylorite mine 1.2 miles (1.9 km) above Nottingham on the left bank (Locality 65) and at White Landing on the right bank (Locality 66), the Woodstock is overlain by a thin bed referred to as "zone" 1 of the Calvert Formation by Shattuck (1904). This bed has been determined, on the basis of mollusks, pollen, and dinoflagellates, to be of late Oligocene or early Miocene age. It is lithologically distinct from the underlying Woodstock and the overlying Calvert ("zones" 2–15). The unit may correlate with a similar bed on the Pamunkey, herein termed the Old Church Formation (described later) and with the Belgrade Formation in North Carolina, the Edisto Formation in South Carolina, and the Tampa Formation in Florida.

Along the Potomac River above Mathias Point on the right bank (Locality 67) (see fig. 31) and above and below Popes Creek on the left bank (Localities 53, 68) (see fig. 32), the Woodstock is overlain by transgressive sediments of the Calvert Formation that range from early to middle Miocene in age. The contact is marked by a basal lag concentration of phosphate and quartz pebbles, a burrowed surface, and an abrupt lithic change from glauconitic sands to olive-brown, clayey, phosphatic sand. At the downriver end of the bluffs below

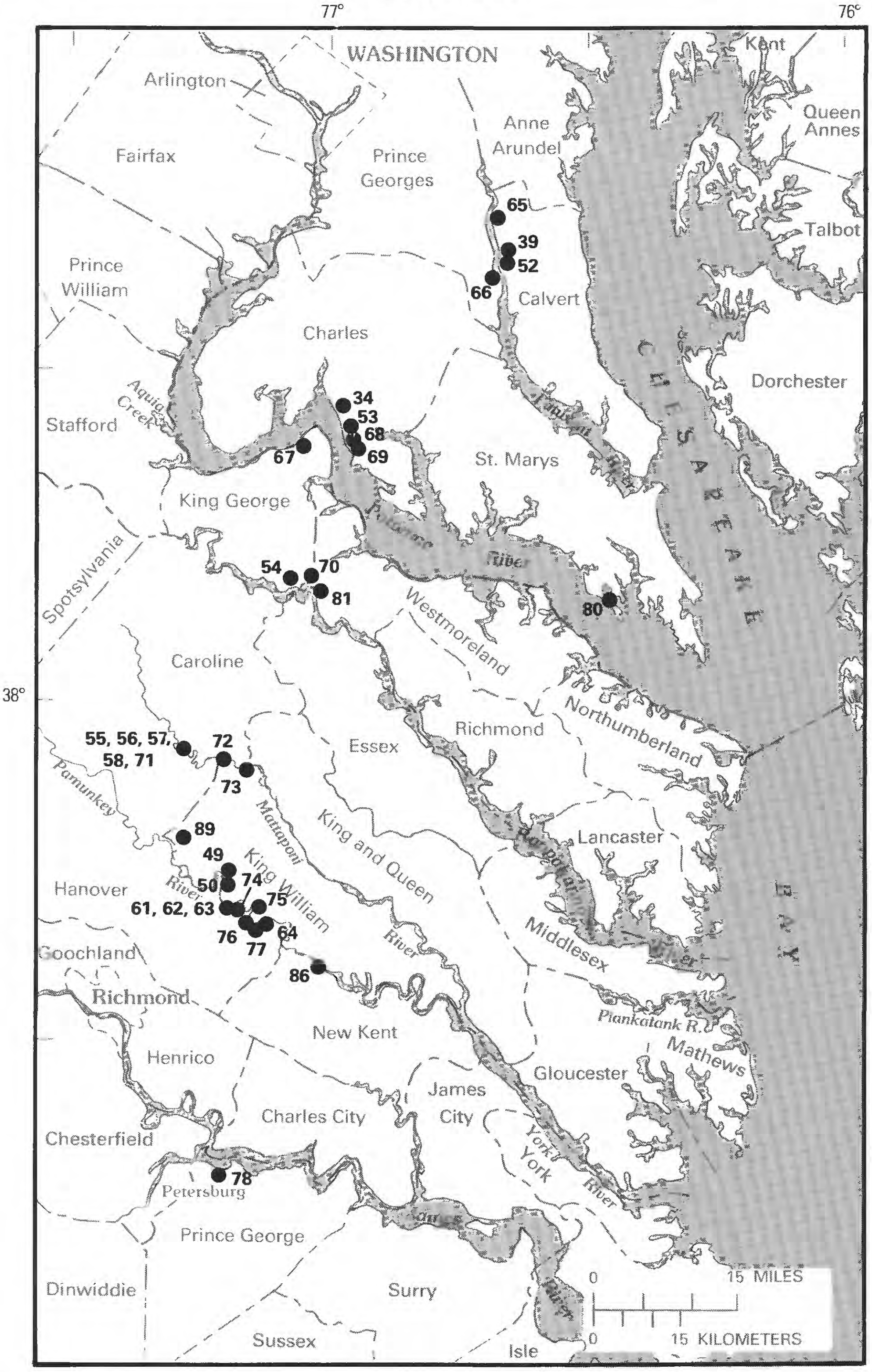

FIGURE 30.—Map showing localities where the Woodstock Member of the Nanjemoy Formation is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

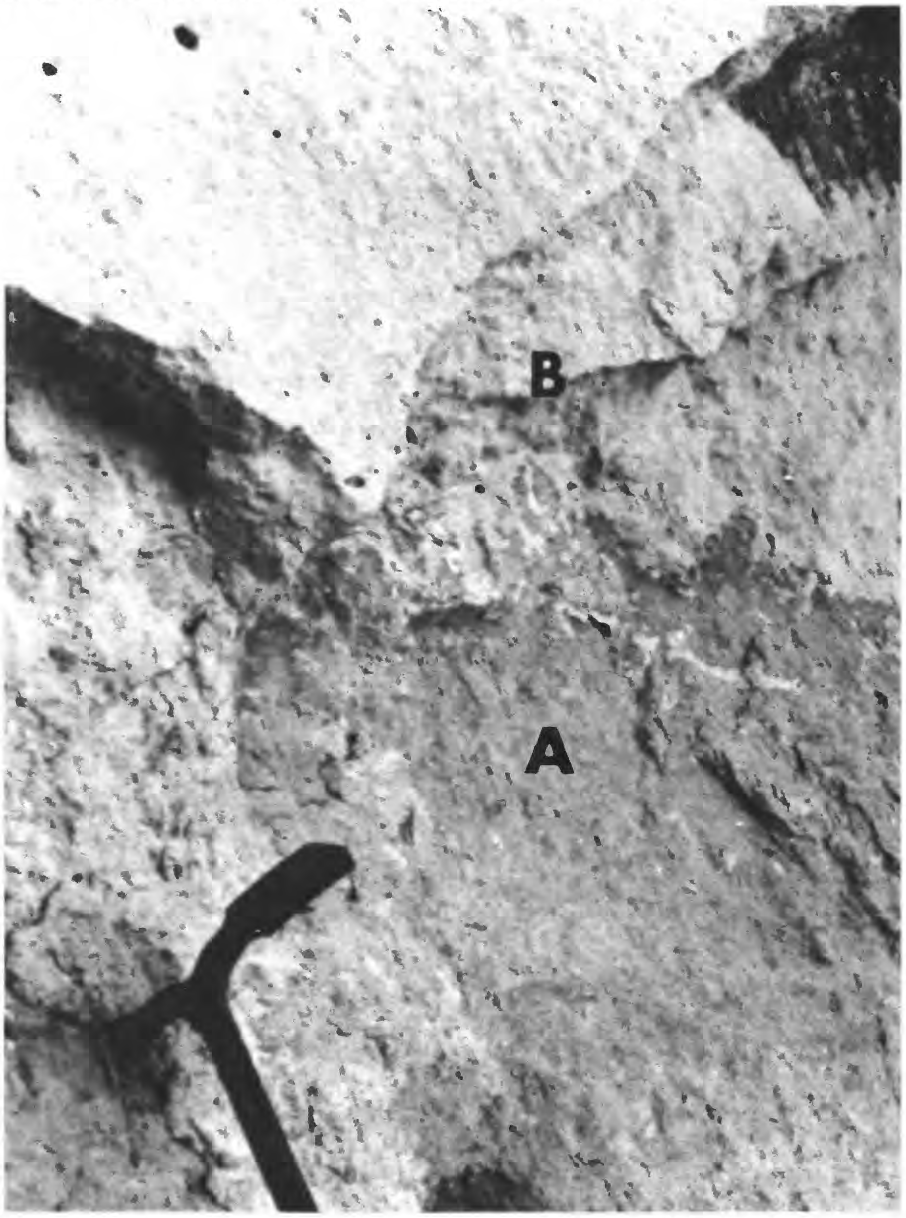

FIGURE 31.—Potomac River, 1.65 miles (2.66 km) above Mathias Point, King George County, Va. (Locality 67). The upper surface of the Woodstock Member (A) of the Nanjemoy Formation is deeply eroded and intensely burrowed. It is overlain by the weathered, yellowish-gray, silty sands and clays of the Calvert Formation (B). The pick is imbedded near the bottom of a sharp cut into the Woodstock.

Popes Creek (Locality 69), a very thin tongue of burrowed gray clay and a bed of glauconitic sand occur between the good, easily recognized Woodstock and the Calvert. These two beds thicken downstream but are beveled off before reaching Popes Creek. Macrofossils are leached from the beds, but dinoflagellates indicate that they are early Eocene in age (L.E. Edwards, oral commun., 1984). It seems best, therefore, to include them in the Woodstock in spite of their very different lithologies. It is believed that these units are represented in the Oak Grove core by the clay and sand beds shown as occurring in the upper Nanjemoy by Reinhardt and others (1980, fig. 1). They probably represent a separate marine pulse from that which resulted in the deposition of the Woodstock (in its strict sense) but are best included in that unit until their stratigraphic and areal relationships can be assessed.

On the Rappahannock River, as much as 4 feet (1.2 m)

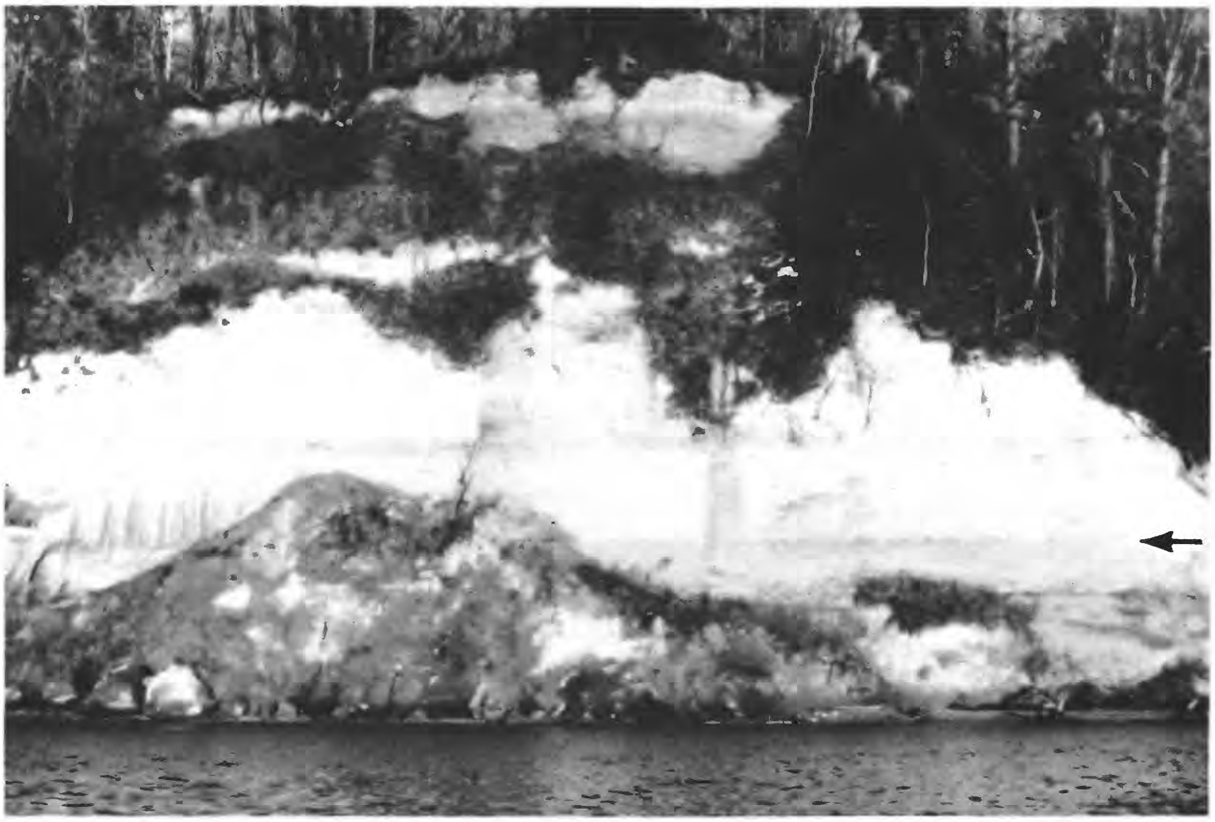

FIGURE 32.—Potomac River, 0.4 mile (0.6 km) above Popes Creek, Charles County, Md. (Locality 53). The Woodstock Member of the Nanjemoy Formation is overlain by the Calvert Formation; an arrow marks the contact.

of the Woodstock Member may be seen on the left bank, just above Greenlaw Wharf (Locality 54) (see fig. 33). It is overlain there by a grayish-yellow, poorly sorted, slightly glauconitic and pebbly sand. The contact between the two units is decidedly undulant and exhibits several feet of relief. A lag of pebbles as well as burrows mark the contact. This previously unrecognized unit (herein provisionally included in the Woodstock Member) is also present at the upriver end of the bluffs below Wilmont Wharf (Locality 70) where it is overlain by the Calvert Formation. On the Mattaponi River, the Woodstock crops out continuously from Reedy Mill on the right bank (Locality 71) to 1.8 miles (2.9 km) (straightline) above the mouth of Maracossic Creek, also on the right bank (Locality 72). At the next exposure downstream, 1.3 miles (2.1 km) above the mouth of Maracossic Creek (Locality 73), the Woodstock has apparently passed below river level and a clean, ripple-marked and pebbly sand crops out. This unit bears a strong resemblance to the previously described bed that overlies the Woodstock on the Rappahannock River at Greenlaw and Wilmont Wharves (Localities 54, 70). From Reedy Mill (Locality 71) to 0.95 mile (1.53 km) east of Reedy Mill (straightline) on the left bank (Locality 55), the olive-black (5 Y 2/1), silty, micaceous sand of the Woodstock overlies the olive-gray (5 Y 4/1) clay of the Potapaco Member (fig. 28). The contact is abrupt, marked by a pebble lag and burrowing, and is easy to delineate owing to marked color differences in the two beds.

The Woodstock Member is probably best seen along the Pamunkey River, where it is almost continuously exposed from the bluff just below the boat landing at Dabneys Millpond (Locality 50, fig. 27) to 0.85 mile (1.37 km) (straightline) southeast of the Newcastle Bridge ruins (Locality 64). Just below Dabneys Millpond (Locality 50), the Woodstock overlies Bed C of the Potapaco Member. The contact is marked by pebbles, a concentration of glauconite, a burrowed contact, and carbonized wood. The next good exposure downriver of the Woodstock begins 0.4 mile (0.6 km) (straightline) below the mouth of Totopotomoy Creek (Locality 63) and continues intermittently for some miles downstream. At Locality 63 and for approximately 0.5 mile (0.8 km) downstream (Localities 61, 62) (see fig. 32), the Woodstock overlies the thin tongue of sediment previously designated Bed D. Here again, the contact is marked by a pebble concentration, burrows, and

FIGURE 33.—Rappahannock River, 0.2 mile (0.3 km) above Greenlaw Wharf, King George County, Va. (Locality 54). The Woodstock Member of the Nanjemoy Formation is overlain by a pebbly, slightly glauconitic sand of uncertain affinity.

wood. Bed D of the Potapaco is considerably more glauconitic than the basal part of the Woodstock and, as a result, is much darker in color. This difference makes tracing of the contact, and accompanying burrows, relatively easy. The Woodstock contains much carbonaceous material and ranges from 15 to 25 feet (4.6 to 7.6 m) in thickness along this section, although it is covered by vegetation and slump over much of the area. Shell material is scattered throughout and increases in size upwards. Glauconite content increases higher in the section and downdip, whereas the wood content decreases higher in the section and downdip.

Along the Pamunkey, the Piney Point Formation (middle Eocene) directly overlies the Woodstock, separated by a sharp, easily recognized unconformity. This relationship is first seen in a ravine 0.63 mile (1.01 km) (straightline) south-southeast of the mouth of Totopotomoy Creek on the right bank of the Pamunkey (Locality 74, fig. 34). There some 15.0 feet (4.6 m) of olive-black (5 Y 2/1), very fossiliferous Woodstock is overlain by 3.0 feet (0.9 m) of yellowish-gray (5 Y 8/1), leached, somewhat indurated, poorly sorted, shelly sand of the Piney Point Formation. At this updip locality, the Piney Point contains less than 5.0 percent glauconite, and its relatively light color is in sharp contrast to the dark, very glauconitic Woodstock. This color and textural difference enables the observer to recognize burrows filled with Piney Point sediment as far as 8.0 feet (2.4 m) down into the Woodstock. Burrows are common, relatively large, and deep there (Locality 74) but are even more numerous downstream, making the collection of uncontaminated samples difficult. As previously mentioned, reworking of sediment and fossils is common along the contact. The elevation of the contact is variable from place to place and does not follow a simple, predictable, regional dip. This variation may have been achieved by the transgression of the Piney Point sea over a deeply dissected Woodstock surface, but it is my opinion that some of these anomalous relationships may be related to structural movements as shown by several beds that dip west or northwest, opposite the normal seaward dip. Numerous exposures of the Woodstock–Piney Point contact are exposed below the Rte. 360 bridge (Localities 75, 76, 77, 64) (see fig. 35). The Woodstock passes below water level (sea level) near the dead end of Rte. 732 at the Pamunkey River (downriver of Locality 64).

Along the James River valley, the Woodstock is known only from a ravine below the mouth of Baileys Creek on the right bank of the James River, Prince George County (Locality 78). There it is directly overlain by a thin tongue of the Cobham Bay Member of the

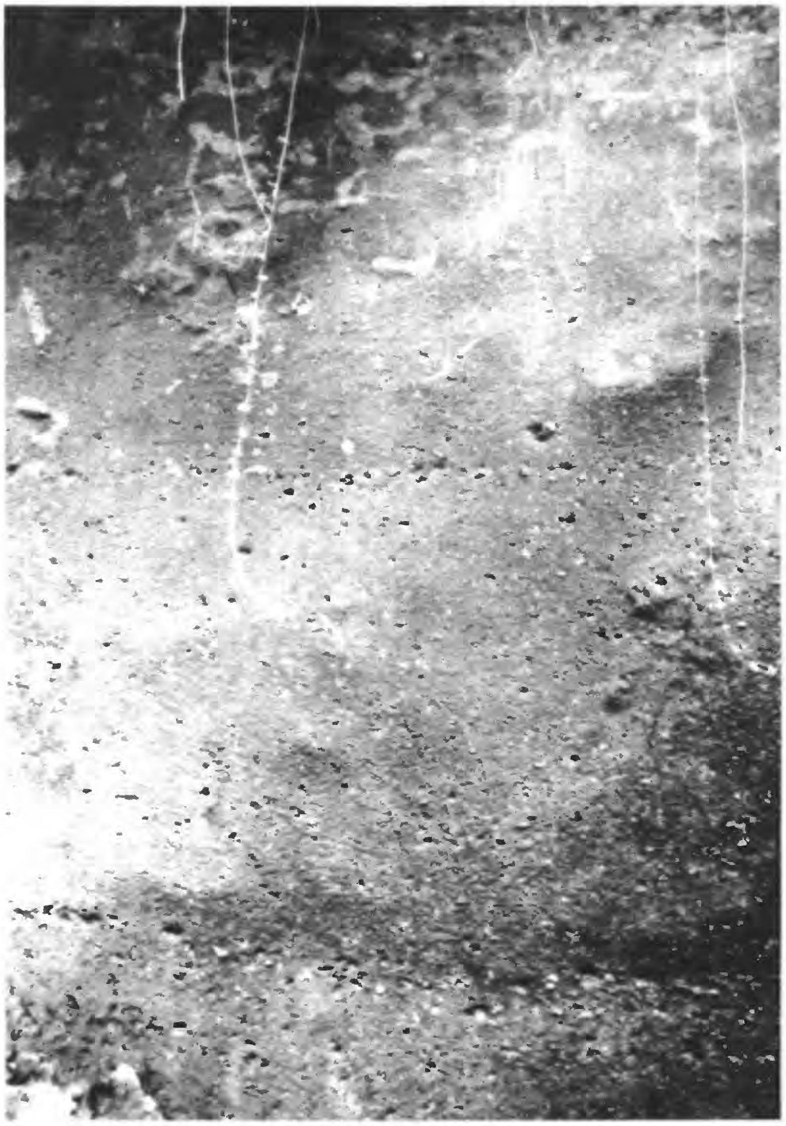

FIGURE 34.—A small ravine along the Pamunkey River, 0.63 mile (1.01 km) south-southeast of the mouth of Totopotomoy Creek, Hanover County, Va. (Locality 74). The upper surface of the Woodstock Member of the Nanjemoy Formation is intensely burrowed as deep as 8 feet (2.4 m). The Woodstock is overlain by the Piney Point Formation, and material from that unit fills the burrows.

Eastover Formation. Its lower contact is not exposed there, but it presumably overlies the Potapaco Member.

The Woodstock sea occupied a broad embayment reaching from at least the Patuxent River in Maryland to a short distance south of the James River in Virginia. The locus of the embayment was somewhat south of the Potomac River. Work by Enright (1969) indicated the presence of a probable lower Eocene equivalent to the Woodstock, the Squankum Member of the Shark River Formation, in New Jersey. No other equivalents of the Woodstock, in the subsurface or otherwise, have been detected along the Atlantic Coastal Plain. The only known possible Gulf Coast equivalent occurs at Hatchetigbee Bluff on the Tombigbee River, Ala. (Locality 79). There, near the top of the lower Eocene section, is a marine bed that unconformably overlies the lagoonal and deltaic facies of the Hatchetigbee Formation. This unit, which by definition is included in the Hatchetigbee, is overlain by the Tallahatta Formation and was numbered Bed 4 by Smith and Johnson (1887, p. 40). The unconformity between this and the underlying bed may mark the same break as that between the Woodstock and Potapaco.

The Woodstock contains a large, diverse molluscan

FIGURE 35.—Contact between the Woodstock Member of the Nanjemoy Formation and the Piney Point Formation along the Pamunkey River. *A*, The termination of Rte. 732, Hanover County, Va. (Locality 64). The lighter colored, more calcareous Piney Point lithology shows in sharp contrast to the darker, very glauconitic Woodstock Member. *B*, Approximately 200 yards upriver of Locality 64, where the Woodstock–Piney Point contact approaches water level (sea level).

fauna. Many of the taxa are new, and their stratigraphic significance is at present poorly understood. A number of species are listed by Clark and Martin (1901) as being present in the Woodstock, but the list is in serious need of updating. Species most often observed by me include the following (pl. 4):

- *Venericardia ascia* Rogers and Rogers, 1839 (figs. 8, 9)
- *Cubitostrea* sp. (figs. 2, 3, 4)
- *Pitar ovata* (Rogers, 1837)
- *Macrocallista subimpressa* (Conrad, 1848) (fig. 6)
- *Corbula aldrichi* Meyer, 1885 (fig. 7)
- *Lucina dartoni* Clark, 1895 (fig. 10)
- *Nuculana* sp. (fig. 5)
- *Glycymeris* sp. (fig. 1)
- *Turritella* sp. (figs. 12, 13)
- *Lunatia* sp. (fig. 11)
- *Cadulus* sp. (fig. 14)

Venericardia ascia Rogers and Rogers, 1839, resembles, but is not identical with, *V. hatcheplata* Gardner and Bowles, 1939, from the Hatchetigbee Formation (lower Eocene) of Alabama. *Pecten choctavensis* Aldrich, 1895, is present in both the Hatchetigbee and the Woodstock but is not common.

Best evidence, at this time, of the age and correlation of the Woodstock is found in the dinoflagellate and calcareous nannofossil assemblages. Calcareous nannofossils in the Putneys Mill core (Locality 86) indicate an approximate equivalence with nannofossil zone NP 12 (L.M. Bybell, oral commun., 1984). This zone was also reported in the Oak Grove core (Gibson and others, 1980) in the interval between 227.0 and 269.4 feet (69.2 and 82.1 m). L.M. Bybell (oral commun., 1984) now believes that only the 69.2-m interval in the Oak Grove core contains calcareous nannofossils indicative of NP 12. That sample lies just above a lithic break shown by Reinhardt and others (1980, p. 3) at 75 m. A sample taken at 75.6 m contains an NP 11 flora and is believed to be near the top of the Potapaco Member. Dinoflagellate data from the Woodstock Member also indicate an equivalence with NP 12 (L.E. Edwards, oral commun., 1984). Edwards says the Woodstock contains the oldest occurrence of *Kisselovia coleothrypta* (Williams & Downie) Lentin & Williams, which to many authors equates approximately with the base of NP 12.

Molluscan assemblages in the Woodstock Member indicate a gradual return to open-marine, shallow-shelf conditions. In the lower one-third of the unit, molluscan diversity is relatively low and the assemblage is dominated by small forms. Carbonized wood and nuts are especially abundant in the lower section. The Woodstock shows a gradual trend towards deeper water with greater distance from the paleoshoreline. Diversity and size of mollusks increase to the east, and the amount of carbonaceous material decreases. Nuts have been reported from the Woodstock by Ruffin (1850), Hollick (in Clark and Martin, 1901), and Mazer and Tiffney (1982). Although wood may be found at many horizons in the Paleocene-Eocene sequence, it is certainly most abundant in the Woodstock. The nuts, which are locally abundant in the Woodstock, are known only from that unit. These fruits are assigned to the genus *Wetherellia*; they are also found in the London Clay and Lower Bagshot Beds in England, both of which are considered to be lower Eocene (Mazer and Tiffney, 1982).

PINEY POINT FORMATION

The Piney Point, where fresh, is an olive-gray (5 Y 4/1), clayey, poorly sorted, very glauconitic, highly fossiliferous sand. It was first described from cuttings taken in a well at Piney Point, St. Marys County, Md. (Locality 80), by Otton (1955). From the first usage, the age and correlation of the Piney Point have caused confusion. Beds on the Pamunkey River herein placed in the Piney Point do, by their inclusion in the original definition, belong in the Pamunkey Formation of Darton (1891). Clark and Martin (1901) elevated the Pamunkey to group rank and proposed two subdivisions: the Aquia Formation and the Nanjemoy Formation. The Nanjemoy Formation, or its upper member, the Woodstock, as originally described by Clark and Martin (1901), did not include the younger beds (Piney Point) seen along the Pamunkey River. In a later work, Clark and Miller (1912) apparently lumped younger beds observed along the Pamunkey River, and now considered to be Piney Point, in the Nanjemoy. Sections described on the James River by Clark and Miller (1912) also include the younger beds with the Nanjemoy. It is clear, however, that the original definition of the Nanjemoy included no beds equivalent to the Piney Point; Clark and Miller's (1912) inclusion of those beds in the Nanjemoy was not an attempt to expand the definition of that stratigraphic concept but, rather, a failure to differentiate the beds. Further, the younger unit may be seen to overlie the Nanjemoy unconformably, the contact being marked by an abrupt lithic, faunal, and floral change indicative of a lengthy hiatus. The lithic characteristics of the Piney Point make it an easily distinguishable unit that can be, and has been, extensively traced and mapped, both on the surface and in the subsurface. I prefer, therefore, to consider the Piney Point a formation within the Pamunkey Group.

One complication of the concept of the Piney Point has been the use of that term for an unnamed upper Oligocene unit (possibly the Old Church Formation defined in this report) that was traced in the subsurface of Maryland, Delaware, and New Jersey (Olsson and others, 1980). Brown and others (1972) listed a number of species of ostracodes and foraminifers from the type well of the Piney Point that clearly show the age of the unit to be middle Eocene (Claibornian). In their figure 2, Olsson and others (1980) indicated that the unit that they called "Piney Point" was not present in their St MEf 56 well, even though they are only a short distance from the type well of the Piney Point where Otton (1955) reported 50 feet (15.2 m) of Piney Point. It is evident that Olsson and others (1980), used the term "Piney Point" for a younger bed, which they showed to be late Oligocene in age and which overlies the Piney Point Formation as conceived by Otton (1955).

Otton (1955) adequately described the Piney Point as consisting of "light gray to yellowish glauconitic sand and interbedded 'rock' or shell layers containing a foraminiferal assemblage distinctive from that of the overlying and underlying deposits." The shell layers that form "rock" are principally *Cubitostrea sellaeformis* (Conrad, 1832). When present in large numbers, this oyster becomes cemented into very hard, thick beds, probably owing to its calcitic shell structure. Like many of the lower Tertiary units, the Piney Point becomes progressively more glauconitic, both in a seaward direction and higher in the section. Generally, the Piney Point is a much lighter color than the underlying Woodstock Member, partly due to its much higher shell content. Where weathered, the bed is yellowish orange (10 YR 7/6) in color because of glauconite decomposition. Where fresh, the Piney Point has a decided "salt and pepper" look to it because of the mixture of dark glauconite grains and small, light shell fragments. The unit is richly fossiliferous and contains a large (around 150 species), well-preserved molluscan assemblage, which is largely unstudied. Most conspicuous is the large oyster *Cubitostrea sellaeformis* (Conrad, 1832), which in some cases makes up a large proportion of the rock.

The Piney Point may be seen along the James and Pamunkey Rivers to overlie the Woodstock Member of the Nanjemoy Formation unconformably (see figs. 36, 37). Best exposures of the contact between the two units occur almost continuously along the Pamunkey from 1.75 miles (2.82 km) above the Rte. 360 bridge over the Pamunkey River (Locality 74, fig. 34) to 1.0 mile (1.6 km) below the ruins of the Newcastle bridge (Locality 64, fig. 35). There the contact is very sharp and is marked by an abrupt lithic change from the very fine, silty, micaceous, dark sands of the Woodstock to the much lighter colored, poorly sorted, clayey, coarse sands of the basal Piney Point. Burrowing of the Woodstock surface is intense; individual burrows filled with Piney Point sediment penetrate as much as 8.0 feet (2.4 m) downward (see fig. 34). Reworking of Woodstock molluscan fossils into the base of the Piney Point is common; double valves of *Venericardia ascia* Rogers and Rogers, 1839, are reworked upward as much as 1.0 foot (0.3 m) into the Piney Point. As previously mentioned in the description of the Woodstock, a slightly glauconitic, pebbly, very clean sand crops out both on the Mattaponi River, below Reedy Mill (Locality 73, fig. 38), and on the Rappahannock River, at Greenlaw Wharf (Locality 54, fig. 33) and at Wilmont Wharf (Locality 70, fig. 39), at the same interval as the Piney Point. This unit occurs at Wilmont Wharf only at the upriver end of the bluffs (upriver of the Wilmont fault of Ward and Blackwelder, 1980). There it may be seen below the steeply dipping beds of the Calvert Formation. Downstream, at a small waterfall in a ravine (Locality 81) where the Calvert beds resume their normal seaward dip, the unit in question is missing and the basal Calvert directly overlies the Woodstock Member. The patchy occurrence of the unknown bed in this area may be due to intermittent movement of the Wilmont fault (see Ward and Blackwelder, 1980).

It has not been paleontologically proven that this sand is an equivalent of the more open marine Piney Point, but the unit rests on known Woodstock and is overlain by the Calvert Formation. It appears to represent a barrier and back-barrier, very near shore sand and clay sequence, which may be a marginal-marine facies of either the Woodstock or the Piney Point. The Piney Point along the Pamunkey River is overlain, in places, by an unnamed upper Oligocene and lower Miocene unit, herein termed the Old Church Formation, and in other places by the Calvert Formation, where beds of the Old Church were not deposited or have been beveled off. The spotty exposure pattern of the Old Church suggests some tectonic control over its occurrence in addition to removal due to erosion. In the type well at Piney Point in St. Marys County, Md. (Locality 80), the Piney Point Formation is underlain by the Nanjemoy and overlain by the Calvert. At Oak Grove in Westmoreland County, Va., somewhat farther inshore and updip, no middle Eocene beds were reported (Reinhardt and others, 1980; Gibson and others, 1980). A core taken at the Baltimore Gas and Electric atomic power plant site in Calvert County, Md. (Locality 82), contained typical Piney Point lithology and large fragments of *Cubitostrea sellaeformis* (Conrad, 1832) at the 330-foot (100.6-m) interval (approximately 210 feet (64 m) below sea level). There the Calvert directly overlies the Piney Point. Along the Patuxent River, the Calvert directly overlies the Woodstock in most places, but at a few localities (Locality 65, 66) a thin remnant

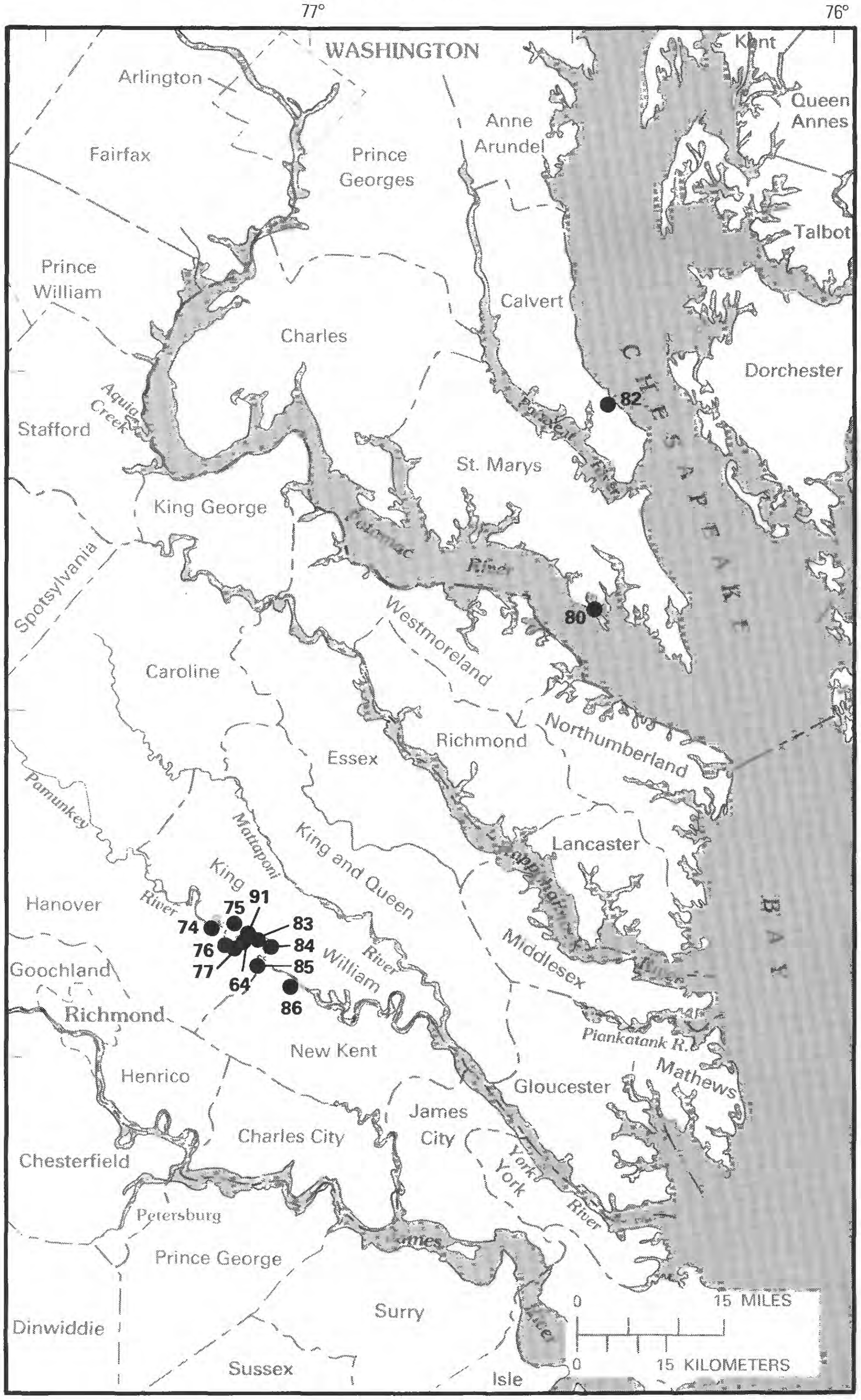

FIGURE 36.—Map showing localities where the Piney Point Formation is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

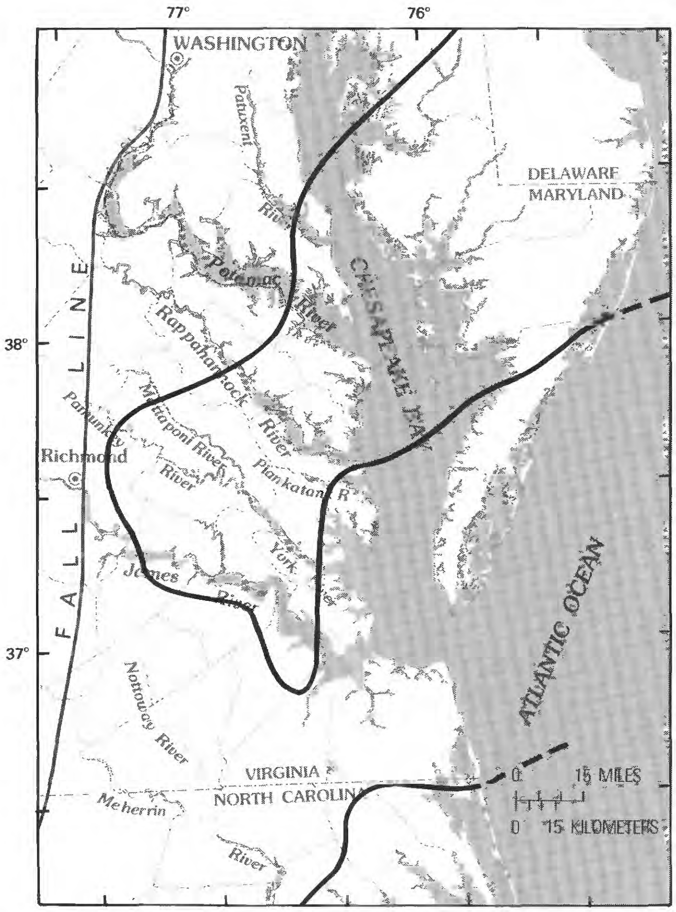

FIGURE 37.—Map showing areal extent of the depositional basin within the Salisbury Embayment in which sediments of the Piney Point Formation were deposited during middle Eocene time. Dashed lines indicate area where boundary data are lacking. Map is based on outcrop and core data used in this report as well as on subsurface data from Brown and others (1972).

of the upper Oligocene and lower Miocene bed (the Old Church Formation(?)) is present. No outcrop of the Piney Point, however, is known from this area.

On the Pamunkey River, where the Old Church Formation overlies the Piney Point, the contact between the two units is sharp and is marked by a basal lag of shell, bone, and pebbles. At Horseshoe on the Pamunkey River, the type section of the Old Church Formation (Locality 83, fig. 40), burrows filled with Calvert sediment penetrate the whole thickness of the Old Church (3 feet (0.9 m)) and then spread horizontally along the Piney Point–Old Church contact. This lateral spreading was presumably due to the lag accumulation of oyster shells concentrated at the top of the Piney Point, which made further downward penetration difficult. Because the Piney Point was named from cuttings from a well in St. Marys County, Md. (Locality 80) and because the unit is so well exposed along the Pamunkey River in Virginia, it is here proposed that the outcrops at Horseshoe (Locality 83) and 0.8 km upstream from Horseshoe (Locality 91) be considered the hypostratotype or reference sections.

The Piney Point on the Pamunkey includes (in ascending order) (A) basal, clayey, glauconitic sand (approximately 8.0 feet (2.4 m)), with a conspicuous line of concretions near the top of the bed, (B) a clayey, glauconitic sand (approximately 15.0 feet (4.6 m)), with an indurated oyster bed (approximately 5.0 feet (1.5 m)) at the top of the bed, and (C) a soft, nonfossiliferous, very burrowed, medium to coarse, glauconitic sand. This sequence is a composite of many small exposures from above the Rte. 360 bridge to below Retreat (Locality 85). The indurated oyster bed at the top of Bed B clearly is lithologically similar to the beds seen upstream; it is present just below Piping Tree Ferry (Locality 84, fig. 41) where it can be seen only at low tide, dipping sharply downstream. There it is directly overlain by the Calvert, the Oligocene having been removed by erosion. Ascending, the next unit (C), the coarse glauconitic sand, is presumed to overlie the oyster beds and seems to be lithologically distinct from other beds of the Piney Point. It crops out only on the right bank of the Pamunkey just below Retreat at the mouth of Whiting Swamp (Locality 85, fig. 42). This bed is represented in a short core taken at Putney Mill, on the right bank of the Pamunkey River, in New Kent County (Locality 86). Preliminary dinoflagellate data from the core indicate a younger age for Bed C than for most of the Piney Point and a possible equivalence with the Gosport Sand of Alabama (late Claibornian) (L.E. Edwards, oral commun., 1984). This age has not been confirmed with samples from the single outcrop at Retreat (Locality 85, fig. 42). In spite of its distinct lithology, I prefer at this time to include this bed in the Piney Point.

The Piney Point outcrop and subsurface distribution patterns indicate a broad, shallow embayment, open eastwardly and northeastwardly to the paleo-Atlantic. To the south, the Norfolk Arch was a positive area and acted as a barrier affecting sedimentary regimes as well as faunal and floral assemblages. While sediment accumulations in the Carolinas and southward consisted principally of carbonates, north of the Norfolk Arch principally glauconite and quartz sands were deposited. Molluscan assemblages reflect a mild to warm-temperate marine environment in the Piney Point embayment, while tropical to subtropical seas dominated to the south.

The Piney Point may be confidently correlated with beds as far south as Texas. It is the equivalent of the Castle Hayne Formation (New Hanover and Comfort Members) in North Carolina, the Santee Limestone

FIGURE 38.—Mattaponi River, 1.3 miles (2.1 km) above the mouth of Maracossic Creek, King William County, Va. (Locality 73). Beds here may represent a marginal-marine facies of either the Woodstock Member of the Nanjemoy Formation or the Piney Point Formation.

(Moultrie Member) and McBean Formation in South Carolina, the Santee Limestone and McBean and Lisbon Formations in Georgia, the Lisbon Formation in Alabama, and the Cook Mountain Formation in Mississippi, Louisiana, and Texas. This correlation may be demonstrated with the molluscan assemblages even though they are incompletely known. The most characteristic taxon, *Cubitostrea sellaeformis* (Conrad, 1832), is common in the middle Eocene (Claibornian) interval over this wide geographic area. This correlation and age assignment are in agreement with dinoflagellate data (L.E. Edwards, oral commun., 1984), ostracode data (J.E. Hazel, oral commun., 1984), planktic foraminifer data (P.F. Huddlestun, oral commun., 1984), and calcareous nannoplankton data (J.A. DiMarzio, oral commun., 1984).

Molluscan assemblages indicate a shallow-shelf, open-marine environment. Diversity among the mollusks is moderate; small bivalves are the most common taxa. Among the more common are the following (pl. 5):

- *Cubitostrea sellaeformis* (Conrad, 1832) (figs. 4–6, 8, 9)
- *Anomia lisbonensis* (Aldrich, 1886) (fig. 10)
- *Plicatula filamentosa* Conrad, 1833 (fig. 7)
- "*Pecten*" sp. (fig. 1)
- "*Pecten*" sp. (fig. 2)
- "*Pecten*" sp. (fig. 3)
- *Glycymeris lisbonensis* Harris, 1919 (fig. 13)
- *Leda semen* Lea, 1833 (fig. 12)
- *Leda coelatella* Van Winkle, 1919 (fig. 11)
- *Venericardia rotunda* Lea, 1833 (fig. 16)
- *Macrocallista perovata* (Conrad, 1833)
- *Anapteris regalis* Van Winkle, 1919 (fig. 14, 15)
- *Caestocorbula fossata* (Meyer and Aldrich, 1886) (fig. 21)
- *Corbula* sp. (fig. 20)
- *Turritella nasuta* Gabb, 1860 (fig. 17)
- *Dentalium* sp. (fig. 18)
- *Dentalium* sp. (fig. 19)

Calcareous nannoplankton from the Piney Point examined by L.M. Bybell (oral commun., 1984) and J.A. DiMarzio (oral commun., 1984) indicate a placement of that unit within NP 16. Dinoflagellate data generated by L.E. Edwards (oral commun., 1984) also indicate an equivalency with NP 16 except for the possible presence of an NP 17 flora in Bed C of the Piney Point. That bed is the possible equivalent of the Gosport Sand in Alabama. Dinoflagellate diversity and composition also reflect a shallow-shelf, near-shore environment, with a fair amount of nutrients available.

FIGURE 39.—Rappahannock River, 0.5 mile (0.8 km) below Wilmont Wharf, King George County, Va. (Locality 70). Slightly glauconitic, pebbly, quartz sand (A) overlain by diatomaceous silty sands of the Calvert Formation (B). The arrow marks the burrowed contact.

CHESAPEAKE GROUP

The term "Chesapeake Formation" was introduced by Darton (1891, p. 433) for a series of beds in southeastern Maryland and Virginia that consist of sands, clays, marls, diatomaceous clays, and shell fragments. Dall and Harris (1892) elevated the unit to group status and included all beds at the same horizon (or age) from Delaware to Florida. Shattuck (1902) subdivided the Chesapeake Group in Maryland into (in ascending order) the Calvert Formation, the Choptank Formation, and the St. Marys Formation. Shattuck (1904) greatly expanded this work and described the units, and their contained molluscan fauna, in detail. Clark and Miller (1906) expanded the definition of the Chesapeake Group by including the Yorktown Formation in Virginia. Clark and Miller (1912) included beds along the Chowan River in Bertie County, N.C., in the Yorktown Formation. Mansfield (1944) also included the Chowan River beds in the Yorktown. Blackwelder (1981) named those beds the Chowan River Formation, split the unit into two members, the Edenhouse Member (lower) and the Colerain Beach Member (upper), and included the new formation in the Chesapeake Group.

I recommend that the Old Church Formation be included in the Chesapeake Group. It is a calcareous, shelly sand that contains only small amounts of glauconite and is therefore easily separated from the underlying, very glauconitic beds of the Pamunkey Group. It is unclear whether Darton (1891) or Clark and Miller (1912) actually observed the bed herein termed the Old Church. Therefore, where they would have placed it is conjectural. If the correlation between the Old Church, at the type section on the Pamunkey River, with "zone" 1 of Shattuck (1904) on the Patuxent River, Calvert and Prince Georges Counties, Md., is correct, then beds equivalent to the Old Church have already been included in the Chesapeake Group.

The following units constitute the Chesapeake Group:

Chowan River Formation	
Colerain Beach Member	upper Pliocene
Edenhouse Member	upper Pliocene
Yorktown Formation	
Moore House Member	upper Pliocene
Morgarts Beach Member	upper Pliocene
Rushmere Member	upper Pliocene
Sunken Meadow Member	lower Pliocene
Eastover Formation	
Cobham Bay Member	upper Miocene
Claremont Manor Member	upper Miocene

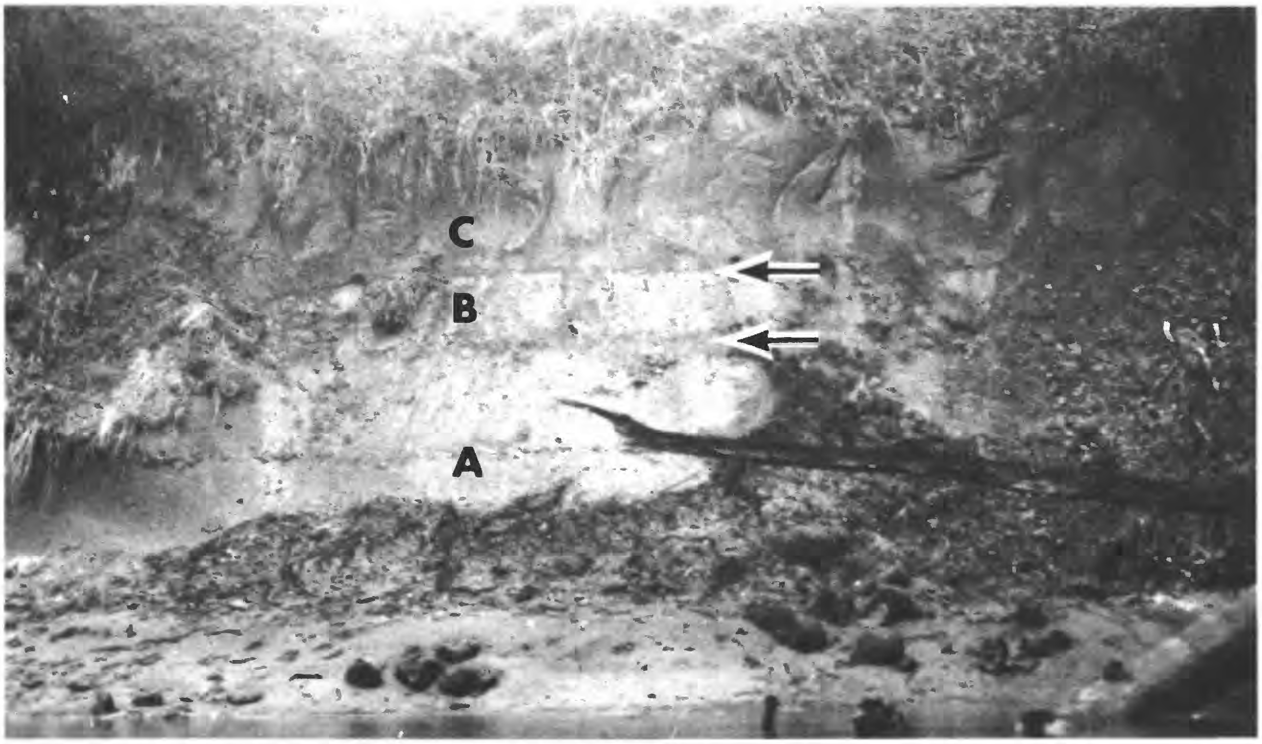

FIGURE 40*A*.—Pamunkey River at Horseshoe, Hanover County, Va. (Locality 83). Type locality (principal reference section) of the Old Church Formation. Hypostratotype or reference section for the Piney Point Formation. The Piney Point Formation (A) is overlain by the Old Church Formation (B), which is in turn overlain by the Calvert Formation (C). Arrows mark the contacts. The thin bed of mollusks in the Piney Point consists principally of *Cubitostrea sellaeformis*. The boulder-sized nodules near the base of the bluff originate in the Old Church Formation.

St. Marys Formation	
Windmill Point beds*	upper middle Miocene
Little Cove Point beds*	upper middle Miocene
Conoy Member	upper middle Miocene
Choptank Formation	
Boston Cliffs Member	middle middle Miocene
St. Leonard Member	middle middle Miocene
Drumcliff Member	middle middle Miocene
Calvert Formation	
Calvert Beach Member	lower middle Miocene
Plum Point Marl Member	lower middle Miocene
Fairhaven Member	lower and lower middle Miocene
Old Church Formation	upper Oligocene and lower Miocene

*Informal name used by Blackwelder and Ward (1976).

OLD CHURCH FORMATION

The presence of possible Oligocene sediments in Virginia was first pointed out by Ward and others (1978, p. 13), who correlated them with Chickasawhayan beds in North Carolina assigned to the River Bend Formation. The upper Oligocene or lower Miocene beds in the outcrop area on the Pamunkey River are herein termed the Old Church Formation. The unit takes its name from the nearby village of Old Church, Hanover County, Va. The unit consists of grayish-olive (10 Y 4/2), clayey, quartz sands containing small amounts of reworked glauconite. $CaCO_3$ content is high owing to shell fragments as well as to the large number of foraminifers and ostracodes, both primary and reworked, within the unit. Aragonitic molluscan fossils are commonly leached, leaving molds and casts. Calcitic mollusks are common and consist of small pectens and oysters. The formation contains irregular indurated masses that occur along the river as large, boulder-sized concretions. The Old Church unconformably overlies the Piney Point Formation and is unconformably overlain by the Calvert Formation. In Virginia the Old Church is known in natural surface exposures only from the Pamunkey River, where it crops out from above Horseshoe (Locality 83, fig. 40) to below the mouth of Matadequin Creek (Locality 87; see fig. 43 for locality map). The exposure on the right bank of the Pamunkey at Horseshoe is

FIGURE 40*B*.—Pamunkey River at Horseshoe, Hanover County, Va. (Locality 83). Type locality (principal reference section) of the Old Church Formation. Blake W. Blackwelder (Tenneco Co., Houston, Tex.) has his pick on the contact between the Old Church Formation and the overlying Calvert Formation.

designated the type section of the Old Church (Locality 83). The unit is 3 feet thick at the type section, but its thickness varies from locality to locality because of beveling by the sea during the Calvert transgression.

A bed that occurs on the Patuxent River in Maryland (Localities 65, 66) and that lies between the Woodstock Member of the Nanjemoy Formation and "zone" 2 of the Calvert Formation may be equivalent to, and belong in, the Old Church Formation. It was included by Shattuck (1904) in the original definition of the Calvert Formation and called "zone" 1. Along the Patuxent River in Maryland, it unconformably overlies the Woodstock Member and unconformably underlies "zone" 2 of the Calvert Formation at the abandoned glauconite mine ("Kaylorite" pit) (Locality 65, fig. 44) and below White Landing on the right bank (Locality 66, fig. 45). If this bed proves to be the equivalent of the Old Church, it is here recommended that the original concept of the Calvert Formation be amended and restricted to include only "zones" 2–15 of Shattuck. The only other known exposure of the Old Church Formation was at the Warren Brothers sand and gravel borrow pits on the Chickahominy River floodplain below Bottoms Bridge (Locality 88). There the Old Church immediately underlies Pleistocene(?) gravels that were mined from 1975 to 1977. Stripping caused the Old Church to be exposed briefly in the bottom of the pits, which, when depleted, were allowed to flood. The mine ceased operations in 1978, and no exposure of the Old Church remains. The upper and lower contacts of the unit were obscured at the pit, but a nearby gulley cutting down to the floodplain through the Chickahominy River escarpment exposed a thick section including the Claremont Manor and Cobham Bay Members of the Eastover Formation as well as the Rushmere Member of the Yorktown Formation, all presumably overlying the Old Church.

It seems clear, on the basis of stratigraphic position and age, that the unit traced in the subsurface of Maryland, Delaware, and New Jersey by Olsson and others (1980) is equivalent to the Old Church Formation, even though they termed it the "Piney Point." Except for the glauconite percentages, the description by Olsson and others (1980) fits well with the Old Church

FIGURE 41.—Pamunkey River at Piping Tree Ferry, King William County, Va. (Locality 84). Thin-bedded, seaward-dipping, indurated, glauconitic sands of the Piney Point Formation are exposed only at low tide. The beds are crowded with oysters (*Cubitostrea sellaeformis*), from which the cement is probably derived.

beds that crop out on the Pamunkey River. Two reasons may account for this difference. Their study indicated that much of the glauconite was reworked from the underlying, more glauconitic Eocene beds. A further explanation may be in the lower percentages of glauconite with increasing proximity to paleoshorelines, as shown throughout the Paleocene and Eocene beds in the Salisbury Embayment. The Brightseat, Aquia, Nanjemoy, and Piney Point Formations all increase in glauconite content in a seaward direction.

Further evidence for the presence of a bed equivalent to the outcropping Old Church is obtained from a study on fossils found in deep wells on the Atlantic Coastal Plain by H.G. Richards (1947). In that work, Richards figured and described a small pecten, "*Pecten*" *seabeensis* Richards, 1947, at a depth of 380 feet (115.8 m) at Camp Peary, York County, Va. The type specimen has been examined and appears identical with specimens from the type section of the Old Church (Locality 83) on the Pamunkey River as well as with specimens from the Warren Brothers pit on the Chickahominy River (Locality 88).

At another locality, Gravatts Millpond on Mill Pond Creek in King William County, Va. (Locality 89), beds probably equivalent to the Old Church are exposed. There, large indurated blocks of a phosphatic, conglomeratic sandstone overlie the fine, micaceous, silty sand of the Woodstock Member and are overlain by the clayey, olive-brown (5 Y 4/4) sands of the basal Calvert Formation. These blocks and some of the phosphate pebbles, cobbles, worn bone, and teeth are believed to be residuum from the erosion of the Old Church. Among the bone fragments found on this contact was a periotic from an odontocete whale that was certainly pre-Calvert and was probably early Miocene or very late Oligocene in age.

The Old Church Formation thins a short distance upstream from Horseshoe (Locality 83) and is less than a foot thick 0.30 mile (0.48 km) above Horseshoe (Locality 90).

The basinal outline of the Old Church is, at present, only partially known (fig. 46). If the correlation of the type Old Church with beds on the Patuxent River in Maryland, beds in the subsurface at Camp Peary, and beds mapped as "Piney Point" by Olsson and others (1980) is correct, then the basin configuration covers

FIGURE 42.—Pamunkey River below Retreat, Hanover County, Va. (Locality 85). The very burrowed, medium to coarse glauconitic sand of unit C of the Piney Point Formation crops out to a height of 9.0 feet (2.7 m). Burrows from an overlying, very weathered, mold and cast, calcareous sandstone may be seen as deep as the arrow indicates. The degree of weathering of this overlying unit has prevented the determination of its exact age.

parts of New Jersey, Delaware, Maryland, and Virginia. Apparently the Norfolk Arch was, again, a high area separating the Old Church embayment from its counterpart in North Carolina. This barrier, or a seaward connection somewhat farther north, probably served to divert the tropical currents that dominated in North Carolina at that time. The result is a temperate, low-diversity, molluscan assemblage strikingly different from that south of the Norfolk Arch but sharing a few of the same taxa.

Because of basic, though minimal, differences of opinion as to the age of Old Church Formation, the precise correlation of that unit to equivalent beds to the south is not yet clear. The consensus of paleontologic data, including mollusks, ostracodes, foraminifers, pollen, and dinoflagellates, brackets the unit in the interval embracing the late Oligocene and early Miocene. That period was a time of widespread climatic change and abrupt, short-term, small-scale, marine pulses. To the south in the Albemarle Embayment (fig. 2) in central and northeast North Carolina, this resulted in the deposition of the River Bend Formation (late Oligocene–Chickasawhayan) and the Belgrade Formation (late Oligocene–early Miocene–Tampan).

Molluscan assemblages of the Old Church Formation indicate a close affinity with both the upper River Bend and Belgrade Formations, though they are less diverse than assemblages in those units. The following taxa are commonly found in the Old Church (pl. 6):

Mercenaria gardnerae Kellum, 1926 (fig. 8)
Anomia ruffini Conrad, 1843 (fig. 4)
"*Pecten*" *seabeensis* Richards, 1947 (fig. 6)
"*Pecten*" sp. (fig. 5)
Lucina sp. (fig. 9, 10)
Plicatula sp. (fig. 14, 15)
Epitonium sp.
Panopea sp. (fig. 13)
Cyclocardia sp. (fig. 16)
Astarte sp.
Pycnodonte sp. (fig. 1, 2, 3)
Isognomon sp. (fig. 11)
"*Cardium*" sp.
Bicorbula idonea (Conrad, 1833) (fig. 7)
Macrocallista sp.
Diadora sp.
Ecphora sp. (fig. 12)
Trophon sp.
Calyptraea sp.

Nonmolluscan macrofossils include solitary corals and two barnacles—a hesperabalanid and a balanid. Aragonitic mollusks occur only as molds and were identified with the aid of latex casts. Calcitic mollusks are abundant and well preserved. *Mercenaria gardnerae* Kellum, 1926, made its first appearance in the upper part of the River Bend Formation but is also abundant in the Belgrade. It closely resembles *Venus marionana* Mansfield, 1937, from the Tampa Formation of Florida and is the first known occurrence of the genus *Mercenaria*.

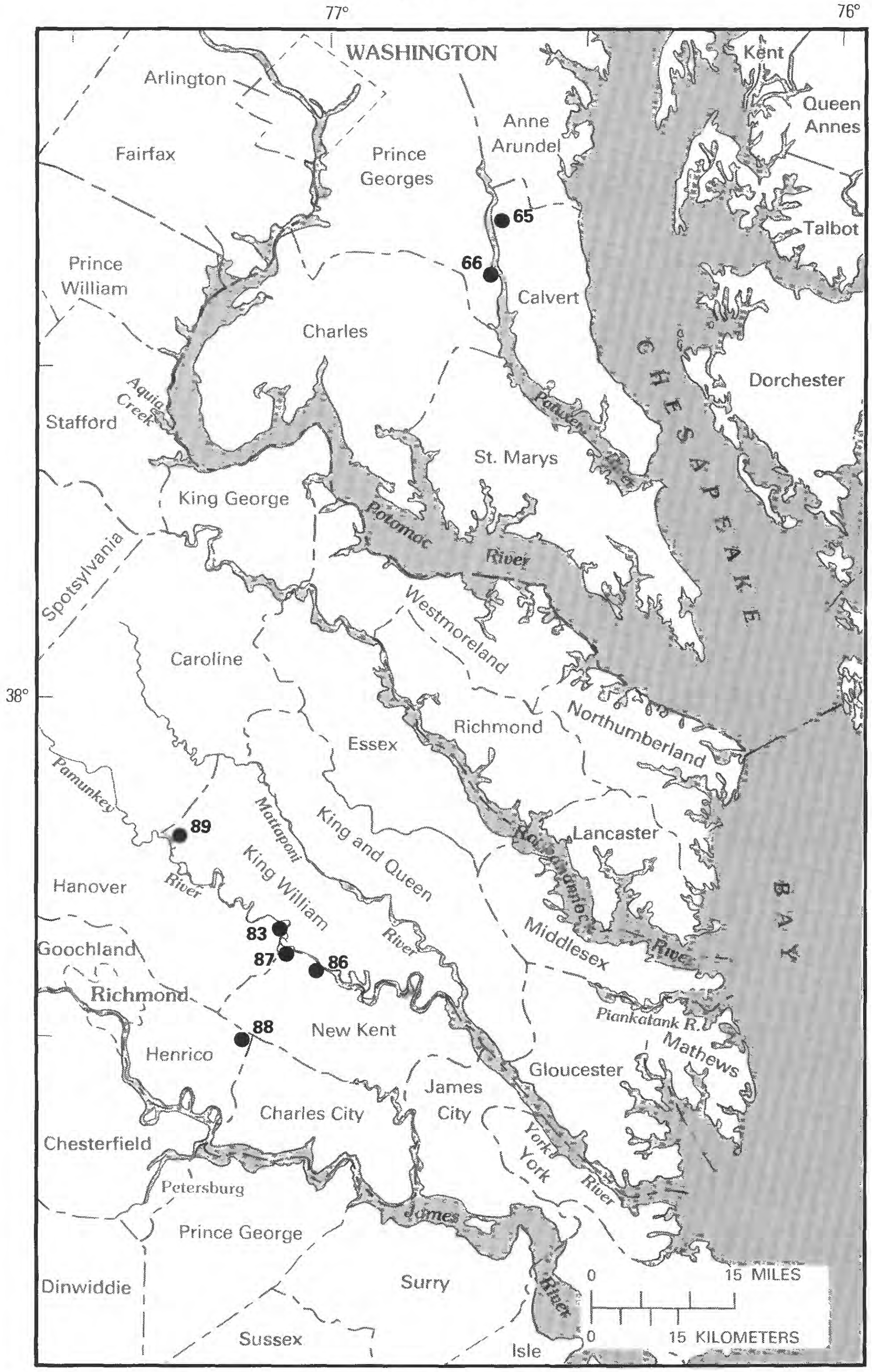

FIGURE 43.—Map showing localities where the Old Church Formation is exposed or found in cores used in this study. Numbers refer to localities mentioned in the text.

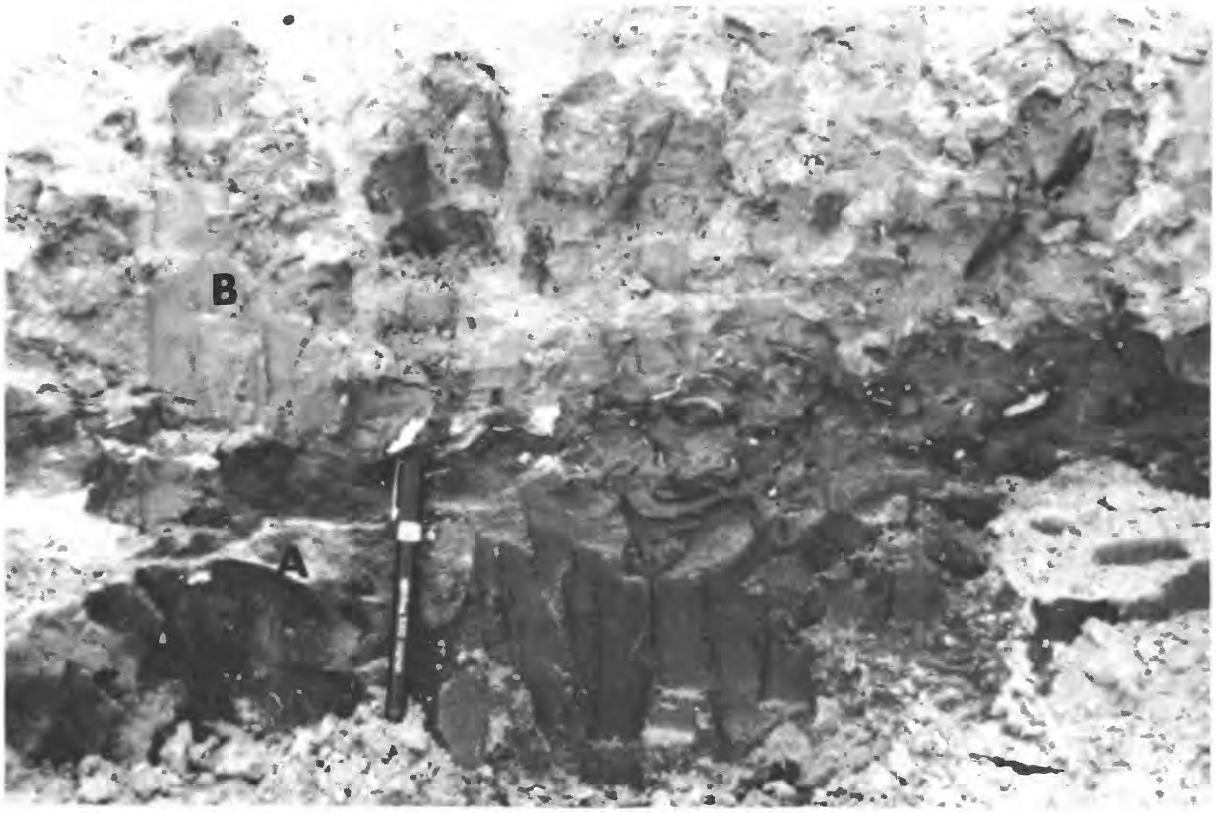

FIGURE 44.—Patuxent River at the "Kaylorite" pit at the termination of Landing Road, Calvert County, Md. (Locality 65). The contact of the Woodstock Member of the Nanjemoy Formation (A) with the Old Church Formation(?) (B) occurs at the top of the pen. Burrows on the upper surface of the Old Church(?) (zone 1 of Shattuck, 1904) are filled with white sand from the overlying basal sands of the Fairhaven Member of the Calvert Formation (zone 2 of Shattuck, 1904).

Anomia ruffini Conrad, 1843 (=*Anomia mcgeei* Clark, 1895), was collected on Edmund Ruffin's property along the Pamunkey River and is the probable senior synonym of *Anomia taylorensis* Mansfield, 1940, from the Chickasawhay of Alabama and Mississippi and *Anomia onslowensis* Richards, 1943, from the River Bend and Belgrade Formations. "*Pecten*" *seabeensis* Richards, 1947, is known only from the Old Church, but "*Pecten*" sp. is also present in the upper beds of the Ashley Formation of South Carolina. The *Lucina* sp. that is so common in the Old Church is also present in large numbers in the Ashley Formation in South Carolina and is probably the taxon reported from "zone" 1 of the Calvert Formation by Shattuck (1904) to be "*Phacoides contractus*." The species may, in fact, be more closely related to *Phacoides hernandoensis* Mansfield, 1937, from the Suwannee Limestone of Florida. The *Pycnodonte* sp. is similar to an oyster from the lower Miocene of Florida that Dall named *Ostrea podagrina* Dall, 1896. That taxon, or one very similar, is common in the Ashley in South Carolina, the River Bend in North Carolina, and the Old Church in Virginia. The presence of the genus *Isognomon* is revealed only by exterior molds (xenomorphism) of that taxon on the ventral valves of a few specimens of *Pycnodonte*. *Isognomon* had been absent along the Atlantic coast of North America since the Late Cretaceous. The genus is present, but not common, in the Haywood Landing Member of the Belgrade Formation. Both *Bicorbula* and *Macrocallista* are known from the Belgrade Formation. The *Ecphora* sp. is known also from the Haywood Landing in North Carolina. Molluscan evidence, therefore, indicates a correlation with the Belgrade Formation in North Carolina and brackets the age of the Old Church as late Oligocene or early Miocene. Further work on the European type sections is necessary before a more definite age determination is possible.

This same conclusion is in agreement with results from workers on the various microfossil groups. Ostracode data indicates a late Oligocene age assignment and equivalency with the Ashley Formation of the Cooper Group (J.E. Hazel, oral commun., 1984). Reworking is

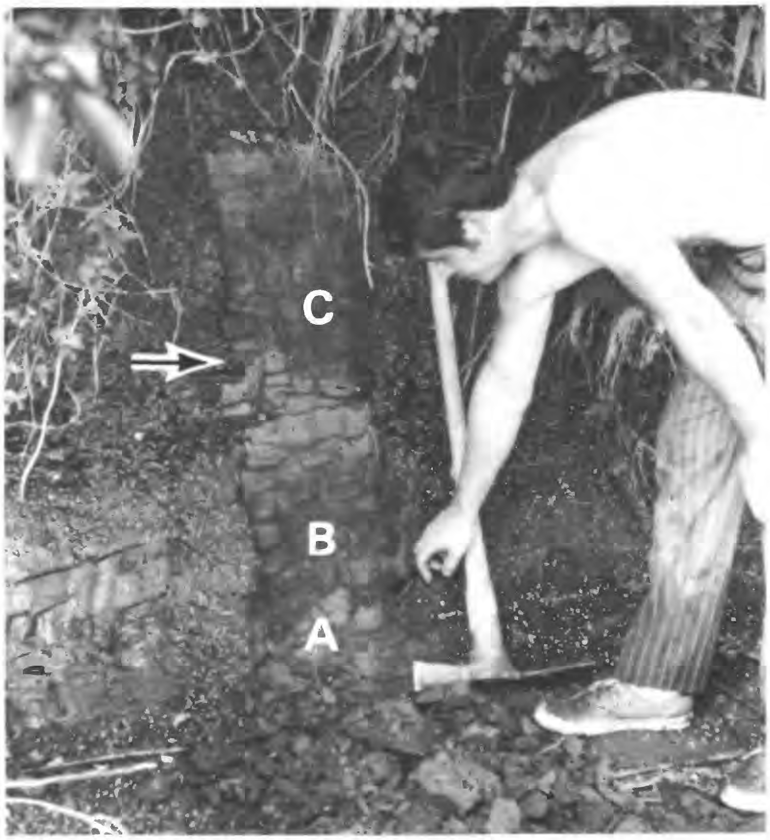

FIGURE 45.—Patuxent River at White Landing, Prince Georges County, Md. (Locality 66). B.W. Blackwelder (Tenneco Co., Houston, Tex.) is pointing at the contact between the Woodstock Member of the Nanjemoy Formation (A) and the Old Church Formation(?) (B). The Old Church(?) (zone 1 of Shattuck, 1904) is overlain by the basal sands of the Fairhaven Member of the Calvert Formation (C) (zone 2 of Shattuck, 1904). An arrow marks the contact between the Old Church(?) and the Fairhaven.

a problem with microfossil evaluation, as demonstrated by R.Z. Poore (written commun., 1984) for planktic foraminifers. In a sample from the type locality (Locality 83) of the Old Church, the following planktics were identified by R.Z. Poore: *Globigerina praebulloides* Blow, *G. ciperoensis* Boli, *G. juvenilis* Boli, and *Morozovella aequa* (Cushman and Renz). The *M. aequa* (Cushman and Renz) was reworked from the Paleocene (Aquia Formation) or lower Eocene (Nanjemoy Formation), but the other taxa indicate a late Oligocene or early Miocene age. A sample from the Old Church Formation at the Warren Brothers pit on the Chickahominy (Locality 89) included the following planktics: *Globigerina praebulloides* Blow, *G. ciperoensis* Boli, *G. angustiumbilicata* Boli, and *G.* sp. This assemblage also brackets the unit within the late Oligocene and early Miocene. Pollen samples from the type section at Horseshoe (Locality 83) examined by N.O. Frederiksen (written commun., 1984) contained the following taxa:

Quercus sp.
Carya sp.
Myrica sp.
Liquidambar sp.
Boehlensispollis hohlii Krutzsch, 1962
Tetracolporopollenites lesquereuxianus (Traverse, 1955) Frederiksen, 1980
Pinus sp.
Momipites spackmanianus (Traverse, 1955) Nichols, 1973
Momipites annulatus Frederiksen and Christopher, 1978
Milfordia sp. indet.
Ulmipollenites undulosus Wolff, 1934
Ulmipollenites krempii (Anderson, 1960) Frederiksen, 1979
Tilia sp.

Frederiksen concluded that the assemblage was more suggestive of late Oligocene than early Miocene but that the evidence was somewhat inconclusive.

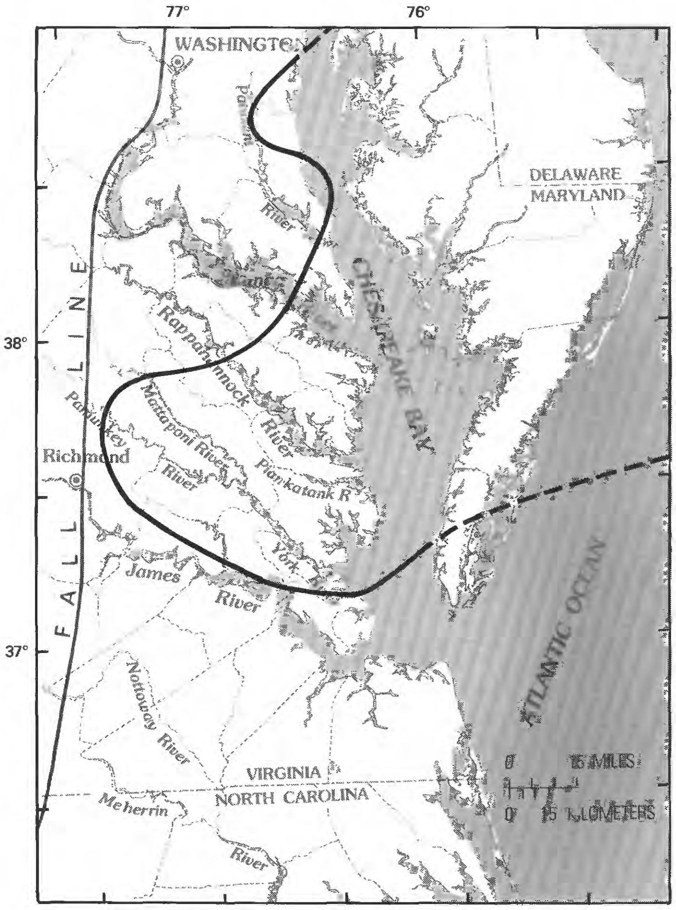

FIGURE 46.—Map showing areal extent of the depositional basin within the Salisbury Embayment in which sediments of the Old Church Formation were deposited during the latest Oligocene or earliest Miocene. Dashed lines indicate area where boundary data are lacking. Map is based on outcrop and core data used in this report as well as on subsurface data from Brown and others (1972).

SUMMARY OF LOWER TERTIARY STRATIGRAPHY AND ONLAP-OFFLAP RECORD

The Salisbury Embayment and the entire Atlantic Coastal Plain have had a complex history. In contrast to the implications of the term "passive margin," this was a structurally dynamic area whose sedimentary history clearly shows the effects of structural movement as well as of global sea-level events. To identify and eliminate local tectonic "noise" and detect actual global sea-level changes, one must compare the detailed stratigraphic records of several embayments. In figure 47, the sea-level curves of three principal Atlantic Coastal Plain basins (Salisbury Embayment, Albemarle Embayment, and Charleston Embayment) are plotted. A fourth curve for the Atlantic Coastal Plain combines the data obtained in the three basins and attempts to represent the actual record of sea-level fluctuations. These curves are plotted against the cycles and supercycles of Vail and Mitchum (1979). The curves are based on my interpretations of onshore outcrop and subsurface data. I have made no attempt to plot sea-level changes beyond the present coastline.

PALEOCENE

The following trends may be observed by examining the onlap relationships of formations in the three basins. In the middle early Paleocene, there is agreement for a moderately strong marine pulse. This pulse is recorded by the Brightseat Formation in the Salisbury Embayment, the Jericho Run Member of the Beaufort Formation in the Albemarle Embayment, and the Black Mingo Formation in the Charleston Embayment. Another strong onlap sequence occurred during the late Paleocene and lasted almost that entire period. In the Salisbury Embayment, beds associated with the event are included in the Aquia Formation. There are at least two recognizable pulses, represented by the Piscataway and Paspotansa Members, involved in that sequence, however. A final small transgression, probably only in the Salisbury Embayment, resulted in the deposition of the Marlboro Clay. In the Albemarle Embayment, late Paleocene beds include the Beaufort Formation, while in the Charleston Embayment they are placed in the Black Mingo Formation. More detailed work in these latter two basins will probably reveal a series of small pulses within the major units.

EOCENE

During the early Eocene a moderately strong transgression occurred in the Salisbury Embayment (Potapaco Member of the Nanjemoy Formation), Albemarle Embayment (unnamed, subsurface only), and Charleston Embayment (Fishburne Formation, subsurface), again indicating a general sea-level rise. In the late early Eocene a second pulse occurred, which is reflected by sedimentation in the Salisbury Embayment (Woodstock Member of the Nanjemoy Formation) but not in North or South Carolina. There is evidence of a pulse in the stratigraphic sequence at Hatchetigbee Bluff on the Tombigbee River, Ala. If indeed the resulting marine bed is correlative with beds of the Woodstock, then the pulse may be deemed to have been more than just local subsidence. From the Atlantic record alone, however, it appears to be a result of individual basin subsidence in the Salisbury Embayment.

The most extensive transgression during the Tertiary occurred in the middle Eocene. In Virginia it took place during the middle middle Eocene and resulted in the deposition of the Piney Point Formation. To the south this transgression is represented by carbonate beds: Castle Hayne Formation in North Carolina, Moultrie Member of the Santee Limestone and McBean Formation in South Carolina and Georgia, and Lisbon Formation in Georgia and Alabama. Beds associated with this event are present in all areas of the Gulf Coastal Plain. It is clear, then, that these deposits record a global sea-level rise. At least five small pulses are reflected in the middle Eocene sequence, but they are plotted as one in figure 47 due to the lack of correlative data. Each apparently was of short duration but was significant enough, when sufficient stratigraphic refinement is accomplished, to correlate from basin to basin. During the late middle Eocene, a final sharp pulse resulted in a relatively thin series of beds in most of the basins from Alabama to Virginia. This transgression resulted in beds of the Gosport Sand in Alabama, the Cross Member of the Santee Limestone in South Carolina, the Spring Garden Member of the Castle Hayne Formation in North Carolina, and possibly Bed C of the Piney Point Formation in Virginia. The unconformity between beds associated with this onlap and those of the middle middle Eocene is well developed and sharp, but molluscan fossil evidence indicates that this break represents a relatively brief period of time. The geographically widespread stratigraphic record suggests that this event was global in nature. During the late Eocene, a small-scale transgression took place in South Carolina (Cooper Group, Harleyville and Parkers Ferry Formations) and Virginia (Chickahominy Formation of Cushman and Cederstrom, 1945). This small thickness contrasts with the thick stratigraphic sequence deposited in the Gulf area at that time. That record suggests a high sea-level stand, but the meager upper Eocene record in the Atlantic basins indicates a general sea-level lowering, unless most of that area was tectonically emergent.

OLIGOCENE

During the early Oligocene, a thick sequence of beds was deposited in the Gulf, while in the Atlantic region there are no confirmed units of that age. In the late Oligocene, there is agreement as to a relative high stand, which resulted in the deposition of beds in the Charleston Embayment (Ashley Formation of the Cooper Group), Albemarle Embayment (River Bend Formation), and the Gulf. During the very late Oligocene or very early Miocene a brief, small-scale, high stand left a sedimentary record in the Salisbury Embayment (Old Church Formation), Albemarle Embayment (Haywood Landing Member of the Belgrade Formation), Charleston Embayment (Edisto Formation), and Florida (Tampa Formation). In spite of the thinness of these deposits, their wide occurrence is good evidence for a global sea-level rise or the submergence of most of the Atlantic Coastal Plain.

LOCALITIES AND MEASURED SECTIONS

1. (USGS Locality 26330) Right bank of Aquia Creek, 0.5 mile (0.8 km) above Thorney Point, Stafford County, Va., Widewater 7.5-min quadrangle (see figs. 5*A*, 10)

	Ft	*(m)*
Sloped and covered by vegetation	3.0	(0.9)
Aquia Formation (Piscataway Member)		
Sand, grayish-orange (10 YR 7/4), silty, fine, very glauconitic, poorly sorted, weathered, and leached; some molds and casts	9.0	(2.7)
—Unconformity—		
Brightseat Formation		
Sand, dark-olive-black (5 Y 2/1), micaceous, clayey, silty, very fine, well sorted in the lower half, weathered to grayish orange in the upper half; an 8-inch (20-cm) indurated capping present at the lower end of the exposure but beveled off at the upper end of the exposure	7.0	(2.1)
—Unconformity—		
Patapsco Formation (Lower Cretaceous)		
Sand, well consolidated, clayey, silty, light-blue-gray (5 B 7/1); very irregular, burrowed and eroded upper surface	0–1.0	(0–0.3)
—Sea Level—		

2. (USGS Locality 26331) Right bank of the Rappahannock River, 1.85 miles (2.98 km) east of Greenfield, Spotsylvania County, Va., Guinea 7.5-min quadrangle (see fig. 5*B*)

	Ft	*(m)*
Covered by vegetation	10.0	(3.0)
Brightseat Formation (lower Paleocene)		
Sand, weathered, light-olive-gray (5 Y 5/1), micaceous, silty, very well sorted, very fine; small blades of gypsum common; trace amounts of glauconite; calcareous material leached	8.0	(2.4)
—Unconformity—		
Patapsco Formation (Lower Cretaceous)		
Sandstone, tan, coarse; burrowed upper surface	1.5	(0.4)
Silt, well-consolidated, blue-gray	6.0	(1.8)
Sand, crossbedded, fine, well-sorted	10.0	(3.0)
—Sea Level—		

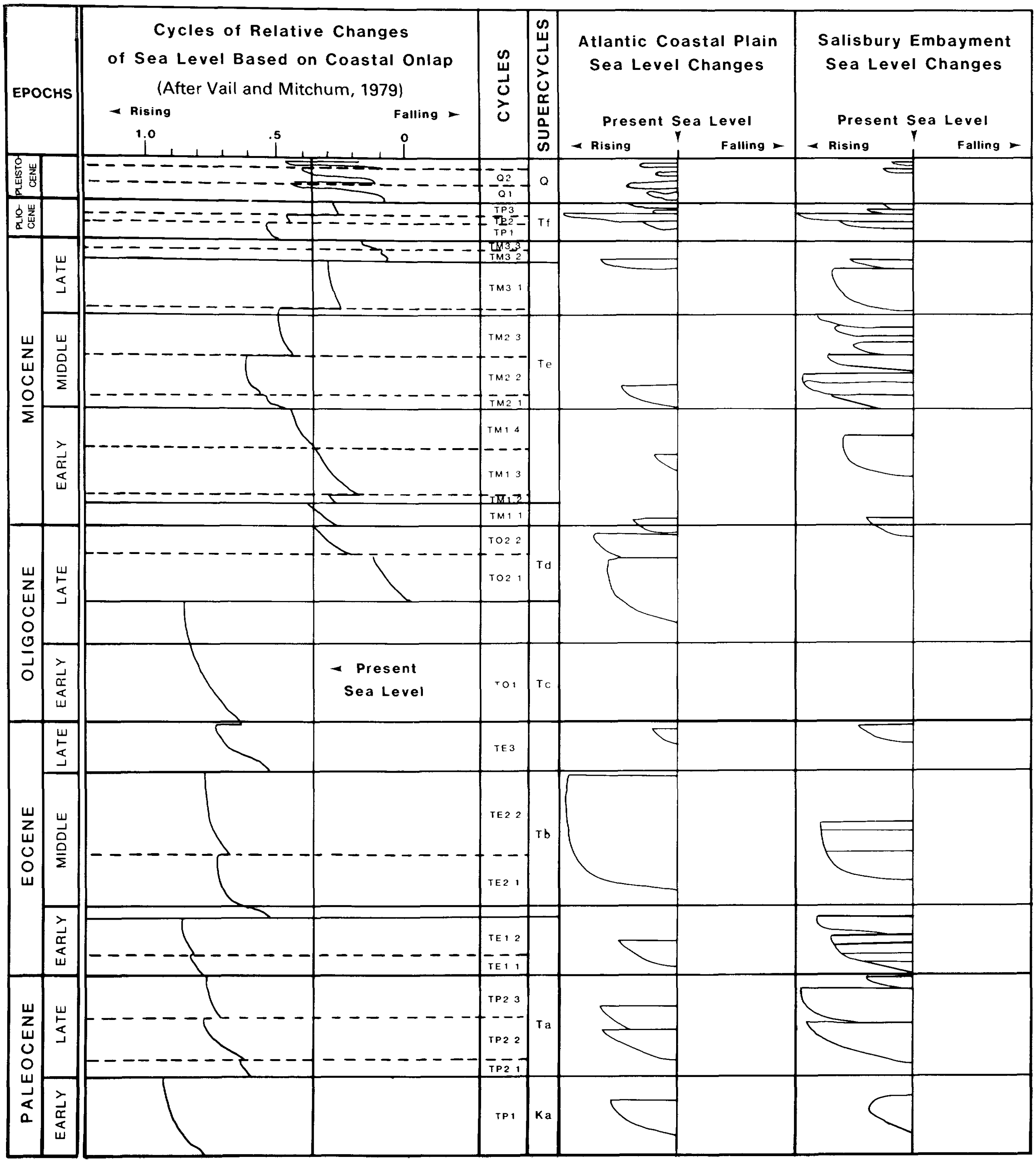

FIGURE 47.—Sea-level fluctuations in the Salisbury, Albemarle, and Charleston Embayments are plotted against cycles and supercycles by Vail and Mitchum (1979). Data from the three basins are combined to approximate global sea-level events as seen along the Atlantic coastal margin. The marine climate curve represents conditions in the Salisbury Embayment and is based on data from fossil molluscan assemblages.

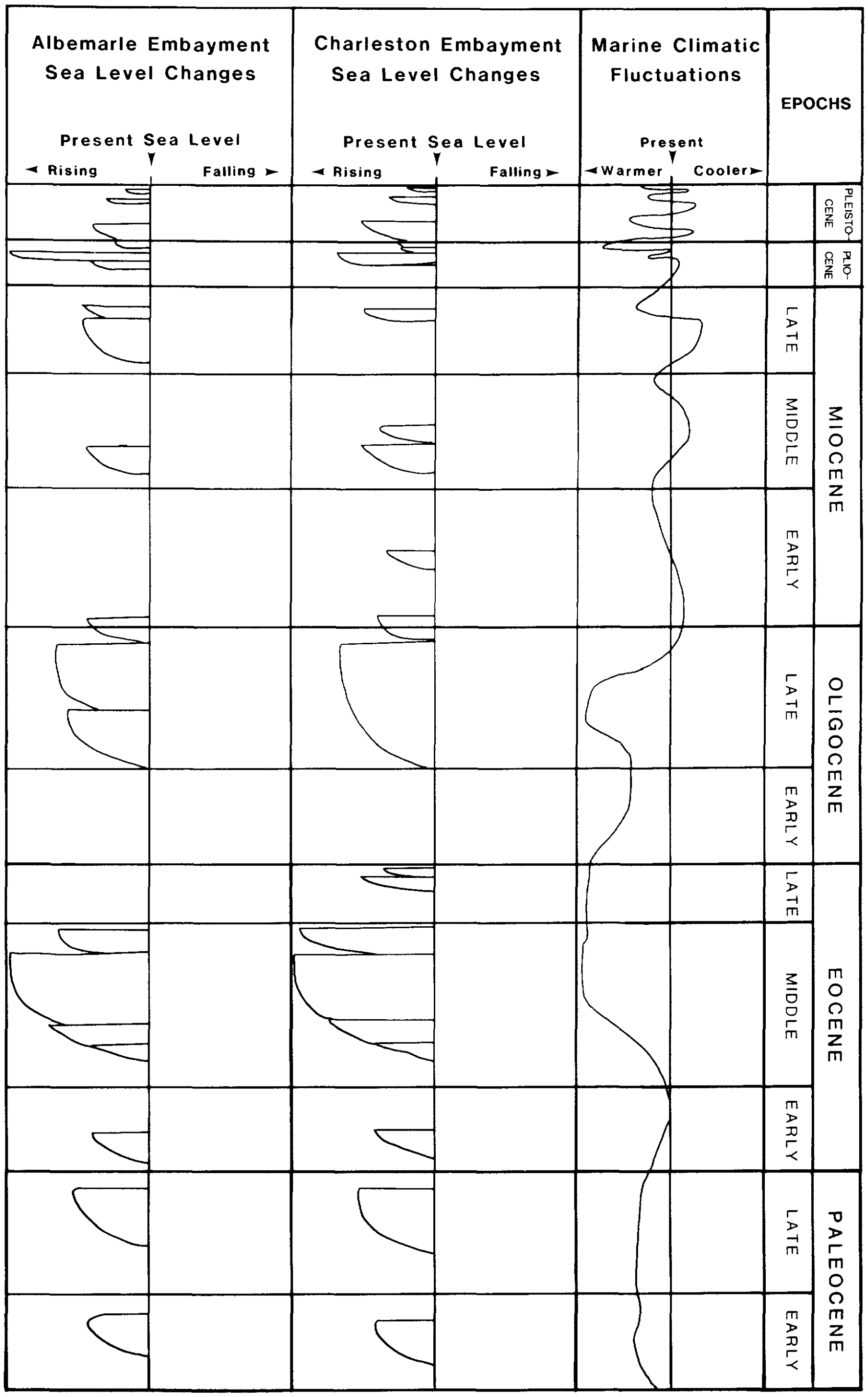

FIGURE 47.—Continued.

3. (USGS Locality 26332) Right bank of the Potomac River, 1.5 miles (2.4 km) below the mouth of Aquia Creek and Youbedam Landing, Stafford County, Va., Passapatanzy 7.5-min quadrangle. Principal reference section (lectostratotype locality) of the Aquia Formation and the Piscataway and Paspotansa Members (see fig. 16)

	Ft	*(m)*
Covered	5.0	(1.5)
Nanjemoy Formation		
Sand, yellowish-gray (5 Y 8/1), weathered, moderately glauconitic, fine	5.0	(1.5)
Marlboro Clay		
Clay, light-gray (N 8), weathered; where this bed is absent there is a distinct line between the Aquia and the overlying bed	0.0–0.75	(0.0–0.23)
Aquia Formation (Paspotansa Member)		
Sand, weathered, grayish-orange (10 YR 7/4), glauconitic, fine; contains large numbers of *Turritella* in lenses, bands, and large indurated masses	35.0	(10.7)
Sand, olive-black (5 Y 2/1), fine, well-sorted, silty; scattered poorly preserved *Turritella*	25.0	(7.6)
Sand, olive-black (5 Y 2/1), glauconitic, very fine, well sorted; many *Turritella* ("zone" 6 of Clark and Martin, 1901)	1.5	(0.5)
—Unconformity—		
Aquia Formation (Piscataway Member)		
Sandstone, light-olive-gray (5 Y 6/1), indurated, glauconitic; many molds and casts, some siliceous replacements ("zone" 5 of Clark and Martin, 1901)	2.0	(0.6)
Sand, olive-gray (5 Y 4/1), very glauconitic, silty, clayey, very shelly, poorly sorted; packed with large bivalves and *Turritella*, appears light-olive-gray (5 Y 6/1) from a distance due to large numbers of mollusks present; preservation poor to moderate; irregularly indurated in beds where *Ostrea* are concentrated	12.0	(3.7)
—Sea Level—		

The section given by Clark (1896b, p. 40) for the bluff at Aquia Creek and by Clark and Martin (1901, p. 69, Sect. III) at the same locality are clearly composite sections giving the maximum thicknesses of the units observed between Aquia and Potomac Creek. It is evident that the measurements for the thickness of the Piscataway were taken at the northwest end of the bluffs, while the measurements of the bed they placed in the Pleistocene was apparently taken at the southeast end of the bluffs. It has been found that the "light-yellow" sand they placed in the Pleistocene is weathered Nanjemoy. The "white clay" at the base of the sand is Marlboro Clay. The upper 10 feet of the Paspotansa that Clark and Martin call "Zone 10" lies below the Marlboro Clay and is weathered Paspotansa (not Nanjemoy as shown on their Plate VI, Section III). Because of the composite nature of Clark's (1896b) and Clark and Martin's (1901) sections, it is advisable to choose a specific locality as a principal reference section (lectostratotype). The section chosen has, by necessity, a smaller thickness of both Piscataway and Nanjemoy, but all beds are present.

4. (USGS Locality 26333) Right bank of the Rappahannock River, 0.15 mile (0.2 km) below the mouth of Snow Creek, Caroline County, Va., Rappahannock Academy 7.5-min quadrangle

	Ft	*(m)*
Covered with vegetation	10.0	(3.0)
Aquia Formation (Piscataway Member)		
Sand, olive-gray (5 Y 4/1), clayey, poorly sorted, glauconitic; many bivalves, moderate to good preservation	5.0	(1.5)
—Sea Level—		

5. (USGS Locality 26334) Blantons Pond, 1.2 miles (1.9 km) west of Milford, Caroline County, Va., Woodford 7.5-min quadrangle

Core taken by R.B. Mixon, U.S. Geological Survey, Reston, Va.

6. (USGS Locality 26335) Left bank of the Pamunkey River, 0.65 mile (1.05 km) below the confluence of the North Anna and South Anna Rivers, Caroline County, Va., Ashland 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	10.0	(3.0)
Aquia Formation (Piscataway Member)		
Sand, grayish-orange (10 YR 7/4), silty, very weathered; very poorly preserved bivalves	3.0	(0.9)
Cobbles, in matrix of sand and gravel; believed to be reworked into base of Aquia	1.5	(0.5)
—Unconformity—		
Patuxent Formation (Lower Cretaceous)		
Clay, greenish-blue, mixed with gravel, sand, and cobbles	3.0	(0.9)
—Water Level—		

7. (USGS Locality 26336) Right bank of the Pamunkey River, 1.1 miles (1.8 km) (straightline) southeast of the confluence of the North Anna and South Anna Rivers, Hanover County, Va., Ashland 7.5-min quadrangle. 0.8 mile (1.3 km) downriver of Locality 6

	Ft	*(m)*
Sloped and covered	3.0	(0.9)
Aquia Formation (Piscataway Member)		
Sand, same as below but weathered to grayish-orange (5 YR 7/4); many mollusks including *Turritella, Ostrea, Dosiniopsis, Pitar*	6.0	(1.8)
Sand, olive-gray (5 Y 5/1), clayey, poorly sorted, glauconitic and quartzose; many moderately to poorly preserved large bivalves including *Cucullaea, Crassatellites,* and *Ostrea*	3.0	(1.9)
Cobbles, basal conglomerate	2.5	(0.8)
—Water Level—		

8. (USGS Locality 26337) Right bank of the Pamunkey River, 0.5 mile (0.8 km) east of Wickham Crossing, Hanover County, Va., Ashland 7.5-min quadrangle (see figs. 9, 11)

	Ft	*(m)*
Pleistocene (undiff.)		
Sand and gravel, orange	6.0	(1.8)
—Unconformity—		
Formation (?)		
Sand, reworked(?), weathered to grayish-orange, glauconitic, poorly sorted	4.0	(1.2)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), glauconitic, silty, micaceous, very fine, very well sorted	3.0	(0.9)
—Unconformity—		
Aquia Formation (Piscataway Member)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, poorly sorted, many bivalves, especially *Crassatella*	3.0	(0.9)
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, poorly sorted; many *Turritella*	3.5	(1.1)
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, poorly sorted; many small bivalves and *Ostrea*	2.5	(0.8)
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, poorly sorted; many large bivalves	3.0	(0.9)
Cobbles, basal conglomerate	1.5	(0.5)
—Unconformity—		
Patapsco Formation (Lower Cretaceous)		
Clay, blue-green (covered at high water level	1.0	(0.3)
Sand, blue, medium, cross-bedded (covered at normal water level)	1.0	(0.3)
—Water Level—		

9. (USGS Locality 24338) Right bank of the Pamunkey River, 1.6 miles (2.6 km) east of Wickham Crossing, Hanover County, Va., Ashland 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	10.0	(3.0)
Eastover Formation (Claremont Manor Member)		
Sand, tan and orange, weathered, fine, burrowed	5.0	(1.5)
Sand, light-grayish-yellow, fine	3.0	(0.9)
Sand, yellowish-brown, poorly sorted, clayey	4.0	(1.2)
—Unconformity—		
Calvert Formation		
Clay, olive-brown (5 Y 4/4), silty, sandy; some phosphate along contact	1.5	(0.5)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, very fine, well-sorted, micaceous, silty, glauconitic, olive-black (5 Y 2/1) where fresh in the lower portions, light-olive-gray (5 Y 6/1) where weathered above, indurated nodules at 15 feet (4.5 m). Burrows in top of unit contain sediments from the Marlboro Clay and Bed A of the Potapaco Member. These two units were present but were beveled off here leaving only their sediments filling burrows. 300 feet (91.4 m) downstream at Locality 33 both of these units are exposed; *Turritella* common throughout but concentrated in beds (molds only)	30.0	(9.1)
—Water Level—		

10. (USGS Locality 26339) Right bank of the James River, 1.0 mile (1.6 km) above the mouth of the Turkey Island Cutoff, just above Fishpond, Chesterfield County, Va., Hopewell 7.5-min quadrangle (see fig. 12)

	Ft	*(m)*
Covered	2.0	(0.6)
Pleistocene(?)		
(?)Formation		
Clay, white, sandy, weathered	14.0	(4.3)
—Unconformity?—		
(?)Formation		
Conglomerate, weathered, grayish-yellow, sand, gravel, cobbles, some reworked glauconitic sand	2.5	(0.8)
—Unconformity—		
Aquia Formation (Piscataway Member)		
Sand, olive-gray (5 Y 4/1, medium to fine, clayey, glauconitic, poorly sorted; contains numerous mollusks, moderately preserved (*Crassatellites, Turritella, Ostrea*)	2.0	(0.6)
Cobbles, sand and gravel conglomerate; glauconitic, contains shark teeth	1.0	(0.3)
—Sea Level—		

11. (USGS Locality 26340) Bull Bluff, right bank of the Potomac River at the mouth of Potomac Creek, King George County, Va., Passapatanzy 7.5-min quadrangle (see fig. 14*A*). Section has been modified from Clark and Martin (1901) because of the present slumping at the locality.

	Ft	*(m)*
Covered		
Sand, yellow and orange	15.0	(4.6)
Calvert Formation (Fairhaven Member)		
Clay, silty, weathered	5.0	(1.5)
—Unconformity—		
Nanjemoy Formation (Potapaco Member)		
Sand, clayey, glauconitic	35.0	(10.7)
Sand, clayey, glauconitic; thin beds of *Venericardia* (Bed B of this report)	16.0	(4.9)
Sand, clayey, glauconitic; scattered molds and casts (may be Bed A of this report)	25.0	(7.6)
—Unconformity—		
Marlboro Clay		
Clay, light-gray (N 7)	0.5	(0.15)
Aquia Formation (Paspotansa Member)		
Sand, weathered, yellowish-gray, glauconitic, fine, irregularly indurated, many *Turritella*	12.0	(3.7)
Sand, olive-black (5 Y 2/1), fresh near water level, glauconitic, fine; *Turritella* numerous in several beds; *Ostrea sinuosa, Crassatellites alaeformis*, and *Cucullaea gigantea* common	25.0	(7.6)
—Sea Level—		

12. (USGS Locality 26341) Right bank of the Potomac River, 0.1 mile (0.16 km) below the mouth of Passapatanzy Creek, King George County, Va., Passapatanzy 7.5-min quadrangle (see fig. 14*B*)

	Ft	*(m)*
Covered		
Sand, tan, gravelly	8.0	(2.4)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), silty, fine, micaceous; many *Turritella*, small gastropods common	6.0	(1.8)
—Sea Level—		

13. (USGS Locality 26342) Right bank of the Potomac River, 1.75 miles (2.8 km) below the large wharf at Fairview Beach, King George County, Va., King George 7.5-min quadrangle (see fig. 15)

	Ft	*(m)*
Sloped and covered	5.0	(1.5)
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, grayish-yellow, weathered, clayey, fine, poorly sorted, glauconitic	6.0	(1.8)
—Unconformity—		
Marlboro Clay		
Clay, light-gray (N 7), somewhat weathered, blocky	6.0	(1.8)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, grayish-yellow, silty, very weathered; molds of *Turritella mortoni*	2.5	(0.7)
—Sea Level—		

14. (USGS Locality 26343) Left bank of the Rappahannock River, 1.05 miles (1.68 km) above the mouth of Ware Creek, King George County, Va., Rappahannock Academy 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	3.0	(0.9)
Aquia Formation (Paspotansa Member)		
Sand, same as below but weathered, grayish-orange (10 YR 7/4)	3.0	(0.9)
Sand, olive-black (5 Y 2/1), glauconitic, micaceous, silty, well sorted; many *Turritella mortoni*	7.0	(2.1)
—Sea Level—		

15. (USGS Locality 26344) Right bank of the Rappahannock River, 0.35 mile (0.56 km) below the mouth of Ware Creek, Caroline County, Va., Rappahannock Academy 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	40.0	(12.2)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, glauconitic, micaceous; contains many *Turritella*	4.0	(1.2)
—Sea Level—		

16. (USGS Locality 26345) Left bank of the Rappahannock River, 0.45 mile (0.72 km) above the mouth of Lambs Creek, King George County, Va., Rappahannock Academy 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	15.0	(4.6)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, glauconitic, micaceous	4.0	(1.2)
—Sea Level—		

17. (USGS Locality 26346) Left bank of the Rappahannock River, 0.4 mile (0.6 km) below the mouth of Lambs Creek, King George County, Va., Passapatanzy 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	10.0	(3.0)
Aquia Formation (Paspotansa Member)		
Sand, grayish-orange (10 YR 7/4), weathered, leached, fine, silty	3.0	(0.9)
Sand, olive-black (5 Y 2/1), fine, silty, micaceous, well-sorted, glauconitic; contains discontinuous bands of *Turritella mortoni*	6.0	(1.8)
—Sea Level—		

18. (USGS Locality 26347) Left bank of the Rappahannock River, 0.3 mile (0.5 km) above Hopyard Landing, King George County, Va., Port Royal 7.5-min quadrangle

	Ft	*(m)*
Covered with vegetation	13.0	(4.0)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, micaceous, well-sorted, glauconitic; *Turritella* common; line of concretions at +4 feet (+1.2 m)	7.0	(2.1)
—Sea Level—		

19. (USGS Locality 26348) Left bank of the Rappahannock River, 0.65 mile (1.05 km) below the mouth of Jones Top Creek, King George County, Va., Port Royal 7.5-min quadrangle

	Ft	*(m)*
Covered	2.0	(0.6)
(?)Formation		
Conglomerate, coarse, sandy	2.0	(0.6)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, glauconitic, micaceous; small shell fragments; line of indurated nodules at +4 feet (+1.2 m)	10.0	(3.0)
—Sea Level—		

20. (USGS Locality 26349) 1.0 mile (1.6 km) northwest of Wrights Corner, where Rte. 634 crosses Hobby Swamp, Caroline County, Va., Woodford 7.5-min quadrangle

Core taken by R.B. Mixon, U.S. Geological Survey, Reston, Va.

21. (USGS Locality 26350) Smoots Pond, near the millrace, just north of Rte. 640, in Camp A.P. Hill, Caroline County, Va., Bowling Green 7.5-min quadrangle

Core taken by R.B. Mixon, U.S. Geological Survey, Reston, Va.

22. (USGS Locality 26351) Right bank of the Mattaponi River, 0.15 mile (0.24 km) above the Rte. 301 bridge, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	*(m)*
Covered	6.0	(1.8)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), glauconitic, silty, fine, micaceous, well-sorted, somewhat weathered; *Turritella* and other mollusks common but poorly preserved	6.0	(1.8)
—Water Level—		

23. (USGS Locality 26352) Left bank of the Mattaponi River, in a small stream cut just below the Rte. 654 bridge, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	(m)
Pleistocene(?)		
Gravel, coarse, white	2.0	(0.6)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, poorly sorted, glauconitic; *Venericardia potapacoensis* molds concentrated in thin beds but also scattered throughout	10.0	(3.0)
Nanjemoy Formation (Potapaco Member, Bed A?)		
Sand, olive-gray (5 Y 5/1), silty	2.0	(0.6)
—Water Level—		

24. (USGS Locality 26353) Left bank of the Pamunkey River, 0.65 mile (1.05 km) below Sturgeon Hole, just below the mouth of Mill Creek, Caroline County, Va., Hanover 7.5-min quadrangle (see fig. 21)

	Ft	(m)
Pleistocene(?)		
Gravel, yellow, sandy	6.0	(1.8)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, olive-black (5 Y 2/1), fine, silty, glauconitic, micaceous; no molds	2.0	(0.6)
—Unconformity—		
Marlboro Clay		
Clay, light-gray (N 7); very burrowed from above	0.5	(0.2)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, glauconitic, micaceous; many *Turritella* present throughout but concentrated in beds, preservation moderate	8.0	(2.4)
—Water Level—		

25. (USGS Locality 26354) Left bank of the Pamunkey River, 0.25 mile (0.40 km) below the Rte. 301 bridge (Littlepage Bridge), Caroline County, Va., Hanover 7.5-min quadrangle

	Ft	(m)
Pleistocene(?)		
Gravel, sandy	3.0	(0.9)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, yellow-orange, weathered, glauconitic	12.0	(3.7)
Sand, olive-black (5 Y 2/1), fine, well-sorted, glauconitic, micaceous; numerous *Turritella* in bands, preservation moderate	8.0	(2.4)
Nodules, thin bed, indurated, intermittent	0.5	(0.2)
Sand, olive-black (5 Y 2/1), fine, well-sorted, glauconitic, micaceous; scattered *Turritella*, preservation poor to moderate	4.0	(1.2)
—Water Level—		

26. (USGS Locality 26355) Left bank of the Pamunkey River at Sturgeon Hole, 0.75 mile (1.21 km) below the Rte. 301 bridge (Littlepage Bridge), Caroline County, Va., Hanover 7.5-min quadrangle (see fig. 17)

	Ft	(m)
Covered	10.0	(3.0)
Aquia (?)		
Sand, yellowish-orange, clayey, weathered	3.0	(0.9)
Sand, olive-black (5 Y 2/1), fine, well sorted; shell material leached	2.5	(0.8)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), silty, glauconitic, well-sorted, micaceous; many *Turritella*	8.0	(2.4)
Concretions, intermittent, glauconitic	1.0	(0.3)
Sand, olive-black (5 Y 2/1), silty, glauconitic, well-sorted; micaceous; many *Turritella*, some *Ostrea sinuosa*	6.0	(1.8)
—Water Level—		

27. (USGS Locality 26356) Left bank of the James River, 1.1 miles (1.8 km) above Shirley Plantation, Charles City County, Va., Hopewell 7.5-min quadrangle

	Ft	(m)
Covered	20.0	(6.1)
Aquia Formation (Paspotansa Member)		
Sand, olive-gray (5 Y 4/1), somewhat weathered, well-sorted, fine, micaceous, glauconitic; some carbonaceous material; molds of *Turritella* and *Crassatellites alaeformis*	6.0	(1.8
—Sea Level—		

28. (USGS Locality 26357) City Point, right bank of the James River at the mouth of the Appomattox River, Hopewell, Prince George County, Va., Hopewell 7.5-min quadrangle

	Ft	(m)
Covered	25.0	(7.6)
Aquia Formation (Paspotansa Member)		
Sand, dark-olive-black (5 Y 2/1), fine, micaceous, leached	3.0	(0.9)
—Sea Level—		

29. (USGS Locality 26358) Right bank of the James River, just below the mouth of Bailey Creek, Prince George County, Va., Westover 7.5-min quadrangle

	Ft	(m)
Covered (sloped)	20.0	(6.1)
Marlboro Clay		
Clay, pink (10 R 7/4) in lower one-third, gray (N 7) in upper two-thirds, gypsum crystals common throughout; rare small gastropod molds	10.0	(3.0)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, fine, well-sorted, glauconitic, weathered, reddish-yellow, somewhat indurated	0.5	(0.2)
Sand, olive-black (5 Y 2/1), fine, silty, micaceous, well-sorted, glauconitic; scattered poorly preserved *Turritella* and *Crassatellites*	12.0	(3.7)
Sand, olive-black (5 Y 2/1), fine, weathered, well-sorted, glauconitic; shell material poorly preserved, numerous *Turritella*, *Ostrea*	5.0	(1.5)
—Sea Level—		

30. (USGS Locality 26359) Right bank of the Potomac River, 0.3 mile (0.5 km) above Belvedere Beach, King George County, Va., Passapatanzy 7.5-min quadrangle

	Ft	*(m)*
Covered	5.0	(1.5)
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, silty, micaceous, glauconitic; numerous *Turritella*, scattered as well as in distinct bands, common *Ostrea sinuosa*, moderate molluscan diversity	12.0	(3.7)
—Sea Level—		

31. (USGS Locality 26360) Right bank of Rappahannock River, directly across from Goat Island, Caroline County, Va., Port Royal 7.5-min quadrangle

	Ft	*(m)*
Covered	20.0	(6.1)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), very clayey, fine, glauconitic; bands of *Venericardia*	4.0	(1.2)
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, olive-black (5 Y 2/1), fine, clayey, glauconitic; small shells common	6.0	(1.8)
—Sea Level—		

32. (USGS Locality 26361) Right bank of the Mattaponi River, just below the Rte. 207 bridge, Caroline County, Va., Woodford 7.5-min quadrangle (see fig. 20)

	Ft	*(m)*
Covered	4.0	(0.9)
Pleistocene(?)		
Gravel, sandy, orange	4.0	(0.9)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, olive-black (5 Y 2/1), glauconitic, silty, some indurated nodules; medium to coarse sand concentrated near base with phosphate and quartz pebbles common; a few scattered molds of bivalves	3.0	(1.5)
—Unconformity—		
Marlboro Clay		
Clay, gray (N 7); upper surface burrowed, burrows filled with Potapaco sediment	2.0	(0.9)
—Water Level—		

33. (USGS Locality 26362) Right bank of the Pamunkey River, 0.95 mile (1.53 km) straightline above the Rte. 301 bridge (Littlepage Bridge), Hanover County, Va., Ashland 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Eastover Formation		
Sand, weathered, grayish-yellow, fine, burrowed	8.0	(2.4)
—Unconformity—		
Calvert Formation		
Clay, weathered, yellowish-gray (5 Y 7/2), diatomaceous	3.0	(0.9)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, weathered, brownish-gray (5 YR 4/1), clayey, poorly sorted, moderately glauconitic, micaceous	4.0	(1.2)
—Unconformity—		
Marlboro Clay		
Clay, gray (N 7); burrows filled with sand from Potapaco Member	1.5	(0.5)
—Unconformity—		
Aquia Formation (Paspotansa Member)		
Sand, olive-black (5 Y 2/1), fine, micaceous, silty, well-sorted, glauconitic, somewhat weathered on the surface; upper surface burrowed, burrows filled with sediment from Potapaco and Marlboro	10.0	(3.0)
Covered by slump	10.0	(3.0)
—Water Level—		

34. (USGS Locality 26363) Left bank of the Potomac River, 2.5 miles (4.0 km) above Popes Creek, 1.7 miles (2.7 km) southeast of Windmill Point, Charles County, Md., Mathias Point 7.5-min quadrangle (see fig. 26)

	Ft	*(m)*
Holocene		
Soil, contains *Crassostrea* as artifacts	3.0	(0.9)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, grayish-yellow, very weathered, glauconitic, clayey; abundant carbonaceous material	4.0	(1.2)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, grayish-yellow, weathered, glauconitic, clayey; line of concretions near top of bed	2.0	(0.6)
Sand, olive-gray (5 Y 4/1), very clayey, glauconitic; thin beds of *Venericardia potapacoensis*	4.0	(1.2)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed B?)		
Clay, olive-black (5 Y 2/1), silty, sandy, glauconitic, burrowed	4.0	(1.2)
—Sea Level—		

35. (USGS Locality 26364) Right bank of the Rappahannock River, 0.2 mile (0.3 km) below the mouth of Ware Creek, Caroline County, Va., Rappahannock Academy 7.5-min quadrangle

	Ft	*(m)*
Pleistocene(?)		
Gravel, grayish-orange, sandy	7.0	(2.1)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), glauconitic, clayey; prominent thin bands where *Venericardia* have been leached	5.0	(1.5)
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, olive-black (5 Y 2/1), glauconitic, silty; scattered small shells	10.0	(3.0)
Slump	12.0	(3.7)
—Sea Level—		

36. (USGS Locality 26365) Left bank of the Mattaponi River, 1.5 miles (2.4 km) (straightline) above the Rte. 207 bridge, Caroline County, Va., Woodford 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	15.0	(4.6)
Nanjemoy (Potapaco Member, Bed A)		
Sand, olive-black (5 Y 2/1), silty, fine, moderately glauconitic, some pebbles; scattered molds of *Venericardia*	4.0	(1.2)
—Water Level—		

37. (USGS Locality 26366) Left bank of the Mattaponi River, next to the Rte. 605 bridge at Bowling Green Park, Caroline County, Va., Woodford 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	15.0	(4.5)
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, olive-gray (5 Y 4/1), micaceous, glauconitic, fine, silty; molds of *Venericardia* common	4.0	(1.2)
—Water Level—		

38. (USGS Locality 26367) Left bank of the Pamunkey, 0.65 mile (1.04 km) above Normans Bridge (Rte. 614), King William County, Va., Hanover 7.5-min quadrangle (see fig. 24)

	Ft	*(m)*
Pleistocene (?)		
Gravel, sandy	1.0	(0.3)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), very clayey, glauconitic, burrowed; many *Venericardia potapacoensis* in thin bands	6.0	(1.8)
—Disconformity—		
Nanjemoy Formation (Potapaco Member, Bed A)		
Sand, olive-black (5 Y 2/1), glauconitic, fine, silty; upper surface uneven, burrowed	4.0	(1.2)
—Water Level—		

39. (USGS Locality 26368) Left bank of the Patuxent River, 0.85 mile (1.37 km) below Nottingham, Calvert County, Md., Lower Marlboro 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Calvert Formation		
Clay, yellowish-gray (5 Y 8/1), weathered, diatomaceous	3.0	(0.9)
Sandstone, indurated, yellowish-gray (5 Y 8/1), fine- to medium-grained; some pebbles, *Pecten humphreysii* as molds	0.5	(0.2)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-gray (5 Y 4/1), silty, glauconitic, well-sorted, fine, pebbles along base	3.0	(0.9)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Clay, olive-gray (5 Y 4/1), very burrowed, fine- to medium-sand-sized glauconite filling burrows	7.0	(2.1)
Sand, olive-gray (5 Y 4/1), clayey, glauconitic, fine to medium, compact	8.0	(2.4)
—Sea Level—		

40. (USGS Locality 26369) Left bank of the Patuxent River, 0.55 mile (0.89 km) below the mouth of Lyons Creek, Calvert County, Md., Lower Marlboro 7.5-min quadrangle

	Ft	*(m)*
Sloped	10.0	(3.0)
Calvert Formation		
Clay, light-yellowish-gray (5 Y 9/1), highly diatomaceous, weathered, blocky	5.0	(1.5)
Sandstone, yellowish-gray (5 Y 8/1), indurated, medium-grained; molds of mollusks	1.0	(0.3)
Sand, yellowish-gray (5 Y 8/1), medium, unconsolidated	0.5	(0.2)
—Unconformity—		
Nanjemoy Formation (Potapaco Member)		
Sand, glauconitic, weathered, partially covered and sloped	35.0	(10.7)
Sand, olive-gray (5 Y 4/1), clayey, compact, very glauconitic, fine calcareous material leached	8.0	(2.4)
—Sea Level—		

41. (USGS Locality 26370) Right bank of the Potomac River, 2.7 miles (4.3 km) below the big pier at Fairview Beach, King George County, Va., King George 7.5-min quadrangle

	Ft	*(m)*
Covered	3.0	(0.9)
Pleistocene(?)		
Conglomerate, sand, gravel, cobbles, orange	20.0	(6.1)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic; bands of bedded *Venericardia potapacoensis*	15.0	(4.6)
—Sea Level—		

42. (USGS Locality 26371) Right bank of the Rappahannock River, 1.0 miles (1.6 km) (straightline) below the mouth of Ware Creek, Caroline County, Va., Rappahannock Academy 7.5-min quadrangle

	Ft	*(m)*
Covered	15.0	(4.6)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic; scattered *Venericardia*	8.0	(2.4)
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic; *Venericardia* in thin beds	8.0	(2.4)
Slumped and covered	20.0	(6.1)

—Sea Level—

43. (USGS Locality 26372) Right bank of Mill Creek, just below the dam at Millers Pond (now drained), 150 feet (54.7 m) upstream from the Rte. 17 bridge, Camp A.P. Hill Military Reservation, Caroline County, Va., Port Royal 7.5-min quadrangle

	Ft	*(m)*
Sloped and covered	6.0	(1.8)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, somewhat weathered, olive-gray (5 Y 4/1), clayey, glauconitic; leached thin bands of *Venericardia* molds	8.0	(2.4)

—Water Level—

44. (USGS Locality 26373) Left bank of the Rappahannock River, 0.4 mile (0.6 km) above the mouth of Gingoteague Creek, King George County, Va., Port Royal 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Nanjemoy Formation (Potapaco Member, Bed C)		
Clay, olive-gray (5 Y 4/1), very burrowed, very glauconitic; fresh in lower 4 feet (1.2 m) and weathered to grayish-yellow (5 Y 8/4) in upper 6 feet (1.8 m)	10.0	(3.0)

—Sea Level—

45. (USGS Locality 26374) Left bank of the Mattaponi River, 1.0 mile (1.6 km) east of Reedy Mill, 1.8 miles south of Shumansville, Caroline County, Va., Penola 7.5-min quadrangle (see fig. 25)

	Ft	*(m)*
Covered	3.0	(0.9)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic; a thin bed of concretions in lower 2 feet (0.6 m); thin bands of *Venericardia* extending from below water level to approx. 6 feet (1.8 m) above water level	8.0	(2.4)

—Water Level—

46. (USGS Locality 26375) Right bank of the Mattaponi River, 0.38 mile (0.61 km) northeast of the intersection of Routes 601 and 663, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	*(m)*
Covered	8.0	(2.4)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1) clayey, fine, glauconitic; thin bands of *Venericardia* dipping upstream (northwest) at approximately 4°	6.0	(1.8)

—Water Level—

47. (USGS Locality 26376) Right bank of the Mattaponi River, 0.48 mile (0.77 km) east of the intersection of Routes 601 and 663, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	*(m)*
Covered	25.0	(7.6)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, greenish-gray, glauconitic; thin bands of poorly preserved *Venericardia*	10.0	(3.0)

—Water Level—

48. (USGS Locality 26377) Right bank of the Pamunkey River, 0.8 mile (1.3 km) below Hanovertown, just below a sharp bend, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic; thin bands of *Venericardia potapacoensis*, *Cubitostrea* common; beds dip upriver (northwest) at approximately 4°	5.0	(1.5)

—Water Level—

49. (USGS Locality 26378) Left bank of the Pamunkey River, 0.85 mile (1.37 km) northwest of the boat landing above Dabneys Millpond, King William County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), fine, massive, silty, well-sorted, glauconitic; calcareous material leached	5.0	(1.5)
Slumped and covered	10.0	(3.0)
—Contact not visible—		
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic; thin bands of *Venericardia*	5.0	(1.5)
Slumped	5.0	(1.5)

—Water Level—

50. (USGS Locality 26379) Left bank of the Pamunkey River, at a tall bluff on the river bend just below the boat landing at the end of Rte. 602 at Dabneys Millpond, King William County, Va., Manquin 7.5-min quadrangle (see fig. 27)

	Ft	*(m)*
Pleistocene(?)		
Sand and gravel, orange	20.0	(6.1)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 4/1), silty, fine, very glauconitic, massive; bed of large concretions in lower 2 feet (0.6 m), pebbles, wood along lower contact, grayish yellow where weathered	5.0	(1.5)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), very burrowed, very glauconitic, clayey, grayish-yellow where weathered; three planes of glauconite concentration mark short-term diastems within the unit	10.0	(3.0)
—Gradational contact—		
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconite; numerous thin bands of *Venericardia; Cubitostrea* common	4.0	(1.2)
—Water Level—		

51. (USGS Locality 26380) Right bank of the Pamunkey River, at Hanovertown, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Nanjemoy Formation (Potapaco Member, Bed B)		
Sand, olive-gray (5 Y 2/1), clayey, fine, glauconitic; thin bands of *Venericardia* dipping downstream	8.0	(2.4)
—Water Level—		

52. (USGS Locality 26381) Left bank of the Patuxent River, 0.3 mile (0.5 km) above Jones Point, Calvert County, Va., Lower Marlboro 7.5-min quadrangle

	Ft	*(m)*
Covered	30.0	(9.1)
Calvert Formation		
Clay, light-yellowish-gray (5 Y 9/1), blocky, weathered, diatomaceous	8.0	(2.4)
Sandstone, yellowish-gray (5 Y 8/1), medium-grained; molds of *Pecten humphreysii*	1.0	(0.3)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, micaceous, silty, glauconitic; pebbles along the lower contact	12.0	(3.7)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), very burrowed, very glauconitic, very clayey; grayish yellow (5 Y 8/4) where weathered	15.0	(4.6)
—Sea Level—		

53. (USGS Locality 26382) Left bank of the Potomac River, 0.4 mile (0.6 km) above Popes Creek, Charles County, Md., Popes Creek 7.5-min quadrangle (see fig. 32). Bed C was exposed at beach level in 1969 but now is covered with beach sand.

	Ft	*(m)*
Pleistocene(?)		
Sand, orange	15.0	(4.6)
—Unconformity—		
Calvert Formation (Fairhaven Member)		
Clay, yellowish-gray (5 Y 8/1), weathered, blocky, diatomaceous; this bed is associated with the second sedimentation pulse	10.0	(3.0)
Sand, olive-brown (5 Y 4/4), silty, phosphatic, poorly sorted, fine to medium, pebbles along contact; fining upward; contains diatoms; this bed is associated with the first sedimentation pulse	10.0	(3.0)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), well-sorted, fine, silty, glauconitic	6.0	(1.8)
Sand, olive-black (5 Y 2/1), compact, well-sorted, fine, silty, glauconitic, burrowed	18.0	(5.5)
—Sea Level—		

54. (USGS Locality 26383) Left bank of the Rappahannock River, 0.2 mile (0.3 km) above Greenlaw Wharf, King George County, Va., Rollins Fork 7.5-min quadrangle (see fig. 33)

	Ft	*(m)*
Covered	10.0	(3.0)
Nanjemoy Formation(?)		
Sand, grayish-yellow (5 Y 8/4), medium to pebbly, poorly sorted, slightly glauconitic; fine, lower contact undulant and burrowed	5.0	(1.5)
—Unconformity (?)—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), fine, silty, micaceous, well-sorted, glauconitic, burrowed; molds and casts	4.0	(1.2)
—Sea Level—		

55. (USGS Locality 26384) Left bank of the Mattaponi River, 0.95 mile (1.53 km) east of Reedy Mill, 1.85 miles (2.98 km) south of Shumansville, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	*(m)*
Covered	8.0	(2.4)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; contact with lower unit sharp	2.0	(0.6)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, burrowed	6.0	(1.8)
—Water Level—		

56. (USGS Locality 26385) Left bank of the Mattaponi River, 0.8 mile (1.3 km) east of Reedy Mill, 1.95 miles (3.24 km) south of Shumansville, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	*(m)*
Covered	3.0	(0.9)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; contact with lower unit sharp but burrowed	6.0	(1.8)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, burrowing throughout	3.0	(0.9)
—Water Level—		

57. (USGS Locality 26386) Right bank of the Mattaponi River, 0.5 mile (0.8 km) east of Reedy Mill, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	*(m)*
Covered	6.0	(1.8)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; contact with lower unit sharp	6.0	(1.8)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, fine, gray-green, glauconitic, burrowing throughout; upper surface burrowed	3.0	(0.9)
—Water Level—		

58. (USGS Locality 26387) Right bank of the Mattaponi River, 0.8 mile (1.3 km) southeast of Reedy Mill, Caroline County, Va., Penola 7.5-min quadrangle (see fig. 28)

	Ft	*(m)*
Covered	12.0	(3.7)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; contact with lower unit sharp	7.0	(2.1)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, fine, glauconitic, burrowing throughout; upper surface burrowed	6.0	(1.8)
—Water Level—		

59. (USGS Locality 26388) Right bank of the Pamunkey River, 1.0 mile (1.6 km) southeast of Hanovertown, 0.55 mile (0.89 km) east of the intersection of Rtes. 604 and 605, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	3.0	(0.9)
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, burrowed, fine, glauconitic	6.0	(1.8)
Covered	3.0	(0.9)
—Water Level—		

60. (USGS Locality 26389) Right bank of the Pamunkey River, 1.45 miles (2.33 km) southeast of Hanovertown, 1.3 miles east of the intersection of Rtes. 604 and 605, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, burrowed, fine, glauconitic; line of concretions at +4 feet (+1.2 m)	5.0	(1.5)
—Water Level—		

61. (USGS Locality 26390) Right bank of the Pamunkey River, 0.58 mile (0.93 km) (straightline) below the mouth of Totopotomoy Creek, 0.75 mile (1.21 km) northwest of the intersection of Rtes. 360 and 605, Hanover County, Va., Manquin 7.5-min quadrangle (see fig. 29)

	Ft	*(m)*
Covered	15.0	(4.6)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, micaceous, glauconitic; clayey and poorly sorted at base, becoming silty and very well sorted upward; carbonaceous material abundant, scattered small shells throughout	10.0	(3.0)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed D)		
Sand, dark-olive-black (5 Y 1/1), silty, clayey, very fine, burrowed, very glauconitic, micaceous; large concretions, some phosphate pebbles	2.0	(0.6)
—Disconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Clay, olive-gray (5 Y 4/1), abundant fine-sand-sized glauconite, very burrowed; small mollusk fragments common	1.0	(0.3)
Covered	4.0	(1.2)
—Water Level—		

62. (USGS Locality 26391) Right bank of the Pamunkey River, 0.55 mile (0.89 km) (straightline) below the mouth of Totopotomoy Creek, 0.80 mile (1.29 km) northwest of the intersection of Rtes. 605 and 360, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	20.0	(6.1)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, micaceous, silty, glauconitic; clayey and poorly sorted near base, becoming silty and very well sorted upward; carbonaceous material abundant, scattered small shells	4.0	(1.2)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed D)		
Sand, dark-olive-black (5 Y 1/1), silty, clayey, very fine, burrowed, very glauconitic, micaceous; large concretions, some phosphate pebbles	2.0	(0.6)
—Disconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Clay, olive-gray (5 Y 4/1), clayey, glauconitic, very burrowed	2.0	(0.6)
Covered	3.0	(0.9)
—Water Level—		

63. (USGS Locality 26392) Right bank of the Pamunkey River, 0.4 mile (0.6 km) (straightline) below the mouth of Totopotomoy Creek, 0.95 mile (1.53 km) northwest of the intersection of Rtes. 360 and 605, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	15.0	(4.6)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), fine, well-sorted, micaceous, silty, glauconitic; clayey and poorly sorted near base, becoming silty and very well sorted upward, phosphate pebbles along base; scattered small molds, wood, nuts common	15.0	(4.6)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed D)		
Sand, dark-olive-black (5 Y 1/1), silty, clayey, very fine, burrowed, very glauconitic, micaceous, some phosphate pebbles; large concretions	2.0	(0.6)
—Disconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Clay, olive-gray (5 Y 4/1), abundant sand-sized glauconite, very burrowed	2.5	(0.8)
—Water Level—		

64. (USGS Locality 26393) Right bank of the Pamunkey River at the northern termination of Rte. 732, 1.35 miles (2.17 km) northeast of Farmers Shop Corner, Hanover County, Va., Manquin 7.5-min quadrangle (see fig. 35*A*)

	Ft	*(m)*
Covered	10.0	(3.0)
Old Church Formation(?)		
Sand, grayish-olive (10 Y 4/2), weathered, clayey, moderate amounts of glauconite	3.0	(0.91)
Piney Point Formation		
Sand, light-olive-gray (5 Y 6/1), very calcareous, slightly glauconitic; many mollusks, somewhat indurated at base; Woodstock fossils (*Venericardia, Glycymeris*) reworked into base	15.0	(4.6)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), very fine, silty, micaceous, well-sorted, very glauconitic; numerous small, well-preserved mollusks; upper contact sharp and burrowed; burrows extend as much as 3 feet (0.9 m) downward	9.0	(2.7)
—Sea Level—		

65. (USGS Locality 26394) Left bank of the Patuxent River, at the "Kaylorite" pit at the end of Landing Road, 1.2 miles (1.9 km) above Nottingham, in Calvert County, Md., Lower Marlboro 7.5-min quadrangle (see fig. 44)

	Ft	*(m)*
Calvert Formation (Fairhaven Member)		
Clay, light-yellowish-gray (5 Y 9/1), weathered, very diatomaceous, blocky	10.0	(3.0)
Sand, yellowish-gray (5 Y 8/1), indurated; fine to medium; molds of *Pecten humphreysii* and other bivalves	1.0	(0.3)
Sand, yellowish-gray (5 Y 8/1), soft, fine to medium	0.5	(0.2)
—Unconformity—		

7. (USGS Locality 26395)—Continued

	Ft	*(m)*
Old Church Formation(?)		
Sand, pinkish-gray (5 YR 7/1), clayey, silty, weathered; molds and casts of Lucinids; upper surface very burrowed	1.0	(0.3)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; becoming very clayey in upper 5 feet (1.5 m)	13.0	(4.0)
Sloped and covered	15.0	(4.6)
—Sea Level—		

66. (USGS Locality 26395) Right bank of the Patuxent River at White Landing, Prince Georges County, Md., Lower Marlboro 7.5-min quadrangle (see fig. 45)

	Ft	*(m)*
Covered	10.0	(3.0)
Calvert Formation (Fairhaven Member)		
Clay, light-yellowish-gray (5 Y 9/1), weathered, diatomaceous	1.0	(0.3)
Sand, yellowish-gray (5 Y 8/1), coarse, indurated	1.5	(0.5)
Sand, yellowish-gray (5 Y 8/1) to olive-gray (5 Y 6/1), coarse, soft	0.5	(0.2)
—Unconformity—		
Old Church Formation (?)		
Sand, grayish-olive (10 Y 4/2), clayey, silty, poorly sorted; many molds along contact, Lucinids common	1.5	(0.5)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous; some molds	1.0	(0.3)
—Sea Level—		

67. (USGS Locality 26396) Right bank of the Potomac River, 1.65 miles (2.66 km) above Mathias Point, King George County, Va., Mathias Point 7.5-min quadrangle. Principal reference section (lectostratotype locality) of the Woodstock Member (see fig. 31 for Woodstock-Calvert contact)

	Ft	*(m)*
Pleistocene(?)		
Sand, orange, coarse	5.0	(1.5)
Conglomerate, sand, gravel, cobbles, boulders	3.0	(0.9)
—Unconformity—		
Calvert Formation (Fairhaven Member)		
Clay, yellowish-gray (5 Y 8/1), silty, somewhat sandy near base, weathered, blocky, diatomaceous; phosphate and sand along contact	17.0	(5.2)
—Disconformity—		
Clay, yellowish-gray (5 Y 8/1), silty, somewhat sandy towards base, weathered, blocky; phosphate, bone, and teeth along lower contact; as much as 3.0 feet (1.0 m) of relief along the lower contact	10.0	(3.0)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, pale-greenish-yellow (10 Y 8/2), weathered, fine, micaceous; molds and casts; upper surface very eroded and burrowed with as much as 3 feet (1.0 m) of relief	25.0	(7.6)
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; small mollusks with moderate preservation	15.0	(4.6)
—Sea Level—		

68. (USGS Locality 26397) Left bank of the Potomac River, 0.95 mile (1.53 km) below the mouth of Popes Creek, Charles City County, Va., Popes Creek 7.5-min quadrangle

	Ft	(m)
Pleistocene(?)		
Conglomerate, yellowish-orange, weathered; gravel, sand, cobbles, boulders	25.0	(7.6)
Calvert Formation (Fairhaven Member)		
Clay, light-yellowish-gray (5 Y 9/1), blocky, diatomaceous	10.0	(3.0)
Sand, yellowish-gray (5 Y 8/1), silty	2.0	(0.6)
—Disconformity—		
Clay, light-yellowish-gray (5 Y 9/1), blocky	0.5	(0.2)
Sand, yellowish-gray (5 Y 8/1), silty	5.0	(1.5)
Sand, olive-brown (5 Y 4/4), silty, phosphatic, pebbles	1.5	(0.5)
Sand, yellowish-gray (5 Y 7/2), silty	2.5	(0.8)
Sand, olive-brown (5 Y 4/4), silty, phosphatic, pebbles	2.0	(0.6)
—Unconformity—		
Nanjemoy Formation (?) The following two units are provisionally referred to the Woodstock Member		
Sand, olive-gray (5 Y 4/1), medium, very glauconitic; many molds and casts; unit becoming thicker downstream	0.75	(0.23)
—Disconformity—		
Clay, olive-gray (5 Y 4/1), very burrowed; burrows filled with glauconite, possibly from bed above	0.25	(0.08)
—Disconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), very fine, micaceous, silty, glauconitic; many small mollusks, poorly preserved	5.0	(1.5)
Concretions, olive-gray (5 Y 4/1), calcareous, sandy, glauconitic, rounded	5.0	(1.5)
Sand, olive-black (5 Y 2/1), very fine, micaceous, silty, glauconitic; many small mollusks, moderate preservation	5.0	(1.5)
—Sea Level—		

69. (USGS Locality 26398) Left bank of the Potomac River, 0.6 mile (1.0 km) above the Route 301 bridge (Harry W. Nice Bridge), Charles County, Md., Colonial Beach North 7.5-min quadrangle

	Ft	(m)
Covered	20.0	(6.0)
Calvert Formation (Fairhaven Member)		
Sand, olive-brown (5 Y 4/4), silty, slightly phosphatic, pebbles along lower contact; burrows extending down into underlying unit	6.0	(1.8)
—Unconformity—		
Nanjemoy Formation(?) The following two units are provisionally referred to the Woodstock Member		
Sand, olive-gray (5 Y 4/1), fine, glauconitic; molds of mollusks abundant	4.0	(1.2)
—Disconformity—		
Clay, olive-gray (5 Y 4/1), very burrowed; burrows filled with glauconitic sand, probably from overlying bed	1.0	(0.3)
—Disconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic; small shells abundant	1.0	(0.3)
—Sea Level—		

70. (USGS Locality 26399) Left bank of the Rappahannock River, 0.5 mile (0.8 km) below Wilmont Wharf, King George County, Va., Rollins Fork 7.5-min quadrangle (see fig. 39)

	Ft	(m)
Covered	25.0	(7.6)
Calvert Formation (Fairhaven Member)		
Clay, light-yellowish-gray (5 Y 9/1), silty, sandy along lower contact, very weathered, blocky, very diatomaceous	12.0	(3.7)
Sand, grayish-brown (5 YR 3/2) silty, very fine, pebbles, phosphatic sand, teeth, bone along lower contact, becoming more clayey in upper portion	4.0	(1.2)
—Unconformity—		
Nanjemoy Formation(?) (possibly Woodstock Member)		
Sand, yellowish-gray (5 Y 8/1), weathered, poorly sorted, medium, some glauconite, clean, pebbles, dipping sharply downstream; burrows of unit above in upper 1 foot (0.3 m)	4.0	(1.2)
—Sea Level—		

71. (USGS Locality 26400) Right bank of the Mattaponi River, 0.2 mile (0.3 km) below the Rte. 647 bridge at Reedy Mill, Caroline County, Va., Penola 7.5-min quadrangle

	Ft	(m)
Covered	4.0	(1.2)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, glauconitic	6.0	(1.8)
—Unconformity—		
Nanjemoy Formation (Potapaco Member, Bed C)		
Sand, olive-gray (5 Y 4/1), clayey, glauconitic, burrowed	3.0	(0.9)
—Water Level—		

72. (USGS Locality 26401) Right bank of the Mattaponi River, 1.8 miles (2.9 km) (straightline) above the mouth of Maracossic Creek, King William County, Va., Sparta 7.5-min quadrangle

	Ft	(m)
Pleistocene(?)		
Sand, tan and orange, coarse	8.0	(2.4)
Calvert Formation		
Clay, yellowish-gray (5 Y 8/1), weathered, blocky, diatomaceous	2.0	(0.6)
Sand, grayish-brown (5 YR 3/2), silty, clayey, slightly phosphatic; pebbles along lower contact	8.0	(2.4)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1) silty, very fine, micaceous, weathered in upper portions	10.0	(3.0)
—Water Level—		

73. (USGS Locality 26402) Right bank of the Mattaponi River, 1.3 miles (2.1 km) (straightline) above the mouth of Maracossic Creek, King William County, Va., Sparta 7.5-min quadrangle (see fig. 38)

	Ft	*(m)*
Covered	2.0	(0.6)
Nanjemoy Formation(?) (Woodstock Member?)		
Sand, olive-gray (5 Y 4/1), silty, glauconitic, massive; molds and casts	6.0	(1.8)
Sand, white (N 9), clean, quartz, some molds and casts	0.25	(0.08)
Sand, greenish-yellow (10 Y 8/2), weathered, very clean, quartz, some glauconite; thin clay laminae showing ripple marks, burrowed	4.0	(1.2)
—Water Level—		

This deposit may represent a remnant of the nearshore facies of either the Woodstock Member or the Piney Point Formation.

74. (USGS Locality 26403) Right bank of the Pamunkey River, in a small ravine, 0.63 mile (1.01 km) south-southeast of the mouth of Totopotomoy Creek, 0.55 mile (0.89 km) north of the intersection of Rtes. 360 and 605, Hanover Co., Va., Manquin 7.5-min quadrangle (see fig. 37)

	Ft	*(m)*
Covered	3.0	(0.9)
Piney Point Formation (Bed A)		
Sand, yellowish-gray (5 Y 8/1), very calcareous, poorly sorted, fine to coarse, pebbly, partially indurated, leached; calcitic mollusks preserved (*Cubitostrea sellaeformis*); lower contact uneven, burrows projecting as much as 8 feet (2.4 m) into underlying unit	3.0	(0.9)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, massive, glauconitic; contains large numbers of well-preserved mollusks scattered throughout, large *Venericardia* concentrated in several thin bands, much carbonaceous material	15.0	(4.6)
Covered	6.0	(1.8)
—Water Level—		

75. (USGS Locality 26404) Left bank of the Pamunkey River, 0.85 mile (1.37 km) (straightline) below the Rte. 360 bridge, King William County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Piney Point Formation (Bed A)		
Sand, light-olive-gray (5 Y 6/1), very calcareous, moderately glauconitic, fine to medium, poorly sorted, partially indurated; containing many well-preserved mollusks; burrows from this unit extend downward through the Woodstock and below water level	2.0	(0.6)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, very glauconitic, well-sorted, micaceous; numerous well-preserved mollusks, most conspicuous are large *Venericardia*	5.0	(1.5)
—Sea Level—		

76. (USGS Locality 26405) Right bank of the Pamunkey River, at the waterfall just above the old Newcastle Bridge, 1.35 miles (2.17 km) (straightline) below the Rte. 360 bridge, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	2.0	(0.6)
Piney Point Formation (Bed A)		
Sand, yellowish-gray (5 Y 8/1), weathered, indurated, calcareous, coarse to medium, pebbly, poorly sorted; aragonitic shells leached, calcitic shells preserved; forms indurated ledge for small waterfall	2.0	(0.6)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, very glauconitic, micaceous, well-sorted; many well-preserved mollusks throughout, large *Venericardia* concentrated in several thin bands, burrows from overlying Piney Point as deep as 5 feet (1.5 m)	7.0	(2.1)
Covered	5.0	(1.5)
—Sea Level—		

77. (USGS Locality 26406) Right bank of the Pamunkey River, 0.5 mile (0.8 km) below the ruins of the old Newcastle Bridge, 0.45 mile (0.72 km) above the northern termination of Rte. 732, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	15.0	(4.6)
Piney Point Formation		
Sand, light-greenish-gray (5 GY 7/1), calcareous, medium, quartz, glauconitic; mollusks abundant, *Cubitostrea sellaeformis* common; lower contact uneven, burrows extending down into the underlying unit	2.5	(0.8)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous, well-sorted, very glauconitic; many small mollusks	1.5	(0.5)
—Sea Level—		

78. (USGS Locality 26407) Right bank of the James River, in a ravine downriver from the mouth of Baileys Creek at the northern termination of Rte. 644, 1.40 miles (2.25 km) (straightline) above Jordan Point, Prince George County, Va., Westover 7.5-min quadrangle

	Ft	*(m)*
Covered	50.0	(15.2)
Yorktown Formation (Morgarts Beach Member)		
Clay, blue-gray (4 B 4/1), silty; shells small and mostly leached	15.0	(4.6)
—Grades sharply—		
Yorktown Formation (Rushmere Member)		
Sand, blue-gray (5 B 5/1), medium, quartz; numerous large bivalves, especially *Chesapecten madisonius* and *Mercenaria tridacnoides*	4.0	(1.2)
—Unconformity—		
Eastover Formation (Cobham Bay Member)		
Sand, blue-gray (5 B 5/1) where fresh, medium, quartz, phosphatic; numerous large bivalves (*Isognomon, Chesapecten middesexensis, Euloxa*)	1.0	(0.3)
—Unconformity—		

78. (USGS Locality 26407)—Continued

	Ft	(m)
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous; mollusks common, poorly preserved	12.0	(3.7)
Covered	20.0	(6.1)

79. (USGS Locality 26408) Right bank of the Tombigbee River, at Hatchetigbee Bluff, Washington County, Ala.
Section is described by Smith and Johnson (1887, p. 40).

80. (USGS Locality 26409) Left bank of the Potomac River, 0.8 mile (1.3 km) northeast of the Piney Point Lighthouse on Piney Point, St. Marys County, Md., Piney Point 7.5-min quadrangle
The following is a summary of the well log taken by Otton (1955, p. 303-306) from the type well of the Piney Point. For more detail refer to that report. Well altitude: 5 feet (1.5 m)

	Thickness		Depth	
	Ft	(m)	Ft	(m)
Pleistocene deposits	120	(36.6)	0–120	(0–36.6)
Calvert Formation	100	(30.5)	120–220	(36.6–67.1)
Piney Point Formation	50	(15.2)	220–270	(67.1–83.3)
Nanjemoy Formation	130	(39.6)	270–400	(82.3–121.9)
Aquia Formation	10	(3.0)	400–410	(121.9–125.0)

81. (USGS Locality 26410) Left bank of the Rappahannock River, 0.2 mile (0.3 km) below the mouth of Bristol Mine Run, at a ravine and waterfall, 0.95 mile (0.29 km) above Owl Hollow, Westmoreland County, Va., Rollins Fork 7.5-min quadrangle

	Ft	(m)
Covered	50.0	(15.2)
Calvert Formation (Fairhaven Member)		
Clay, olive-brown (5 Y 4/4), silty, blocky, very diatomaceous, sandy and pebbly along a sharp lower contact	20.0	(6.1)
—Disconformity—		
Sand, olive-brown (5 Y 4/4), silty, clayey, quartz and phosphate pebbles, teeth, bone along irregular, burrowed lower contact; grades into blocky, diatomaceous clay in upper one-half	4.5	(1.4)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), silty, very fine, micaceous	1.5	(0.5)
Covered	2.0	(0.6)
—Sea Level—		

82. (USGS Locality 26411) West shore of the Chesapeake Bay, 2 miles (3.2 km) below Long Beach, 2.25 miles (3.6 km) above Rocky Point, just above the Baltimore Gas and Electric powerplant, Calvert County, Md., Cove Point 7.5-min quadrangle
Summary of data on a core taken at the B.G. and E. powerplant site by F.C. Whitmore and T.G. Gibson in September 1967. Examination of lower 9.0 feet (2.7 m) of the core has confirmed the presence of the Piney Point Formation on the basis of lithology, mollusks (*Cubitostrea sellaeformis*), and dinoflagellates. Used with the permission of F.C. Whitmore (written commun., 1984). Altitude of well 120 feet (36.6 m) above sea level.

	Thickness		Depth	
	Ft	(m)	Ft	(m)
Pleistocene(?)	29	(8.8)	0–29	(0– 8.8)
St. Marys Formation	55	(16.8)	29–84	(8.8–25.6)
Choptank Formation	50	(15.2)	84–134	(25.6–40.8)
Calvert Formation				
Plum Point Marl Member	84	(25.6)	134–218	(40.8–66.4)
Fairhaven Member	111	(33.8)	218–329	(66.4–100.3)
Piney Point Formation	9	(2.7)	329–338	(100.3–103.0)

83. (USGS Locality 26412) Right bank of the Pamunkey River at Horseshoe, Hanover County, Va., Manquin 7.5-min quadrangle. Type locality of the Old Church Formation. Hypostratotype or reference section for the Piney Point Formation (see fig. 40)

	Ft	(m)
Covered	10.0	(3.0)
Calvert Formation		
Sand, olive-brown (5 Y 4/4), clayey, phosphatic; quartz and phosphate pebbles and sand along sharp contact; some burrows extend downward through the Old Church and spread laterally along Old Church-Piney Point contact; fining to a blocky clay upward	6.0	(1.8)
—Unconformity—		
Old Church Formation		
Sand, grayish-olive (10 Y 4/2), clayey, poorly sorted; some glauconite present, probably reworked from below; very calcareous owing to microfossil content, both primary and reworked; large concretions mark center of bed; mollusks common but small and poorly preserved, molds of Lucinids	3.0	(0.9)
—Unconformity—		
Piney Point Formation (Bed B)		
Sand, olive-gray (5 Y 4/1), clayey, very glauconitic, very calcareous owing to shell fragments and microfossils; many well-preserved mollusks, several distinct thin beds of *Cubitostrea sellaeformis*	15.0	(4.6)
—Sea Level—		

84. (USGS Locality 26413) Left bank of the Pamunkey River, just below Piping Tree Ferry, King William County, Va., King William 7.5-min quadrangle (see fig. 41)

	Ft	(m)
Covered	20.0	(6.1)
Piney Point Formation		
Sand, greenish-gray (5 GY 6/1), clayey, glauconitic; partially indurated, concentrations of *Cubitostrea sellaeformis* in thin, cemented beds dipping downstream are exposed at very low water	4.0	(1.2)
—Sea Level—		

There are exposures at places along the bluffs downriver from Piping Tree Ferry. Slumps in this area expose up to 15.0 feet (4.6 m) of silty clays of the Calvert Formation overlying the Piney Point. The Old Church Formation is absent. In some exposures the Eastover Formation can be seen overlying the Calvert.

85. (USGS Locality 26414) Right bank of the Pamunkey River, below Retreat, 0.05 mile (0.01 km) below the mouth of Whiting Swamp, Hanover County, Va., Manquin 7.5-min quadrangle (see fig. 42)

	Ft	(m)
Covered and sloped	20.0	(6.1)
Calvert Formation		
Clay, very weathered, silty, light gray	2.0	(0.6)
Formation(?)		
Sand, fine, moderately glauconitic, quartz, poorly sorted; cemented with poor molds and casts of mollusks; contact with underlying unit very irregular; deep burrows into underlying unit	3.0	(1.0)
—Unconformity—		
Piney Point Formation (Bed C)		
Sand, olive-black (5 Y 2/1), coarse to medium, very glauconitic, weathered to yellowish-gray in upper portions; many small burrows weather out; no molds or casts; pink claystone concretions occur in upper portion	9.0	(2.7)
—Sea Level—		

86. (USGS Locality 26415) Right bank of the Pamunkey River at Putneys Mill, 2.2 miles (3.5 km) north of Tunstall Station, New Kent County, Va., Tunstall 7.5-min quadrangle

Core taken by L.E. Edwards, L.M. Bybell, and T.G. Gibson (all of USGS). Formational picks by L.E. Edwards. Altitude of drilling site: 10 feet (3.0 m) above sea level.

	Thickness		Depth	
	Ft	(m)	Ft	(m)
Pleistocene	21	(6.4)	0–21	(0–6.4)
Old Church Formation	6	(1.8)	21–27	(6.4–8.2)
Piney Point Formation	33	(10.0)	27–60	(8.2–18.3)
Uncertain	8	(2.4)	60–68	(18.3–20.7)
Nanjemoy Formation	49	(14.9)	68–117	(20.7–35.7)
Marlboro Clay	13	(4.0)	117–130	(35.7–39.6)

87. (USGS Locality 26416) Right bank of the Pamunkey River, 0.50 mile (0.80 km) below the mouth of Matadequin Creek, New Kent County, Va., Tunstall 7.5-min quadrangle

	Ft	(m)
Covered	8.0	(2.4)
Old Church Formation		
Sand, grayish-olive (10 Y 4/2), clayey, fine, very calcareous due to high microfossil content; some molds, few solitary corals	4.0	(1.2)
—Sea Level—		

88. (USGS Locality 26417) Warren Brothers sand pits, 1.4 miles (2.3 km) southeast of Bottoms Bridge, 2.0 miles (3.2 km) northeast of Elko, Henrico County, Va., Roxbury 7.5-min quadrangle. The Yorktown and Eastover Formations are exposed in an adjacent river escarpment. The Old Church Formation was exposed in the bottom of the pit below the terrace gravels.

	Ft	(m)
Covered	5.0	(1.5)

88. (USGS Locality 26417)—Continued

	Ft	(m)
Yorktown Formation (Rushmere Member)		
Sand, grayish-orange (5 Y 8/4), weathered, fine, very shelly; many *Chesapecten madisonius, Ostrea sculpturata, Chama congregata*	10.0	(3.0)
—Unconformity—		
Eastover Formation (Cobham Bay Member)		
Sand, blue-gray (5 B 5/1), fine, phosphatic, pebbles along lower contact; contains *Chesapecten middlesexensis, Isognomon*	1.0	(0.3)
—Unconformity—		
Eastover Formation (Claremont Manor Member)		
Clay, greenish-gray (5 GY 3/1), silty	15.0	(4.6)
Covered	50.0	(15.2)
Bottom of the terrace gravels that were quarried here.		
—Unconformity—		
Old Church Formation		
Sand, grayish-olive (10 Y 4/2), fine, quartz, partially indurated, somewhat weathered; most aragonitic mollusks leached, calcitic forms well preserved (*Pycnodonte, Anomia, Pecten*)	3.0	(0.9)

89. (USGS Locality 26418) Gravatts Millpond, on Millpond Creek, 0.9 mile (1.4 km) west of Etna Mills, King William County, Va., Hanover 7.5-min quadrangle

	Ft	(m)
Covered	10.0	(3.0)
Eastover Formation (Claremont Manor Member)		
Clay, grayish-yellow (5 Y 8/4), blocky, silty, weathered	5.0	(1.5)
Sand, grayish-yellow (5 Y 8/4), fine; many molds and casts, especially *Glossus, Turritella*	0.25	(0.08)
Sand, grayish-yellow (4 Y 8/4), weathered, fine, clayey	1.5	(0.5)
Clay, greenish-gray (5 GY 3/1), blocky, silty	4.0	(1.2)
Sand, greenish-gray (5 GY 3/1), fine, clayey, cobbles and pebbles along base	1.5	(0.5)
—Unconformity—		
Calvert Formation		
Sand, olive-brown (5 Y 4/4), clayey, phosphatic; fining upward to diatomaceous clay; phosphate pebbles along base, fining to sand-sized above; phosphatized whale bone and vertebrate teeth along base; middle Miocene articulated whale, porpoise, and turtle skeletons common near base	8.0	(2.4)
—Unconformity—		
Old Church Formation(?)		
Sandstone, grayish-olive (10 Y 4/2), weathered; large, residual, cobble- to boulder-sized concretions occur along contact with lower unit	1.0	(2.4)
—Unconformity—		
Nanjemoy Formation (Woodstock Member)		
Sand, olive-black (5 Y 2/1), very fine, silty, micaceous, glauconitic; contains carbonaceous material, nuts	1.5	(0.5)

90. (USGS Locality 26421) Right bank of the Pamunkey River, 0.30 mile (0.48 km) above Horseshoe, Hanover County, Va., Manquin 7.5-min quadrangle

	Ft	*(m)*
Covered	10.0	(3.0)
Pleistocene(?)		
Sand, orange, gravelly, cross-bedded	4.0	(1.2)
—Unconformity—		
Eastover Formation (Claremont Manor Member)		
Sand, greenish-gray (5 GY 5/1), fine to medium, silty, clayey, poorly sorted; pebbles along contact with burrows extending down into underlying clay; few molds of *Glossus*	8.0	(2.4)
Clay, greenish-gray (5 GY 5/1), silty and sandy near basal contact; grades upward into blocky, diatomaceous clay	15.0	(4.6)
—Unconformity—		
Calvert Formation		
Clay, olive-brown (5 Y 4/4); silty in lower 10.0 feet (3.0 m), grades to blocky diatomite above, phosphate along lower contact	15.0	(4.6)
—Unconformity—		
Old Church Formation (Bed B)		
Sand, grayish-olive (5 Y 4/1), clayey, fine; partially indurated	0.8	(0.25)
Piney Point Formation		
Sand, olive-gray (5 Y 4/1), clayey, very glauconitic, very calcareous owing to shell fragments and microfossils	15.0	(4.6)

91. (USGS Locality 26454) Right bank of the Pamunkey River, on a bend 0.5 mile (0.8 km) west of Horseshoe, 2.4 miles (3.8 km) north of Glimpses Corner, Hanover County, Va., Manquin 7.5-min quadrangle. Hypostratotype or reference section for the Piney Point Formation

	Ft	*(m)*
Eastover Formation (?)		
Sand, weathered, grayish-yellow, fine	9.0	(2.7)
Calvert Formation (zones 12-13 of Shattuck, 1904)		
Clay, weathered, light-gray, silty near base, becoming blocky above	6.0	(1.8)
Old Church Formation		
Sand, weathered, yellowish-gray	0.25	(0.07)
Piney Point Formation (Bed B)		
Sand, olive-gray (5 Y 5/1), fine, very calcareous, very glauconitic, weathered and leached in upper 10.0 feet (3.0 m); burrows containing much glauconite extend as much as 2.0 feet (0.6 m) into underlying bed	14.0	(4.2)
Piney Point Formation (Bed A)		
Sand, light-olive gray (5 Y 6/1), very calcareous, fine; boulder-sized concretions 2.0 feet (0.6 m) from upper contact; contact burrowed	5.1	(1.5)
—Sea Level—		

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PLATES 1–6

Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225.

PLATE 1

[Mollusks common in the Piscataway Member of the Aquia Formation. All specimens were collected from the Pamunkey River, 0.5 mile (0.8 km) east of Wickham Crossing, Hanover County, Va. (Locality 8) (USGS Locality 26337)]

FIGURE 1, 2, 4, 5. *Ostrea alepidota* Dall, 1898.

1. Left valve of specimen (USNM 366470); length 73.5 mm, height 85.1 mm.
2. Right valve of specimen (USNM 366470); length 65.4 mm, height 82.6 mm.
4. Left valve of specimen (USNM 366472); length 58.9 mm, height 74.3 mm.
5. Left valve of specimen (USNM 366473); length 36.3 mm, height 44.6 mm.

3. *Turritella humerosa* Conrad, 1835.
Apertural view of an incomplete specimen (USNM 366471); height 32.5 mm.

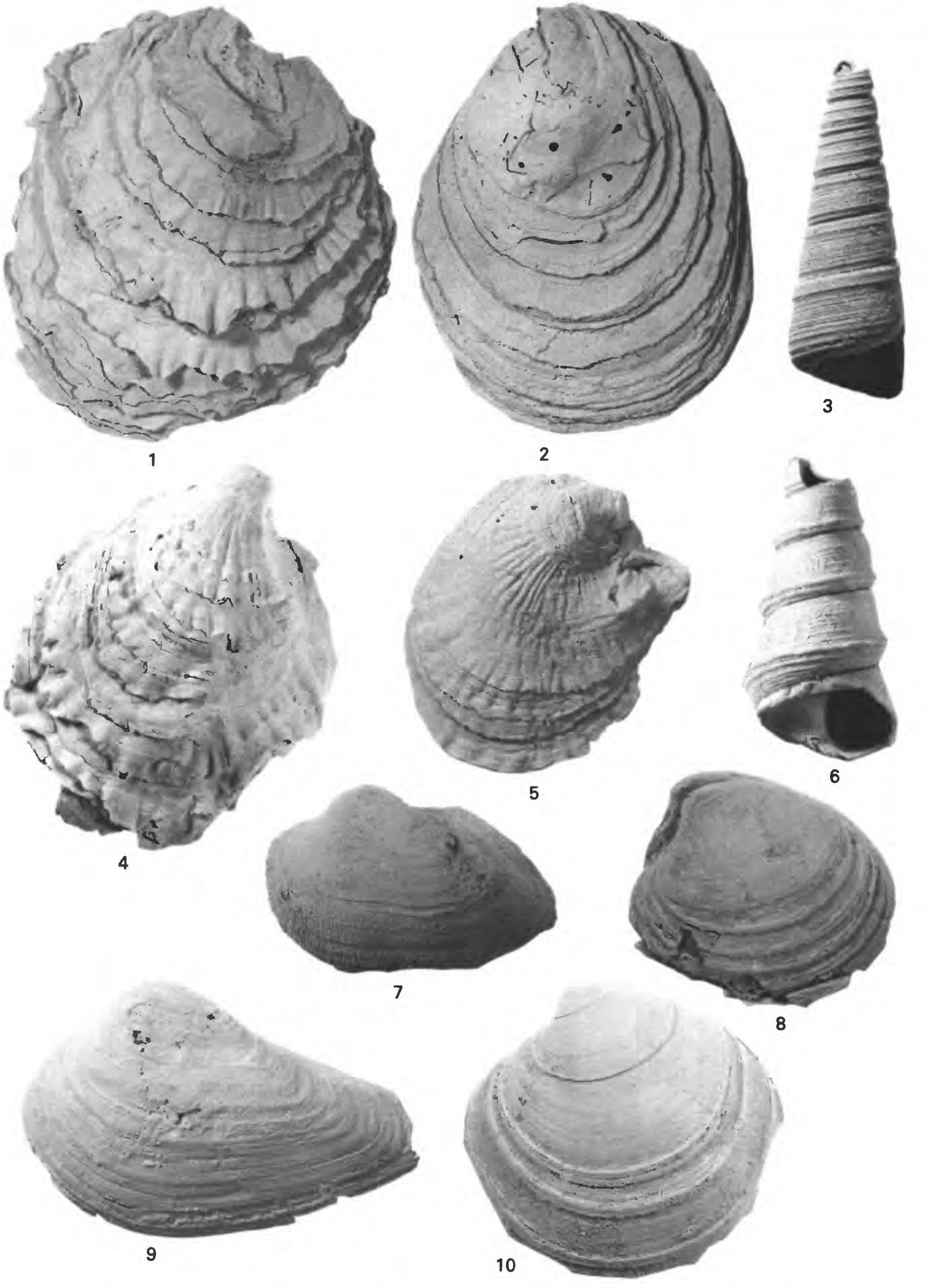
6. *Turritella mortoni* Conrad, 1830.
Apertural view of an incomplete specimen (USNM 366474); height 35.8 mm.

7. *Cucullaea gigantea* Conrad, 1830.
Left valve of specimen (USNM 366475); length 42.4 mm, height 27.4 mm.

8. *Pitar pyga* Conrad, 1845.
Left valve of a double-valved specimen (USNM 366476); length 46.3 mm, height 38.9 mm.

9. *Crassatellites capricranium* (Rogers, 1839).
Left valve of specimen (USNM 366477); length 59.1 mm, height 38.6 mm.

10. *Dosiniopsis lenticularis* (Rogers, 1839).
Left valve of specimen (USNM 366478); length 47.1 mm, height 44.5 mm.



OSTREA ALEPIDOTA, TURRITELLA HUMEROSA, TURRITELLA MORTONI, CURULLAEA GIGANTEA, PITAR PYGA, CRASSATELLITES CAPRICRANIUM, DOSINIOPSIS LENTICULARIS

PLATE 2

[Mollusks common in the Paspotansa Member of the Aquia Formation. All except figure 5 were collected from the Potomac River, 0.3 mile (0.5 km) above Belvedere Beach, King George County, Va. (Locality 30)]

FIGURE 1. *Cucullaea gigantea* Conrad, 1830.
Left valve of specimen (USNM 366479); length 83.3 mm, height 71.8 mm.

2. *Pycnodonte* sp.
Left valve of specimen (USNM 366480); length 74.2 m, height 74.6 mm.

3. *Turritella mortoni* Conrad, 1830.
Apertural view of specimen (USNM 366481); height 105.0 mm.

4, 8. *Ostrea sinuosa* Rogers and Rogers, 1837.
4. Left valve of specimen (USNM 366482); length 152.8 mm, height 134.3 mm.
8. Right valve of specimen (USNM 366482); length 98.8 mm, height 118.3 mm.

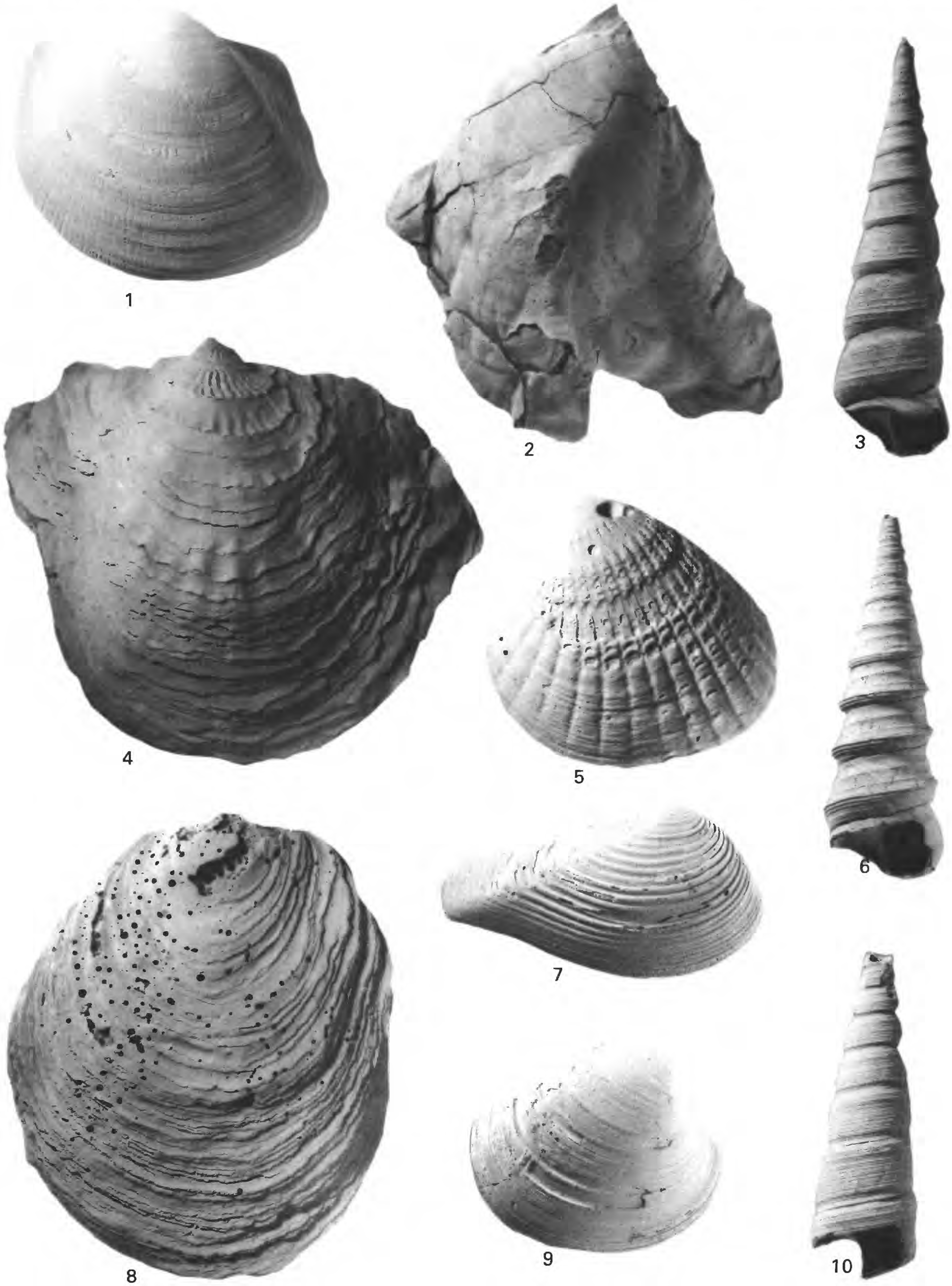
5. *Venericardia regia* Conrad, 1865.
Left valve of specimen (USNM 366483) from the Potomac River 0.1 mile (0.3 km) below the mouth of Passapatanzy Creek, King George County, Va. (Locality 12) (USGS Locality 26341); length 75.4 mm, height 71.7 mm.

6. *Turritella mortoni* Conrad, 1830.
Apertural view of nearly complete specimen (USNM 366484); height 92.3 mm.

7. *Crassatellites alaeformis* Conrad, 1830.
Right valve of specimen (USNM 366485); length 51.9 mm, height 22.7 mm.

9. *Pitar pyga* Conrad, 1845.
Right valve of specimen (USNM 366486); length 33.6 mm, height 28.1 mm.

10. *Turritella humerosa* Conrad, 1835.
Apertural view of an incomplete specimen (USNM 366487); height 49.8 mm.



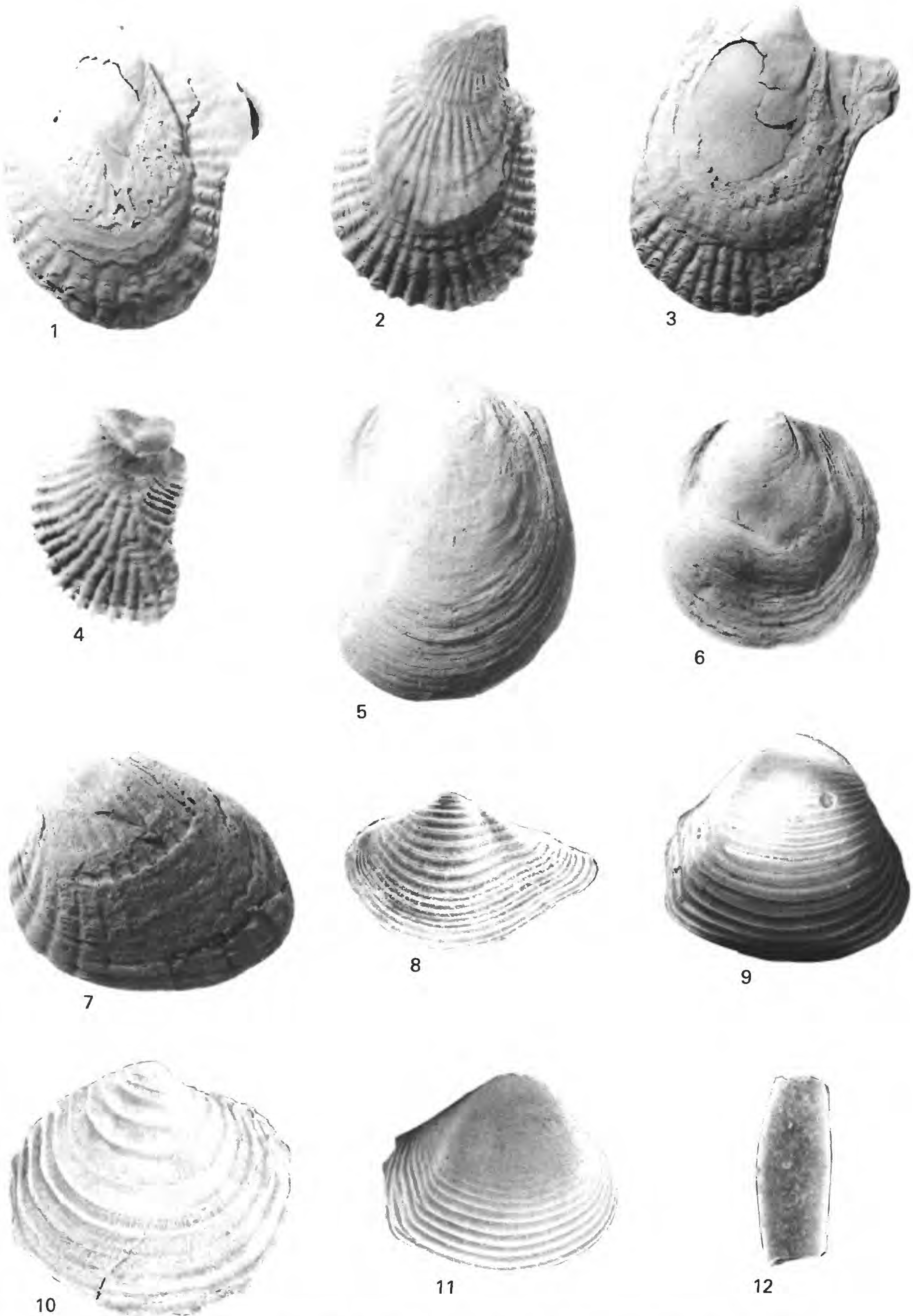
CUCULLAEA GIGANTEA, PYCNODONTE sp., *TURRITELLA MORTONI, OSTREA SINUOSA VENERICARDIA REGIA, CRASSATELLITES ALAEFORMIS, PITAR PYGA, TURRITELLA HUMEROSA*

PLATE 3

[Mollusks common in the Potapaco Member of the Nanjemoy Formation. Figures 1, 3, and 5 from the Pamunkey River, 0.8 mile (1.3 km) below Hanovertown, Hanover County, Va. (Locality 48) (USGS Locality 26377). Figures 2, 4, and 6 from the Pamunkey River, 0.45 mile (0.72 km) above the mouth of Millpond Creek on the right bank, Hanover County, Va. (USGS Locality 26424). Figures 7-9, 11, and 12 from the Potomac River, 2.3 miles (3.9 km) above Popes Creek, Charles County, Md. (USGS Locality 26425). Figure 10 from the Rappahannock River, opposite Goat Island, Caroline County, Va. (Locality 31) (USGS Locality 26360)]

FIGURE

1. *Cubitostrea* sp.
   Left valve of specimen (USNM 366488); length 48.5 mm, height 51.6 mm.
2. *Cubitostrea* sp.
   Left valve of specimen (USNM 366489); length 35.7 mm, height 50.4 mm.
3. *Cubitostrea* sp.
   Left valve of specimen (USNM 366490); length 37.7 mm, height 58.5 mm.
4. *Cubitostrea* sp.
   Left valve of specimen (USNM 366491); length 18.7 mm, height 27.6 mm.
5. *Cubitostrea* sp.
   Right valve of specimen (USNM 366492); length 47.9 mm, height 56.2 mm.
6. *Cubitostrea* sp.
   Right valve of specimen (USNM 366493); length 18.8 mm, height 21.4 mm.
7. *Venericardia potapacoensis* Clark and Martin, 1901.
   Left valve of specimen (USNM 366494); length 29.0 mm, height 24.1 mm.
8. *Nuculana parva* (Rogers, 1837).
   Right valve of specimen (USNM 366495); length 4.62 mm, height 2.85 mm.
9. *Vokesula* sp.
   Right valve of specimen (USNM 366496); length 4.48 mm, height 4.20 mm.
10. *Lucina* sp.
    Right valve of specimen (USNM 366497); length 5.14 mm, height 4.66 mm.
11. *Vokesula* sp.
    Right valve of specimen (USNM 366498); length 4.29 mm, height 3.65 mm.
12. *Cadulus* sp.
    Lateral view of incomplete specimen (USNM 366499); length 3.45 mm.



CUBITOSTREA sp., *VENERICARDIA POTAPACOENSIS*, *NUCULANA PARVA*, *VOKESULA* sp., *LUCINA* sp., *CADULUS* sp.

PLATE 4

[Mollusks common in the Woodstock Member of the Nanjemoy Formation. Figures 5, 6, and 10–14 from the Pamunkey River, in a small ravine, 0.63 mile (1.01 km) south-southeast of the mouth of Totopotomoy Creek, Hanover County, Va. (Locality 74) (USGS Locality 26403). Other localities are as described below]

FIGURE 1. *Glycymeris* sp.
Right valve of specimen (USNM 366500) from the Pamunkey River at the termination of Rte. 732, Hanover County, Va. (Locality 64) (USGS Locality 26393); length 22.0 mm, height 21.0 mm.

2–4. Specimens from the Potomac River, 0.95 miles (1.53 km) below the mouth of Popes Creek, Charles County, Md. (Locality 68) (USGS Locality 26397).

2. *Cubitostrea* sp.
Left valve of specimen (USNM 366501); length 13.8 mm, height 20.2 mm.

3. *Cubitostrea* sp.
Left valve of specimen (USNM 366502); length 11.8 mm, height 17.0 mm.

4. *Cubitostrea* sp.
Right valve of specimen (USNM 366503); length 12.0 mm, height 22.0 mm.

5. *Nuculana* sp.
Right valve of specimen (USNM 366504); length 4.14 mm, height 2.56 mm.

6. *Macrocallista subimpressa* (Conrad, 1848).
Left valve of specimen (USNM 366505); length 21.3 mm, height 13.9 mm.

7–9. Specimens from the Pamunkey River, just upstream of the old Newcastle Bridge, Hanover County, Va. (Locality 76) (USGS Locality 26405).

7. *Corbula aldrichi* Meyer, 1885.
Right valve of specimen (USNM 366506); length 10.0 mm, height 7.5 mm.

8. *Venericardia ascia* Rogers and Rogers, 1839.
Right valve of specimen (USNM 366507); length 41.4 mm, height 37.5 mm.

9. *Venericardia ascia* Rogers and Rogers, 1839.
Right valve of specimen (USNM 366508); length 62.6 mm, height 54.1 mm.

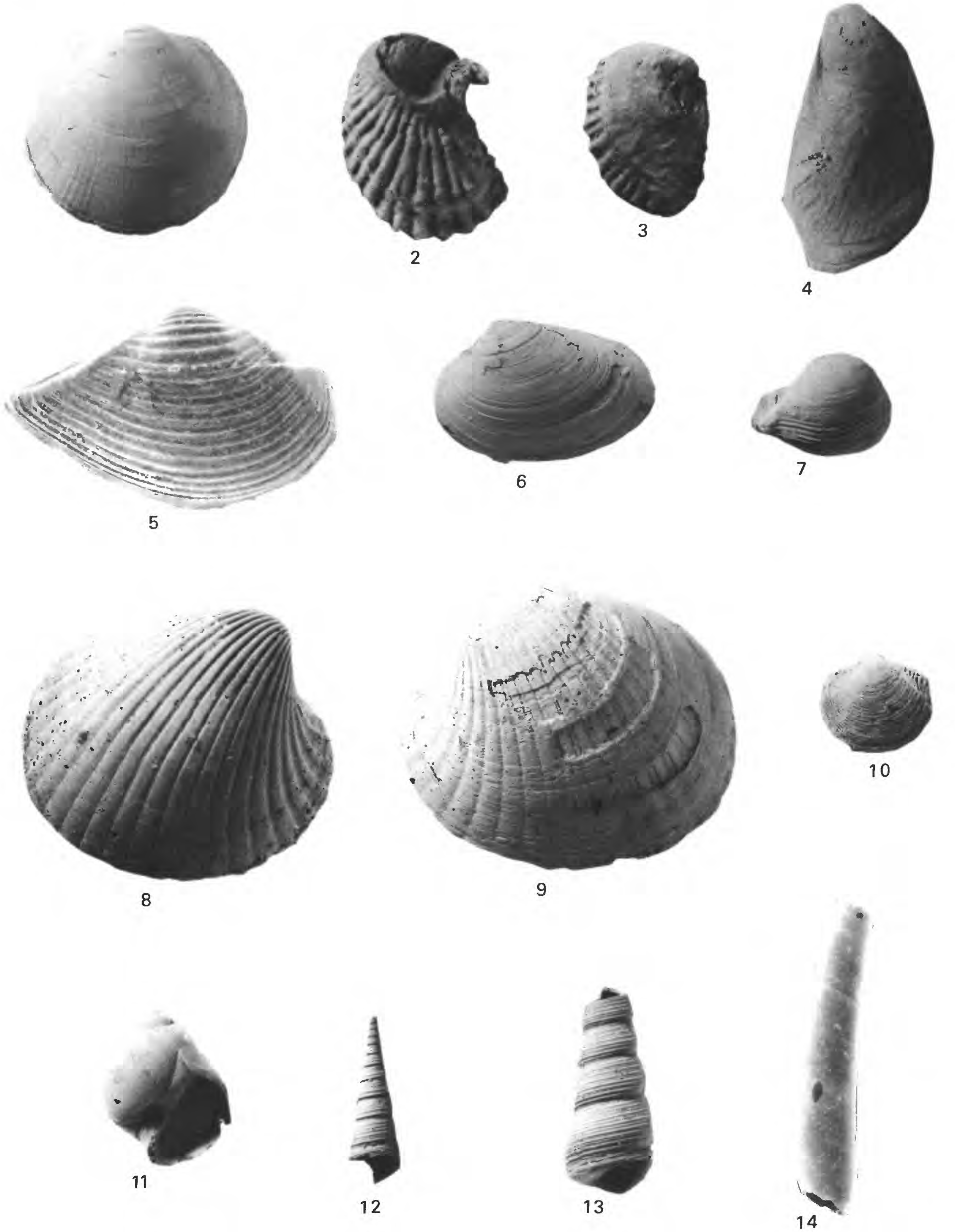
10. *Lucina dartoni* Clark, 1895.
Left valve of specimen (USNM 366509); length 6.1 mm, height 5.2 mm.

11. *Lunatia* sp.
Apertural view of specimen (USNM 366510); height 14.2 mm.

12. *Turritella* sp.
Apertural view of incomplete specimen (USNM 366511); height 12.2 mm.

13. *Turritella* sp.
Apertural view of incomplete specimen (USNM 366512); height 14.4 mm.

14. *Cadulus* sp.
Lateral view of nearly complete specimen (USNM 366513); height 4.93 mm.



GLYCYMERIS sp., *CUBITOSTREA* sp., *NUCULANA* sp., *MACROCALLISTA SUBIMPRESSA*, *CORBULA ALDRICHI*, *VENERICARDIA ASCIA LUCINA DARTONI*, *LUNATIA* sp., *TURRITELLA* sp., *CADULUS*

PLATE 5

[Mollusks common in the Piney Point Formation. Figures 1-3, 8-19, and 21 from the Pamunkey River, 1.0 mile (1.6 km) west of Horseshoe, Hanover County, Va. (USGS Locality 26427). Figures 4 and 20 from the Pamunkey River at the termination of Rte. 732, Hanover County, Va. (USGS Locality 26426). Figures 5-7 from the Pamunkey River at Horseshoe, Hanover County, Va. (Locality 83) (USGS Locality 26412)]

FIGURE 1. *"Pecten"* sp.
Right valve of specimen (USNM 366514); length 15.0 mm, height 15.8 mm.

2. *"Pecten"* sp.
Right valve of specimen (USNM 366515); length 7.1 mm, height 7.6 mm.

3. *"Pecten"* sp.
Right valve of specimen (USNM 366516); length 11.7 mm, height 12.4 mm.

4-6, 8, 9. *Cubitostrea sellaeformis* (Conrad, 1832).
- 4. Left valve of a double-valved individual (USNM 366517); length 110.9 mm, height 99.7 mm.
- 5. Left valve of specimen (USNM 366518); length 77.7 mm, height 76.3 mm.
- 6. Right valve of specimen (USNM 366519); length 70.7 mm, height 82.3 mm.
- 8. Left valve of specimen (USNM 366521); length 16.1 mm, height 24.2 mm.
- 9. Left valve of specimen (USNM 366522); length 11.1 mm, height 19.7 mm.

7. *Plicatula filamentosa* Conrad, 1833.
Right valve of incomplete specimen (USNM 366520); length 10.5 mm, height 9.2 mm.

10. *Anomia lisbonensis* (Aldrich, 1886).
Left valve of specimen (USNM 366523); length 17.5 mm, height 19.4 mm.

11. *Leda coelatella* Van Winkle, 1919.
Left valve of specimen (USNM 366524); length 15.3 mm, height 6.8 mm.

12. *Leda semen* Lea, 1833.
Right valve of specimen (USNM 366525); length 11.2 mm, height 5.8 mm.

13. *Glycymeris lisbonensis* Harris, 1919.
Right valve of specimen (USNM 366526); length 18.5 mm, height 16.9 mm.

14, 15. *Anapteris regalis* Van Winkle, 1919.
- 14. Left valve of specimen (USNM 366527); length 15.5 mm, height 8.5 mm.
- 15. Left valve of specimen (USNM 366528); length 14.5 mm, height 7.6 mm.

16. *Venericardia rotunda* Lea, 1833.
Left valve of specimen (USNM 366529); length 14.5 mm, height 14.0 mm.

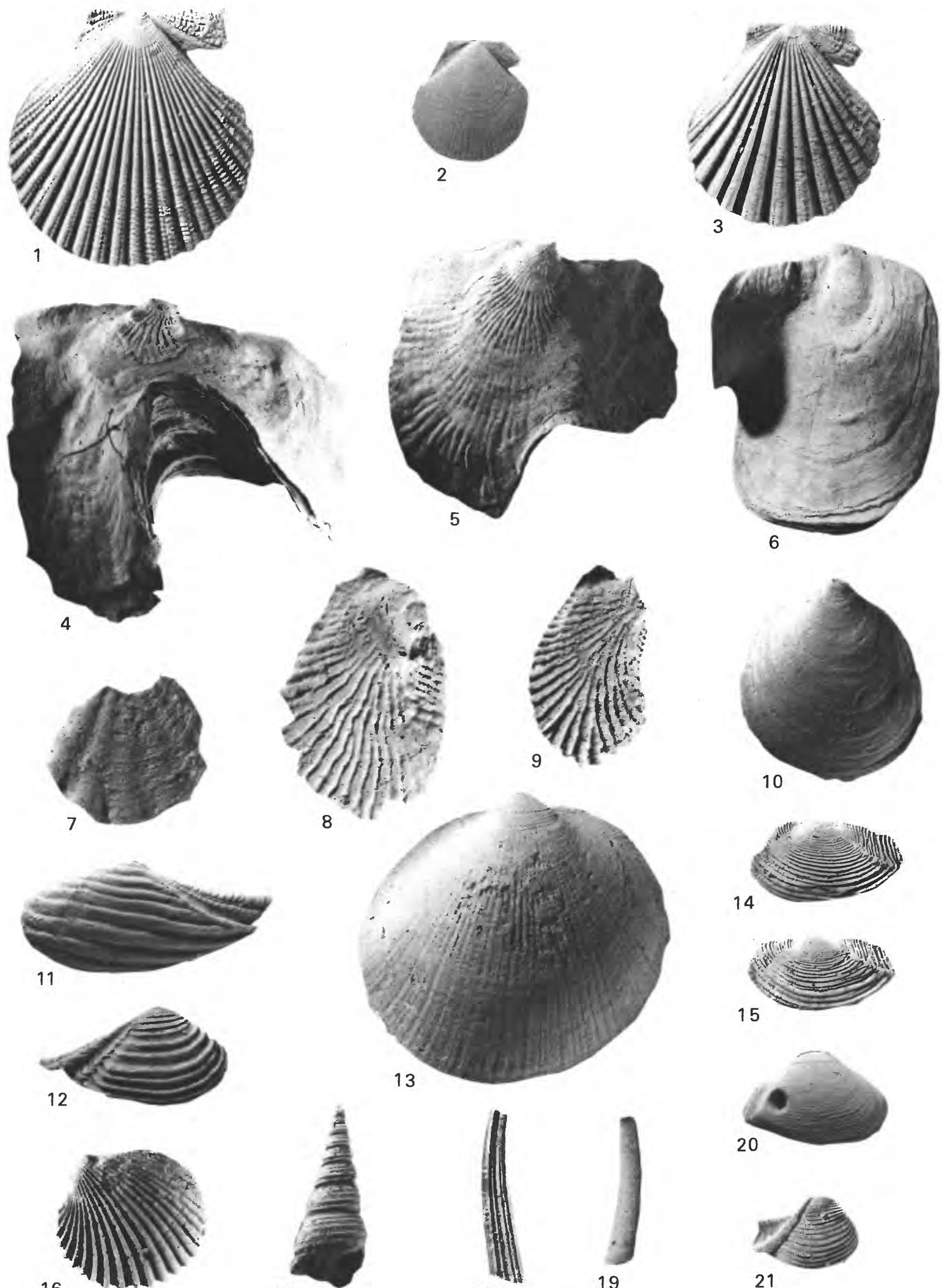
17. *Turritella nasuta* Gabb, 1860.
Apertural view of incomplete specimen (USNM 366530); height 11.1 mm.

18. *Dentalium* sp.
Lateral view of specimen (USNM 366531); height 11.4 mm.

19. *Dentalium* sp.
Lateral view of specimen (USNM 366532); height 9.2 mm.

20. *Corbula* sp.
Right valve of specimen (USNM 366533); length 8.7 mm, height 5.5 mm.

21. *Caestocorbula fossata* (Meyer and Aldrich, 1886).
Right valve of specimen (USNM 366534); length 6.9 mm, height 4.6 mm.



"PECTEN" sp., *CUBITOSTREA SELLAEFORMIS, PLICATULA FILAMENTOSA, ANOMIA LISBONENSIS, LEDA COELATELLA, LEDA SEMEN, GLYCYMERIS, ANAPTERIS REGALIS, TURRITELLA NASUTA, DENTALIUM* sp., *CORBULA* sp., *CAESTOCORBULA FOSSATA*

PLATE 6

[Mollusks common in the Old Church Formation. All specimens from the Warren Brothers sand pit, 1.4 miles (2.3 km) southeast of Bottoms Bridge, Henrico County, Va. (Locality 88) (USGS Locality 26417)]

FIGURE 1–3. *Pycnodonte* sp.
1. Left valve of specimen (USNM 366535); length 80.9 mm, height 66.7 mm.
2. Left valve of specimen (USNM 366536); length 53.9 mm, height 57.0 mm.
3. Right valve of specimen (USNM 366535); length 60.2 mm, height 59.2 mm.

4. *Anomia ruffini* Conrad, 1843.
Left valve of specimen (USNM 366537); length 49.5 mm, height 47.7 mm.

5. "*Pecten*" sp.
Right valve of specimen (USNM 366538); length 11.5 mm, height 12.3 mm.

6. "*Pecten*" *seabeensis* Richards, 1947.
Right valve of specimen (USNM 366539); length 11.3 mm, height 11.5 mm.

7. *Bicorbula idonea* (Conrad, 1833).
Latex cast of right valve (USNM 366540); length 23.9 mm, height 18.7 mm.

8. *Mercenaria gardnerae* Kellum, 1926.
Latex cast of right valve (USNM 366541); length 44.5 mm, height 38.4 mm.

9. *Lucina* sp.
Internal mold of left valve (USNM 366542); length 30.7 mm, height 25.7 mm.

10. *Lucina* sp.
Latex cast of hinge area of double-valved individual (USNM 366543); length 36.4 mm.

11. *Isognomon* sp.
Partial external mold of right valve (USNM 366544); length 87.4 mm, height 56.0 mm.

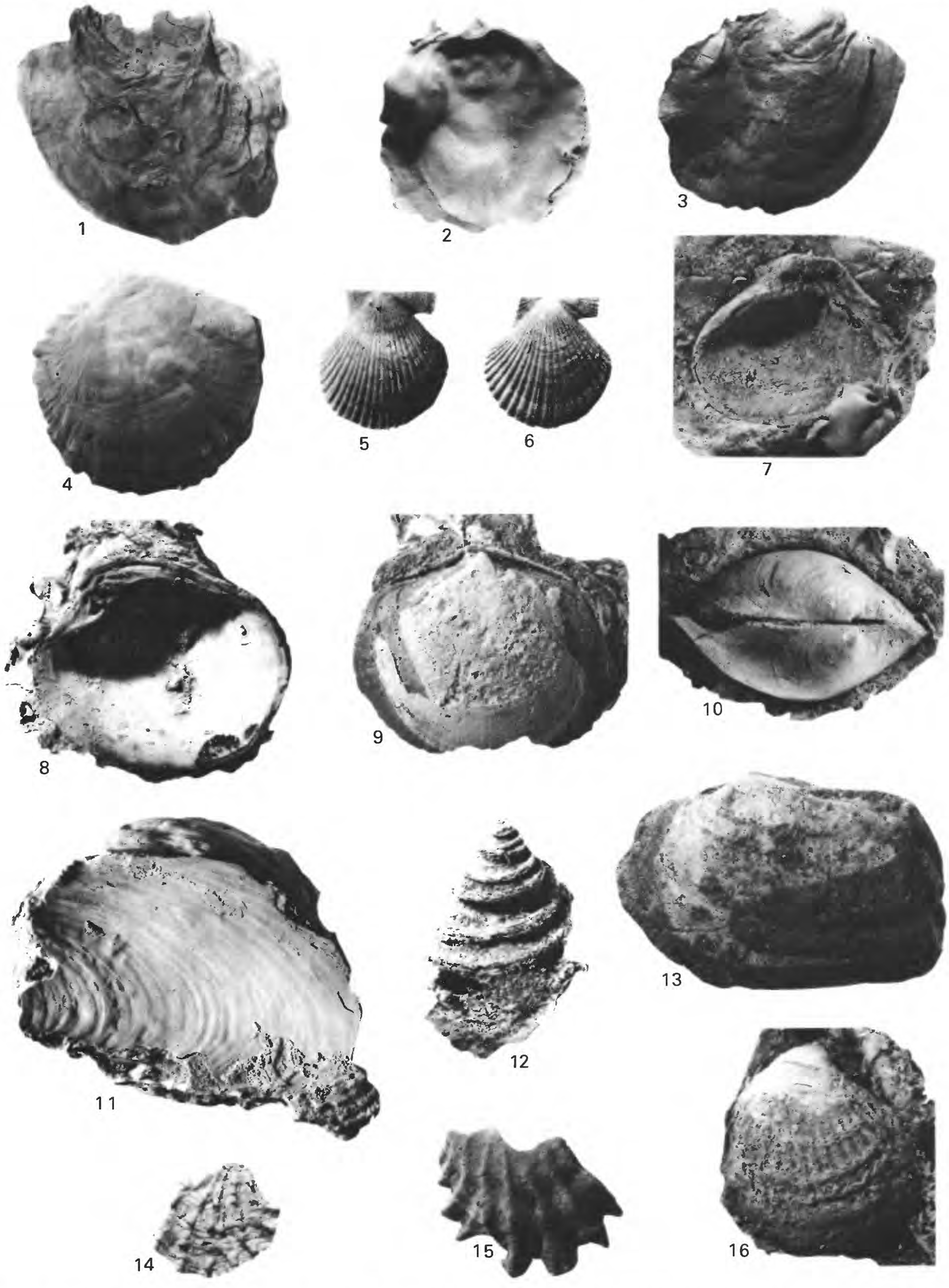
12. *Ecphora* sp.
Latex cast of incomplete specimen (USNM 366545); height 16.6 mm.

13. *Panopea* sp.
Internal mold of left valve of specimen (USNM 366546); length 45.6 mm, height 30.1 mm.

14. *Plicatula* sp.
Exterior view of a fragment (USNM 366547); length 11.6 mm, height 11.2 mm.

15. *Plicatula* sp.
Exterior view of a fragment (USNM 366548); length 16.0 mm, height 15.1 mm.

16. *Cyclocardia* sp.
Latex cast of right valve of specimen (USNM 366549); length 15.3 mm, height 15.9 mm.



PYCNODONTE sp., *ANOMIA RUFFINI*, *"PECTEN"* sp., *"PECTEN" SEABEENSIS*, *BICORBULA IDONEA*, *MERCENARIA GARDNERAE*, *LUCINA* sp., *ISOGNOMON* sp., *ECPHORA* sp., *PANOPEA* sp., *PLICATULA* sp., *CYCLOCARDIA* sp.