MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

GUIDEBOOK NO.3

ENVIRONMENTAL HISTORY OF MARYLAND MIOCENE

by

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Dept. of Geological Sciences
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GEOLOGICAL SOCIETY OF AMERICA

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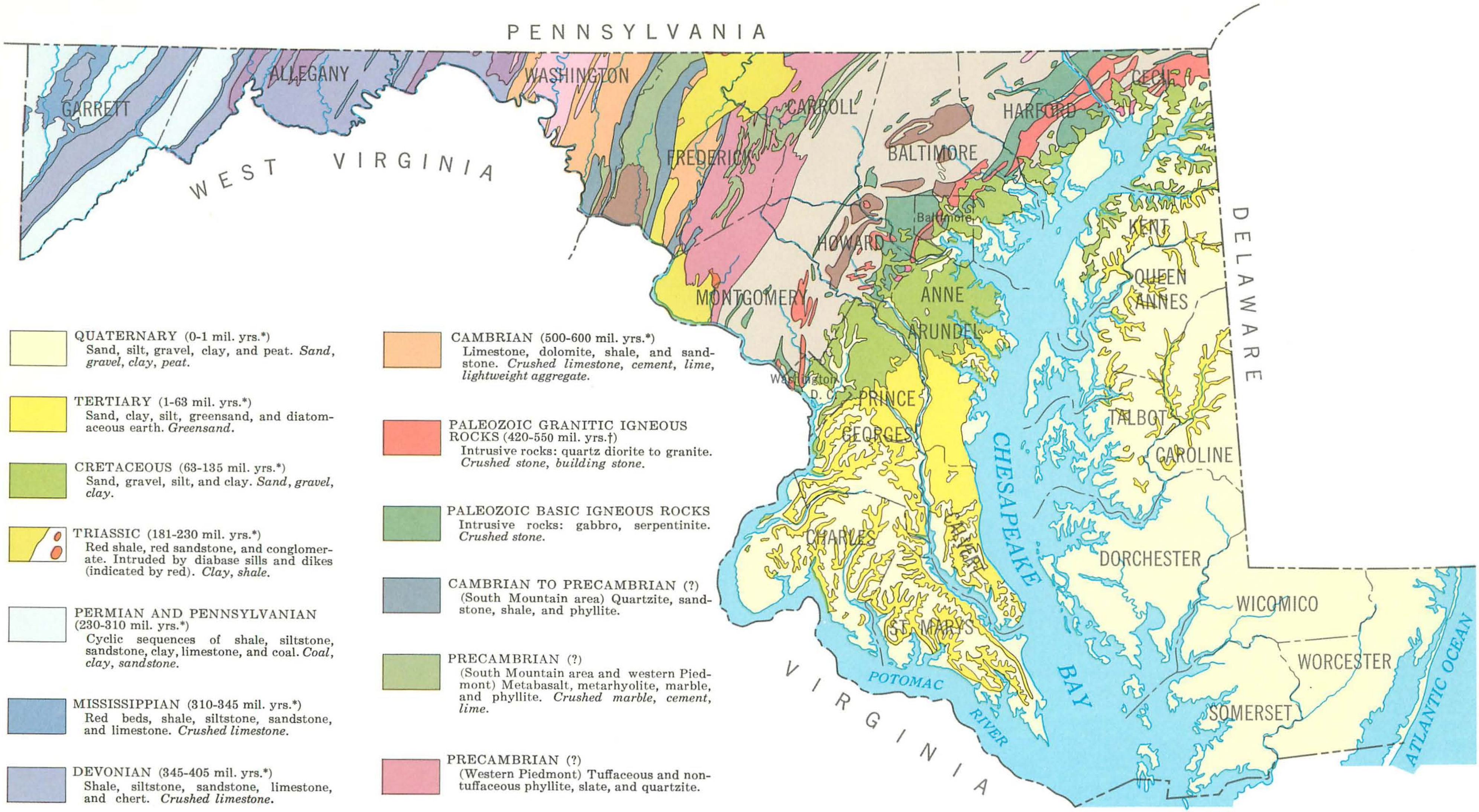

QUATERNARY (0-1 mil. yrs.*)
Sand, silt, gravel, clay, and peat. *Sand, gravel, clay, peat.*

TERTIARY (1-63 mil. yrs.*)
Sand, clay, silt, greensand, and diatomaceous earth. *Greensand.*

CRETACEOUS (63-135 mil. yrs.*)
Sand, gravel, silt, and clay. *Sand, gravel, clay.*

TRIASSIC (181-230 mil. yrs.*)
Red shale, red sandstone, and conglomerate. Intruded by diabase sills and dikes (indicated by red). *Clay, shale.*

PERMIAN AND PENNSYLVANIAN (230-310 mil. yrs.*)
Cyclic sequences of shale, siltstone, sandstone, clay, limestone, and coal. *Coal, clay, sandstone.*

MISSISSIPPIAN (310-345 mil. yrs.*)
Red beds, shale, siltstone, sandstone, and limestone. *Crushed limestone.*

DEVONIAN (345-405 mil. yrs.*)
Shale, siltstone, sandstone, limestone, and chert. *Crushed limestone.*

SILURIAN (405-425 mil. yrs.*)
Shale, mudstone, sandstone, and limestone. *Glass sand, crushed limestone.*

ORDOVICIAN (425-500 mil. yrs.*)
Limestone, dolomite, shale, siltstone, and red beds. Slate and conglomerate in northern Harford County. *Crushed limestone, cement, clay, lime.*

CAMBRIAN (500-600 mil. yrs.*)
Limestone, dolomite, shale, and sandstone. *Crushed limestone, cement, lime, lightweight aggregate.*

PALEOZOIC GRANITIC IGNEOUS ROCKS (420-550 mil. yrs.†)
Intrusive rocks: quartz diorite to granite. *Crushed stone, building stone.*

PALEOZOIC BASIC IGNEOUS ROCKS
Intrusive rocks: gabbro, serpentinite. *Crushed stone.*

CAMBRIAN TO PRECAMBRIAN (?)
(South Mountain area) Quartzite, sandstone, shale, and phyllite.

PRECAMBRIAN (?)
(South Mountain area and western Piedmont) Metabasalt, metarhyolite, marble, and phyllite. *Crushed marble, cement, lime.*

PRECAMBRIAN (?)
(Western Piedmont) Tuffaceous and nontuffaceous phyllite, slate, and quartzite.

PRECAMBRIAN (?)
(Eastern Piedmont) Schist, metagraywacke, quartzite, marble, and metavolcanic rocks. *Crushed stone, crushed marble, building stone.*

PRECAMBRIAN BASEMENT COMPLEX (1100 mil yrs.†)
Gneiss, migmatite, and augen gneiss.

MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

GENERALIZED GEOLOGIC MAP OF MARYLAND‡

1967

10 0 10 20 30 40
1 inch equals 25 miles

Most important mineral products in italics.
* Age ranges from Kulp, J. L., 1961, Geologic time scale: Science, v. 133, no. 3459, p. 1105-1114.
† Radiometric dates made on Maryland rocks.

‡ A detailed Geologic Map of Maryland, 1968 at a scale of 1 inch equals 4 miles, is also available.

ACKNOWLEDGMENTS

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MIOCENE OF THE MIDDLE ATLANTIC COASTAL PLAIN*

Thomas G. Gibson

Introduction

The Miocene is one of the most widespread stratigraphic units in the Atlantic Coastal Plain. It crops out almost continuously from southern Florida northward to Cape Cod, and is found offshore to the east of Cape Cod on Georges Bank (Gibson, 1965). Because the overlying deposits are thin, outcrops of the Miocene are relatively common throughout much of the Coastal Plain.

Although most Cenozoic strata presently appear because of erosion as a general offlap series to the east, some Miocene formations form large overlaps over Oligocene, Eocene, Paleocene, and Lower and Upper Cretaceous rocks. In some places in the central Coastal Plain, Miocene beds lie unconformably on metamorphic and igneous rocks of the Piedmont Province. In the northern part of the Coastal Plain, the middle Miocene, represented in part by the Calvert and Kirkwood Formations, forms one of the largest regional transgressions in the Cenozoic; in the southern part, the Yorktown and Duplin Formations of late Miocene age form a significant transgressive unit.

In the field trip area, Miocene strata transgress Eocene, Paleocene, and Cretaceous strata, and rest as outliers on crystalline rocks of the Piedmont near Washington (Darton, 1951).

Basins and Deposition

Although Miocene deposits are virtually continuous along the Atlantic Coastal Plain, certain lithostratigraphic and/or biostratigraphic units are regionally restricted (Mansfield, 1929; Stephenson and others, 1932; Gibson, 1970). Two basins generally covering over 5,000 square miles were present in the Coastal Plain segment from North Carolina to New Jersey. The depositional centers within the large basins shifted through time, as can be seen from the distribution of the formations (Figs. 1-4). In general, the Virginia to New Jersey segment of the Coastal Plain contained a well developed basin (Salisbury embayment) during the middle Miocene (Fig. 5), although the size of the depositional basin decreased through this time interval. In the other basin in North Carolina (Albemarle embayment), the basin size as reflected by the sedimentary strata was largest during the late Miocene. Both the structural features separating the two basins and those that subdivide the depositional areas within the basins run in a generally east-west to northwest-southeast direction (Fig. 6). The major positive features

* Publication authorized by the Director, U.S. Geological Survey

include the Norfolk arch or Fort Monroe high in southern Virginia and the Cape Fear arch in southern North Carolina. Other unnamed positive features are in the vicinity of New Bern, North Carolina, and in the area of the Potomac River in Northern Virginia.

A change in the tectonic and sedimentary patterns in the Miocene from those earlier in the Cenozoic was suggested by Gibson (1970) based upon a combination of on- and offshore data including both the lithology and the thickness of the section. The deposits of Paleocene and Eocene age consist of glauconitic clays and sands onshore and largely chalks offshore. The Oligocene is composed of carbonates both on and offshore. The entire interval from uppermost Cretaceous through the Oligocene is relatively thin, and maintains an essentially constant thickness on and offshore (Fig. 7).

In the Miocene, however, the strata are considerably thicker and contain much more coarse terrigenous detritus. In the middle Miocene most of the thickening and increase in terrigenous component occurs in the northern part of the Coastal Plain, particularly in New Jersey and its offshore margin. In the northern extension of the Coastal Plain off Cape Cod and in the region south of Maryland the rocks consist mainly of diatomite, glauconitic and phosphatic sand and clay, and limestone. The Choptank and St. Marys Formations in Maryland continue the terrigenous influx. In the latest Miocene, represented by the Yorktown Formation and equivalents, the flood of terrigenous detritus extends from New Jersey through South Carolina. Weaver (1968, p. 61) reported a similar situation in northern Florida.

The change from a low influx of terrigenous detrital material in the early and middle Tertiary to a heavy influx in the late Miocene is interpreted as the result of a rejuvenation of the source, the Appalachian area. The progression southward through time suggests that this uplift was initiated in the northern Appalachians and moved southward during the later middle and late Miocene.

Figs. 1-4 give isopachs of the various Miocene Formations in the middle Atlantic region. The thickness of the total Miocene reaches a maximum onshore of 1450 feet in the Maryland Esso No. 1 well, drilled almost on the Atlantic shore of the northeastern part of the Eastern Shore of Maryland (Anderson, 1948). Other areas of a thick Miocene section include the southeastern part of New Jersey near Cape May, the mouth of Chesapeake Bay near Norfolk, and the Cape Hatteras region of North Carolina, where the total Miocene section exceeds 700 feet. Fig. 7 is a cross-section through New Jersey showing the considerable thickening offshore in the Miocene to thicknesses approaching 5,000 feet.

The lithologies present in the Miocene are similar to the recent sediments found off the Atlantic Coast, showing the same general northward decrease in carbonate content. The Miocene strata in Florida, Georgia, South Carolina, and southern North Carolina contain a considerable percentage of beds with a moderate

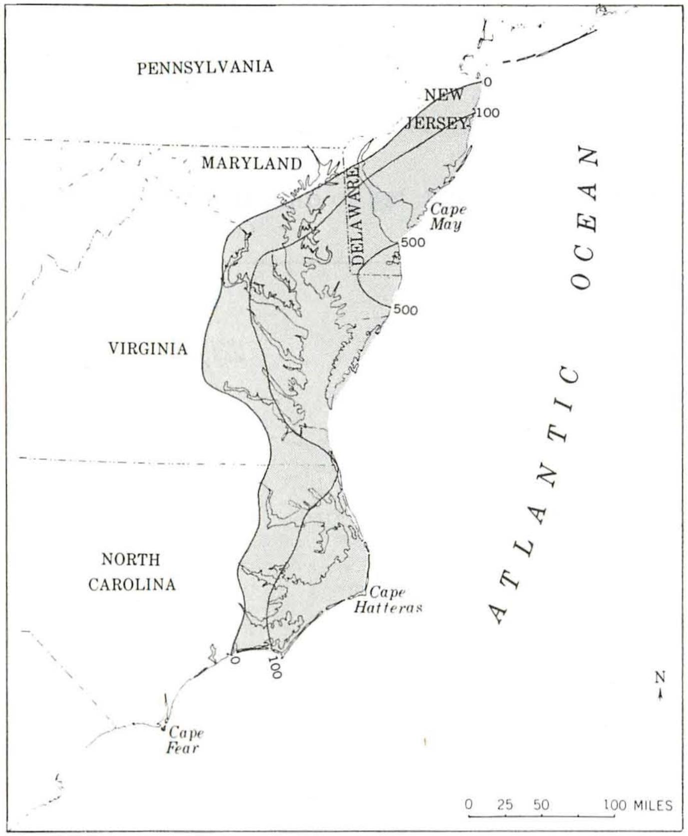

Fig. 1. Isopach map of Calvert Formation and equivalent strata. Contours are in feet (from Gibson, 1970).

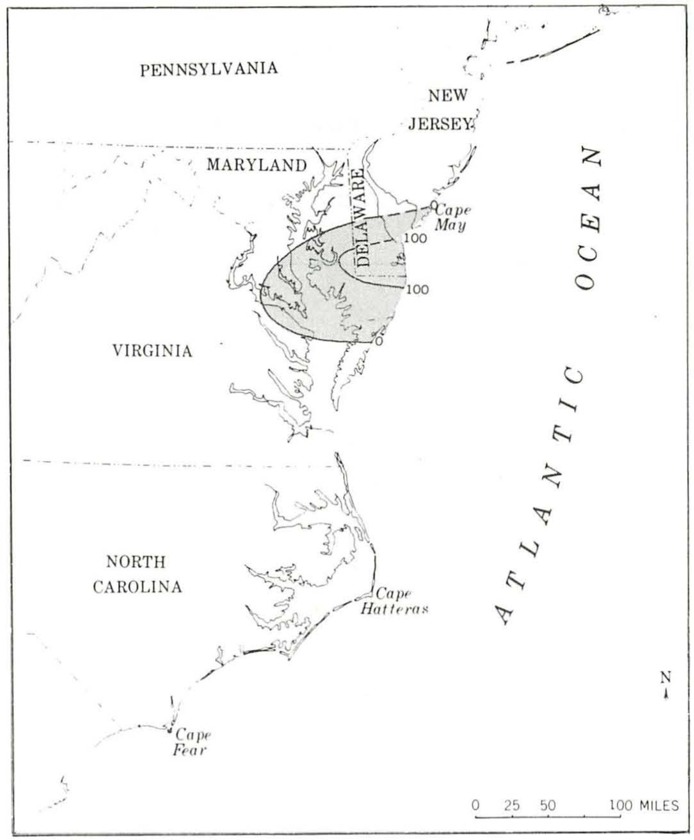

Fig. 2. Isopach map of Choptank Formation. Contours are in feet; contours are dashed where approximately located (from Gibson, 1970).

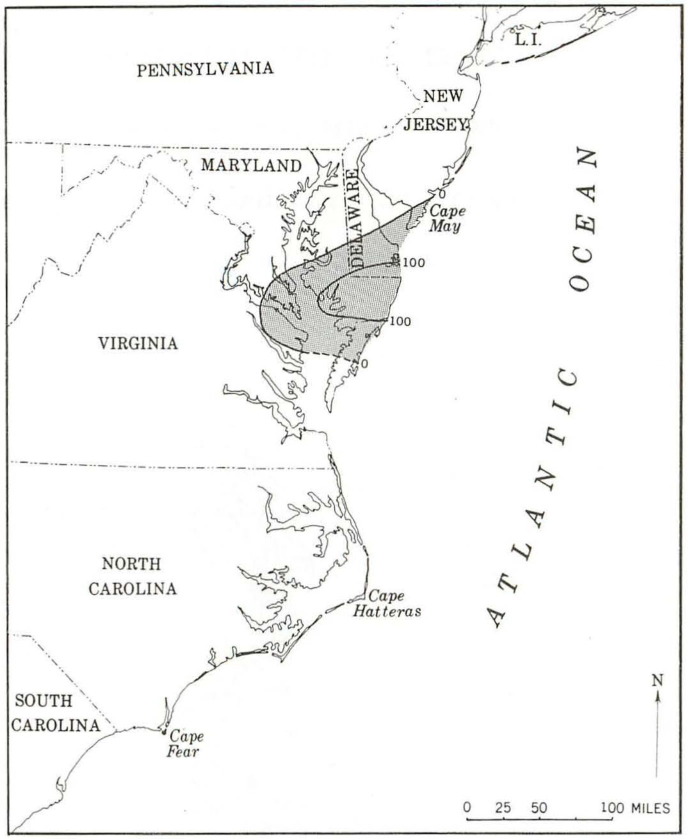

Fig. 3. Isopach map of St. Marys Formation. Contours are in feet; contours are dashed where approximately located (from Gibson, 1970).

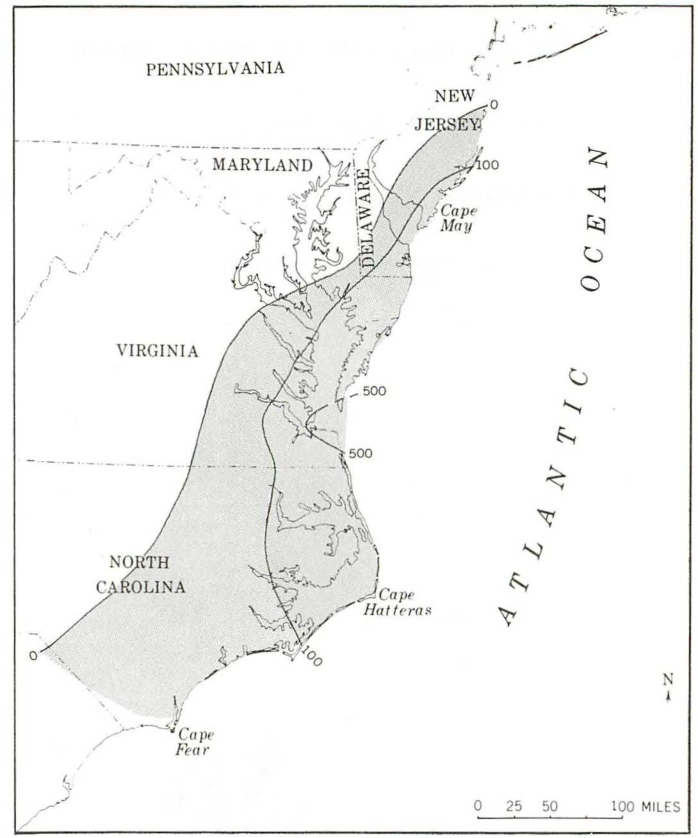

Fig. 4. Isopach map of Yorktown Formation and equivalent strata. Contours are in feet; contours are dashed where approximately located (from Gibson, 1970).

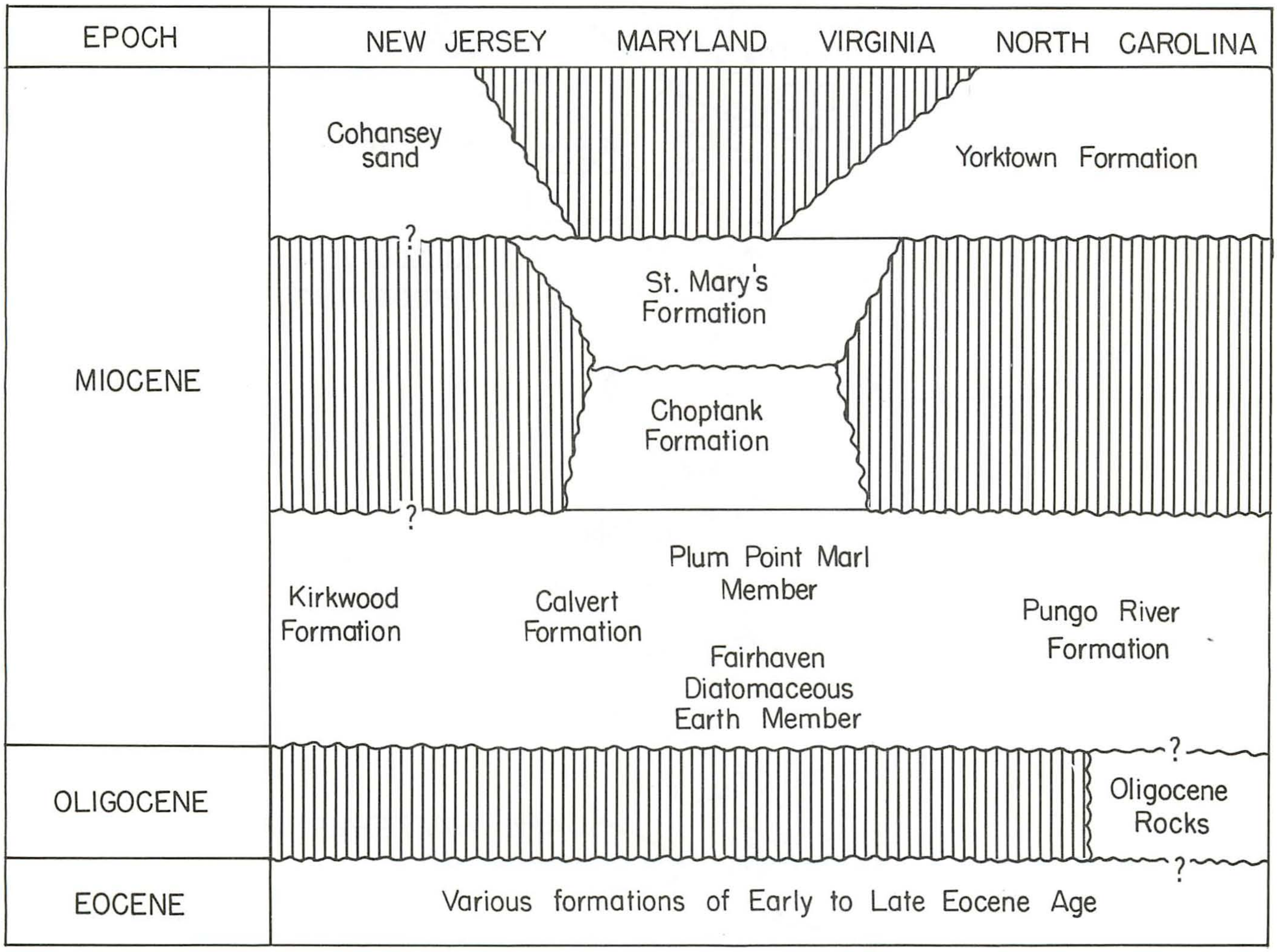

Fig. 5. Chart showing relationship of Miocene formations from New Jersey to central North Carolina. Vertical lines indicate nondeposition.

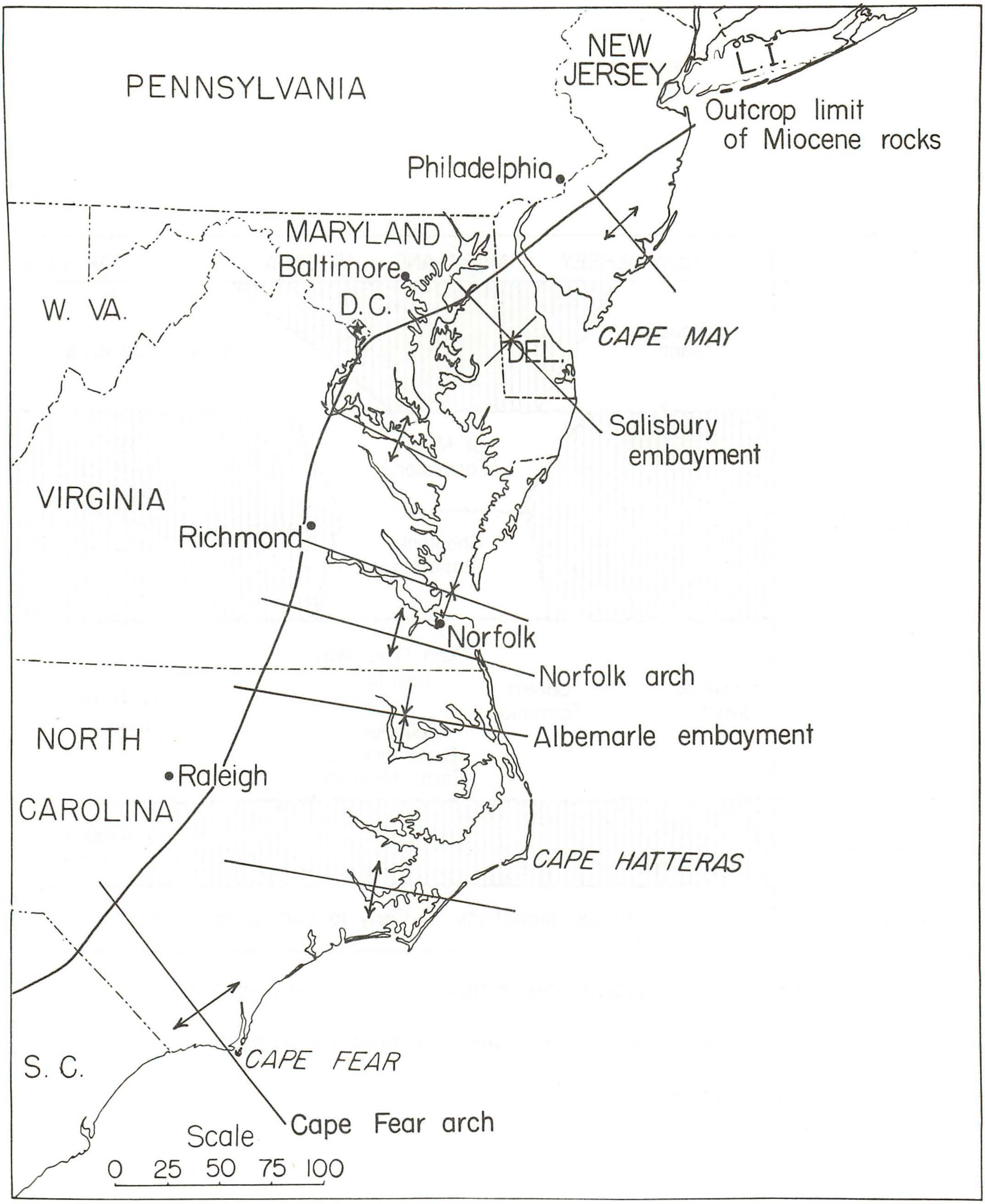

Fig. 6. Map showing major structural features of middle Atlantic Coastal Plain.

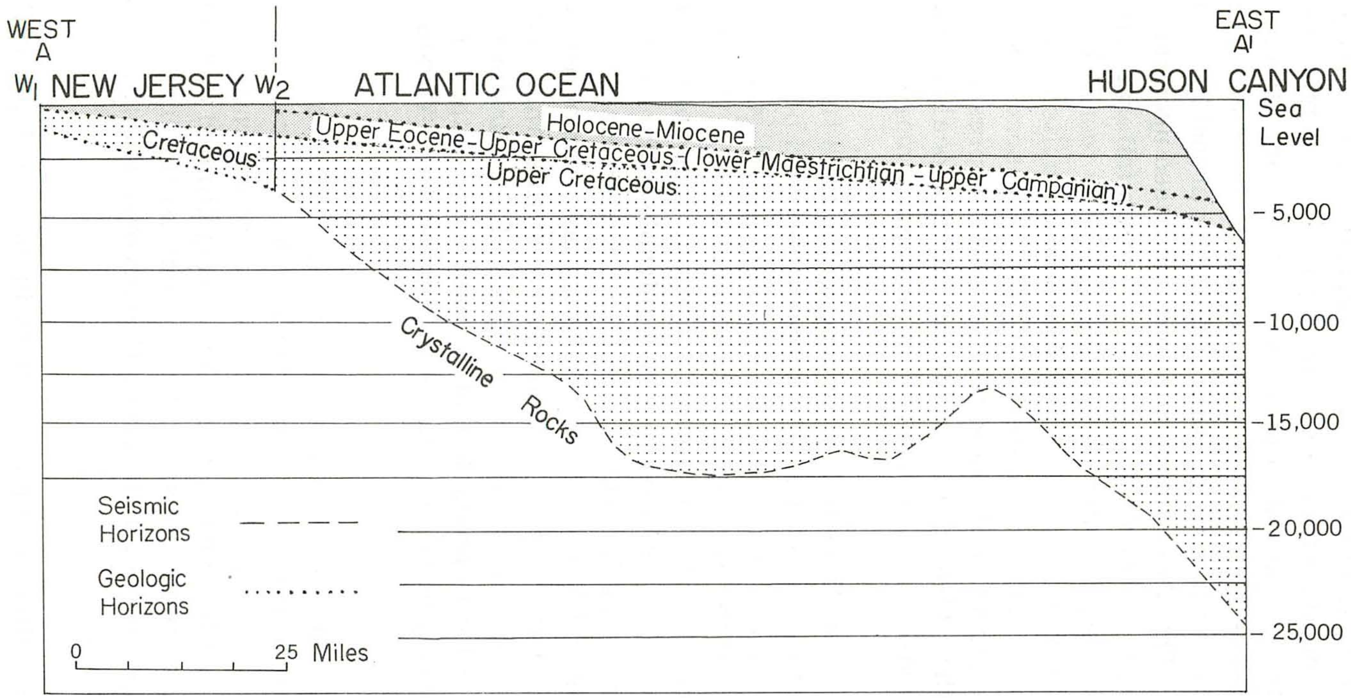

Fig. 7. Cross section through the New Jersey Coastal Plain and across the shelf and slope into Hudson Canyon. The offshore depth to crystalline basement profile is constructed from Drake and others (1968, Fig. 11), with thicknesses in feet (from Gibson, 1970).

to high carbonate content. In some instances there are indurated limestones, but generally they consist of sands and clays with varying percentages of bioclastic carbonate. A northward change to sediments generally low in carbonate occurs in North Carolina, with the strata to the north consisting of clays, silts, and sands; the low amount of carbonate present occurs primarily as entire shells and tests.

Most of the Miocene strata in the field trip area were deposited in relatively shallow waters of less than 100 m depth, with much being deposited at depths less than 60 m. This is particularly true of the outcropping parts of the formation, especially the Choptank and St. Marys Formations. Most of the Calvert Formation also was deposited at depths shallower than 60 m, with a few units probably forming at depths approaching 100 m. The above interpretations are based upon the benthonic foraminiferal assemblages and benthonic-planktonic foraminiferal ratios. Eastward, in subsurface sections, deeper water strata are generally found, but the Eastern Shore of Maryland is a major exception. Some Miocene units in the subsurface of eastern North Carolina and Southeastern Virginia represent deposition at depths as great as 150 m. The strata on the field trip generally represent shallow water depositions at depths less than 30-60 m except for the Calvert locality which has units which may have been deposited at depths of 60 m or slightly more.

We will visit the lower three formations in the Miocene on the field trip (also see Stephenson, Cooke, and Mansfield, 1932; Glaser, 1968). They will be visited in order of decreasing age, and include the Calvert Formation at Stop 1, the Choptank Formation at Stops 2 and 4, and the St. Marys Formation at Stop 3. The youngest formation in the Chesapeake Group, the Yorktown Formation, does not crop out on the western shore of Chesapeake Bay, at least in a recognizable marine facies. Some of the sand units overlying the fossiliferous Miocene in southern Maryland have been suggested by Stephenson and MacNeil (1954) as being non-marine equivalents of the Yorktown Formation. The evidence is inconclusive at this time, but shallow water fossiliferous marine and marginal marine facies of the Yorktown occur in northernmost Virginia, and it is probable that at least some of the non-fossiliferous units immediately overlying the St. Marys in Maryland are Yorktown equivalents.

The strata underlying the Miocene vary considerably in age. As mentioned previously, the Miocene strata are transgressive and overlie middle Eocene deposits in much of the area near Chesapeake Bay. The Oligocene is not represented in Maryland and northern Virginia, and the upper Eocene has a very limited distribution in this area. To the west of the field trip stops the Miocene strata progressively transgress middle and early Eocene, Paleocene, Cretaceous, and then rest on crystalline rocks of the Piedmont.

The deposits overlying the fossiliferous Miocene strata in Maryland generally have been considered Pliocene and Pleistocene in age (Shattuck, 1906), except for the possibility of late Miocene as noted above. For the Pleistocene units in the southeastern U.S.A., Cooke (1931) designated a series of marine terraces to represent various stands of the sea. Although the terrace concept as proposed by Cooke has been questioned (Hack, 1955; Schlee, 1957; Cooke, 1958), the Pleistocene age designation has largely remained. Hack (1955), however, suggested that these deposits represent upland stream gravels and other deltaic and fluviatile deposits of Miocene and possibly younger age. Some of the sands were considered to be non-marine equivalents of the Choptank, with the sands to the east representing equivalents of the later Miocene and possibly younger units. Oaks and Coch (1963) and Hoyt and Hails (1967) proposed more complex histories for the terraces and deposits.

General Stratigraphy and Age Relationships

The Chesapeake Group traditionally is considered Miocene in age, with the Calvert Formation placed in the early middle Miocene, the Choptank in the middle middle Miocene, the St. Marys in the late middle and early late Miocene, and the Yorktown in the late Miocene (Cooke and others, 1943). Correlation with the European type equivalents has not been refined, and in reality these formations and their ages represent a standard section for the Atlantic Coast with somewhat uncertain relationships with the type stages of the Miocene in Europe.

The planktonic Foraminifera are probably the most promising group at the present time for intercontinental correlation, and a large number of publications are available on regional and world-wide zonations. Unfortunately, because of the shallow-water nature of the Miocene strata in the Atlantic Coastal Plain, planktonic Foraminifera are rare in most of the beds. Those that are found are largely characteristic of temperate faunal realms, whereas the planktonic zonations are established on tropical assemblages.

Because of these limitations, a dating by means of planktonic Foraminifera has been accomplished at only three localities, one in the Calvert Formation, one in the Pungo River, and one in the Yorktown. Both unit 10 in the Plum Point Marl Member of the Calvert Formation in Maryland and the upper beds of the Pungo River Formation in eastern North Carolina contain adequate suites indicative of the same general age. As mentioned above, they lack some of the tropical elements which allow the finest subdivisions, but fit into the interval covered by two zones. They are the *Globigerinatella insueta-Globigerinoides bisphericus* zone of Blow (1959) and the overlying *Globorotalia fohsi barisanensis* zone of Bolli (1957). These zones are now called by Blow (1969) the Neogene 8 and 9 zones respectively. Zone N 8 is considered latest early Miocene and zone N 9 earliest middle Miocene by Blow, so these horizons in the formations are around the early-middle Miocene boundry. Dates on the lower parts of the Pungo River and Calvert Formations are unavailable at present. The presence of a thick sequence of diatomaceous clay in the lower part of the Calvert Formation and highly phosphatic sands and clays in the lower and middle part of the Pungo River Formation raises a question as to the amount of time involved in what appears to be slow sedimentary regimes. Some faunal elements suggestive of Oligocene ages have been found in the lower beds of the Pungo River in North Carolina (Gibson, 1967). The question of age for the lower units, particularly those additions found in the thicker subsurface sections, is still open.

A similar problem exists for ages in the uppermost Miocene, the Yorktown Formation. The only planktonic date so far available is the Globorotalia menardii menardii zone of Blow (1959) for the lower beds of the Yorktown in northern North Carolina (Gibson, 1967). In terms of the Blow (1969) zonation this would be in Neogene zone 16, which is placed in the early to middle late Miocene. With the occurrence of relatively large changes in the faunas, both macro and micro, in the overlying Yorktown beds, it is entirely possible that units placed in the upper Yorktown will range considerably into the Pliocene in age, but this reassignment will be dependent upon finding adequate planktonic assemblages.

Calvert Formation and equivalents

The Calvert Formation contains the oldest strata in the Miocene of Maryland. Although this unit is widespread geographically (Fig. 1), its greatest extent and thicknesses are in the Virginia to New Jersey segment of the Coastal Plain. Time equivalents, at least in part, are found in the Kirkwood Formation in New Jersey and the Pungo River Formation in North Carolina. The maximum thickness onshore of 530 feet is in the Ohio Oil Co., L. G. Hammond No. 1 well on the Eastern Shore of Maryland; thicknesses exceeding 500 feet occur in southeastern New Jersey, over 300 feet at the mouth of Chesapeake Bay, and between 400-500 feet in eastern North Carolina in Albemarle and Pamlico Sounds and surrounding areas.

Probably the greatest diversity of lithic types in the Miocene is found in this formation and equivalents. In New Jersey the formation is composed almost entirely of terrigenous clastics, grading from sands to clays rich in organic matter. The environments represented appear to be deltaic, other marginal marine and shallow marine (Isphording, 1970). To the south, in Maryland and Virginia, the lower part of the Calvert Formation is composed of diatomaceous clays with parts being highly diatomaceous. In this area many of the farthest inland outcrops are composed largely of diatomaceous clays, and thus appear to be of very shallow marine origin. These clays generally grade into non-diatomaceous sands and clays in a down-basin direction, although in the Eastern Shore of Maryland the diatomaceous sections thicken to the east. The thick deposits of apparently shallow water origin may indicate a highly productive area for diatoms, a long accumulation, or some combination. In either case, there was slow transportation of other clastic material into the area.

The distribution of the diatomites in North Carolina is in marked contrast to those of the inshore locations in Maryland and Virginia. In North Carolina the inshore or updip deposits are primarily calcareous sandstones, with the diatomaceous beds representing offshore or down-basin facies (Kimray, 1965).

The Plum Point Marl Member is the upper part of the Calvert Formation in Maryland, with the term marl referring to the large number of essentially entire shells, not a fine carbonate matrix. This member consists of sands and clays, with some units being highly fossiliferous. The influx of terrigenous clastics increases considerably in this member, probably reflecting the increased flow from the raised Appalachian source area.

Southward from Maryland, the Calvert Formation and the equivalent Pungo River Formation have decreasing amounts of terrigenous material. In southern Virginia, the inshore outcrops are predominately diatomaceous clay which becomes phosphatic sands and clays in subsurface sections to the east. In North Carolina the Pungo River consists of phosphatic beds, diatomaceous beds, and carbonates with lesser amounts of terrigenous material than in Maryland and northward. The Appalachian source area apparently did not furnish any appreciable amount of clastics to the Albemarle basin during this time. Although deposits of Calvert age are not present in southern North Carolina and most of South Carolina, in Georgia and Florida a pattern similar to northern North Carolina is found, with phosphatic sands and clays and carbonates predominating.

An unconformity separates the Calvert Formation and equivalents from the overlying Yorktown Formation of late Miocene age and its equivalents in much of the central and southern Coastal Plain. There appears to have been virtually continuous deposition through this interval in Maryland, represented by the Choptank and overlying St. Marys Formations, although an unconformity is thought to exist between the latter two units (Gernant, 1970). The restriction or shrinking of the basins is probably the result of the general uplift of the Appalachian area, leaving a much smaller negative area in the central part of the Salisbury embayment.

Choptank Formation

The Choptank Formation (Fig. 2) is a clastic unit composed of sands, silts, and clays. The large supply of clastics indicates a fairly prominent source area, and it is likely that the Appalachians were a prominent positive area in this region at this time. The Choptank basin was considerably reduced in area with much of New Jersey, Virginia, and North Carolina no longer receiving sediments. The maximum thickness of the formation is 104 feet in two wells on the Eastern Shore of Maryland.

Although it has been customary to assume a gentle southeast dip for Miocene beds in the Coastal Plain, with those progressively farther east being deposited in increasing water depths, parts of the Choptank Formation do not support this. The Choptank beds on the Eastern Shore of Maryland, along the Choptank River and in surrounding creeks, represent deposition in very shallow waters. In most cases the depth was as shallow as, if not shallower than, the depth of equivalent strata:a on the western shore. In subsurface cores from the Eastern Shore, much of the formation is represented by very coarse sands, highly organic clays, and glauconite probably reworked from the Lower Tertiary deposits. This is similar to the deltaic sequence found in the Kirkwood Formation in New Jersey. Some structural prominence must have been present on the Eastern Shore during Choptank time, resulting in deltaic and near shore marine sedimentary sequences in this area.

St. Marys Formation

The St. Marys Formation (Fig. 3) has a similar distribution to that of the underlying Choptank Formation. The type area of the formation is in St. Marys County, along the western shore of Chesapeake Bay in Southern Maryland. The formation also occurs in the subsurface on the Eastern Shore of Maryland, and probably in southeastern New Jersey (Richards and Harbison, 1942). Exposures in central and southern Virginia have been placed in partial equivalence to the upper part of the St. Marys and in part considered younger than any of the strata in Maryland (Mansfield, 1943). My investigations indicate that the strata in Virginia are connected in a depositional continuum with the overlying Yorktown and occur in areas that do not have age equivalents of the Maryland St. Marys. This could indicate either non-deposition or later erosion of the Maryland St. Marys age deposits. The record to date would indicate the former as no unquestionable pockets of strata of Maryland St. Marys age are found. However, L. W. Ward (oral commun., 1971) has examined a locality along the Rappahannock River in Northern Virginia which may prove to be of Maryland St. Marys age, and the boundary of non-deposition may have to be moved slightly southward. The St. Marys strata in Maryland are composed of sands and clays, reflecting a moderately high influx of clastics. Fossil mollusks are locally abundant, with some of the densest layers of shells in the Miocene strata occurring in this formation. The maximum thickness is 193 feet in the Hammand well on the Eastern Shore of Maryland.

The locus of deposition of strata that have been placed in the St. Marys Formation shifted with time. The type St. Marys is a restricted unit that was deposited in the central part of the Salisbury embayment; it is virtually absent south of the Potomac River. A southward shift of the locus of deposition into Virginia causes the younger strata, usually placed in the St. Marys, but herein placed in the Yorktown, and the immediately overlying Yorktown to have their maximum thickness in Virginia with no marine record left on the western shore of Maryland. Thus, the western shore of Maryland, up to this time a site of extensive transgression in the Chesapeake Group, became largely a positive area during Yorktown time with deposition limited to non-marine or marginal marine sediments.

Yorktown Formation and equivalents

The Yorktown Formation and equivalents are a widespread transgressive unit over much of the Atlantic Coastal Plain (Fig. 4). In Virginia and North Carolina they transgress areas that had not received sediment since Calvert time, and they and the first Miocene deposits in much of North Carolina and South Carolina. The maximum transgression is in southern Virginia and North and South Carolina, but coarse clastic beds are also found in New Jersey, including at least part of the Cohansey Formation. Yorktown beds are found in the subsurface on the Eastern Shore of Maryland in Wicomico, Somerset, and Worcester Counties, indicating that this area remained within the depositional basin (includes strata provisionally assigned by Anderson (1948) and unpublished well data).

Practically all the strata of the Yorktown and its equivalents are relatively coarse terrigenous clastics. This widespread presence of quartz sand in the central and northern Coastal Plain and in Northern Florida (Weaver, 1968) reflects the uplift of the Appalachians along their entire length. In Virginia and the Carolinas the sediments are predominately sands, with generally only moderate amounts of clay. In southern North Carolina and South Carolina sands still dominate, although there is an increasing contribution of carbonates.

The greatest thicknesses measured so far are over 500 feet near the mouth of Chesapeake Bay and over 300 feet near Cape Hatteras.

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BRIEF STRATIGRAPHIC CONSIDERATIONS

Robert E. Gernant

Three major units were long ago recognized in the Maryland Miocene and were called the Calvert, Choptank, and St. Marys Formations (Figs. 8, 9). Within these major units, Shattuck (1904) established a total of 24 sub-units as "zones." Clearly, this term is used incorrectly as its formal usage is proper only as a biostratigraphic designation. From field evidence and Shattuck's definitions none of the 24 sub-units should be included in that category. Since they all qualify as rock units, they should be redefined and appropriately reclassified. Based on this analysis, Gernant (1970) redefined Shattuck's "zones" 16 through 20 as the Calvert Beach, Drumcliff, St. Leonard, Boston Cliffs, and Conoy Members, respectively (see Fig. 9). The remaining 19 "zones" of Shattuck will be referred to here as "units" in an attempt to avoid confusion over stratigraphic nomenclature.

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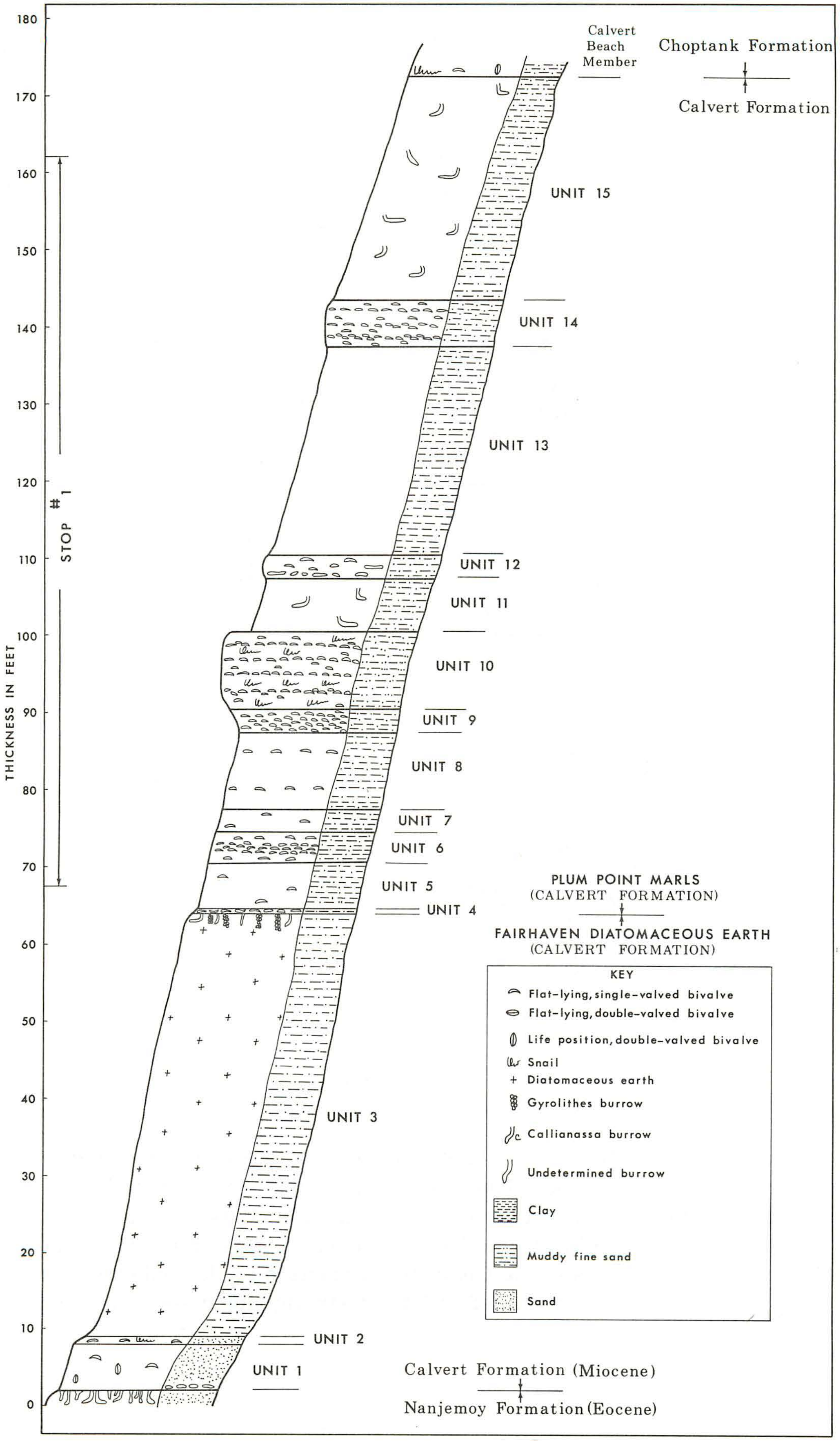

Figure 8: Generalized stratigraphic column for the middle Miocene Calvert Formation of Maryland. Illustrates both typical fossil distribution and sediment types. Unit numbers to right refer to Shattuck's (1904) stratigraphic designations. Double-headed arrow to left points out stratigraphic section seen at Stop #1.

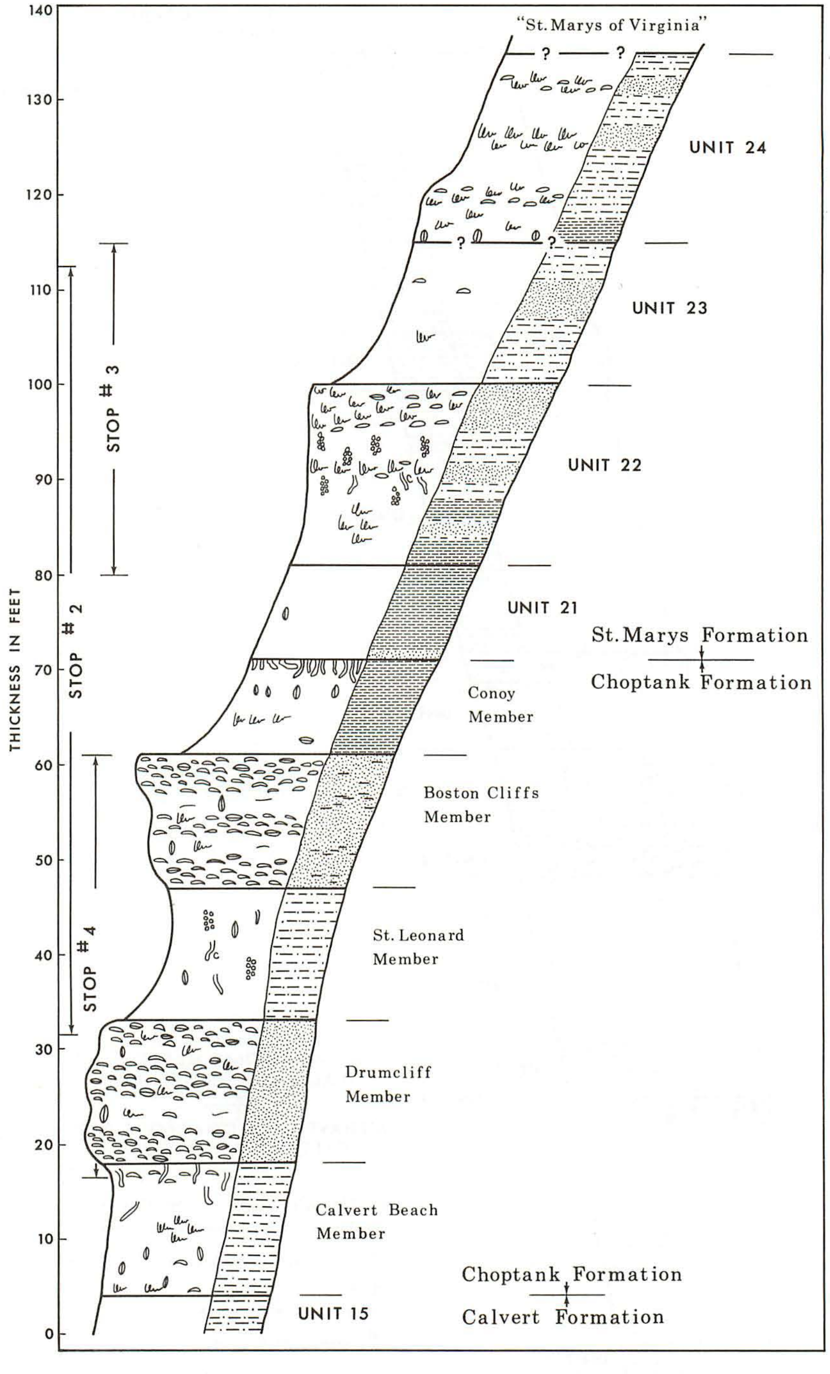

Figure 9: Generalized stratigraphic column for the Middle Miocene Choptank and St. Marys Formations of Maryland. Illustrates both typical fossil distribution and sediment types. Unit numbers to right refer to Shattuck's (1904) stratigraphic designations. Names Calvert Beach, Drumcliff, St. Leonard, Boston Cliffs, and Conoy designate individual members of the Choptank Formation as described by Gernant (1970). Double-headed arrows to left point out stratigraphic sections seen at Stops #2, 3, and 4.

INVERTEBRATE BIOFACIES AND PALEOENVIRONMENTS

Robert E. Gernant

Introduction

The study of Maryland Miocene invertebrate fossils has a long and rich history. Not long after Captain John Smith settled and explored this general area in the early 1600's the first figured fossil from the New World was collected from Maryland Miocene exposures. Since then thousands of amateur and professional paleontologists have collected specimens from the richly fossiliferous beds, but few have attempted paleoenvironmental interpretation of specific faunal assemblages.

The analysis presented here for the Calvert and St. Marys Formations is new. Discussion of Choptank biofacies for the most part follows Gernant (1969, 1970).

Biofacies Analysis

The basic approach to paleobiofacies interpretation used in this study might be called an "assemblage approach," comparing Miocene invertebrate assemblages with living ones. In the interest of keeping this field guidebook brief, few comparisons will be made between Miocene facies and possible modern analogs. The reader should be assured, however, that this step was not deleted from the research.

Paleoautecologic information is also used. For extant taxa, their environmental preferences are inferred for the fossil occurrences. In the case of the Foraminifera and Ostracoda, the habitat extrapolation is at the specific and generic level, whereas for the Mollusca it is primarily at the generic level.

Additionally, morphology of the Bivalvia and Gastropoda was interpreted functionally and provided important environmental implications. Also, certain species and assemblages are studied through the use of empirical methods; e.g., unknown habitats are bracketed by the more easily interpreted ones, and certain species with unknown environmental preferences are interpreted in light of the remainder of the assemblage.

Use of these various analytic tools makes possible the reconstruction of individual environments. Unfortunately, this provides a comprehension of only isolated environments, in many cases with no relationship to the total continuum. Figures 10 and 11 are depth-substrate, biofacies cross-sections of my interpretation of the integrated environmental matrix.

Biofacies and Paleoenvironments

Calvert Formation

Maryland Miocene strata lie unconformably on the greensands of the Eocene Nanjemoy Formation. The first beds of the Fairhaven Member (Calvert Formation) contain great concentrations of fossil diatoms.

A few Fairhaven outcrops contain molluscan assemblages represented by molds and casts. Of the three Fairhaven subunits, the first and last contain occasional specimens of the bivalve Lucinoma contracta. Pecten humphreysii also occurs in unit 1 (of Shattuck, 1904). This is a common mode of occurrence for lucinid bivalves, i.e., with very few other organisms. These molluscs are particularly well-adapted for conditions where food and oxygen levels are very low. Perhaps the diatomaceous substrate which L. contracta adapted to was inhospitable to other infaunal molluscs.

Foraminifera and Ostracoda normally are leached out of Fairhaven outcrops. Exceptions do occur in the uppermost sediments which contain ostracodes dominated by (in order of abundance) Pterygocythereis, Cytheretta ulrichi, Echinocythereis, Heterocyprideis, and Cushmanidea. This total assemblage is indicative of a dense mud substrate in approximately 35 to 50 meters depth in open marine water.

Unit 2 in the Fairhaven is a thin sand with a much more normal open-marine fauna, but one that is still probably shallow subtidal. The molluscs include Lyropecten, Panope, Thracia, Astarte, Chione, Corbula, Ecphora, Venericardia, and others. With the decrease of diatom deposition and/or increase of clastic sediments a more diversified population of benthonic animals invaded the area.

The Fairhaven is set apart from the overlying Plum Point Marls by a slight angular unconformity in the outcrop area. This relationship plus surrounding fossil evidence indicate that following deposition of the Fairhaven the region was uplifted and tilted toward the sea. During this event the top of the Fairhaven was a surface of erosion or nondeposition which was burrowed and bored into by a variety of organisms. Among these was an undetermined animal, probably a decapod, that left behind the biogenic structure Gyrolithes marylandica. Throughout the Maryland Miocene this organism was restricted to marginal marine environments. Consequently, the nondeposition environment was much shallower than the sedimentological regimes preceding and following the unconformity.

During the period of nondeposition, large specimens of the moderately deep water oyster Pyncnodonte percrassa attached to the hard clay substrate and were later ripped up and deposited in the basal Plum Point Marls. The associated ostracodes are dominated by Muellerina, Pterygocythereis, and Cushmanidea. The total fauna of the P. percrassa bed indicates an environmental depth of about 25 to 35 meters.

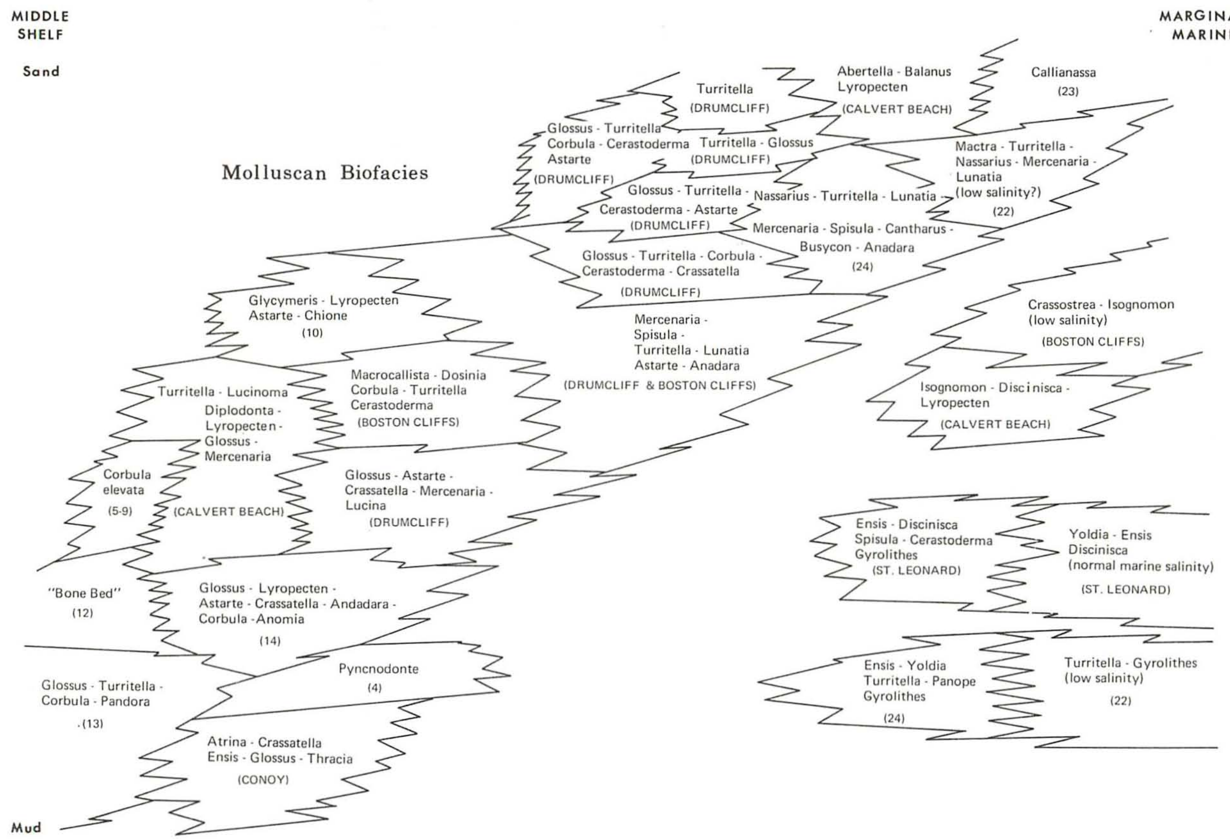

Figure 10: Molluscan biofacies of the Maryland Miocene. Abscissa represents the generalized depth trend, with facies on the left offshore of those to the right. Ordinate represents the generalized sediment characteristics of the substrate with sandier facies above and muddier facies below. Biofacies are denoted by the prominent genera, in most cases molluscs, but also biogenic structures and inarticulate brachiopods. Numbers below name correspond to Shattuck's (1904) stratigraphic units and refer to units where biofacies can be found. Names Calvert Beach, Drumcliff, St. Leonard, Boston Cliffs, and Conoy correspond to stratigraphic members described by Gernant (1970).

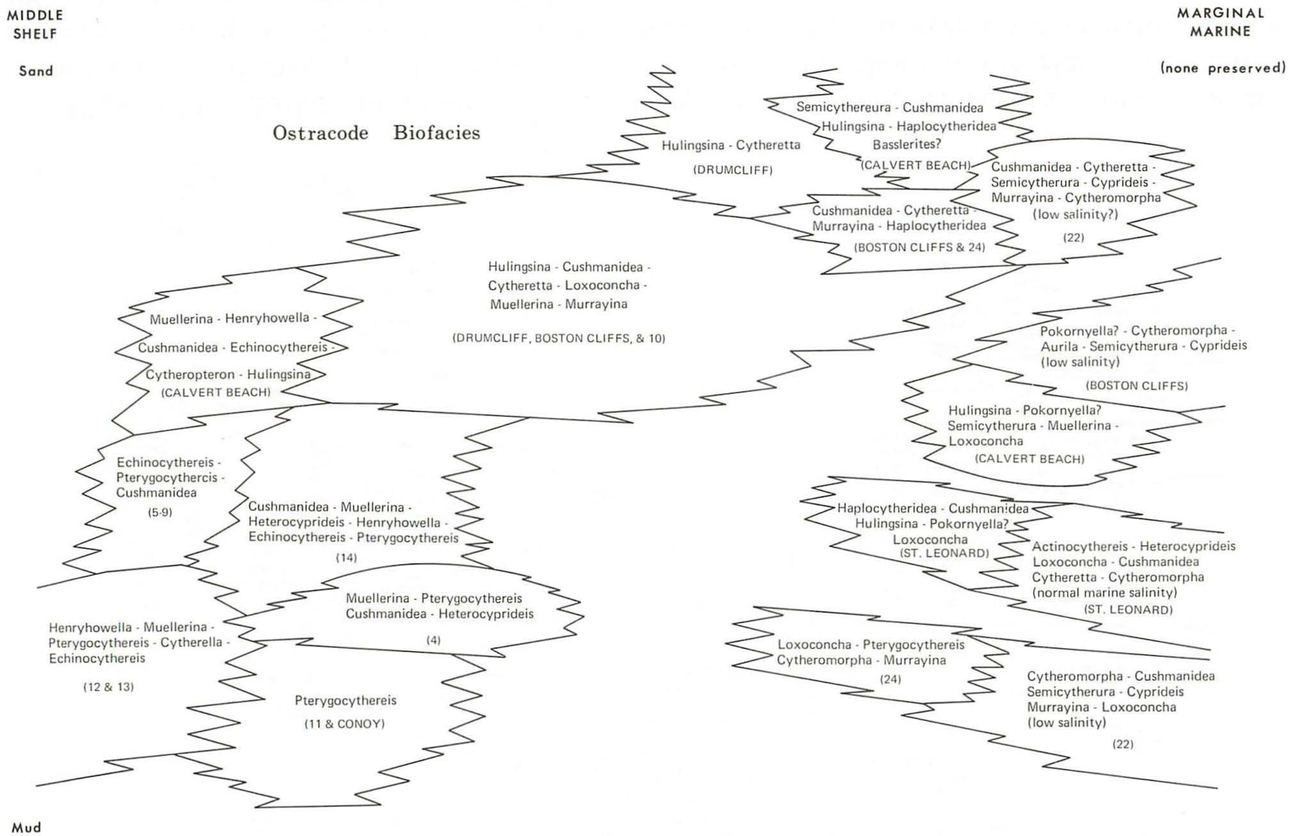

Figure 11: Ostracode biofacies of the Maryland Miocene. Abscissa represents the generalized depth trend, with facies on the left offshore of those to the right. Ordinate represents the generalized sediment characteristics of the substrate with sandier facies above and muddier facies below. Biofacies are denoted by the prominent ostracode genera. Numbers below name correspond to Shattuck's (1904) stratigraphic units and refer to units where biofacies can be found. Names Calvert Beach, Drumcliff, St. Leonard, Boston Cliffs, and Conoy correspond to stratigraphic members described by Gernant (1970).

Following the ripping up of the Pyncnodonte banks which form unit 4, sediments were deposited in a series of conformable units. Macroassemblages in units 5-9 are strongly dominated by the small bivalve Corbula elevata. The most abundant ostracode is a moderately deep sublittoral species, Echinocythereis clarkana. Cushmanidea, Pterygocythereis, Cytheretta ulrichi, and Actinocythereis are of lesser abundance. The large increase from unit 4 in E. clarkana, Henryhowella, Aequacytheridea, and Cytherella points out the depth increase in units 5-9, an increase that resulted in possibly 40 to 55 meters of open ocean water. The greatest depth achieved was during deposition of unit 8.

Unit 9 was deposited during the beginning of a shallowing phase. The increased diversity and change in composition of the macrofauna reflect this trend. In addition to the bivalve Corbula elevata, the assemblage includes Lyropecten, Turritella, and Balanus. Turritella plebeia is exceedingly abundant in most of the shallower facies in the Maryland Miocene and reappears in unit 9 after being absent in units 5-8. The Echinocythereis-Cytheretta ulrichi-Hulingsina-Cushmanidea dominated ostracode assemblage also shows the shallowing since Henryhowella, Pterygocythereis, and Cytherella all decrease in abundance while certain shallow water forms, such as Cytheretta burnsi and Hulingsina, increase to become more numerous.

The tremendous accumulation of fossil shells in unit 10 signals a significant environmental change. While the faunal list is very long, the following are some of the more abundant forms: Glycymeris, Lyropecten, Astarte, Chione, Anadara, Anodontia, Turritella, Crassatella, and Corbula elevata. It is important to note that certain shallow water molluscs are very common in various parts of the Choptank and St. Marys and are sparse or absent in the Calvert. Included among these are bivalves Mercenaria and Panope and snails Nassarius, Mangelia, and other shallow water prosobranchs.

Ostracode assemblages dominated by Hulingsina, Cytheretta burnsi, C. ulrichi, and Cushmanidea point out the distinct shallowing from the lower units. Yet some of the deeper water ostracodes (Table 1) are present in modest abundance. Based on all faunal evidence, it appears that unit 10 originated in approximately 30 to 45 meters of open ocean water. The possible origins of the shell beds themselves are discussed in another paper in this guidebook.

Unit 11 is a dense clay and contains very few macrofossils. The ostracode assemblages indicate a transition back to deeper waters and are dominated by Pterygocythereis, which prefers muddy, deep substrates. Cytheropteron reappears as one of the more abundant species. In contrast, the shallow-water forms, Hulingsina, Cushmanidea, and Cytheretta burnsi, are significantly reduced in numbers.

Unit 12 is a prolific source of marine mammal remains, but nearly all shells are beat up and poorly preserved. They include Lyropecten, Discinisca, Astarte, Turritella, Cerastoderma, Balanus, Crassatella, Anomia, Ecphora, Mercenaria, and Chione. On the other hand the microfauna is quite abundant and well preserved. The dominant ostracodes, in order of abundance, are Henryhowella, Cytheretta ulrichi, Muellerina, Pterygocythereis, Cytherella, Echinocythereis, and Cytheropteron. This is the deepest-water assemblage of ostracodes I have seen in the Maryland Miocene (see Table 1). Based on all the evidence observed, unit 12 was deposited in water perhaps as deep as 75 or 80 meters. This unit may represent a prolonged accumulation of bones and shells with a low rate of sedimentation which is not unusual in deeper water.

Unit 13 is sparsely fossiliferous. Because of a lack of data on this unit little can be said about the environment except that surrounding units seem to have similar environments. Until suitable evidence is available, unit 13 probably should be included in this environmental framework.

Unit 14 is the uppermost, prominent shell bed in the Calvert. The macrofauna consists of the following epifaunal and shallow infaunal organisms: Glossus, Lyropecten, Anomia, Chione, Astarte, Corbula, Lucinoma, and Ecphora. The accompanying Ostracoda include, in order of abundance: Cushmanidea, Muellerina, Heterocyprideis ?, Actinocythereis, Cytheretta ulrichi, Henryhowella, Echinocythereis, and Pterygocythereis. The fauna and sediments of unit 14 resemble those of unit 12, but differences indicate a distinct regression to approximately 35 to 50 meters of open ocean water.

Macrofossils are exceedingly rare in unit 15. As of yet only Turritella plebeia has been found. Even this correlates with some of the North Atlantic Turritella communities. To date, no microfossils have been recovered from unit 15. Considering the fact that the surrounding stratigraphic units all have generally similar ostracode faunas, unit 15 is tentatively included in this group.

Choptank Formation

The following analyses of Choptank assemblages include both a review of Gernant (1970) and new research. The lowest member of this formation is the Calvert Beach, and in the lower part of this member are found the deepest and coldest water assemblages of fossils in the Choptank. The molluscs from this downdip facies are dominated by Turritella, Hiatella, Lyropecten, Anomia, Yoldia, and Thracia. This group strongly resembles "Amphiura" communities of Thorson (1957, p. 510-513), found at depths of 15 to 100 meters in the North Atlantic. The ostracode assemblage is dominated by Muellerina, Henryhowella, and Cushmanidea with one-third of the fauna made up of deep water forms (see Table 1). This fauna indicates environments in 45 to 60 meters of open ocean water and resembles life in the modern Virginian biogeographical province (Cape Cod to Cape Hatteras).

Table 1: Maryland Miocene ostracode environmental indicators. Species and genera which seem particularly useful for facies interpretation. These ostracodes should not be used individually nor should they be considered restricted to the marine regions indicated. Determined on the basis of modern distribution, facies associations, and empirical evidence.

<table>
<tr><th colspan="2">Marginal Marine</th><th colspan="2">Shallow Shelf</th><th colspan="2">Mid-Shelf</th></tr>
<tr><td colspan="2">Cyprideis aff. floridana</td><td colspan="2">Cushmanidea spp.</td><td colspan="2">Henryhowella evax</td></tr>
<tr><td colspan="2">Pokornyella ? punctistriata</td><td colspan="2">Hulingsima ashermani</td><td colspan="2">Echinocythereis clarkana</td></tr>
<tr><td colspan="2">Semicytherura spp.</td><td colspan="2">Cytheretta burnsi</td><td colspan="2">Cytheropteron n. spp.</td></tr>
<tr><td colspan="2">Aurila sp.</td><td colspan="2">Murrayina spp.</td><td colspan="2">Pterygocythereis americana</td></tr>
<tr><td colspan="2">Cytheromorpha warneri</td><td colspan="2">Loxoconcha spp.</td><td colspan="2">Cytherella n. sp.</td></tr>
<tr><td colspan="2">Actinocythereis n. sp.</td><td colspan="2"></td><td colspan="2">Aequacytheridea n. sp.</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2">Cytheretta ulrichi</td></tr>
<tr><td></td><td colspan="2">Haplocytheridea bassleri</td><td colspan="2">Muellerina lienenklausi</td><td></td></tr>
<tr><td></td><td colspan="2">Proteoconcha redbayensis</td><td colspan="2"></td><td></td></tr>
</table>

The central Calvert Beach Member has shallower assemblages, and in many places they are autochthonous. One prominent autochthonous macrofacies consists of Diplodonta, Lucinoma, and Mercenaria which are shallow to medium depth burrowers. The Miocene environment probably consisted of a very muddy substrate that was low in food and oxygen, which is the typical habitat of living Lucinacea (Allen, 1958).

The updip equivalent of this facies as well as the assemblage found stratigraphically just above has a more diverse population and occurs in sandier sediments. The most important additions to the shallow to medium depth burrowers mentioned above are benthic carnivores and epifauna. The ostracode assemblage dominated by Cushmanidea, Heterocyprideis?, and Pterygocythereis and the foraminiferal assemblage dominated by Cibicides lobatulus both indicate a shallowing environment.

In the updip portion of the Calvert Beach outcrop some sandy units of much shallower origin interfinger. This environmental interpretation is supported by the epimacrofaunal assemblage, Abertella, Balanus, and Lyropecten, by the dominant Ostracoda, Semicytherura, Cushmanidea, Hulingsina, Haplocytheridea, and Proteoconcha, and by the dominant Foraminifera, Cibicides lobatulus, Valvulineria, and Textularia gramen.

Continued shallowing in the upper part of the Calvert Beach is indicated by the epifaunal assemblages of Isognomon, Discinisca, Lyropecten, Balanus, and Crucibulum. The absence of infaunal species seems to indicate that the substrate was a hard mud bottom. In places this facies includes an unusual foraminiferal fauna of over 90% Cibicides lobatulus, a shallow and marginal marine species. The dominant ostracodes, Hulingsina, Pokornyella?, and Cytheromorpha, also indicate a shallow or marginal marine environment.

The following unit, the Drumcliff Member, is a major shell bed containing a very diverse fauna. Many characteristics of the macrofossils require a very shallow marine origin: abundant epifaunal organisms, common burrowing Veneracea and Pholadacea, abundant shell borings of the shallow water annelid Polydora, and others.

Turritella plebeia dominates the Drumcliff macrofauna with Lunatia as the second most numerous snail. Mercenaria and Spisula are prominent bivalves. This Drumcliff assemblage compares closely with the "Venus (= Mercenaria) communities" of Thorson (1957, p. 508-510) from the cold water of the North Atlantic. The populations are found on sandy ocean bottoms in water depths of 10 to 40 meters. In the Mercenaria-Spisula-Turritella-Lunatia community an increase in loose sand would produce more Spisulas and Turritellas. The Drumcliff assemblages directly parallel this characteristic.

The ostracodes are dominated by Hulingsina, Cushmanidea, Cytheretta, and Loxoconcha, and the foraminifers are dominated by Cibicides lobatulus, Valvulineria, and Textularia. Both are shallow shelf assemblages. In Maryland, the Drumcliff was probably deposited in 8 to 25 meters of open ocean water.

In certain places the upper Drumcliff contains several low diversity molluscan assemblages of very shallow burrowers and sessile epifauna in local lenses and other discontinuous beds. Most of the bivalves appear to be autochthonous and occur in fine to medium well-sorted sand. The rare microfossils are suggestive of very shallow water. The various characteristics of these deposits suggest they originated in a region of shifting sand substrates probably in less than 10 meters of marine water.

The next unit, the St. Leonard Member, contains two prominent facies in the outcrop region. The first is an unfossiliferous brown sand facies measuring 3 to 5 feet in thickness, whereas the second is a moderately fossiliferous, blue muddy silt measuring 20 feet thick along the Calvert Cliffs. In the vicinity of the village of St. Leonard, these two facies can be found within 3 miles of one another. The macrofauna of the second facies consists of three categories: mud burrowers (Yoldia, Ensis, and Nuculana), epifauna (Discinisca, Balanus, Mytilus, Anadara, and Anomia), and shallow plowers (Turritella).

In the updip areas of the member the Foraminifera are strongly dominated by Buccella mansfieldi, but in a downdip direction they are increasingly typical of shallow marine assemblages. The ostracodes are dominated updip by Actinocythereis n. sp., a typical marginal marine and nearshore genus. Downdip, Haplocytheridea, another marginal marine to nearshore ostracode, becomes dominant. Further downdip is a typical nearshore assemblage of Hulingsina and Cushmanidea. Additionally, the unit has numerous Gyrolithes and Calianassa burrows, which are indicative of very shallow to marginal marine water. These characteristics and others are interpreted as meaning that the updip blue, muddy silt facies was produced by a lower bay environment mixing downdip with a more typical, very shallow marine environment.

The general shallowing trend in the first three members of the Choptank was reversed in the fourth, the Boston Cliffs Member. This unit is similar to the Drumcliff, probably indicating an environmental repetition. Within the Boston Cliffs two prominent facies are recognized, one on the Eastern Shore, the other on the Western Shore. The muddier Western Shore facies has macroassemblages with lower faunal diversity and higher faunal dominance. The sandier Eastern Shore facies has macroassemblages with higher faunal diversity and lower faunal dominance. Both facies contain many of the same species and are considered Miocene examples of Thorson's (1957) "Mercenaria communities." On the other hand, variations in relative abundance of the specias can be used to distinguish the two facies. Corbula inaequalis, Lunatia, Spisula, Isognomon, and Crassostrea are distinctly more abundant in the Eastern Shore assemblage, whereas Anadara, Cerastoderma, and Lyropecten are more numerous in the Western Shore assemblage. Shell excavations by the very shallow water annelid Polydora are much more abundant and larger in the Eastern Shore facies.

Within the ostracodes the brackish to very shallow marine Pokornyella ? punctistriata, Cytheromorpha, Aurila, Semicytherura, Haplocytheridea, and Cyprideis are more abundant in the Eastern Shore faunas. Both areas have a Cibicides lobatulus-Buccella-Textularia foraminiferal assemblage, but Textularia, Rotalia, and Quinqueloculina, genera often favoring brackish or very shallow water, are more abundant in the Eastern Shore populations. From these considerations and others the Western Shore facies was deposited in less than 25 to 35 meters of open ocean water, whereas, the Eastern Shore facies was deposited in less than 15 meters of slightly brackish water.

The deepening trend begun in the Boston Cliffs continued into the last Choptank member, the Conoy. Macrofossil assemblages include thin-shelled, deeper water organisms, including autochthonous beds of Atrina harrisii. Other molluscs found include Turritella, Thracia, Glossus, Dosinia, Ensis, Margaritaria, and Crassatella. The deeper water microfossils include the ostracodes, Pterygocythereis, Cytheretta burnsi, C. ulrichi, and Cushmanidea, and Nonion, Buccella, and Lagena dominate the foraminiferal fauna. The Conoy was deposited in about 35 to 50 meters of open ocean water.

St. Marys Formation

Following deposition of the Choptank Formation, a slight upwarp occurred in the southern part of the Miocene outcrop area, leaving a shallow basin in the northern region. In the center of the basin the sediments of the St. Marys Formation are conformable to the Choptank, but southward on the basin margins an angular discordance exists between the two units. South of this, very discontinuous stringer sands were deposited on the top of Choptank with the lower few feet of St. Marys sediments missing. The disconformable surface between the two units was extensively burrowed and bored by infaunal invertebrates. The excavations were then filled with basal St. Marys sediment.

Unit 21 of the St. Marys is found only in the basin mentioned above and was deposited in shallower environments than prevailed at the close of the Choptank. Macrofossils are scarce and include Lyropecten and Ensis. Beds of Atrina may be allochthonous. The shallow-water ostracode assemblage includes Cushmanidea, Actinocythereis, Cytheretta, Murrayina, and Heterocyprideis ?. Cibicides lobatulus, Buccella, and Nonion dominate the Foraminifera. The paleoenvironment was either in the very shallow subtidal area or in a restricted region.

At Little Cove Point unit 22 is an alternating series of densely shelly sands and sparsely fossiliferous clays. The allochthonous shell beds are cross-bedded, have sharp basal contacts with shell lag deposits, contain preferentially oriented shells, and contain well worn shells. Macrofossils are quite diverse and include predominantly Turritella, Spisula, Nassarius, Mangelia, Lunatia, and Mercenaria. The Turritella-Spisula-Lunatia-Mercenaria fauna is distinctly similar to molluscs in the Calvert and Choptank shell beds, but the great numbers of Nassarius and Mangelia reflect the shallower water environment of unit 22. Also of interest is the abundance of Anadara with large Polydora tubes. The Cushmanidea-Semicytherura-Cyprideis ostracode assemblage is from very shallow water, but of special interest is the phenotypic noding on Cyprideis which is usually indicative of brackish environments. All of these characteristics indicate that the unit 22 shell bed facies, at Little Cove Point, had a marginal marine origin.

The sparsely fossiliferous blue clay facies, containing Gyrolithes, Turritella, and Mercenaria and a greatly bioturbated sediment, originated in an extremely shallow or marginal marine environment.

North of Cove Point unit 22 is much sandier and less fossiliferous. Several different sedimentological patterns occur in this area including blue clay interbedded with well-sorted cross-bedded fine sand in 5 to 10 cm. thick couplets, strongly mottled medium-grained sand, poorly-sorted sand, and very well-sorted medium-grained sand extensively burrowed by Calianassa as well as a few other organisms. These updip facies are even more definitely marginal marine than the downdip facies.

Unit 23 is a sparsely fossiliferous, muddy, fine to very fine sand. The rare Mercenaria, Lunatia, and Anadara specimens are strongly reminiscent of the "Mercenaria communities" seen lower in the section. Since the sediments and macroassemblages seem similar to those lower in the section at Little Cove Point, the environment was probably similar, i. e., very shallow to marginal marine.

Unit 24 consists of two primary facies, a brown sandy shell bed facies and a less fossiliferous blue clay facies. The latter contains an autochthonous molluscan assemblage of Ensis, Yoldia, Turritella, Nassarius, and Panope. Loxoconcha, Pterygocythereis, and Cytheromorpha characterize the ostracodes, with the first and last pointing out the very shallow marine origin and the second reflecting the muddy substrate.

The shell bed facies of unit 24 contains Nassarius, Turritella, Lunatia, Cantharus, Busycon, Mercenaria, Anadara, Spisula, and many other molluscs. Polydora shell excavations are particularly large and abundant in this unit. Though some species are new and proportions of major taxa have changed from the Calvert and Choptank, the characteristic constituents of the North Atlantic "Merceneria communities" are still present in prominent abundance. Prosobranchs are particularly more abundant in this unit, and these indicate a shallower and perhaps lower energy environment than the shell bed assemblages in the Calvert and Choptank. The ostracodes include

Cushmanidea, Cytheretta burnsi, Murrayina, Haplocytheridea, Loxoconcha, and Proteoconcha. This is a typical shallow marine population from probably less than 30 meters depth.

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VERTEBRATE BIOFACIES AND PALEOENVIRONMENTS*

Frank C. Whitmore, Jr.

The Chesapeake Bay area is noted for the occurrence of Miocene marine mammals, which are also well known from the Antwerp Basin of Belgium, the Rhone Basin of France, the Piedmont Basin of northern Italy, Switzerland, the Vienna Basin of Austria, the Los Angeles area, and the Oregon coast. There are other scattered localities in the Atlantic Coastal Plain. A few genera are common to both sides of the Atlantic, but correlation at the species level has not been accomplished.

The vertebrate fauna of the Chesapeake Group is dominated by Cetacea and sharks. Also present are Sirenia, birds, crocodiles, turtles, and bony fishes (especially noticeable are remains of drumfish and of large scombroids such as marlin). Land-mammal bones are occasionally found.

Articulated skeletons of porpoises are fairly common, whereas bones of the larger whales (baleen and sperm) are usually scattered, probably as a result of the rending by sharks of a floating carcass, after which the bones were scattered by bottom currents. Shark teeth are very numerous and represent a large number of genera. They are most commonly found on the beach at the strand line. A few articulated skeletons of Sirenia (sea cows) have been found, and isolated bones are not uncommon. Turtle remains are fairly common but are restricted in stratigraphic occurrence. Crocodile teeth are often found in the Calvert, Choptank, and St. Marys Formations.

Some of the fossil vertebrates of the Chesapeake Group are of value as paleoecologic indicators because they are conservative forms, modern representatives of which have well-developed ecologic limitations. Chief among these are the sea cows and some turtles. Sharks have wider temperature tolerance, but the number of individuals and variety of genera in the Chesapeake Group have probable ecologic significance. Cetacea are less valuable ecologically: the occurrence of a cetacean in a deposit is more indicative of where the animal died than of where it lived (Kellogg and Whitmore, 1957). Nevertheless, the presence of large numbers of fossil cetaceans in a limited area can help in interpreting the general characteristics of neighboring seas. Similarly, remains of land animals in a marine formation are indicators of a terrestrial environment that was probably not more than a few miles away.

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Faunal changes within the Chesapeake Group.

Cetacea: Approximately the lower half of the Calvert Formation (Zones 1 through 8) is dominated by porpoises. They are of three types: squalodonts (primitive shark-toothed porpoises), short-beaked porpoises approximating the modern type, and four genera of long-beaked porpoises which may have dwelt in estuaries.

Zone 9 of the Calvert Formation marks the first appearance of cetotheres (primitive baleen whales). These were small forms, but more than 15 feet long, in contrast to their modern relatives which attain a length of 100 feet. Zone 9 also marks the first appearance of sperm whales, again much smaller than their modern relatives.

Zones 13 and 14 mark the appearance of large cetotheres, including Pelocetus calvertensis Kellogg, the largest cetothere yet described from eastern United States, with a skull $6\frac{1}{2}$ feet long. However, vertebrae found in the Chesapeake Group indicate the presence of a larger whale. These zones contain the most varied cetacean fauna of the Chesapeake Group: in addition to numerous cetotheres, long-beaked porpoises are still abundant, but short-beaked porpoises have declined in numbers, and squalodonts have disappeared. Sperm whales are present.

In beds above Zone 14, the cetacean fauna is less well known. This is probably in part because outcrops of the Choptank and St. Marys Formations are not as extensive as are those of the Calvert Formation.

The Calvert Beach Member of Gernant (1970) of the Choptank Formation has yielded two genera of long-beaked porpoises, a small cetothere (Parietobalaena palmeri, which here makes its last appearance after being fairly abundant in Zones 9 through 14), and a large cetothere in addition to those of the upper Calvert Formation.

The Drumcliff Member of Gernant (1970) of the Choptank Formation contains long-beaked porpoises, two sperm whales, two large cetotheres, and a precursor of the modern finback whale. The finback is a member of the family Balaenopteridae, which also includes the modern blue and sei whales. The appearance of a balaenopterid in the Drumcliff Member foreshadows the increasing importance of this family, probably at the expense of the more primitive Cetotheriidae, in the overlying St. Marys Formation. This faunal change is apparent in the St. Marys Formation of Virginia; our knowledge of the whale fauna of the St. Marys Formation in Maryland is as yet too scanty to draw any such conclusions.

Above the Drumcliff Member, very few whale specimens have been collected. The few specimens that have been found indicate that more extensive search will probably yield a fauna worthy of study.

Sirenia: Sea cows have been found in the Calvert Formation but not in the Choptank or St. Marys. One specimen was collected from the lower Calvert at Fairhaven, Maryland: sea cows are also found in Zones 7, 8, and 10, and they are well represented in Zones 11, 12, and 14. The modern dugong, to which the sea cow from the Calvert is most closely related, now ranges in the Indian Ocean from Africa to Australia and north to the Philippine Islands. Dugongs live in rivers that flow to the sea. They prefer fresh water but can live in salt or brackish water. They prefer a water depth of about 15 feet and eat soft water plants, including algae.

Crocodilia: Remains of the extinct crocodilian Thecachampsa antiqua (Leidy) have been found in place in Zone 12 of the Calvert Formation (at least four occurrences), in the Drumcliff and Boston Cliffs Members of Gernant (1970) of the Choptank Formation, and in the St. Marys Formation. Specimens found in place, but with incomplete data, and beach finds indicate that the population of Thecachampsa was of appreciable size.

Thecachampsa is represented by closely related species on both sides of the Atlantic in Miocene time; it may have been capable of high-seas migration (A. C. Myrick, Jr., oral communication). If this is so, ecologic analogy with modern crocodiles is not justified.

Turtles: Seven genera have been reported from the Calvert Formation; the greatest concentration is in Zone 10, with a few occurrences in Zones 12 and 13. Sea turtles are common in the Calvert Formation but have not been found in the Choptank or St. Marys. Turtles of paleoecologic significance are:

> Psephophorus, a leather-back turtle. The modern leather-back ranges over all intertropical seas.
>
> Syllomus, which is also pelagic.
>
> Taphrosphys, a pleurodire (side-necked turtle). It belongs to a suborder of fresh-water turtles now dwelling almost entirely in the Southern Hemisphere (South America, Madagascar, Africa, Australia, New Guinea). The Calvert species probably is a holdover from the Cretaceous.
>
> Testudo, land tortoise. Many recent species of Testudo and the closely related Gopherus prefer dry sandy areas, require warmth (75^{o}-95^{o}F.), and cannot survive dampness (Collins and Lynn, 1936, p. 172-173).

On the basis of the turtles, Collins and Lynn (1936) estimated the mean temperature in Calvert time in the Chesapeake area as about 67^{o}F or higher, similar to that of Beaufort, South Carolina.

Fishes: Fragments of bony fishes (Teleostei) are common in the Chesapeake Group, but no comprehensive studies have been made. Shark teeth are the most abundant vertebrate fossils in the Chesapeake but their stratigraphic ranges are imperfectly known because many specimens have been collected from the beach. The fauna includes the six-gilled or cow shark Hexanchus, the mackerel or mako shark Isurus, the tiger shark Galeocerdo, the requiem shark Hemipristis, the gray shark Carcharinus, the white shark Carcharodon, the sand shark Odontaspis, and several genera of rays (Kellogg, 1966, p. 67). Almost all the genera in the Chesapeake Group survive today.

Birds: Four species of sea birds are known from the Calvert Formation: two boobies, a shearwater, and an auk (Wetmore, 1940). One of the boobies and the shearwater are common.

Plants: Leopold (1970, p. 409, and oral communication) points out that, on the basis of pollen, most of the plant groups in the Calvert, Choptank, and St. Marys Formations are represented in the modern flora of the region. There are a few exceptions: Gordonia and the family Sapotaceae, found in the Calvert Formation, are southeast Coastal Plain taxa, in essence subtropical. Engelhardtia or Alfaroa have been identified in the Calvert and Choptank. The former is a member of the Evergreen Sclerophylous forest (subtropical) of China, and the latter grows in warm temperate highlands in Costa Rica and Central America. Leopold concludes that the Calvert flora is primarily warm temperate, that the Choptank climate was slightly cooler, and that the flora of the St. Marys Formation was more like that of today.

Land mammals: The nearshore character of the Chesapeake Group is emphasized by occasional occurrences of land-mammal bones (Gazin and Collins, 1959; Kellogg, 1966, p. 67). They are particularly common in the Calvert Formation but have also been found in the Choptank and St. Marys. The Calvert land-mammal fauna includes Gomphotherium calvertensis Gazin and Collins, probably the earliest mastodont in the Western Hemisphere; Cynorca proterva (Cope), a peccary; Tomarctus marylandica Berry, a small dog; Amphicyon sp., a very large dog; Tapiravus cf. T. validus (Marsh), a tapir; and Aphelops ? sp., a rhinoceros. The horses Archaeohippus sp. and Merychippus sp. Gomphotherium may also occur in the Choptank, which has also yielded Hesperhys (Desmathyus ?) sp., a larger peccary than the Calvert genus, and bones of cervids. The St. Marys Formation (Zone 24) has yielded a partial shoulderblade of a large artiodactyl, probably a camel.

At least two important land-mammal specimens have been found on the beach. One is a tooth of the horse Hipparion cf. H. phosphorum Simpson (see note on Field Trip Stop #2). The other is a tooth of the large dog Aelurodon, known from the Miocene and Pliocene of the western United States.

Most of the genera of land mammals found in the Chesapeake Group are known from the widely-exposed Miocene deposits of the West; this gives a subjective impression of faunal uniformity over what is now the United States. The fossil land mammals allow at least a tentative correlation with the continental Tertiary beds of the West. Gazin and Collins (1950) regarded the Calvert Formation as latest Hemingfordian or early Barstovian (upper middle or lower upper Miocene), and Woodburne (1969) regarded the Calvert as early Barstovian.

Ecology of the Chesapeake Group

Articulated skeletons of porpoises are common throughout the Calvert Formation. Long-beaked porpoises are consistently present, which may indicate an environment of estuaries and rivers. Beginning in Zone 9 of the Calvert Formation, baleen whale skeletons are present. In contrast to the porpoises, most of them have been disarticulated and scattered. Most of the baleen whales are young individuals, suggesting that the Chesapeake Bay area in the Miocene was a calving ground similar to Scammon's Lagoon, Baja California, which is now frequented by gray whales.

Sea cows and gopher turtles indicate a climate that rarely if ever reached freezing and that attained a high of 75°F. or more during much of the year. Evidence for such a mild climate is strong in the Calvert Formation. Crocodiles and sea cows frequented shallow water. Sea cows and gopher turtles are not known above the Calvert.

Plants indicate a cooling trend through the time represented by the Chesapeake Group.

Notes on field trip stops

1. Camp Roosevelt. The Calvert Formation here yields a great variety of shark teeth, remains of a predaceous shark-toothed porpoise, and three species of long-beaked porpoises, probably estuarine in habit. These predators preyed on baleen whales, also found here, and on fish. A side-necked turtle indicates a warm fresh-water habitat. Hair seals congregated on the coast or on nearshore islands.

2. Baltimore Gas and Electric Company Site. The vertebrate faunal list here is longer than for the other stops because of intensive collecting done as part of the paleoecology project of the Maryland Academy of Sciences. This is especially true of the shark fauna of the Drumcliff Member of the Choptank Formation. Long-beaked porpoises were probably estuary or river dwellers, whereas the presence of sperm whale, baleen whale, and marlin indicates access to the open sea. The jaw of the primitive mastodont *Gomphotherium*, found near the base of the Drumcliff Member, shows that land was not far away.

The vertebrate fauna of the Boston Cliffs Member of the Choptank Formation is smaller than that of the Drumcliff Member but is consistent with the same sort of environment.

The finding on the beach of a tooth of the horse Hipparion cf. H. phosphorum Simpson, described from the lower Bone Valley Formation of Florida, implies the presence in this area of beds of Pliocene age.

3. Little Cove Point. The vertebrate faunal list from this area is small, consisting of a crocodile, two long-beaked porpoises, and a large primitive baleen whale. This site yielded one of the first fossil vertebrate specimens in the National Museum collections--the type of Lophocetus calvertensis Harlan, collected in 1841.

4. Drumcliff. The presence of crocodile, hair seal, sperm whale, and primitive baleen whale indicates a nearshore environment with access to the open sea.

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ORIGIN OF SHELL BEDS

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The first figured New World fossil was collected from a St. Marys Formation shell bed, and paleontologists have extensively collected these rich deposits since that time. However, few workers have suggested origins for the great density of shells in these beds.

Mongin (1959) felt the Choptank shell beds resulted from transgressive beach deposits. Fowler (1966) considered the same units plus unit 10 (of Shattuck, 1904) to have been "concentrations formed by storm waves which winnowed out the clay sized particles." Gernant (1970) suggested that the Drumcliff and Boston Cliffs shell beds were concentrated as a result of marine swells sweeping through the area creating zones of traction and accumulation in bottom deposits.

For the purposes of this discussion, "shell beds" are considered as deposits in which fossils are fairly prominent. Instead of analyzing these units in stratigraphic sequence, I will consider them in three major genetic groupings (see Table 2). The first category consists of _autochthonous beds_, in which the majority of fossils lived, died, and were buried in the same place. _Allochthonous beds_ contain organisms that did not live, die, and become buried in the same place. _Allochthonous-autochthonous beds_ include organisms which practically speaking might be considered autochthonous since life, death, and burial were probably very closely related, but the identifying characteristics of autochthonous fossils are absent.

Autochthonous Shell Beds

Autochthonous beds of _Atrina harrisii_ occur in the Drumcliff and Conoy Members. The epifaunally attached bivalves are double valved, in life position, tightly packed side-by-side, and with bottom shell tips all aligned on a plane. Along with these, the deep-burrowing _Panope americana_ is found in the bottom of burrows that terminate at the same surface as _Atrina_. The burrows of both species were filled with sediments of the following depositional regime. In the Conoy, some specimens occur singly.

A disseminated autochthonous deposit occurs in the Calvert Beach Member, made up of _Diplodonta_ and _Lucinoma_. These beds consist of double-valved, life-position bivalves that burrowed into deep inner shelf, muddy sediments. Along with these two characteristic genera, _Mercenaria_, _Dosinia_, _Glossus_, _Crassatella_, and _Ensis_ are typically found double-valved, in life position and sometimes in the bottom of burrows.

Table 2 GENETIC LISTING OF SHELL BED ORIGINS

Autochthonous		"Allochthonous-Autochthonous"		Allochthonous		
Biostromal Banks	Dispersed	Swell-Traction	Natural Benthonic Accumulation	Wave- or Current-Worked	Normal Nektonic Accumulation	Reworked
1) Atrina beds (Drumcliff Mbr.) 2) Atrina beds (Conoy Mbr.)	1) Lucinoma-Diplodonta beds (Calvert Beach Mbr.) 2) Ensis-Yoldia (St. Leonard Mbr.) 3) Ensis-Yoldia-Panope (Unit 24)	1) Major sandy shell bed (Unit 10) 2) Major sandy shell bed (Unit 14) 3) Major sandy shell bed (Drumcliff Mbr.) 4) Major sandy shell bed (Boston Cliffs Mbr.)	1) Isognomon beds (Drumcliff Mbr.)	1) Corbula elevata beds (Units 5-9) 2) Turritella plebeia lenses (Calvert Beach Mbr.) 3) Balanus-Lyropecten-Abertella lenses (Calvert Beach Mbr.) 4) Turritella plebeia (Drumcliff Mbr.) 5) Crassostrea-Isognomon (Boston Cliffs Mbr.) 6) Turritella plebeia lenses (Conoy Mbr.)	1) "Bone bed" (Unit 12) 7) Turritella plebeia lenses (Unit 22) 8) Major sandy shell beds (Unit 22) 9) Sandy shell beds (Unit 22)	1) Pyncnodonte percrassa bed (Unit 4)

Another disseminated autochthonous shell bed can be found in unit 24, in which Ensis, Yoldia, and Panope are double-valved, in life position with the snails Nassarius and Turritella. Based on the molluscs and the ostracode assemblage of Loxoconcha, Pterygocythereis, and Cytheromorpha this bed was deposited in quiet, muddy, shallow inner shelf waters. The environment was sufficiently peaceful to allow organisms to die in their subsurface dwelling and not be reworked by later shifting bottom sediments.

Allochthonous-Autochthonous Shell Beds

Two subvarieties of allochthonous-autochthonous shell beds are found. The first is a natural accumulation of benthonic remains, and the second is a concentration of shells within the substrate.

Examples of the first type were discussed by Gernant (1970) and are called the Isognomon beds. These units occur in the upper Calvert Beach Member and contain a few species, all of which were epifaunal, living attached to the hard substrate, attached to other animals, freely motile on the substrate, or freed from substrate control by a swimming existence. These fossils accumulated naturally in a low sedimentation environment in which they themselves created favorable living habitats for following generations of epifauna.

The most fossiliferous beds are unit 10 in the Calvert Formation and the Drumcliff and Boston Cliffs Members in the Choptank. These, perhaps along with unit 14, appear to have been formed by the same mechanism, although different facies clearly exist. Gernant (1970) analyzed the characteristics and origin of the Choptank shell beds, and at this time units 10 and 14 appear to have the same genesis.

In light of the shell bed characteristics, Gernant (1970) considered several possible origins documented in modern depositional environments. Of the processes analyzed, a concentration method proposed by Powers and Kinsman (1953) seemed the best explanation for the features seen.

In their investigation, they found shell beds within the substrate at depths of 45 to 145 feet in the North Atlantic. Here Powers and Kinsman recognized two zones in the substrate, a lower one with abundant macrofauna and an upper one with very little macrofauna. They felt that vertical sorting in the substrate produced this effect and that this was related to the influence on the substrate of passing marine swells. They pointed out that a typical swell would establish a pressure gradient on the bottom causing flow into the sediment. Following passage of the swell, flow out would be accompanied by effusion of the substrate. Powers and Kinsman (1953) and Gernant (1970) felt that the lower limit of this lifting defined the base of "the traction zone" (see Fig. 12). The "accumulation zone" results from the heavier materials in the substrate settling out first after the effusion.

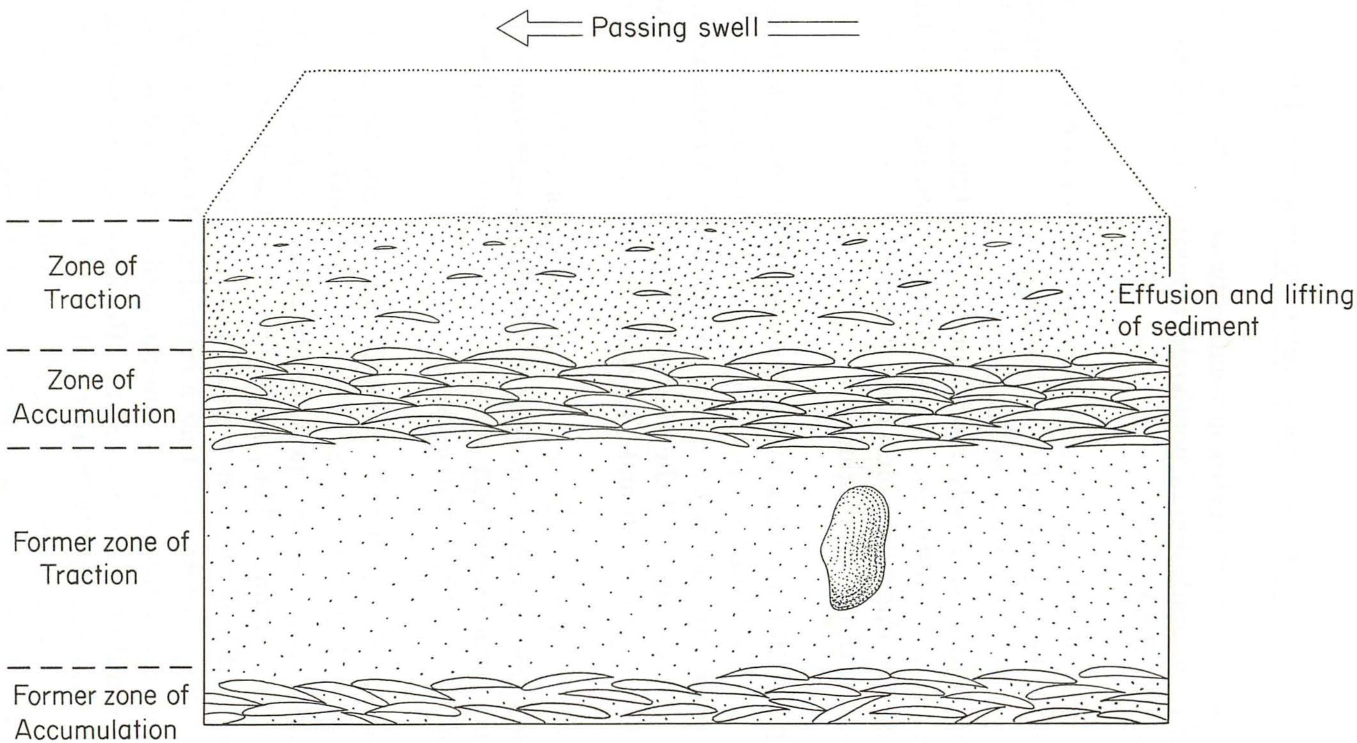

Figure 12: Proposed swell-traction mechanism of shell bed accumulation for Units 10 and 14 of the Calvert Formation and the Drumcliff and Boston Cliffs Members of the Choptank Formation. Note shallow and medium depth infaunal bivalves in flat-lying positions in zone of accumulation and deep burrowing Panope in life position. (After Gernant, 1970).

This mechanism of passing marine swell creating sorting and differentiation in the substrate seems adequate to produce the many features of units 10 and 14 and the Drumcliff and Boston Cliffs Members as discussed in detail by Gernant (1970). The process was probably very complicated, however. As a swell consists of a group of waves, the substrate is subjected to the same number of cycles of inward pressure followed by release. During all this turmoil, infaunal bivalves are thrashed about, reoriented, and subjected to taking in harmful amounts of sediment. This last action alone may be enough to kill the animal and place it in a passive role under the influence of the following traction. Following death, the activity of traction would stack up the heavier shells as a lag deposit in the zone of accumulation. For most of the shells the lifting of the sediment around them would put them in an unstable position and probably change their original orientation. In the releasing phase the shells would fall back to the base of the traction zone and there they would more likely fall back on a flat side rather than on edge. Because of this concentration procedure, shells need not be moved more than one or two feet during the whole process.

For practical purposes these fossils could be considered autochthonous. On the other hand, the sorting operation probably mixes animals from somewhat different environments as well as moving them somewhat. Also the most definitive autochthonous characteristics are absent. For these reasons the assemblage has a certain but limited allochthonous aspect. As a result, I have termed this an allochthonous-autochthonous shell bed.

Occurrences of the deep burrowing Panope are especially significant for determining the effective limit of traction. Since specimens of this genus are always found in living position, the operative limit must have been less than their living depth of about 2 feet.

For a more complete discussion of this mechanism and its relationship to Miocene shell beds, the reader is referred to Gernant (1970).

Allochthonous Shell Beds

Among the allochthonous shell beds is a biostromal deposit which occurs consistently within the lower several inches of the Plum Point Marls. Unit 4 consists of a rather dense concentration of large specimens of the oyster Pyncnodonte percrassa. The stratigraphic arrangement of this bed is particularly significant in that it parallels the top surface of the Fairhaven Member which is angularly unconformable with the basal sediments of the Plum Point Marls. Since the Pyncnodonte bed parallels this older surface of erosion or nondeposition but it at an angle with the sediments that surround it, the living oysters must have been dependent on the former sea floor rather than on the new sediments. This evidence, in addition to the fact that the shells are disarticulated and rather well worn, seems to indicate that Pyncnodonte lived attached to the hard clay substrate formed by the top of the Fairhaven and was then worked into basal sediments of the new deposits.

Though these units have a definite biostromal configuration, other lensoid molluscan accumulations only appear to be when viewed from a distance. These beds occur throughout the Maryland Miocene; in units 5 through 9 they consist primarily of the bivalve Corbula elevata, but primarily of the gastropod Turritella plebeia in the Calvert Beach, Drumcliff, and Conoy Members of the Choptank Formation and units 21 through 24 of the St. Marys Formation. The difference in faunal composition may be related to the deeper water environments of the Corbula beds as opposed to the Turritella beds. The similarity of geometric configurations, however, probably indicates a similar producing mechanism.

Van Straaten (1960, p. 110) described Recent shell deposits from near the Rhone delta that may be modern analogues of these lensoid pockets. He felt that the effect of currents in certain areas along this shelf was to eliminate or at least considerably reduce sedimentation. Large numbers of shells then accumulated in these nondepositional environments in depths between about 10 and 50 meters, the same depth range as postulated for the Miocene beds. Interestingly, the most abundant species in the Rhone deposits is Turritella tricarinata communis. Perhaps similar currents moving along the Miocene shelf produced a nondepositional environment and washed the shells of Turritella and Corbula into irregular small depressions in the substrate. It is also significant that unidirectional orientations of the fossil shells occurs only in the very shallow water deposits of unit 22.

Another environment with low sedimentation rates allowed the accumulation of the disarticulated skeletons and well worn shells which make up unit 12. This bed originated in the deepest environment of any of the shell or bone beds, which, of course, increased the likelihood of a very reduced sedimentation rate.

A concentrated shell bed occurs at the base of the Boston Cliffs along the Choptank River. The assemblage consists of the sessile epifaunal bivalves Crassostrea carolinensis and Isognomon maxillata, which lived attached to the substrate in moderately agitated, very shallow water. Following death of the organisms, waves tossed the shells enough to make them well worn. The accumulation of shells into a hard, shelly substrate would present no problems to the development of following generations. In fact, this would be beneficial in that abundant sites for attachment would be available.

The last subtype of shell bed to be discussed here is the prominent, sandy, concentrated shell beds of units 22 and 24. In contrast to the major Calvert and Choptank shell beds, the lateral continuity of these two is rather limited. Even within single localities, individual horizons appear and disappear, and contacts are very sharp. Perhaps even more important is the fact that some unit 22 fossil accumulations are cross-bedded. The St. Marys shell accumulations also differ from the major ones of the Calvert and Choptank in that a very large percentage of the fossils are well worn. Also, none of the bivalves occur in life position. Though the prominent organisms of the Calvert and Choptank are shallow infaunal and attached epifaunal suspension feeding bivalves, the most abundant animals in the St. Marys are predaceous and scavenging gastropods. Additionally, accumulations of these snails are sometimes unidirectionally oriented. The characteristics of the unit 22 and 24 beds and the faunal composition definitely indicate a very shallow marine allochthonous accumulation.

Van Straaten (1956) described shell beds that are possible modern analogues from tidal channels behind barrier islands in the Dutch Wadden Sea. In these channels shells were concentrated by being washed in with tidal currents, washed in with storm waves, and eroded in from tidal flat deposits of varying ages. As a result the shell assemblages consisted of mixed representatives of various environments.

This tidal channel concentration of heterogeneous associations is an appealing solution to the problem of mixed assemblage elements. Additionally, the geometric configuration of the Miocene coastline was conducive to the development of a system of barrier islands protecting extensive tidal flats. Gibson (1970, p. 1818-1819) has indicated that from distribution of the Miocene formations and environmental considerations, deposition of these units appears to have occurred in pronounced coastal embayments. If this interpretation of the origin of unit 22 and 24 shell beds is correct, several taphonomic types of assemblages could be found in these accumulations.

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ROAD LOG

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The field trip route is shown in Figure 13.

The Shoreham Hotel is located on the eastern border of the Piedmont Province, and soon after leaving the hotel we will cross the fall line and come into the Coastal Plain Province. The Piedmont rocks in the vicinity of the Shoreham Hotel and through Rock Creek Parkway are metamorphic units including the Wissahickon schist and Kensingston granite gneiss. These and other Piedmont rocks are one of the major sources for the sediments of the Cenozoic strata. The age of some of the Piedmont rocks is still somewhat uncertain, but slates have been found which contain Ordovician fossils, and radiometric dates on other units fall within the Cambrian. It appears that many of the Piedmont rocks are early Paleozoic in age, with others being late Pre-Cambrian.

After leaving Rock Creek Park, the route begins to cross the Coastal Plain. As the accompanying map (Fig. 14) indicates, we will be crossing Quaternary alluviam, much of it deposited since 1792. The area where the Lincoln Memorial now stands was the site of a suitable harbor for merchant vessels in 1711, showing the high rate of deposition in this area within the past 200 years. This high rate is attributed by Meade (Bull. Geol. Soc. America, v. 80, p. 1265-1274, 1969) to the cultivation and urbanization of the area. Meade estimates the present sediment loads of streams in the Atlantic states to be four to five times greater than before the settlers landed.

After passing over the alluviam in Washington, we will traverse the older rocks of the Coastal Plain. The oldest sedimentary strata in this area are of Early Cretaceous age, and are gravels, sands, and clays of fresh water origin. These are overlain by Late Cretaceous units, primarily clays and sands. The lower units of the Upper Cretaceous are probably non-marine in origin, but the upper part is a glauconitic sand with marine fossils. The Cretaceous rocks underlie much of the central and eastern District of Columbia.

Because of the generalized southeast dip in this area, younger rocks will be transected eastward. They are primarily the Lower Paleocene Brightseat Formation, the Upper Paleocene Aquia Formation, and the Eocene Nanjemoy Formation. All of these are primarily of marine origin, and vary lithologically from clays to glauconitic sands. Much of the Aquia is a heavily glauconitic unit. After crossing the Anacostia River, we will traverse the Cretaceous for several miles and then come into younger units.

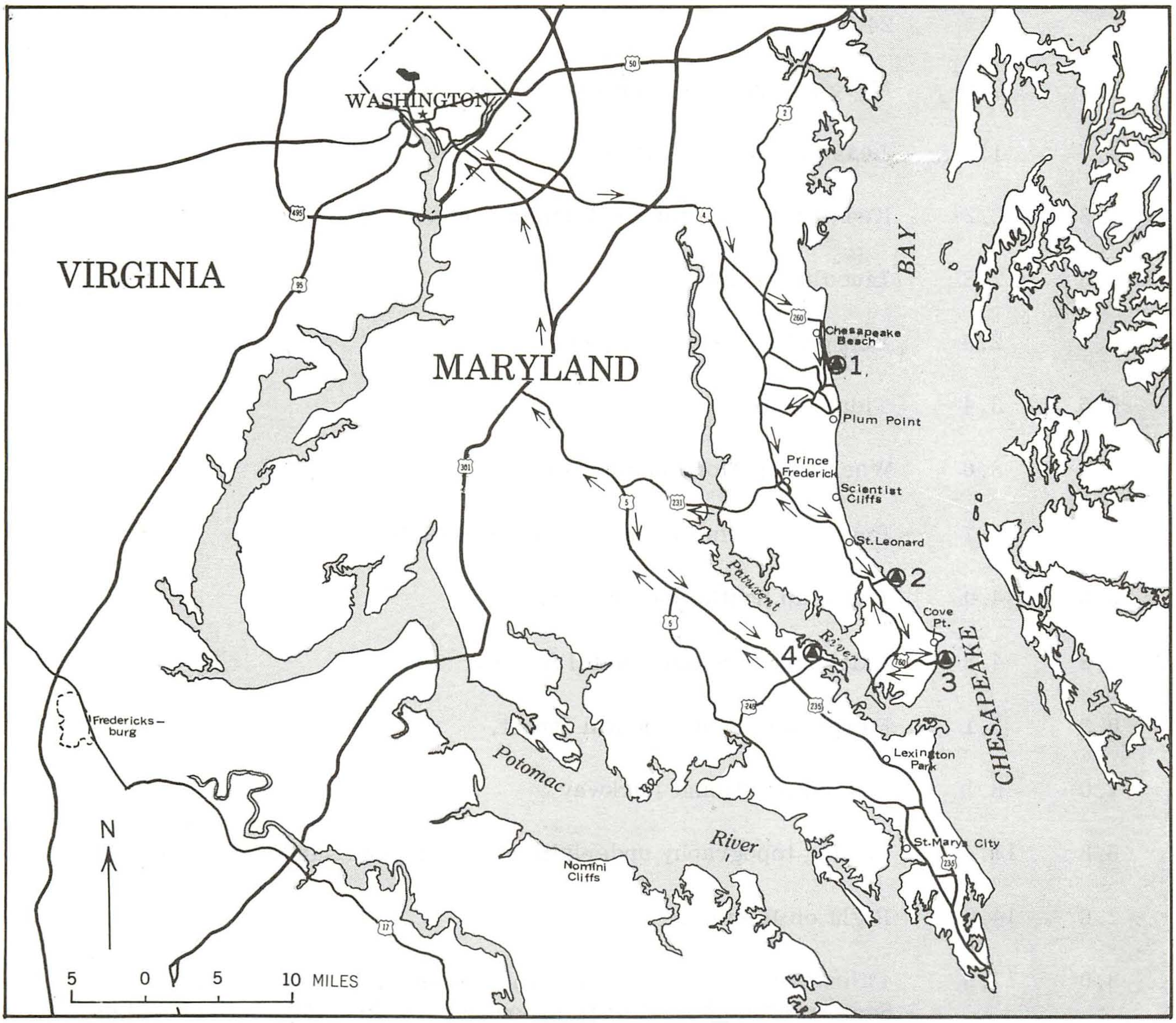

Figure 13: Route of Field Trip.

MILES	CUMU.	
	0.0	Leave Shoreham Hotel, right on Calvert Street, right on 24th Street.
0.2	0.2	Merge right onto Rock Creek Parkway.
1.7	1.9	Leave Rock Creek Park.
0.3	2.2	Kennedy Center for Performing Arts.
0.6	2.8	Lincoln Memorial.
0.1	2.9	Left on Independence Avenue.
0.5	3.4	Tidal Basin.
0.2	3.6	Washington Monument on left.
0.1	3.7	Bureau of Printing and Engraving on left.
0.3	4.0	Left onto Southwest Freeway.
0.8	4.8	Exit right to South Capitol Street.
0.3	5.1	Merge onto South Capitol Street.
1.0	6.1	Left onto Suitland Parkway.
5.3	11.4	Rolling topography underlain by Pleistocene sand and gravel.
2.6	14.0	Right on Route 4.
3.0	17.0	Paleocene glauconitic sands in gully on right side of road. Scattered shell fragments in lower part, becomes buff-greenish in weathered upper part.
4.2	21.2	Cross Patuxent River.
4.2	25.4	Left on Route 260.
7.5	32.9	Right on Route 261.
3.7	36.6	Left on dirt road to Camp Roosevelt.
0.4	37.0	Parking lot for STOP #1. Follow dirt path 0.2 miles to beach, walk south on beach 0.3 miles to cliff.

0.4	37.4	Return to Route 261; turn left.
0.7	38.1	Sharp right, continue on Route 261.
1.1	39.2	Right on Route 263.
3.6	42.8	Left on Routes 2 & 4.
12.1	54.9	Left onto road to BG&E site.
1.2	56.1	Parking for BG&E site. STOP #2.
1.1	57.2	Return to Routes 2 & 4, turn left.
4.6	61.8	Left onto Route 760.
1.1	62.9	Sharp left, follow Route 760.
1.1	64.0	Left into Chesapeake Ranch Club.
0.3	64.3	Left onto Catalina Drive.
2.2	66.5	Right on Beach Drive.
0.1	66.6	Parking lot. STOP #3. Cliffs immediately north of parking lot.
2.6	69.2	Return to Route 760, turn right.
2.2	71.4	Turn right on Routes 2 & 4.
13.8	85.2	Left on Route 231.
4.6	89.8	Crossing Patuxent River.
6.4	96.2	Left on Route 5.
7.5	103.7	Continue straight on Route 235.
7.1	110.8	Left on Jones Wharf Road.
1.4	112.8	Right to Drumcliffs.
0.6	112.8	STOP #4.
2.0	114.8	Return to Route 235, turn right.

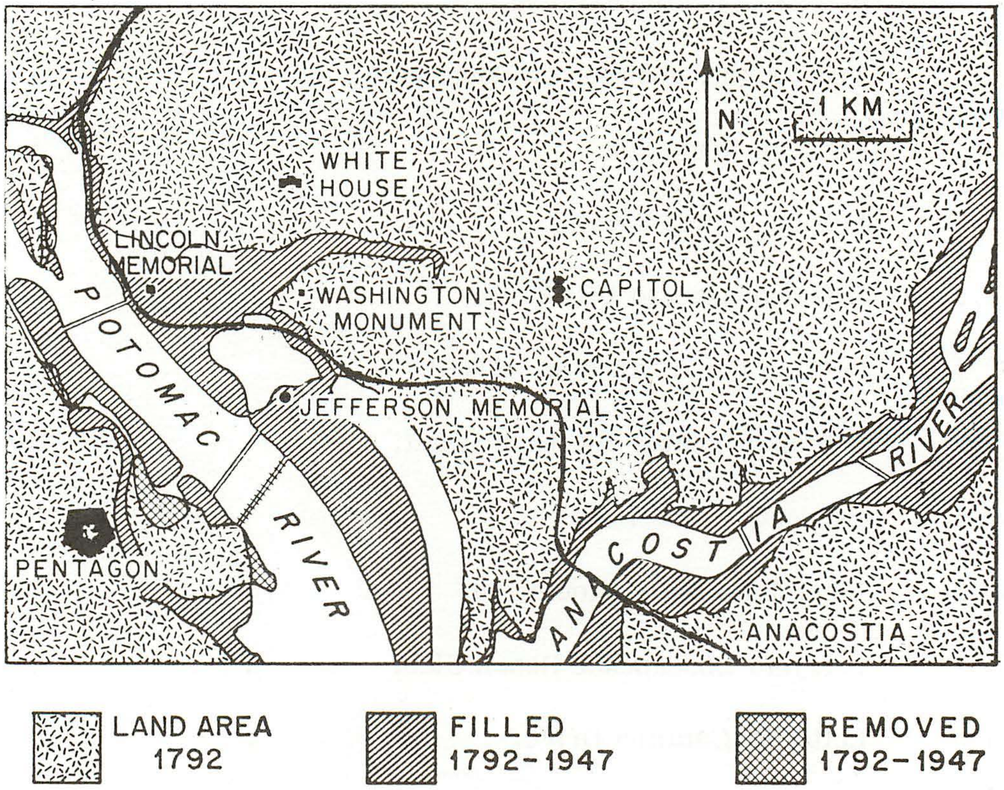

Figure 14: Sites of Recent alluvial fill.

7.1	121.9	Junction of Route 5 and 235.
32.6	154.5	Continue on Route 5 to junction with Suitland Parkway.
4.1	158.6	Junction with South Capitol Street.
0.8	159.4	Left on Canal Street.
0.4	159.8	Left on Independence Avenue.
2.6	162.4	Junction with Rock Creek Parkway.
2.7	165.1	Bear left onto 24th Street.
0.2	165.3	Shoreham Hotel.

DESCRIPTION OF SELECTED MIOCENE EXPOSURES

Robert E. Gernant
Thomas G. Gibson
Frank C. Whitmore, Jr.

Section between Camp Roosevelt and Willows
Beach on Western Shore of Chesapeake Bay,
Calvert County, Maryland

Stop #1

Post - Miocene (7 feet)

Miocene

Calvert Formation

Plum Point Marls Member

Unit 15 (18' 0")---Biogenically mottled, dusky bluish-brown, slightly muddy, fine sand. Fossils very rare. ? Turritella plebia.

Unit 14 (5' 0")---Dusky brown, very slightly muddy, fine sand. Concentrated shell bed including Glossus spp., Astarte spp., Crassatella melina, Anadara subrostrata, Lyropecten madisonius, Corbula idonea, Lucinoma contracta, Ecphora quadricostata, Panope sp.

Unit 13 (27' 0")---Dusky green, very muddy, silt. Fossils very rare.

Unit 12 (3' 0")---Biogenically mottled, dusky brown, slightly muddy, fine sand. Rare shell and bone fragments, poorly preserved.

Unit 11 (6' 4")---Intensely mottled biogenically, light greenish gray, sandy, silt. Very rare small shell fragments.

Unit 10 (15' 1")

(2' 11")---Slightly mottled, light dusky brown, slightly muddy, fine sand. Fossil fragments numerous, upward trend for smaller sizes.

(0' 9")---Dusky orangish brown, fine sand. Sizeable fossils in great abundance. Turritella indenta and Glycymeris parilis most abundant.

(4' 3")---Dusky orangish brown, fine sand. Fossils smaller and less abundant than above and below. Turritella indenta is most prominent.

(0' 8")---Dusky orangish brown, well-sorted, medium sand. Fossils large and profusely packed. Glycymeris parilis, most prominent and many double-valved in horizontal position, also, Andara subrostrata, Chione spp., Turritella indenta, Astarte spp., Dosina acetabula, Anodontia anodonta, and many others.

(2' 0")---Light dusky brown, well-sorted, fine sand. Fossils larger and more abundant than unit below. Anadara subrostrata, Glycymeris parilis, Astarte spp., and Crassatella melina (numerous); Lyropecten madisonius and Chione spp. (few); and many others.

(3' 6")---Strongly mottled, dark dusky gray, muddy, fine sand. Fossils somewhat numerous with Glycymeris parilis, Turritella indenta, and Chione spp. most prominent.

(1' 0")---Strongly mottled, dusky olive green, very muddy, fine sand. Mottles of light gray, well-sorted, fine sand. Fossils few and small, mostly fragments. Most prominent are Glycymeris parilis, Turritella indenta, and Chione spp.

Unit 9 (2' 6")---Biogenically mottled, dusky olive green, very muddy, fine sand. Mottles of light gray, well-sorted, fine sand. Fossils small and profuse. Concentrated bands of Corbula elevata, also rare specimens of Lyropecten madisonius, Turritella plebeia, and Balanus concavus.

Unit 8 (7' 3")---Mottled, dusky olive green, very muddy, very fine sand. Thin, short ripple-drift inorganic structures. Burrows filled with well-sorted, fine sand. Fossils sparse. Thin bands of Corbula elevata. One band of flat-lying Atrina and Discinisca lugubris.

Unit 7 (2' 5")---Slightly mottled, dusky olive green, very muddy, fine sand. Fossils sparse. Mostly Corbula elevata.

Unit 6 (2' 0")---Mottled, dusky greenish brown, muddy, fine sand. Fossils abundant. Concentrated bands of Corbula elevata.

Unit 5 (2' 5")---Biogenically mottled, dusky blue, very muddy, very fine sand. Fossils very rare Corbula elevata.

(Section below covered by beach.)

Vertebrate faunal list, Calvert Formation, Camp Roosevelt, Calvert County, Maryland

Odontaspis cuspidata Agassiz. Sand shark.

Taphrosphys miocenica Collins and Lynn. Side-necked turtle. Zone 10.

Leptophoca lenis True. Hair seal.

Squalodon calvertensis Kellogg. Shark-toothed porpoise. Zone 6.

Orycterocetus sp. Sperm whale. Zone 10 (?) .

Rhabdosteus sp. Long-beaked porpoise. Zone 10.

Eurhinodelphis bossi Kellogg. Long-beaked porpoise. Zone 10.

Zarhachis flagellator Cope. Long-beaked porpoise.

Parietobalaena palmeri Kellogg. Primitive baleen whale. Zone 10.

Cetothere indet. Primitive baleen whale.

Section at Baltimore Gas and Electric Company
Calvert Cliffs Nuclear Power Plant on
Western Shore of Chesapeake Bay, Calvert County, Maryland

Stop #2

Post - St. Marys (?Pliocene, ?Pleistocene) -- (20 feet)

Miocene

St. Marys Formation

Unit 23 (13' 6")---Dusky blue, poorly sorted silt. Contains indurated, duracrust bands. Fossils: molds and casts rare.

Unit 22 (19' 8")

(1' 3")---Interbedded, well-sorted medium sand and clay. Indurated.

(1' 6")---Light orangish brown, well-sorted, fine to medium sand. Extensively burrowed by *Calianassa*.

(2' 0")---Grey, poorly sorted silt. Few fossil molds and casts.

(4' 0")---Brownish orange, poorly sorted medium sand. Fossils absent.

(0' 8")---Dark reddish brown, fairly well sorted, medium manganese sand. Fossils: absent.

(1' 9")---Biogenically mottled, orangish brown, medium sand. Undetermined vertical burrows. Few fossil molds and casts. Cerastoderma sp.

(4' 6")---Interbedded dusky blue clay and cross-bedded, well-sorted, fine sand. Fossils: absent.

(1' 0")---Indurated ledge of orangish brown, muddy, fine sand. Fossils: consist of abundant poorly preserved snails and bivalves. Barnacles also numerous.

(3' 0")---Dusky blue, muddy, fine sand. Fossils: very rare.

Unit 21 (9' 0")---Dusky blue, very muddy very fine sand. At base of unit 1/2" brown sand with fossil hash. Fossils: rare, Atrina sp.

Choptank Formation

Conoy Member (8' 2")---Thick-bedded, dusky blue, very muddy silt. Fossils: rare. Atrina, Crassatella, Ensis, Glossus, and Thracia.

Boston Cliffs Member (11' 0")---Light dusky brown, slightly muddy, fine sand. Fossils gradational in concentration from very abundant, large shells to few, small shells. Very well preserved molluscs and barnacles. Most prominent are bivalves, all flat-lying, both single valves and articulated valves. The more abundant fossils are Lyropecten, Cerastoderma, Crassatella, Balanus, Anadara, Macrocallista, Astarte, Corbula, Turritella, Mercenaria, and Dosinia.

St. Leonard Member (13' 2")

(10' 6")---Dusky blue green, muddy, fine sand. Biogenically mottled with light gray, well-sorted, fine sand. Extensively burrowed (some Gyrolithes). Fossils: rare, including Ensis, Discinisca, Lucina, Cerastoderma, and Dosinia.

(0' 2")---Dusky blue green, very muddy fine sand. Contacts undulating. Fossils: numerous thin-shelled bivalves, flat-lying.

(1' 4")---Dusky blue green, very muddy, fine sand. Fossils: rare fragments. Mostly unidentified small fragments. Ensis, rare.

(0' 2")---Dusky blue green, very muddy, fine sand. Contacts undulating. Fossils: concentrated band of thin-shelled bivalves, including *Ensis*, *Spisula*, *Cerastoderma*, *Corbula*, and *Anadara*.

(0' 10")---Dusky blue green, very muddy, fine sand. Fossils: rare fragments mostly unidentified. *Discinisca lugubris*.

Drumcliff Member (1' 6")---Dusky greenish gray, very muddy, fine sand. Fossils: very abundant and large diversity. *Ensis*, *Anadara*, *Glossus*, *Lyropecten*, *Corbula*, *Cerastoderma*, *Crassatella*, *Turritella*, *Dosinia*, and many more.

(Section below covered by beach.)

Vertebrate faunal list, Baltimore Gas and Electric Co. site, Calvert County, Maryland

St. Marys Formation

Beige sand (slope above Step 2 of stripping area).

Isurus sp. Mako shark.

Myliobatis sp. Eagle ray.

Teleost. Bony fish.

Porpoise, indeterminate.

Choptank Formation

Unit 19.

Hemipristis serra Agassiz. Indian ocean shark.

Carcharodon megalodon Agassiz. Giant white shark.

Carcharhinus sp. Bull, dusky, and similar sharks.

Myliobatis sp. Eagle ray.

Teleost. Bony fish.

Small bird, indeterminate.

Porpoises, two genera, as yet unstudied.

Halicetus ignotus Kellogg. Primitive baleen whale.

Unit 17.

Carcharodon megalodon Agassiz.

Carcharhinus sp.

Galeocerdo sp. Tiger shark.

Isurus sp.

Hemiphristis sp.

Hexanchus sp. Six-gilled shark.

Odontaspis cuspidata Agassiz. Sand shark.

Myliobatis sp.

Aetobatis sp. Eagle ray.

Pogonias sp. Drumfish.

Istiophorus sp. Swordfish.

Thecachampsa antiqua (Leidy) Crocodile.

Turtle, undetermined.

Gomphotherium sp., aff. G. obscurum (Leidy). Primitive mastodon. Possibly from top of Unit 16 (Calvert Formation).

Orycterocetus cf. O. crocodilinus Cope. Sperm whale.

Scaldicetus sp. Sperm whale.

?Ixacanthus. Porpoise.

Schizodelphis crassangulum (Cope). Long-beaked porpoise.

Calvert Formation

Siphonocetus priscus (Leidy). Primitive baleen whale.

Material found on beach in area.

Crocodile teeth.

Sirenian (sea cow) ribs.

Tooth of sperm whale.

Brain cast of toothed whale.

Humerus of *Leptophoca lenis* True (hair seal).

Molar tooth of the horse *Hipparion* cf. *H. phosphorum* Simpson.

Section on Western Shore of Chesapeake Bay near
Little Cove Point on Chesapeake Ranch Club Property,
Calvert County, Maryland

Stop #3

Post - Miocene (24 feet)

18 feet - red to brown sand containing gravel lenses; at base is a three inch thick well-indurated ironstone bed.

6 feet - interbedded clays and sands; sand is fine grained and well sorted.

1.5 feet - blue-gray clay
1.5 feet - red sand
1.5 feet - blue clay with some sandy lenses
1.5 feet - buff sand

Miocene ? (12 feet)

6.5 feet - gray clay, heavily mottled, with lighter gray-brown sand pockets; cross-bedded fine sand and dark gray-blue sandy beds in the bottom three feet; upper foot is heavily iron stained with thin indurated ironstone lenses; at base is a thin, one to two inch ironstone bed.

5.5 feet - gray fine-grained sand with very little clay; slightly more clayey toward the top; small iron spots scattered throughout.

Miocene

St. Marys Formation (30.7 feet)

Unit 23 (10.0 feet)

6.5 feet - slightly clayey sands; variegated colors of brown, gray and gray-green; uppermost one foot is brown clayey sand with abundant shell material with Mercenaria, Anadara, and Lunatia most common; some burrowing of the upper shell bed into underlying part of unit; lower 5.5 feet has molluscan fauna present as molds.

0.5 feet - gray-brown slightly clayey sands; shells common, composed of a varied fauna; one inch ironstone bed at top.

3.0 feet - slightly clayey sand, mottled brown and blue by oxidation; contains scattered shells and molds; laterally channels into underlying unit.

Unit 22 (18.7 feet)

1 foot - blue sandy clay; abundant shells of which approximately 90 percent are Spisula clathrodon; in southern part of the exposure this unit is gone due to channeling of above unit; to north grades into bed containing common Mercenaria; bottom contact burrows into underlying unit.

2.7 feet - brown sand; abundant shell hash with some entire shells, mainly Spisula clathrodon, Balanus, Nassarius, Lunatia, Busycon, Mercenaria and Turritella; burrows from this unit extend into below unit.

1.5 feet - blue clayey sand with scattered shells.

1 foot - blue sand; some shell hash along with many entire shells including abundant Spisula, Turritella, Nassarius, Lunatia, Mercenaria, and Mangelia.

4.5 feet - blue sandy clay; contains thin, lenticular bands of Turritella, but little other megafauna; some mottling and burrowing in unit; bottom contact is undulating surface on shell bed.

0.5-1.0 foot - blue sand; extremely fossiliferous with high-spired snails (Turritella, Nassarius, and Mangelia) most abundant and Mercenaria common; also contains shell hash; top of bed is undulating surface, bottom is fairly straight.

7 feet - blue sandy clay; some shells, mainly in thin bands, primarily Turritella with some Mercenaria.

Unit 21

2 feet to beach - blue clay with no visible megafauna.

Vertebrate faunal list, Cove Point and vicinity, Calvert County, Maryland

St. Marys Formation

Eurhinodelphis bossi Kellogg. Long-beaked porpoise. Possibly from Choptank Formation.

Plesiocetopsis megalophysum (Cope). Primitive baleen whale.

Choptank Formation

Lophocetus calvertensis Harlan. Long-beaked porpoise.

Section at Drumcliff along Patuxent River, St. Marys County, Maryland

Stop #4

Post - Miocene (40 feet)

Miocene

Boston Cliffs Member (11' 1")

(1' 6")---Indurated, pale reddish-brown, slightly muddy, fine sand. Fossils: none seen.

(9' 7")---Pale reddish-brown, slightly muddy, fine sand. Fossils: gradational in concentration from very abundant, large shells to few, small shells. Most prominent are bivalves, all flat-lying, both single valves and articulated valves. The most abundant fossils are Lyropecten, Crassostrea, and Balanus with Anadara, Cerastoderma, Macrocallista, Mercenaria, Turritella, and Ecphora.

St. Leonard Member (6' 0")

(5' 0")---Pale yellowish brown, poorly sorted, muddy, fine sand. Biogenic mottling. Fossils: absent.

(1' 0")---Reddish-brown, poorly sorted, muddy, fine sand. In places, channeled down into Drumcliff Member. Biogenic mottling. Fossils: few molds and casts.

Drumcliff Member (27' 9")

(25' 10")---Very pale yellowish brown to moderate dusky brown, muddy to very well sorted, fine to medium sand. Fossils: gradational in concentration and size of largest shells from beds of very abundant, large shells to few small shells. Bivalves are flat-lying, both single valves and articulated valves, except doubled-valved, life-position occurrence of the deep-burrowing Panope. Very diverse assemblage of bivalves, snails, barnacles, ectoprocts, and inarticulate brachiopods. Among the more abundant are Isognomon, Cerastoderma, Anadara, Spisula, Turritella, Lunatia, Mercenaria, Macrocallista, Corbula, Crassatella, Balanus, Ecphora, Lyropecten, Panope, Apolymetis, Aligena, Cardita, Diplodonta, Anodontia, Pleiorytis, Semele, Calliostoma, Crepidula, Crucibulum, Fissuridea, Hastula, Scaphella, Siphonalia, and Teinostoma.

(1' 11")---Dusky olive blue, muddy, fine sand. Extensively burrowed. Fossils: low diversity, but abundant. Four dominant species: Isognomon maxillata, Astrhelia palmata, Lyropecten madisonius, and Placopecten marylandicus.

(Section below covered by beach. In fact, last described bed is visible only after "heavy water" has swept away most of the beach sand.)

Vertebrate faunal list, Choptank Formation, vicinity of Drumcliff, St. Marys County, Maryland

Isurus hastalis (Agassiz). Mako shark.

Carcharhinus egertoni (Agassiz). Bull, dusky, and related sharks.

Thecachampsa antiqua (Leidy). Crocodile. Found on beach.

Leptophoca lenis True. Hair seal.

Orycterocetus crocodilinus Cope. Sperm whale.

Cetothere. Primitive baleen whale.

MARYLAND GEOLOGICAL SURVEY
Latrobe Hall
The Johns Hopkins University
Baltimore, Maryland 21218

Guidebooks:

1. Coastal Plain geology of Southern Maryland, by J. D. Glaser, 1968.................................. $2.75

2. New interpretations of the eastern Piedmont Geology of Maryland, by W. P. Crowley, M. W. Higgins, T. Bastian, and S. Olsen, 1971........................ $1.75

3. Environmental history of the Maryland Miocene, by R. E. Gernant, T. G. Gibson, and F. C. Whitmore, Jr., 1971 .... $2.50

4. Piedmont crystalline rocks at Bear Island, Potomac River, Maryland, by G. W. Fisher, 1971............... $1.00

Many of the field trip localities are on private property. Before entering, the permission of the property owner should be obtained.